STS 86-0302-1A

ORBITAL SPACECRAFT CONSUMABLES RESUPPLY SYSTEM (OSCRS)

FINAL REPORT

Volume I

EXECUTIVE SUMMARY

(DRD-10)

Prepared for
the
National Aeronautics and Space Administration
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.

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1.0 Introduction

This report summarizes the results of the Orbital Spacecraft Consumable 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 STS86-0109 to the schedule depicted in Figure 1.0-1. This volume summarizes primary conclusions resulting from the trade studies and analyses performed; defines the concept of an earth-storable OSCRS tanker; contains recommendations for further concept development as well as development and fabrication of a production unit to be deployed; identifies ground support equipment and facilities which are necessary to support the OSCRS resupply scenarios; and addresses the operational aspects of the Gamma Ray Observatory (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 GRO at 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.

The primary consideration of the Rockwell OSCRS is to develop a light weight and cost effective design within the constraints of NHB1700.7A, KHB1700.7A, and the OSCRS contract safety and redundancy requirements. Because the OSCRS will execute a potentially hazardous operation (transfer of hydrazine) while in the payload bay, and because EVA astronaut interaction is required for some phases of the OSCRS mission, the fluid subsystem is considered manned and inhabited. The avionics and all other subsystems are considered manned and uninhabited. This philosophy permeates the design, production, and qualification plans whether or not weight and/or cost penalties are is incurred.

The report closes with a review of the estimated costs required to design, develop, qualify, fabricate and deliver a flight tanker and its associated control avionics, ground support equipment (GSE) and processing facilities, and the contractors costs to support the first operations mission (GRO resupply). The Rockwell plan is a low risk approach which can deliver a flight qualified system within 41 months from authority to proceed (ATP).

The estimated cost to design, develop, qualify and deliver the first operational OSCRS (including support of the first operational flight of the monopropellant OSCRS) is $63.2 M. The cost was developed from cost-estimating relationships (CER's) using the RCA Price S&H models.

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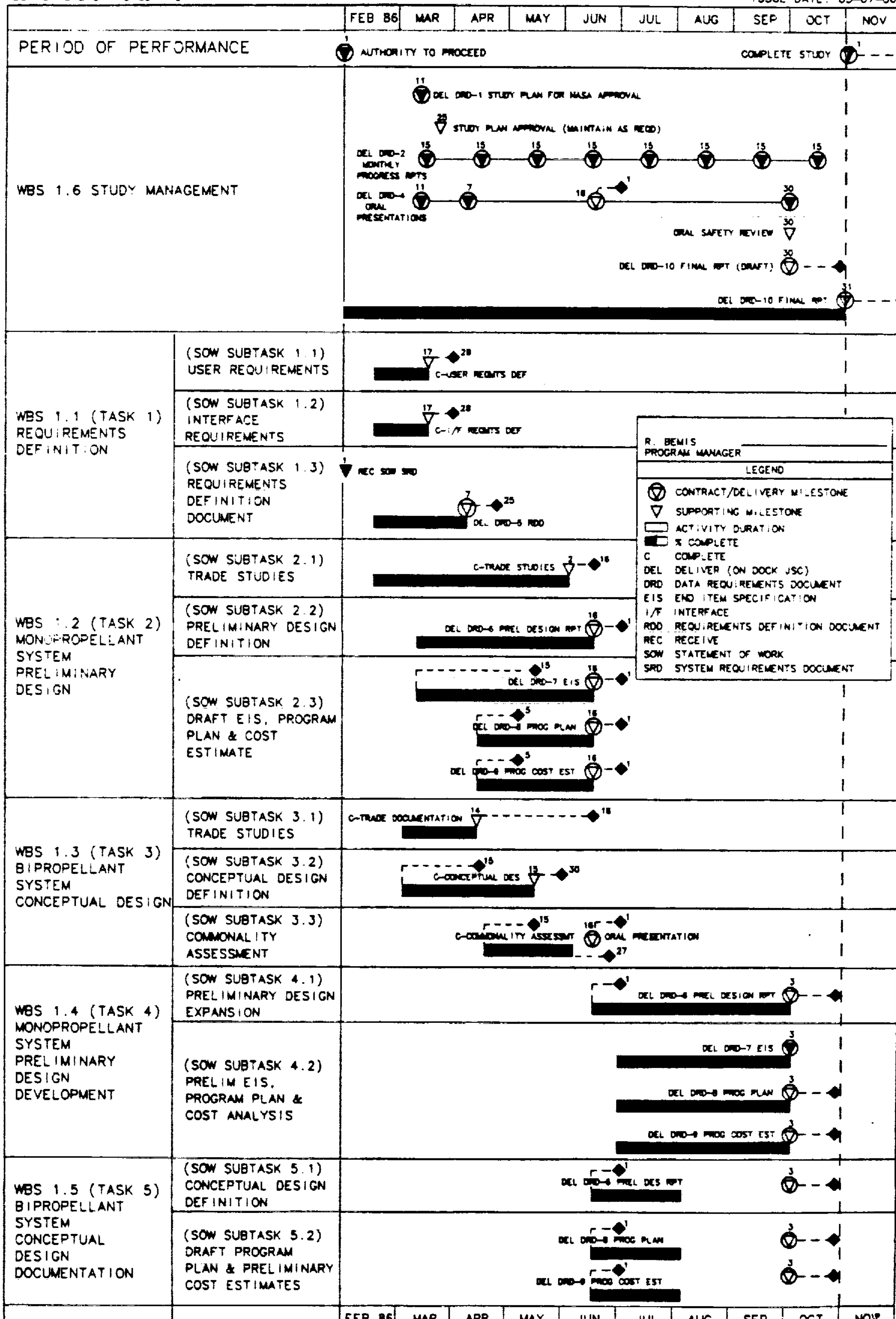
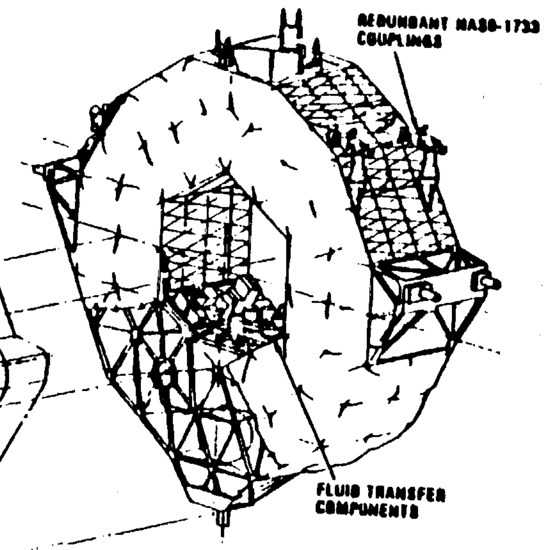
Figure 1.0-1
OSCRS
MASTER SCHEDULE
OMS-01

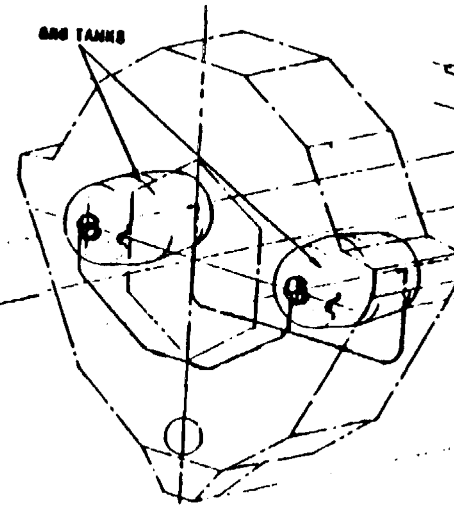
CONTRACT NAS9-17584, WBS 1.6.1
SUPPORTS DRD-1 STUDY PLAN

STATUS AS OF: 10-31-86
ISSUE DATE: 03-07-86

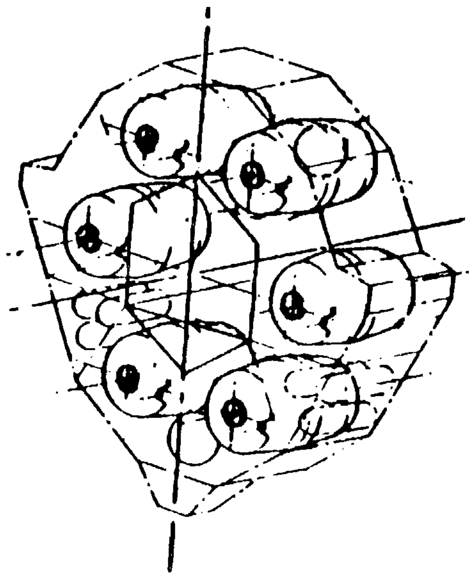




GENERAL COMPONENT ARRANGEMENT



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

In addition to the cost estimate to develop, deliver and operate the first monopropellant tanker, a similar cost estimate was developed for a bipropellant tanker. This estimate was developed by Engineering using commonality and complexity factor comparisons to the monopropellant tanker. The estimated cost through delivery of the first bipropellant tanker is $62.8M. This cost assumes that the bipropellant tanker is being developed and fabricated in parallel with the monopropellant tanker but lagging by 12 months from start to finish.

2.0 Study Conclusions

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. Volume 2 of this report contains the detailed results of these trade studies. Table 2.0-1 cross references the Statement Of Work (SOW) study subtasks to the appropriate Volume 2 reporting paragraphs. The following discussion summarizes the results and conclusions reached in each of the following study areas:

- Users Requirements
- Dedicated Versus Generic Tanker
- Structural Subsystems
- Mechanisms
- Fluid Subsystems
- Thermal Control Subsystems
- Avionic Subsystems
- Resupply Mission Scenario
- Safety and Reliability

2.1 User Requirements

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 nine 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 five foreign governments also responded positively. In addition, data from the existing Rockwell data base and business contacts with potential resupply candidates were used.

The resupply requirements (which were all derived prior to the Challenger incident) indicated a need for a fully developed earth storable OSCRS by 1993. The largest potential user (Space Station) is in the resupply range of 2500 lbm of monopropellant. Some of the DOD satellite programs indicate a need for up to 7000 lbm of bipropellants resupplied.

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

- Resupply up to 2450 lbs. of Hydrazine (N_2H_4) using ullage recompression
  - No pressurant resupply is required
- Provide a berthing interface which is compatible with the Flight Support System (FSS) A' docking latch assembly
- Use the GFE standard fluid interface coupling developed under Contract NAS 9-17333.

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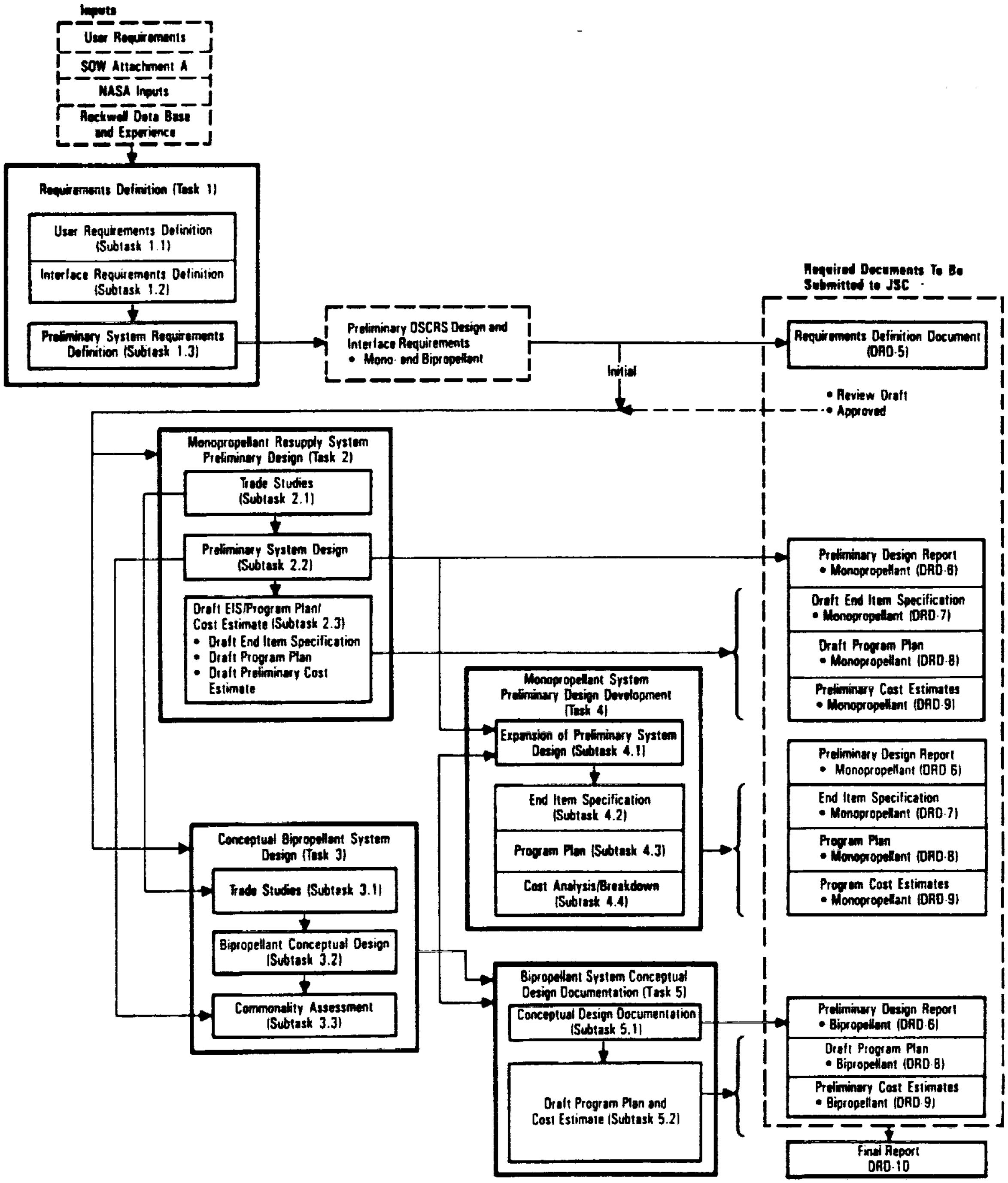

FIGURE 2.0-1 *OSCRS Study Task Flow Diagram*

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TABLE 2.0-1

STATEMENT OF WORK/DRD-10 REPORT
CROSS REFERENCE INDEX

S.O.W. Subtask		Description	DRD-10 Section No.
2.0		Monopropellant System Preliminary Design	
2.1		Trade Studies	
2.1.1		System Requirements Trades	
	a)	Generic vs. Dedicated System Designs	3.1.1.1
	b)	Redundancy Levels	3.1.1.2
	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
	j)	Envelope Studies	3.1.1.10
	k)	Optimized Weight Design Options	3.1.1.11
	l)	Normal and Emergency Spacecraft Demate	3.1.1.12
	m)	Optimize Added Fluid Storage	3.1.1.13
	n)	Options to Permit OSCRS Relocation	3.1.1.14
	o)	Control/Data System Optimization	3.1.1.15
	p)	On-Orbit Venting Limitations	3.1.1.16
2.1.2		Hardware/Software Trades	
	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
	g)	Residual S/C Propellant Disposal Techniques	3.1.2.7
	h)	Thermal Control Techniques/Hardware	3.1.2.8
	i)	Optimization OSCRS Control	3.1.2.9
	j)	Optimization of Data Displays	3.1.2.10
	k)	Redundancy Management and Health Monitoring	3.1.2.11
	l)	Auto vs. Crew Control Transfers	3.1.2.12
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 2.0-1
(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
3.1.1		System Requirements Trades	4.1
3.1.2		Hardware Software Trades	4.1
3.1.3		Operational Trades	4.1
3.2/5.1		Conceptual Design Documentation	4.2
3.3		Commonality Assessment	4.3
5.2.2		Draft Program Plan	4.4 (STS 86-0300)
5.2.3		Preliminary Cost Estimate	DRD-10 Vol III (STS 86-0301)

The initial OSCRS should have growth capability to resupply hydrazine, pressurants, and other fluids to spacecraft other than GRO. Early potential users include commercial (now uncertain), NASA and DOD satellites. The system should be capable of evolving to serve the requirements of the bipropellant user community also. To achieve this latter objective, 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.

2.2 Dedicated Versus Generic Monopropellant Tanker

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 2.2-1). A hybrid tanker has the same structure as a generic tanker, and possesses the same 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 over 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 resulting concept from this trade study was an earth storable propellant tanker structure and associated hardware and software designed to initially support the GRO resupply mission (N 2450 lbm of N_2H_4), while permitting easy and inexpensive growth to a bipropellant tanker capable of resupplying over 7000 lbm of bipropellants. This concept held up throughout the subsequent subsystem trade studies and enhanced achievement of commonality goals between the monopropellant and bipropellant systems. As will be shown in the following discussions, tanker commonality was maximized with minimal weight penalty while providing significant cost saving potentials.

2.3 Structural Subsystems Trade Studies

Two significant structure related issues required resolution in order to select the basic tanker design concept. The first was to decide on the primary structures concept. The second was to determine the weight penalty associated with using a generic (or hybrid) tanker structure sized to carry 7000 lbs of propellant to support a resupply mission in the GRO and Space Station resupply range of 2500 lbm.

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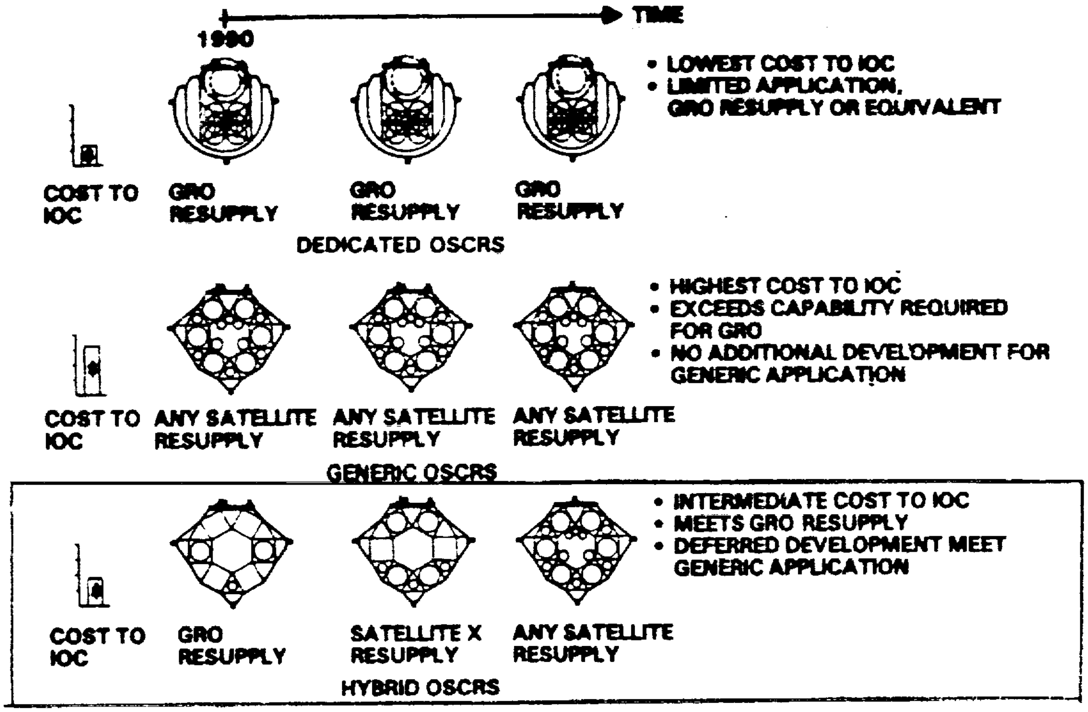
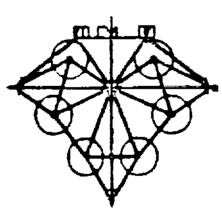
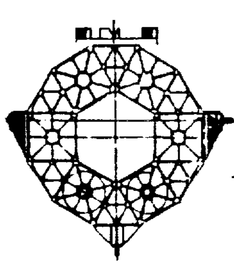


FIGURE 2.2-1 Hybrid OSCRS Concept





	COST		WEIGHT		FLEXIBILITY	COMMONALITY	PRODUCTION	
	INITIAL GRO	TOTAL PRGM	BASIC STR.	TOTAL SYS.	ADDED PROPELLANT	MONO TO BIPROP	TOOLING REQ'D	SCHEDULE RISK
Configuration 1			✓	✓		✓		
Configuration 2	✓	✓		✓	✓	✓	✓	✓

CONCEPTUAL STRUCTURAL DESIGN COMPARISONS

✓ denotes favorable parameter

FIGURE 2.3-1 PRIMARY TANKER STRUCTURE SELECTION

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2.3.1 Structures Concept

Two basic concepts were evaluated, open truss tubular and open truss machined aluminum alloy plate. Two variations of tubular structure were assessed: aluminum alloy tubes and composite/aluminum alloy tubes. The aluminum alloy tube structure had no weight or cost advantage over the machined aluminum alloy plate structure, therefore it was dropped from the final comparison.

The basic composite/aluminum alloy tubular structure was assessed to be lighter than the machined plate structure. The weight advantage decreases significantly, however, when examined at the system level. This is due to relatively simple component mounting onto the machined open truss structure versus greater mounting complexity on the tubular structure. Also, the machined plate structure was assessed to be less costly to fabricate and considerably more flexible for growth into a generic (or hybrid) tanker concept.

Machined aluminum alloy open grid was selected for the tanker primary structure design (Figure 2.3-1).

2.3.2 Generic vs Dedicated Tanker Structure

After selecting machined aluminum plate open grid as the baseline primary structure concept, an evaluation was made to assess the impact of using a common structure for resupply scenarios ranging from 2500 lbs to 7000 lbs of propellant. The generic versus dedicated tanker concept study (Paragraph 2.2) defined a significant program benefit to use identical equipment (tanks, structure, avionics, etc.) for both extremes if the weight penalties were not significant.

Structural analyses show that a hybrid tanker sized to carry 8545 lbs of propellant in 6 GRO size tanks will weigh only 87 lbs more than a dedicated tanker structure designed to handle the GRO resupply quantities of 2450 lbs (Table 2.3-1).

Based on this data, it was decided to use a hybrid primary structure capable of carrying over 7000 lbs of propellant for all tanker applications.

2.4 Mechanisms

Three basic mechanisms evolved from the preliminary design trade studies.

- o Berthing Mechanism
- o CCTV Berthing Aid
- o Fluid Coupling Emergency Separation Device

2.4.1 Spacecraft Berthing Mechanism

The GRO interface is designed to be compatible with the Flight Support System (FSS) A' structure latch assembly. Berthing directly to the +Z interface of the tanker structure was selected over use of the FSS A' structure based on reduced cargo weight and volume, reduced operation complexity, and improved orbital operation timelines. Fixed latches are mounted with explosive bolts to permit emergency separation if required. The FSS latches can be replaced with other berthing mechanisms as future spacecraft interfaces are defined.

Table 2.3-1 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

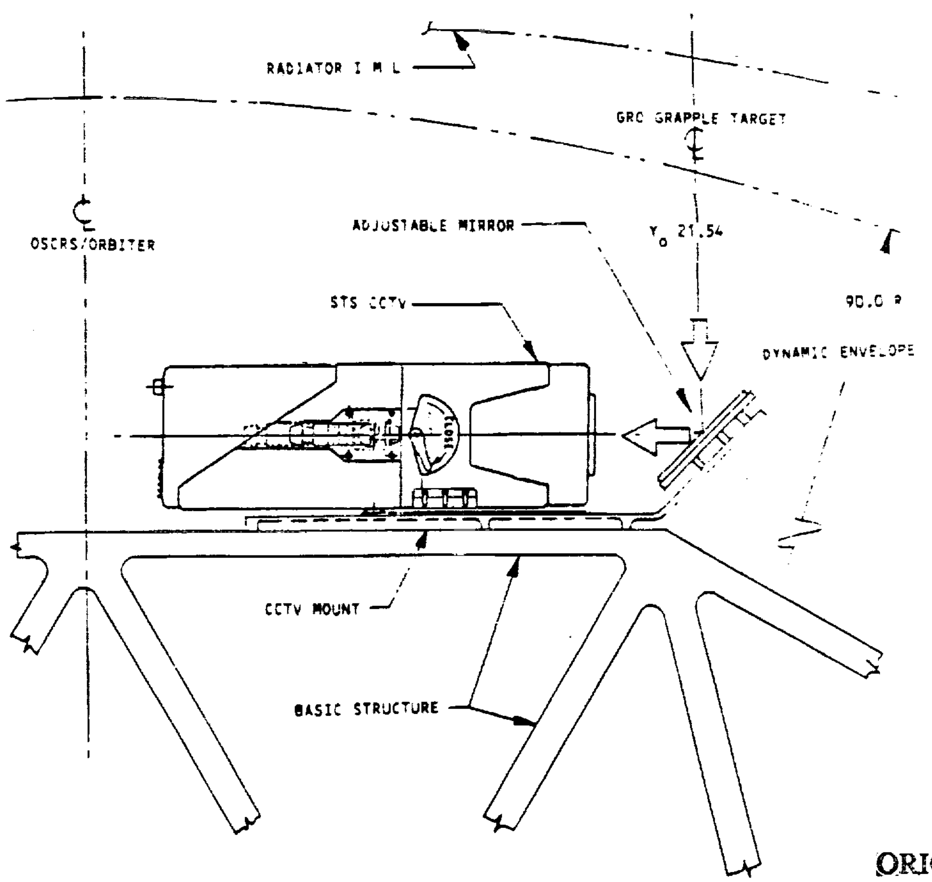


FIGURE 2.4-1 CCTV TRACKS GRO GRAPPLE TARGET

2.4.2 Berthing CCTV

A standard grapple target has been placed on the mating side of the GRO spacecraft to assist in the berthing operations. Since berthing will be controlled from the aft flight desk (AFD), via use of the Remote Manipulator System (RMS), it was concluded the target could only be observed via closed circuit TV (CCTV). Therefore, a berthing TV camera arrangement was installed on top of the tanker to provide the AFD controllers an unobstructed view of the docking process. (Figure 2.4.-1).

2.4.3 Fluid Line Emergency Seperation

In the event of an emergency occuring during the on-orbit operations when the spacecraft is mated to the tanker, it is required that reliable separation of the spacecraft can be achieved without an EVA. The fluid interface connection between the tanker and spacecraft is through the GFE standard fluid coupling per NAS9-17333 which is manually mated and demated. To achieve reliable, leakfree, separation, a dual squib actuated pyrotechnic valve assembly was selected. This valve was placed in the fluid transfer line where the line ties into the tanker fluid distribution system.

Multiple fluid resupplies, which may be required by future spacecraft, necessitate a design change to this fluid coupling configuration to avoid cumbersome, time consuming operations. A remote automatic coupling of TBD configuration is recommended to meet those future requirements.

2.5 Fluid Subsystem

The baseline OSCRS monopropellant tanker fluid subsystem is designed for resupplying the GRO, which requires a resupply quantity of 2,100 to 2,450 lbs of N_2H_4.

The major fluid subsystem design characteristics evolving from the trade studies were:

- o Ullage Blowdown Pump Fed Propellant Transfer
- o Off-the-Shelf Positive Expulsion Propellant Tank
- o 1% Accurate Turbine Flow Meters
- o Subsystem Modularization to Enhance Growth
    - o Additional Propellant and/or Other Fluids
    - o Pressurant Resupply
    - o Ullage/Vent Subsystem
    - o Residual Spacecraft Propellant Storage

2.5.1 Selection of Ullage Blowdown Pump Fed Resupply

The ullage recompression resupply method is required for GRO. Four potential methods were evaluated (Figure 2.5-1). The ullage blowdown pump fed resupply

FIGURE 2.5-1 **GRO RESUPPLY OPTIONS**

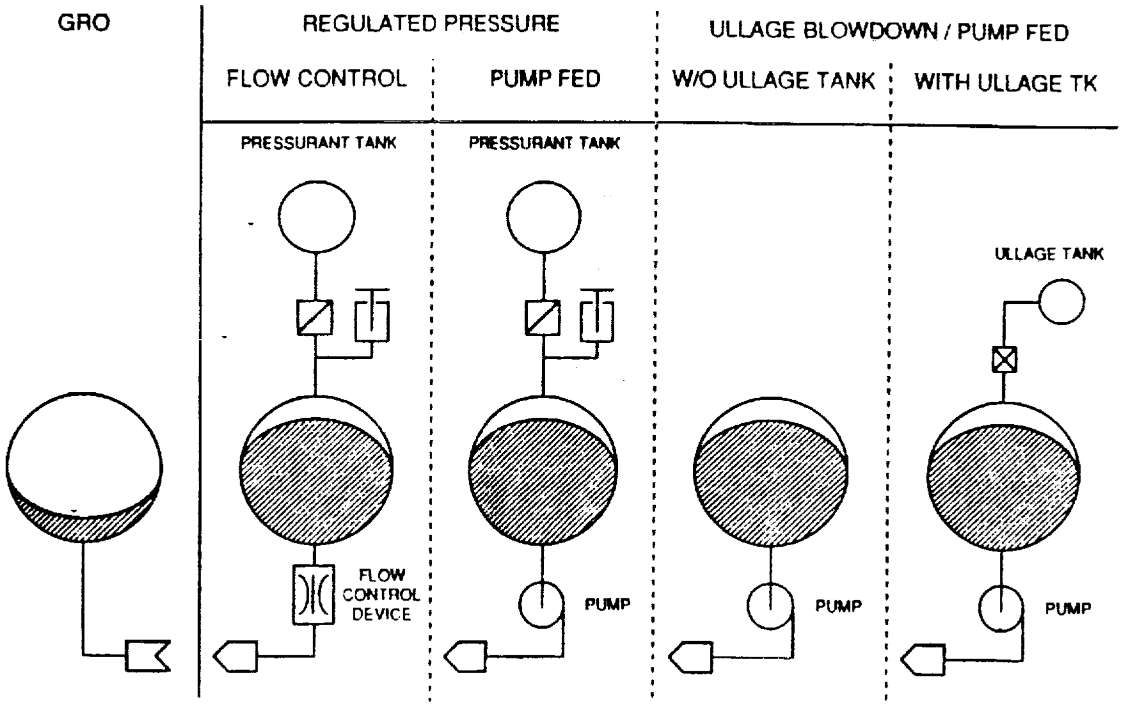


TABLE 2.5-1 MONOPROPELLANT SUPPLY TANK SELECTION

- DIAPHRAGM TANK SELECTED
  - LIGHT WEIGHT
  - HIGH EXPULSION RATE (170 GPM) AND UNLIMITED OPERATIONAL ACCELERATION LEVELS
  - DEFINITIVE BOUNDRY BETWEEN ULLAGE AND PROPELLANT

	APU	TDRS	GRO
• OFF-THE-SHELF HARDWARE			
• TANK WEIGHT/VOLUME (LBS/FT^3)	6.55	4.67	4.67
• OPERATING PRESSURE (PSIA)	340	338	400
• N_2H_4 QUANTITY (LBS)	390	960	1240
• POTENTIAL HYDRAZINE USERS			
• GRO (2100 TO 2450 LBS)	6 - 7 TANKS	3 TANKS	2 TANKS
• SPACE STATION (2330 LBS)	6 TANKS	3 TANKS	2 TANKS

USER REQUIREMENTS CAN BE SATISFIED WITH TWO GRO TANKS WITH TANKER MINIMUM WEIGHT, COST AND COMPLEXITY.

system with an ullage tank is recommended because of lower weight, cost, and greater versatility. The ullage tank allows a low pad pressure in the propellant tanks, provides a greater safety margin for thermal excursions, diminishes dissolved helium in propellants, and improves gauging accuracy.

The blowdown pump fed system weighs 185 less than the pressure fed system. The cost to develop and fabricate the pump fed system was estimated to be 30% less expensive than the pressure regulated system.

In consonance with selecting the pump fed system, centrifugal, gear, and magnetically coupled gear pumps were evaluated. The gear pump was selected as the most effective for the anticipated flow and pressure operational regions.

As will be shown in latter discussions, selection of the ullage blowdown pump fed system supports the baseline concept (to optimize commonality) by providing a resupply method for the pressurant recompression methods common to the hydrazine user spacecraft systems and the ullage disposal requirements common to the bipropellant user spacecraft systems.

2.5.2 Selection of GRO Positive Expulsion Tank for OSCRS

Propellant tank selection could significantly influence the OSCRS tanker program. The tank could be a relatively high cost/high weight item; its physical dimensions influence the tanker design; and its design could limit the resupply mode of operation in terms of operating environments, deliverable quantities, flow rates, and gas free quality.

The selection of a diaphragm acquisition device propellant tank for the baseline monopropellant tanker resulted from evaluating diaphragm tanks,metal bellows, screen tanks, and vane type tanks. Potential existing tanks considered were the APU, TDRS, and GRO propellant tanks. The GRO propellant tank was selected for the monopropellant OSCRS tanker. The user requirements for GRO resupply can be met with two GRO propellant tanks in the baseline monopropellant tanker with minimum tanker weight, cost and system complexity, while optimizing growth potential (Table 2.5-1).

2.5.3 Flowmeter Selection

Spacecraft requirement assessments bracketed the need to determine the quantities of N_2H_4 transferred during a resupply to accuracies ranging from 1 to 5 percent.

Turbine flowmeters were found to be the most accurate gauging system over the broad flow rate range encountered during resupply operations (Table 2.5-2). Three flowmeters in series provide for redundancy and health monitoring. Use of PVT gauging, as a backup to the flowmeters, meets resupply accuracy requirements with minimal risks.

2.5.4 Subsystem Modularization

A subsystem modularization concept was selected that allows for growth capability with no structural modifications. This results in a low development cost for the first article usage (GRO resupply) and limits subsystem scar weight to mission essentials.

The development of the monopropellant tanker modularized fluids subsystem met the objectives of establishing an earth-storable fluids tanker concept to satisfy the initial resupply requirements of GRO for reasonable design, development, and verification costs, while providing for growth capability to satisfy foreseeable future resupply mission requirements such as:

- Additional Propellants and/or Other Liquids
- Pressurant Resupply
- Ullage/Vent Subsystem

2.5.4.1 Fluids Growth

In the context of the initial trade studies of additional fluid capacity, the major goal was always "growth without weight and cost penalty to the baseline monopropellant tanker." As noted in the generic versus dedicated tanker study (Paragraph 2.2) this growth capability was also extended to maximize commonality between the monopropellant and bipropellant tankers. To this end, the OSCRS tanker fluid subsystem provides the necessary storage and transfer capability for resupplying earth storable propellants, and other non-propellant fluids such as pressurants, water, coolants and lubricants.

The monopropellant fluid system utilizes a mechanical coupling with redundant sealing surfaces to add or remove propellant tanks, ullage storage tanks, and/or other fluids required to support future resupply missions. Dedicated bays in the tanker structure are reserved for the future additions. The propellant tank bays (6 total with a N_2H_4 capacity of up to 7428 lbm) have tank mounts designed into the tanker primary forward and aft bulkheads at no added weight (or cost) to the design. Three triangular bays are provided for other fluid storage such as pressurants, coolants, etc. These bays are designed to accept modularized component packages (e.g., pressurant tanks and associated control valves) with no structural scar weight when removed for specific missions.

2.5.4.2 Pressurant Resupply

A modularized pressurant storage system capable of resupplying high pressure (500-4000 psia) gas and/or low pressure (ë 500 psia) gas can be added to the baseline tanker. Up to 20 lbm of deliverable GHe at 4000 psia can be stored in two pressurant bays.

Three resupply techniques were evaluated (Table 2.5.3).

- Compressor (10/1 Compression Ratio)
- Cascade - Compressor Hybrid
- Cascade

The compressor only technique offered no advantage over the hybrid or cascade methods.

The cascade method of pressurant resupply was selected over the hybrid based on lowest cost and development risk, weight, and best mission resupply time.

	PVT	FLOWMETER	DIRECT
• GAUGING OPTIONS			
• 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.

TABLE 2.5-2 FLUID QUANTITY GAGING SELECTION

TABLE 2.5-3 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) PROOF PRESSURE (PSIA) BURST PRESSURE (PSIA)	6,000 7,500 9,000	6,000 7,500 9,000	8,000 12,000 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 COST	SLOW MODERATE	MODERATE MODERATE	FAST LOW

* USING ORBITER POWER

CASCADE RESUPPLY METHOD IS RECOMMENDED.

The cascade only system requires qualification of a relatively new high-strength carbon fiber filament-wound composite fiber/metal pressurant tank to accommodate the high (8000 psia) operating pressure.

The hybrid system is an active system using a compressor. A space qualified compressor does not exist. As an active system it has the inherent potential for failure, preventing complete pressurant transfer. There is also the heat rejection problem which may necessitate an active thermal control system at high compression ratios.

System weight for the cascade only pressurant transfer system is 210 lbs. vs. 297 lbs for the hybrid pressurant transfer system.

2.5.4.3 Ullage/Vent Subsystem

The GRO resupply will be by ullage recompression, therefore, the baseline monopropellant tanker does not have to vent contaminated ullage pressurant overboard. This simplifies the baseline tanker which can vent small line manifold quantities of uncontaminated helium directly into the bayload bay.

Future spacecraft, however, will require disposal of propellant tank ullage gases. This service can be provided by two methods:

- o Ullage Exchange
- o Ullage Vent

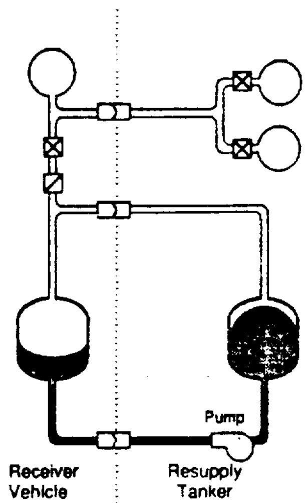
Ullage exchange (Figure 2.5-2) is attractive since no overboard venting is required. Some users, for example Space Station, have severe restrictions concerning overboard ventings. The pump-fed system baselined for OSCRS is designed with the capability to perform an ullage exchange.

Ullage venting from the spacecraft can be either exhausted overboard or stored on-board OSCRS. The latter case turns out to be impractical since the storage vessels would have to be 4 times the size of the spacecraft ullage volume. A sequential transfer by reverse cascade to 4 tanks (of spacecraft tank size) will result in a pressure drop from 250 psi to 16 psi in the spacecraft tank.

The overboard venting techniques are: direct vent of propellant vapor/ullage gas through non-propulsive vents; catalytic decomposition of the propellant vapors; and cold trapping to propellant vapors and storing the condensed liquid.

The preferred method of handling the spacecraft ullage gas is to return it to the OSCRS propellant supply tank (ullage exchange). This is feasible with spacecraft using positive explusion tanks, but requires spacecraft ullage gas management technology for systems employing surface tension devices (screens or vanes). The preferred method of overboard vent of hydrazine ullage gases is to catalytically decompose the N_2H_4 into ammonia, nitrogen and hydrogen (NH_3, N_2, H_2) gases.

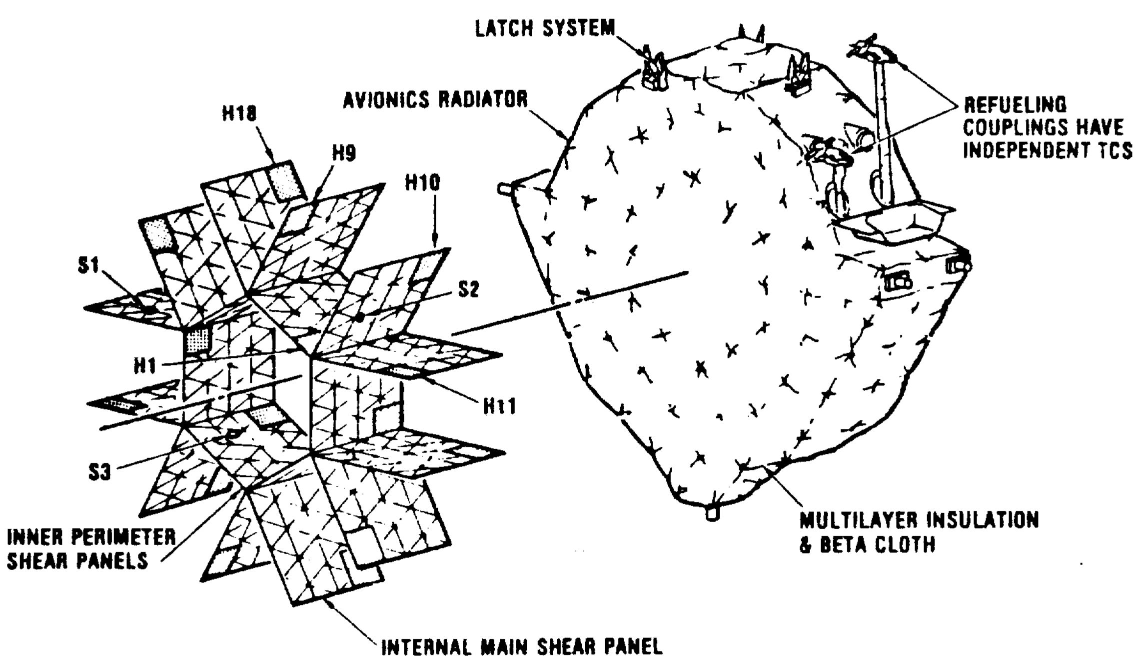
FIGURE 2.5-2 ULLAGE EXCHANGE RESUPPLY METHOD



- 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.

FIGURE 2.6-1

Thermal Control System Concepts



2.5.4.4 Spacecraft Residual Propellant Storage

The removal of residual propellant from the spacecraft may be necessary for three reasons. First, to enable an accurate propellant quantity determination by filling the spacecraft's propellant tanks from the empty state. Second, to remove propellant contaminated due to long-term storage on orbit. Finally, to permit overboard venting, if required, when the spacecraft propellant tank does not have a propellant/ullage separator. The removal of residual propellant in the final case would minimize the quantity of vented by-products by removing most of the liquid propellant from the spacecraft tank before venting.

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

The first method may be a viable option in specific cases, but in general is not considered acceptable. The vented propellant would effectively act like a thruster firing and would generate considerable contamination.

The second method is to store the residual propellant in a storage tank. 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.

Three recommendations were produced by this study.

- Use of residual storage tanks to remove and store residual hydrazine is the best option, since it minimizes problems of contamination or safety with small weight and cost penalities.
- Catalytic venting of hydrazine is a secondary option of residual propellant removal and disposal which is best applied to small quantities of residual propellant.
- A pump transfer system (with a reversible pump) allows more versatility in the residual removal and storage options.

2.6 Thermal Control Subsystem (Figure 2.6-1)

2.6.1 Heater System

A low temperature radiant panel heater concept was selected to thermally control the tanker main compartment. The design was selected over component heaters based on safety, redundancy, and simplicity. The panel type heater is ideal for the modular OSCRS concept. Fluid system modifications, such as tank and/or component change-out, are possible without heater changes.

Several studies of the fluid transfer line and coupling thermal control techniques were performed. A removable insulation system, installed following coupling deployment, used in conjunction with patch and wire heaters to maintain the assembly in the required temperature range under design and failure conditions, was selected.

2.6.2 Avionics Component Radiator

Avionics thermal control using a number of radiator concepts was considered. It was determined that an internally and externally radiating flat panel radiator is adequate for all flight conditions. This panel is mounted on the starboard avionics bay facing outboard.

2.6.3 Temperature Sensors

Thermal instrumentation ranges and temperature monitoring requirements were investigated. Temperature ranges were established and it was found that 102 temperature sensors are required for the GRO mission. Sixty-five are required for thermal control and 37 are required for other purposes (e.g., valve failure detection, PVT gaging, etc.). Table 2.6-1 summarizes the thermal instrumentation purposes for the baseline (GRO) and growth monopropellant tankers.

2.6.4 Insulation

A multilayer insulation (MLI) with a beta fabric cover insulates the entire tanker structure. This insulation will be installed in removable panels to provide quick and easy access to the tanker subsystems for checkout, maintenance, and changeout for mission specific requirements.

2.6.5 Pending Thermal Control Issues

Analysis of in-bay ferry operations indicated that long distance transportation is not a reliable possibility without heating of OSCRS components, which is presently not possible. An improved understanding of Orbiter payload bay ferry conditions will allow better analysis of this mission phase during the phase C/D contract.

Hot case entry and post landing conditions were analyzed. DRD-6 para. 3.3.3.3 shows that overtemperatures are possible through a combination of worst-case conditions which have not been encountered in real flight situations. Proper operational procedures and insulation of very small fluid lines, if any, will prevent overtemperatures from occurring.

2.7 Avionics Subsystem

An avionics system has been defined that will satisfy the requirements for the GRO resupply mission. The system has the inherent growth capability to support an expanded monopropellant system and future bipropellant systems with only minor design changes.

2.7.1 Selection of 3 Active String Avionics

The avionics system defined (Figure 2.7-1) utilizes three redundant strings to satisfy the failure tolerance requirements for critical STS payloads. The three-string system, operating with two-out-of-three voter modules that power fluid system valves and components, was selected over an alternate concept utilizing one active string and one unpowered back-up string (Table 2.7-1). The redundant commands in the three-string system assure continuous operations, even in the event of a failure. Protection from inadvertent valve operations

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TABLE 2.6-1 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

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FIGURE 2.7-1

Avionics Control Concept

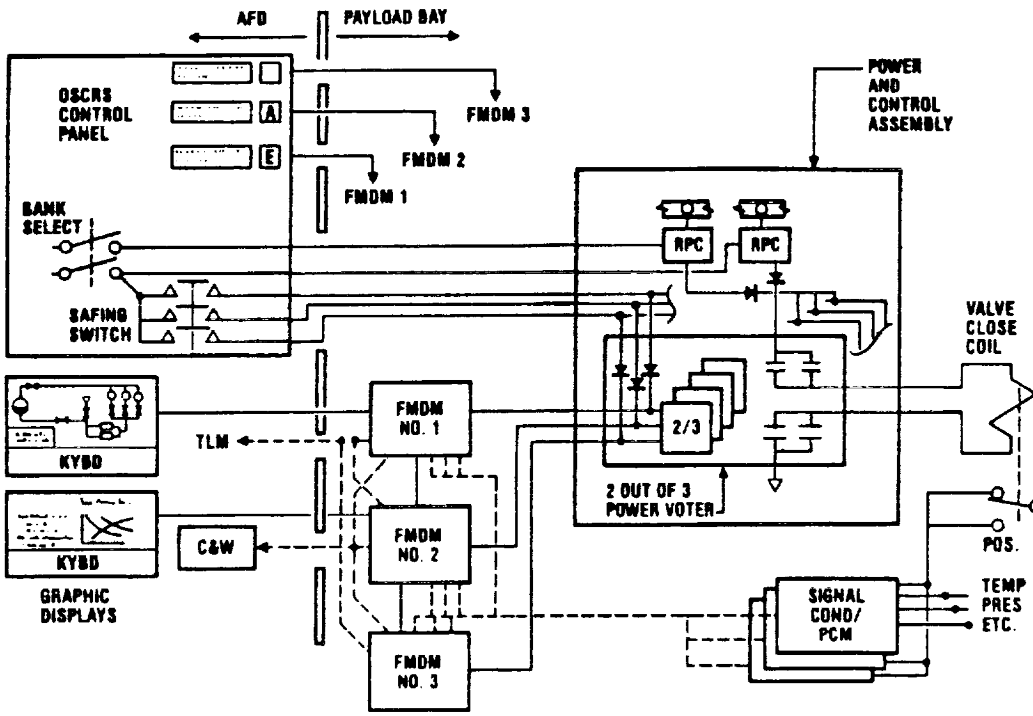

TABLE 2.7-1

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 (3 STRING)

* 1 ACTIVE STRING, WITH 1 UNPOWERED BACKUP

** EXCEPT FOR TWO SIMULTANEOUS FMDM FAILURES is provided by the majority voter, and redundant data paths assure continuous data to the crew even after two failures. Selection of a three-string concept avoids extensive, and often inconclusive single string analysis and verification tasks.

2.7.2 FMDM Selection

OSCRS avionics equipment is located either on the tanker module or on the Orbiter aft flight deck. Located on the tanker, and providing the primary control of the resupply mission, are three Flex Multiplexer Demultiplexer (FMDM) units that are a derivative of the proven Orbiter MDM's. The FMDM's incorporate a microprocessor, memories and special modules, that in addition to the other standard modules, provide a proven integrated package capable of performing all required OSCRS control and data processing functions.

The FMDM was selected over comparable avionics system concepts because of its advanced development. Other systems evaluated (Fairchild C&DH, and Gulton T^2C^2) would require extensive additional development to reach the current FMDM state.

2.7.3 Power Control Assembly (PCA) Concept

The Power and Control Assemblies accept commands from the FMDM's and employ a two-out-of-three voter module to switch power to valves or other components. The voter module represents an advanced concept that greatly simplifies wiring and box interconnections in typical control circuits.

2.7.4 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.

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. The data concept baselined by Rockwell for a three-string data system would satisfy the stated failure tolerance requirements.

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.

2.7.5 Emergency Separation Controller

The tanker avionics also includes the emergency separation controller assembly which houses a number of pyrotechnic initiator controllers (PIC's) that provide the current pulse to fire the ordnance devices used for emergency separation of the receiving satellite from the tanker. The PIC's are fired using crew activated switches on the aft flight deck.

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2.7.6 Aft Flight Deck Avionics

Avionics located on the aft flight deck (Figure 2.7-2) includes a dedicated OSCRS control panel and two GRID computers. The space-proven GRID computers, with their built-in screen, provide the capability for presenting graphic displays of OSCRS fluid system status to the crew, supporting the requirement for a friendly man-machine interface. The dedicated OSCRS control panel provides switches for the crew to control those functions not chosen for automatic control by the FMDM's; such as power ON/OFF control, manual valve safing control, and pyrotechnic device firing commands. Dedicated control paths to each FMDM, operated by the crew to select the next automatic sequence, are also located on the dedicated panel.

2.7.7 Caution and Warning

Included in the display studies was an analysis of OSCRS program Caution and Warning System requirements. It concluded that the standard Orbiter C&W system is available to the OSCRS system. Also, the OSCRS GRID display can be used to provide additional C&W data to supplement the limited Orbiter capabilities.

2.7.8 Software

The software concept defined in the study provides an effective approach to minimizing the potential impact of software reconfiguration due to mission-to-mission requirement changes. Modular software that utilizes core modules that are unchanged between missions can be employed. However, the software architecture must make provisions for software modules that would be changed to incorporate mission-unique control and data requirements. These mission-unique modules can be integrated with the core software prior to a particular mission.

2.8 Resupply Mission Scenario

The simplest resupply scenario involves only the transfer of hydrazine to a spacecraft using a positive expulsion diaphragm. With this type of resupply the spacecraft propellant tank ullage is recompressed, therefore no pressurant resupply is required. This is basically the GRO mission. Under these conditions the scenario is as follows: (Figure 2.8-1).

- o Rendezvous with the inerted spacecraft. Verify that the safing has been accomplished prior to the spacecraft's retrieval and while still a safe distance from the Orbiter.

- o The EVA crew leaves the airlock and translates to the OSCRS.

- o The RMS is moved to the spacecraft and the spacecraft is berthed to the OSCRS under the observation and assistance of the EVA crew. A closed circuit TV is mounted on the OSCRS so that the AFD crew can also directly observe the berthing closure maneuver. After verification by the EVA and AFD crew that the berthing is complete, the RMS is released.

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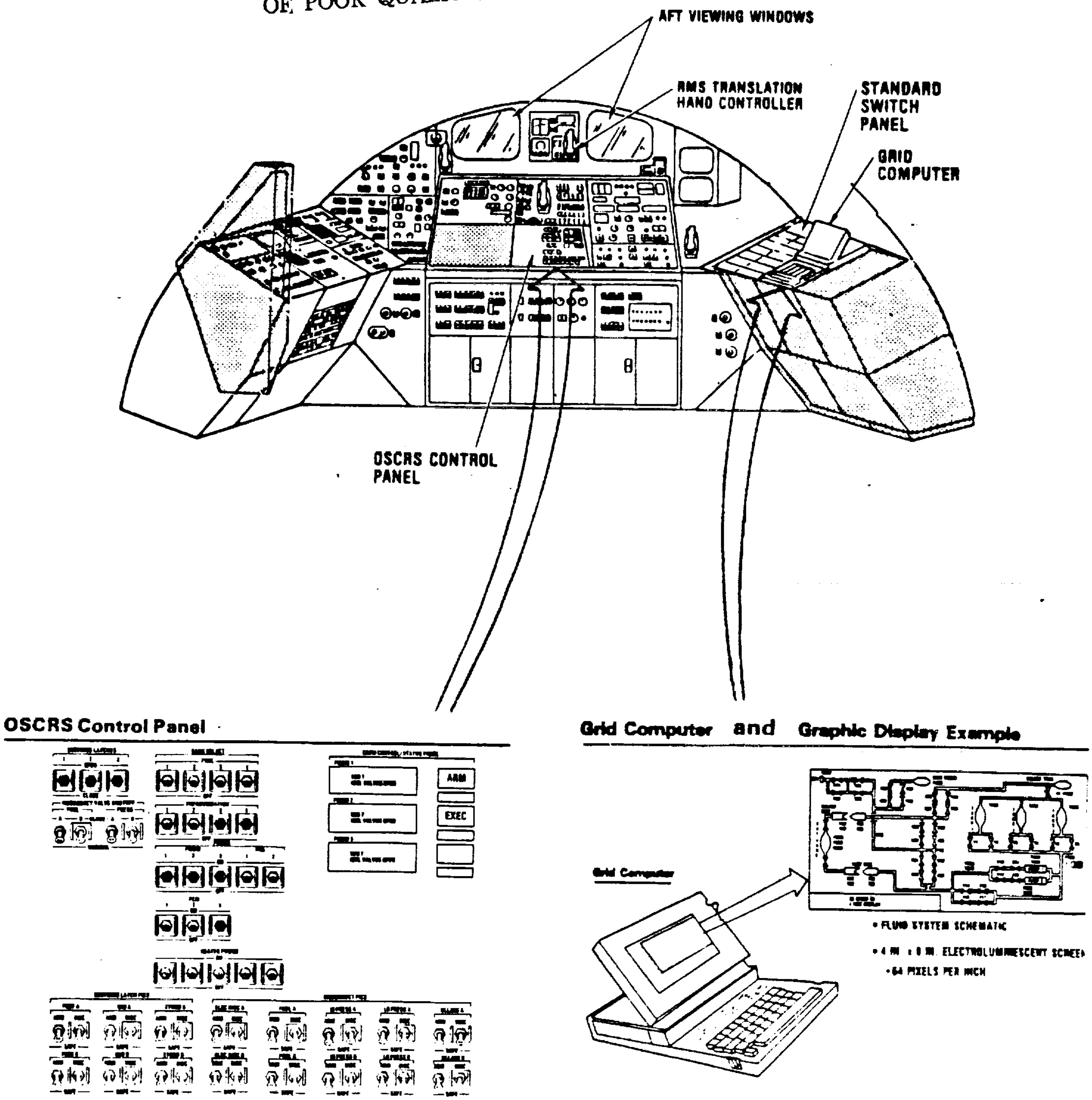
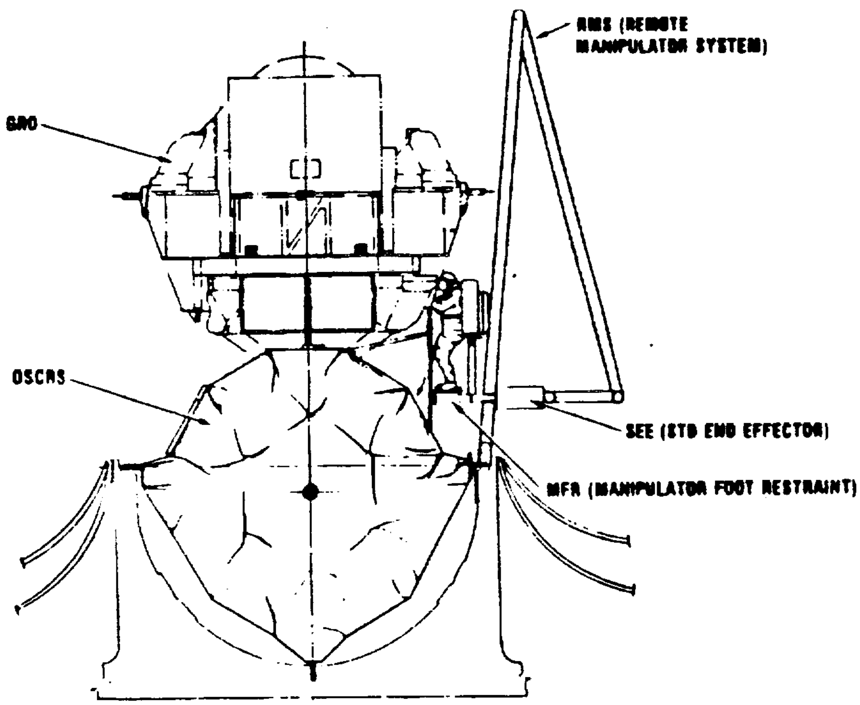


FIGURE 2.7-2 AFD LAYOUT TO SUPPORT OSCRS OPERATIONS

FIGURE 2.8-1

OSCRS/GRO Fluid Transfer



- o The Manipulator Foot Restraint (MFR) is installed on the RMS/SEE (Standard End Effector). Tools are obtained from stowage and attached to the MFR. The EVA crew then moves to the OSCRS/spacecraft umbilical area.
- o The electrical umbilical is connected to the spacecraft by the EVA crew and its continuity is verified from the AFD.
- o The EVA crew then prepares the spacecraft for the fluid transfer coupling. The coupling is attached and the leakage test sequence is completed by the EVA and AFD crew.
- o The EVA crew returns to the airlock or accomplishes additional tasks if necessary. The transfer is initiated and completed under the monitoring and control of the AFD crew. For the purposes of the scenario, it is assumed that the EVA crew will be unavailable during the fluid transfer.
- o After the resupply is complete the EVA crew will return to the OSCRS and accomplish the disconnect sequence. This includes verification by the AFD crew of seal integrity. The fluid coupling is stowed and the electrical connectors disconnected and secured.
- o The AFD crew verifies the spacecraft systems as the EVA crew secures the interface panels of the spacecraft.
- o The spacecraft is positioned for release, checked out, and released by the RMS. The AFD crew also verifies the OSCRS is secure. The EVA crew stows any EVA equipment and returns to the airlock.

The level of complexity of the timeline associated with this scenario and various contingencies increases as the number of fluids or interface requirements with the spacecraft increase. By taking these into account, this generic scenario acts as the basis for development of the OSCRS subsystems and integrated system. It also provides a baseline against which improved or automated methods can be evaluated.

2.9 Safety and Reliability

Safety of personnel, spacecraft, orbiter and facilities and reliability of resupply operations are paramount in the design of the OSCRS tankers and support systems.

2.9.1 Safety

As part of the monopropellant OSCRS preliminary design studies, a safety assessment review was performed and a report was prepared by Safety and submitted to the NASA. The review concluded that the recommended OSCRS design complies with the Safety Policy and Requirements per NHB1700.7A, and the STS Payload Ground Safety, Handbook per KHB1700.7A.

The STS Payload Safety Requirements Applicability Matrix of Table 2.9-1 summarizes the NHB-1700-7A requirements review by subsystem.

- No potential Waiver or Deviations were identified
- Various controls have been identified
- No accepted risk candidates were identified

2.9.2 Reliability

Functional Failure Modes and Effects Analyses (FMEA's) were prepared for spacecraft resupply missions. These FMEA's provide a method for early identification and resolution of potential problem areas. The subsystems are reviewed for potential failure modes so that the system can be designed to be tolerant to any single failure with mission success guaranteed.

All subsystems were evaluated for functions failure modes to ensure reliability concerns were addressed in the design. The fluid subsystem was evaluated at the component level. All systems were assessed to be single fault tolerant toward meeting the operations requirements.

TABLE 2.9-1 **STS PAYLOAD SAFETY REQUIREMENTS APPLICABILITY MATRIX**

1 PAYLOAD: ORBITAL SPACECRAFT CONSUMABLES RESUPPLY SYSTEM | 2 DATE: 9/9/86 | 3 PHASE REVIEW: 0 | 4 PAGE 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	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 REF. GMN HARDWARE	217 EVA/RMS CAPABILITY	218 SERIES PAYLOAD	219 FLAMMABLE ATMOSPHERE	7 REMARKS
FLUID SYSTEMS	X	X	X	–	X	–	X	–	–	/	X	/	/	–	X	–	–	X	–	–	–	–	–	–	–	–	/	X	/	/	–	X	
ELEC/AVIONICS	X	X	X	–	–	–	X	–	–	/	/	/	/	–	–	–	/	–	/	–	–	–	–	–	–	X	/	/	/	/	–	X	
PYROTECHNICS	X	/	X	–	–	X	–	–	–	/	/	/	/	–	–	–	–	–	–	–	–	X	–	–	–	–	/	–	/	/	–	/	
THERMAL CONTROL	X	X	X	–	–	–	–	–	–	/	/	/	/	–	–	–	–	–	–	X	–	–	–	–	–	–	/	–	/	/	–	–	
STRUCTURES	X	/	X	–	–	–	/	–	–	/	X	/	–	X	–	–	–	–	–	–	–	–	–	–	–	–	/	–	/	/	–	–	
MECHANICAL SYSTEMS	X	/	X	–	–	X	X	–	–	/	/	/	–	–	–	–	–	–	–	–	–	–	–	–	–	–	/	–	/	/	–	–	

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		

3.0 OSCRS DESIGN

3.1 Monopropellant Tanker and Associated AFD Avionics

The monopropellant OSCRS consists of a number of discrete elements needed to support and perform a spacecraft resupply mission. These elements include the tanker, its associated control avionics located in the Shuttle Orbiter aft flight deck (AFD), software, ASE, GSE, and the ground support facilities. The discussion within this design section is related to the tanker and its related AFD avionics.

3.2 Monopropellant Tanker

The tanker is the flight system mounted in the Shuttle Orbiter 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 expulsion 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).

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

A major characteristics 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.

The OSCRS structure is constructed to form a 12-sided regular polyhedron periphery around a central hexagon cavity. The structure length (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 three lower triangular 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.

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.

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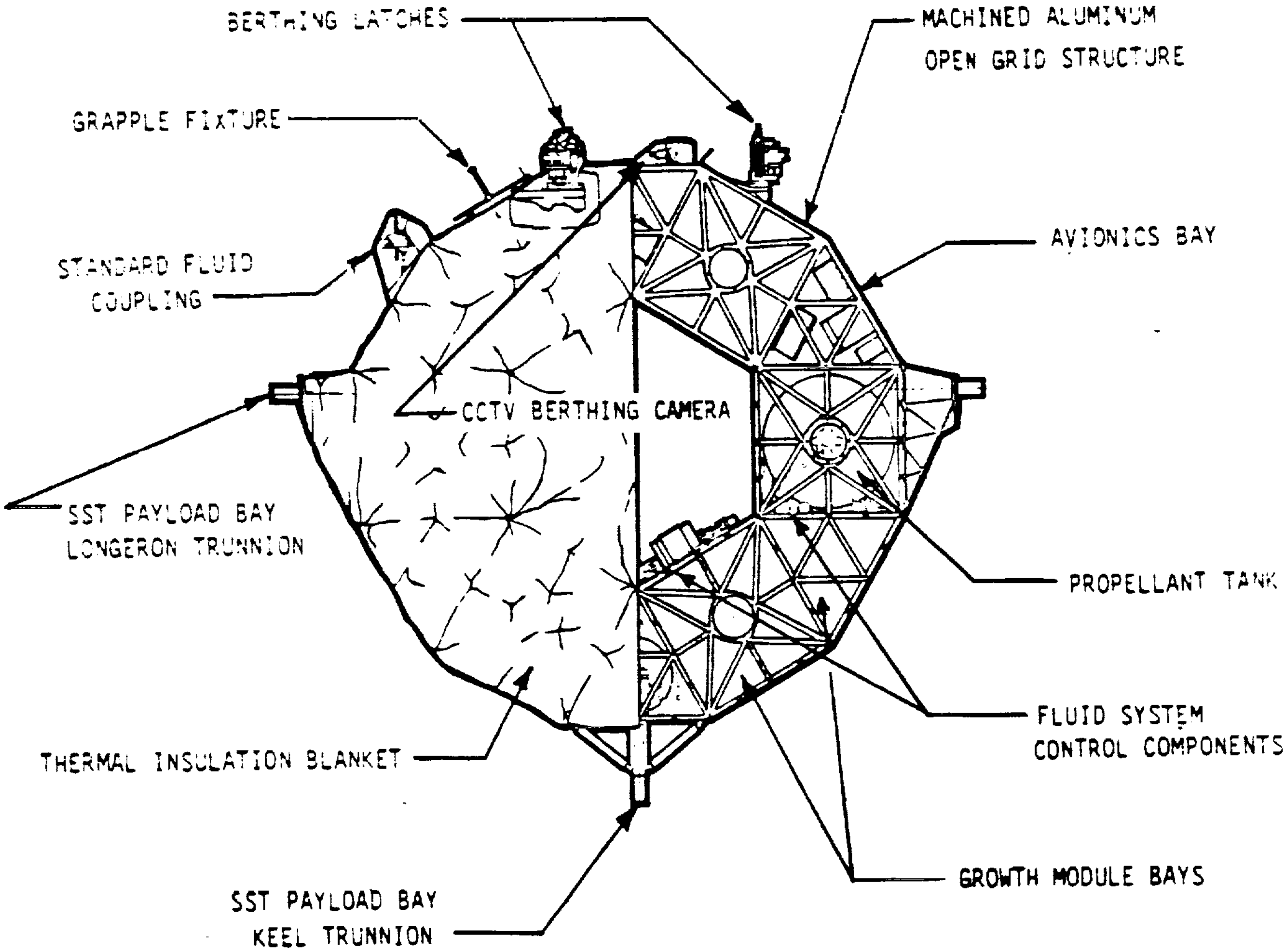


FIGURE 3.2-1 MONOPROPELLANT OSCRS TANKER

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 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 Design

The OSCRS structural configuration is an integrally machined open truss triangular structure with individual members sized as large as possible and constructed to form a 12-sided regular polyhedron periphery around a central hexagon cavity (Figure 3.2-2).

The geometry results in 6 square and 6 triangular full length compartments. All longitudinal surface elements, i.e., shear panels, for these compartments are geometrically identical in length and width, simplifying fabrication and assembly (Figure 3.2-3). An exception to triangular structure design is the integral circular tank mounts provided in six places in both front and back main bulkheads.

Longeron trunnion fittings (i.e., integrally machined aluminum torque boxes) on the structure extend to each side and contain 2 longeron trunnions each. The single keel trunnion fitting is designed in a similar fashion.

For maximum stiffness and minimum weight and cost, all major structure is machined from 2219-T851, 2124-T851 (if welding is desired) or 7075-T7352 aluminum alloy. The structure 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. The 5 trunnions and 4 trunnion scuff plates will be machined from 6AL-4V titanium alloy and chrome plated.

3.2.2 Spacecraft Interfaces (Mechanisms)

Mate/demate provisions between an orbiting spacecraft and the OSCRS-Orbiter system involve three distinct and separate interfaces:

- o The electro-mechanical berthing system
- o Fluid/gas interface connections
- o Electrical/Avionics interface connections

The first planned consumables resupply mission is the GRO spacecraft. The GRO berthing interface is configured to be compatible with the FSS berthing latches. (Figure 3.2-1 shows the latch locations).

FIGURE 3.2-2

Basic Structural Dimensions

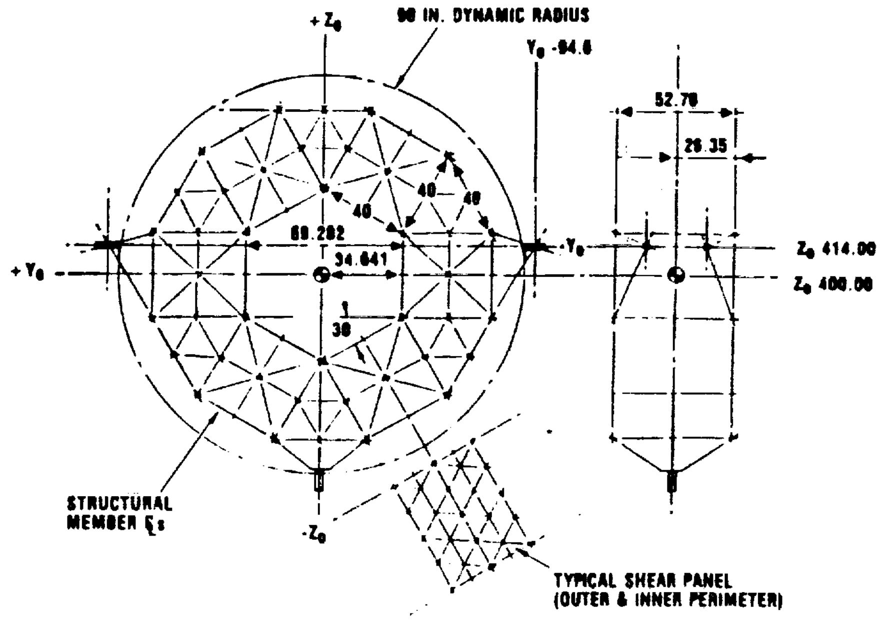
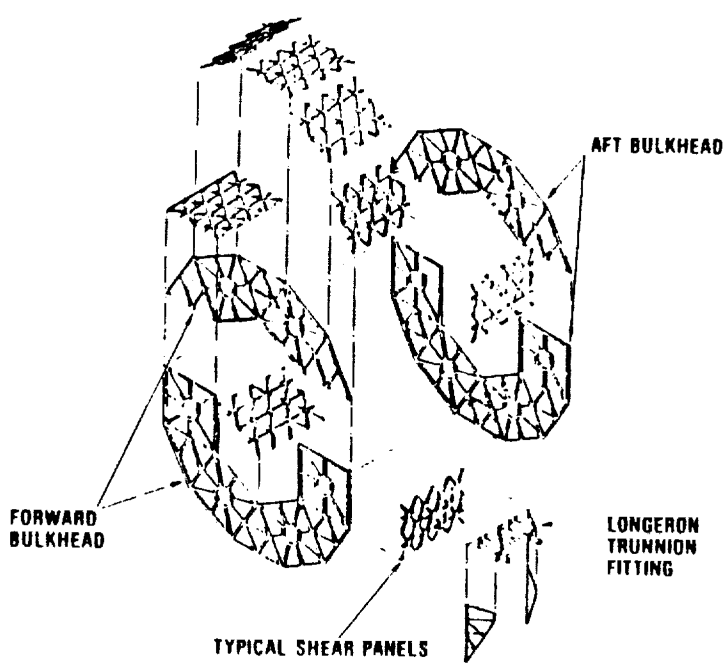


FIGURE 3.2-3

Basic Structure

4,300 LB Monopropellant Tanker



The latch design includes an EVA contingency feature in the event the redundant motors or any single linkage assembly fail. Both latching jaws pivot on threaded removable pins. These pins, which are tethered, may be removed on-orbit allowing the jaw(s) to be manually repositioned to release the captured berthing pin(s).

Pyro-actuated frangible bolts secure each latch assembly to its mounting bracket on the tanker structure (Figure 3.2-4). This permits remote/automatic release of the satellite in the event of the need for FO/FS emergency separation without EVA.

A standard grapple target has been affixed to the mating side of the GRO to aid in controlling the lateral displacement of GRO during mating to the tanker. For the tanker to utilize this target location, a closed circuit TV (CCTV) is employed (Figure 2.4-1). Using an adjustable mirror set at 45°, adequate visual reference in the Z axis is available to the RMS operator in the AFD.

The GRO spacecraft uses the standard refueling coupling being developed and produced by the Fairchild Control Systems Company under contract to NASA-JSC, (NAS9-17333). The standard coupling is manually mated/demated. Emergency separation without EVA dictates that a squib actuated remote separation device be utilized upstream of the tanker transfer hose attachment to the umbilical coupling (Figure 3.2-5).

Electrical/Avionics connectors which satisfy emergency demate requirements are available as qualified components. Since this type of connector typically separates by simply sliding apart along its own axis, the axis orientation is designed to be parallel to the spacecraft separation force axis.

3.2.3 Fluid Subsystem Design

The baseline fluid subsystem can be divided into several convenient units based on their functional operations (Figure 3.2-6).

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.

3.2.3.1 Propellant Storage Unit (Figure 3.2-6.1)

The propellant storage unit is comprised of the OSCRS propellant tankage and the tank interconnect manifold hardware. The baseline monopropellant resupply tanker utilizes two GRO propellant tanks for propellant storage. The baseline tanker resupply capacity of the two GRO tanks is 2476 lbm of hydrazine. Additional GRO tanks can be attached to the baseline design; up to four additional tanks, bringing the resupply capacity to 7428 lbm of hydrazine.

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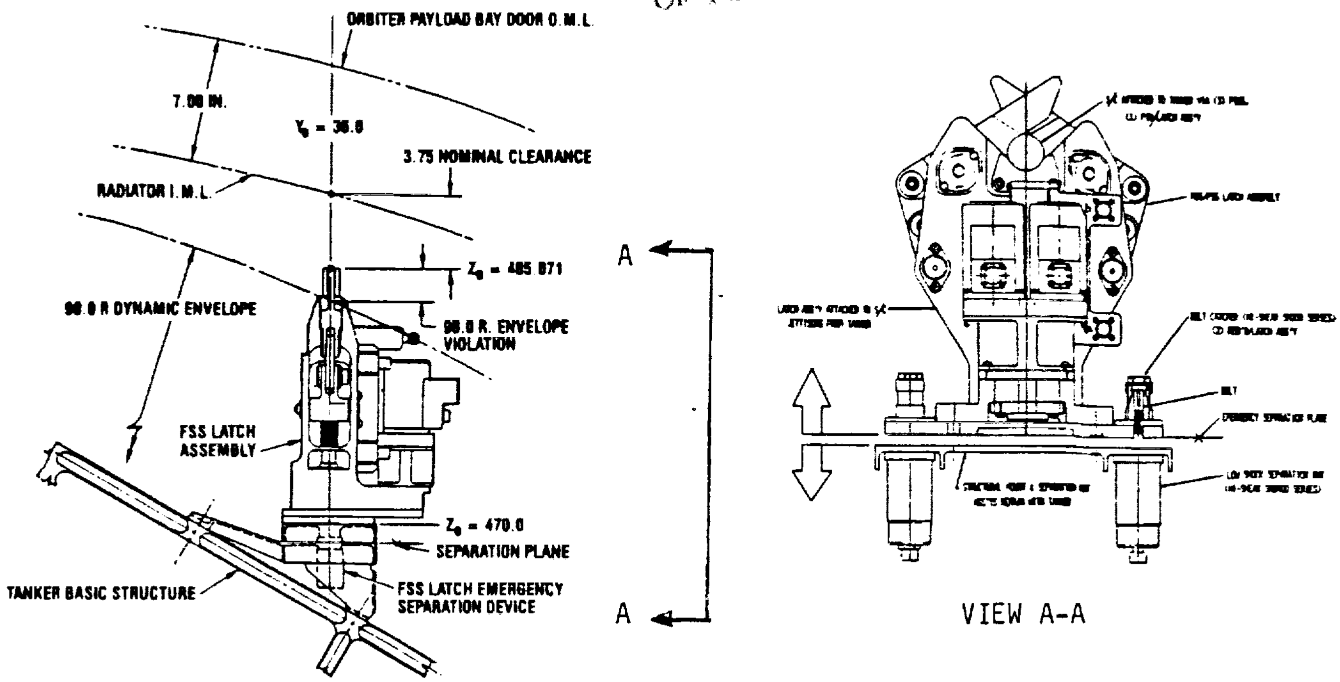


FIGURE 3.2-4 BERTHING LATCH INSTALLATION & EMERGENCY SEPARATION

FIGURE 3.2-5 FLUID TRANSFER EMERGENCY DISCONNECT SEQUENCE

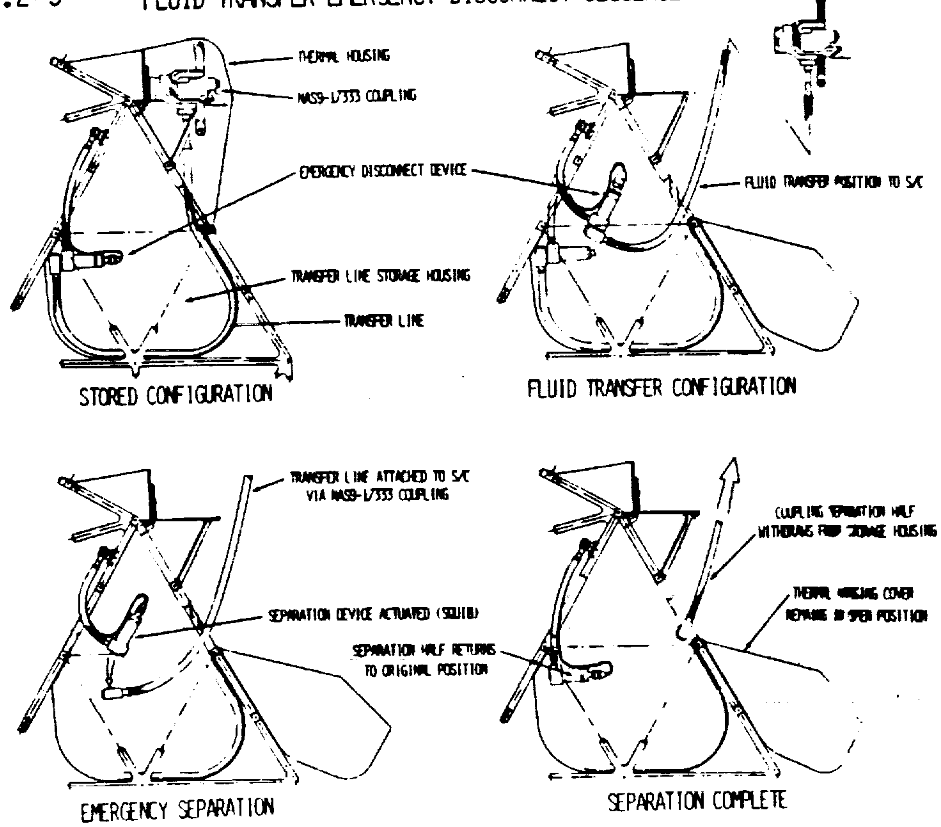
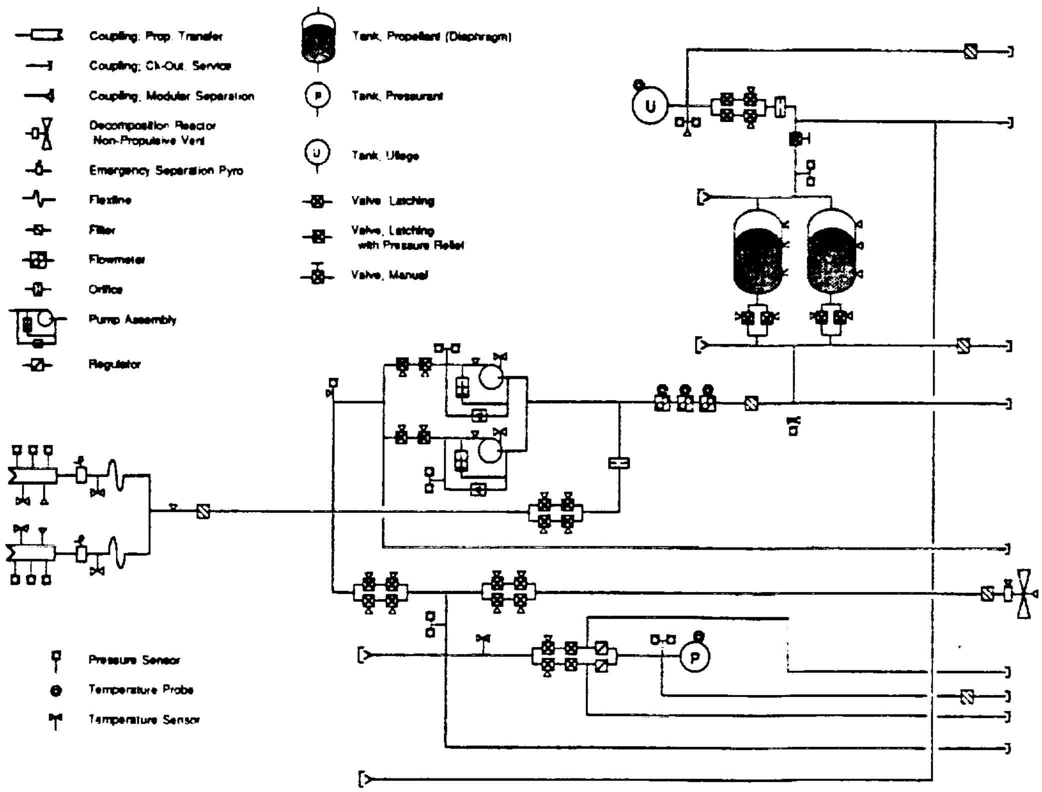


FIGURE 3.2-6

BASELINE MONOPROPELLANT FLUID SUBSYSTEM SCHEMATIC



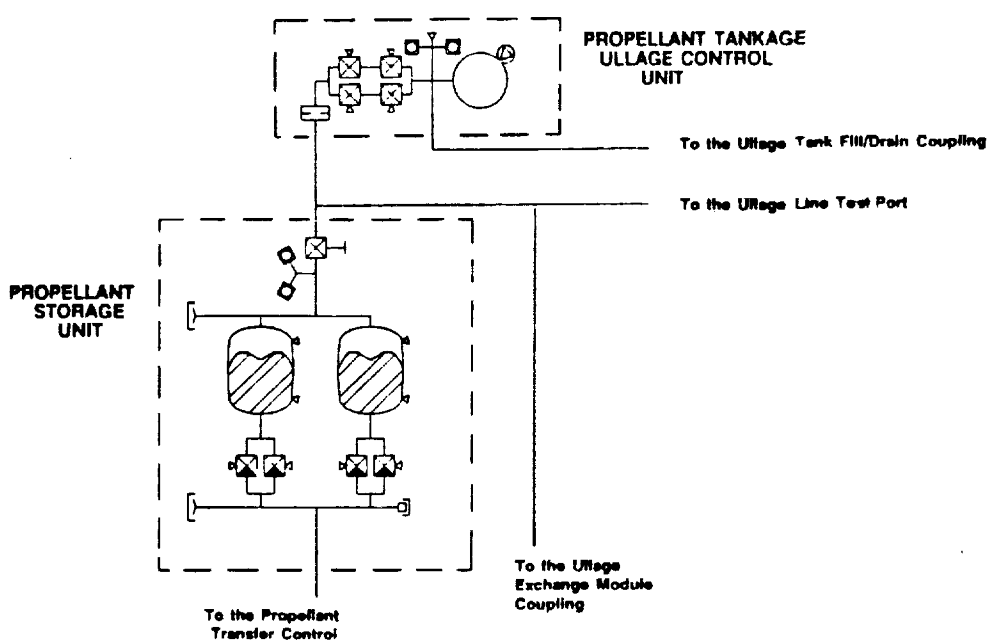


FIGURE 3.2-6.1 Schematic of Propellant Storage and Ullage Control Unit

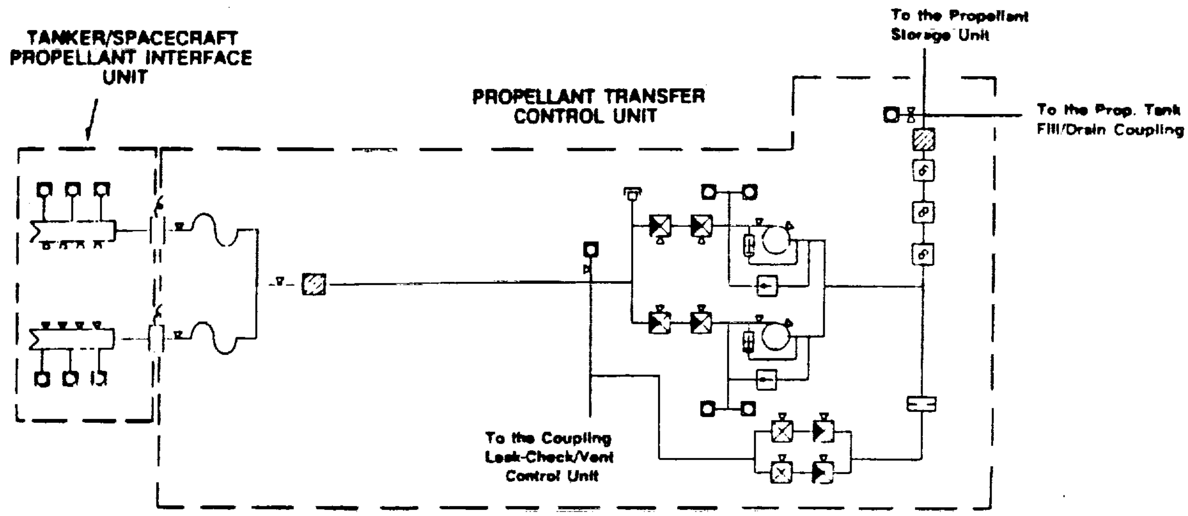


FIGURE 3.2-6.2 Schematic of Propellant Transfer Control Unit

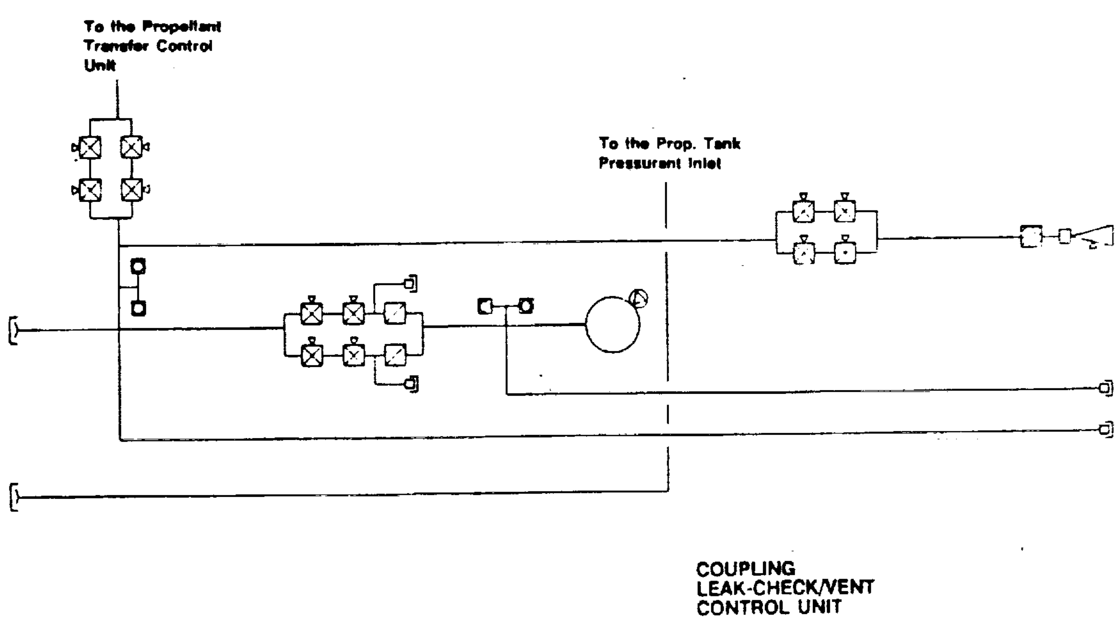


FIGURE 3.2-6.3 Schematic of Coupling Leak/Vent Control Unit

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 a positive expulsion device. The 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 each.

The propellant tanks are interconnected in parallel, with parallel redundant valves at each of the tank outlets. Tank isolation valves latch open and contain a reverse flow pressure relief capability. Mechanical couplings utilized to attach individual propellant tanks to the tank manifold provide convenient modular growth capability.

3.2.3.2 Propellant Tankage Ullage Control Unit (Figure 3.2-6.1)

Prior to the on-orbit activation of the OSCRS fluid transfer system, the propellant pad pressure is kept at a low pressure (50 psia) to insure a minimal percentage of gas saturation. As propellant is transferred out of the tanks the ullage control unit supplies the OSCRS tanks with an auxiliary pressurant to maintain the pump inlet pressure above cavitation levels.

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 (Maximum Expected Operating Pressure) of 2000 psia. The ullage tank is filled to meet the specific needs of each resupply mission.

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

3.2.3.3 Propellant Transfer Control Unit (Figure 3.2-6.2)

The propellant transfer control unit feeds propellant from the OSCRS propellant tankage to the satellite being resupplied.

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 redundant flexline manifolds.

Gauging of resupply propellant is performed by three redundant flowmeters. Turbine type flowmeters are used to provide a propellant mass transfer accuracy of $\pm$ 1%. Three flowmeters, placed in series provide fail safe redundancy. The propellant storage tank PVT is used as a backup gauging system.

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

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Preliminary operational characteristics of a monopropellant pump have selected pump design flowrates of 2.5 and 5 gpm, with a head pressure of approximately 400 psia.

The pump used is dual speed with pumping flowrate capacities of 2.5 gpm and 5.0 gpm with a head pressure of approximately 400 psia. A full range of resupply rates of 2.5, 5.0, 7.5 and 10.0 gpm can be achieved by using single or dual pump operations at the associated pump speeds.

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 spacecraft tankage. Propellant backflow is prevented by a check valve.

A relief valve has been incorporated into each of the pump assemblies to protect the receiver spacecraft propulsion system from overpressurization. In the event that the pump outlet pressure is greater than the desired transfer pressure, the relief valve relieves back to the pump inlet.

Isolation of the pump assemblies is achieved by series redundant latching valves which contain 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. This avoids a concern with potential adiabatic detonation which could be associated with rapid filling of the evacuated coupling manifold.

A flexline manifold connects the propellant transfer control unit to the standard interface coupling. Approximate length of each of the two redundant flexlines is 6 feet. Each flexline is connected to the propellant interface unit by the tanker half of the emergency separation valves (Figure 3.2.5).

3.2.3.4 Coupling Leak-Check/Vent Control Unit (Figure 3.2-6.3)

The coupling leak-check unit is designed to provide a dedicated gas supply to leak check the standard fluid interface coupling (NAS9-17333). The 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 is made of titanium alloy. The approximate diameter of the tank is 8 inches, with an operating pressure 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 of approximately 100 psia.

Propellant contaminated gases and small quantities of raw propellant can be vented overboard, through the non-propulsive catalytic reactor. The effluent is expelled in selected directions, in a non-propulsive manner, to maximize safety. During the GRO resupply the effluent vented will be uncontaminated helium, therefore, it will be vented directly into the Orbiter payload bay.

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

3.2.3.5 Tanker/Spacecraft Propellant Interface Unit (Figure 3.2-6.2)

The propellant interface unit utilizes the NASA/Fairchild standard fluid transfer coupling (NAS9-17333) as the 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.

3.2.3.6 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 3.2-7.

3.2.4 Thermal Control Subsystem Design

The preliminary thermal control system design (Figure 3.2-8) 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 for more specific requirements.

3.2.4.1 Envelope

The outer surface of the OSCRS tanker is insulated with 10 layer MLI (multilayer insulation), covered with beta fabric, to protect the MLI and to obtain the desired optical properties. Construction of the MLI blankets follows typical Orbiter practices.

3.2.4.2 Interior TCS

Internal compartment heating is provided by panel type electrical heaters mounted on each of the 18 internal shear webs. Each panel has 215 square inches of surface area. The heaters are offset forward and aft alternately, 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 heaters are dual circuit type. That is, each heater has two independent electrical heater circuits, either of which can provide the required heater output. The heater system is schematically shown in Figure 3.2-9.

The use of the Remote Power Controllers (RPC's) to power some of the heaters (Figure 3.2-9) 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.

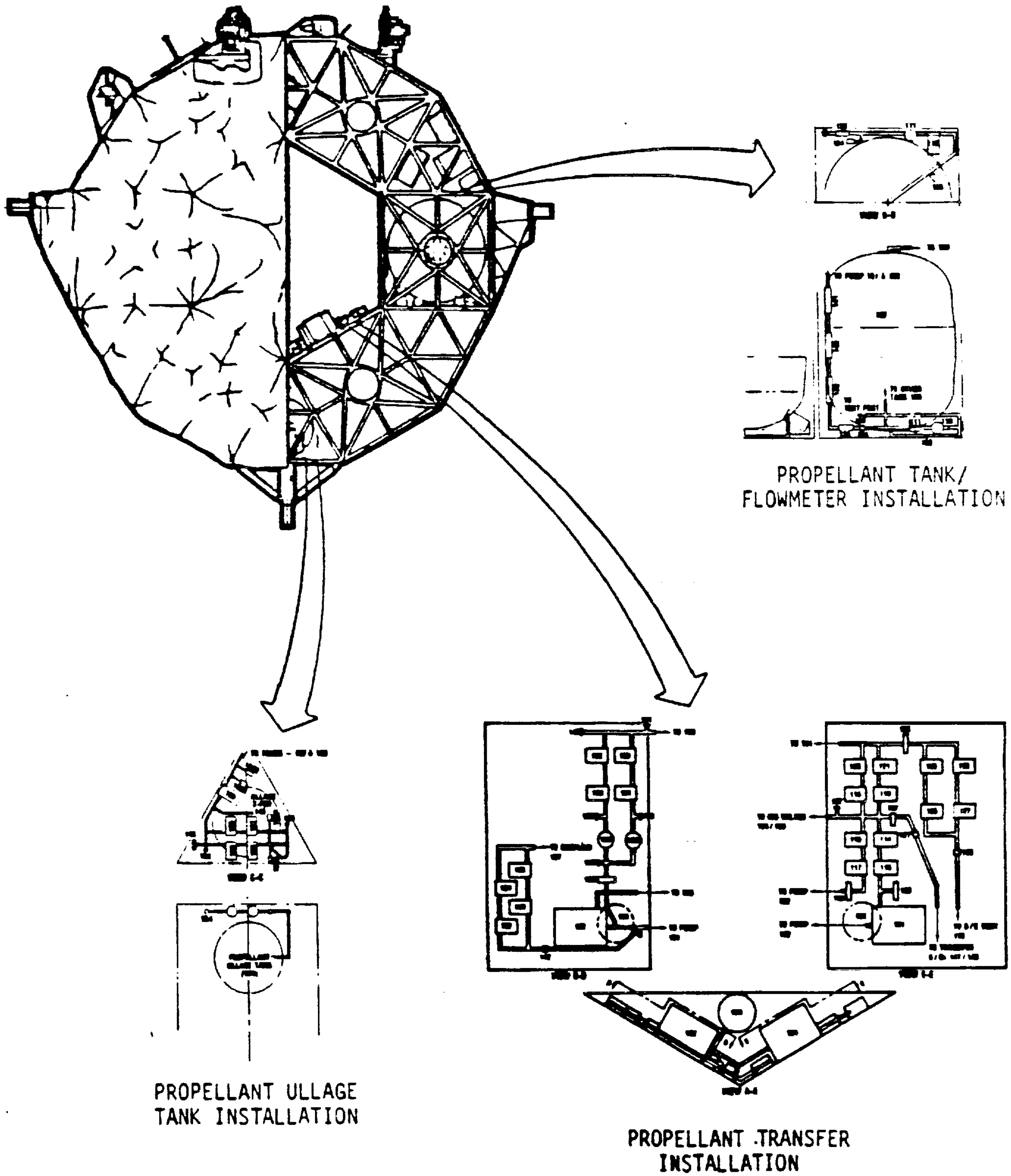

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FIGURE 3.2-7 COMPONENT INSTALLATION

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FIGURE 3.2-8

Thermal Control System Concepts

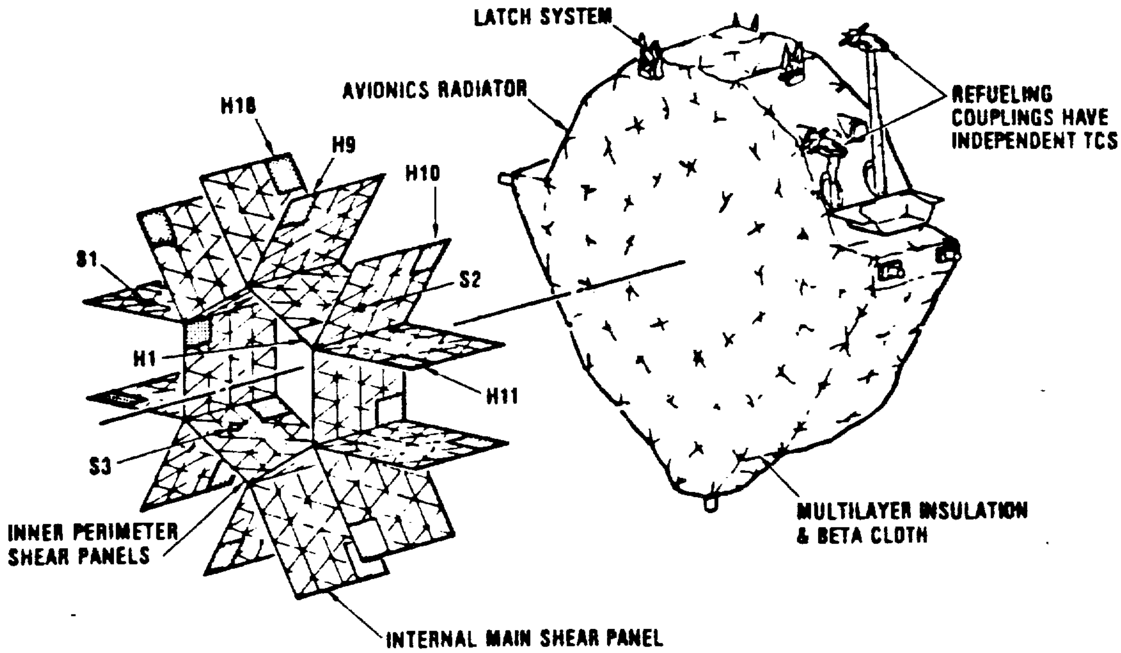
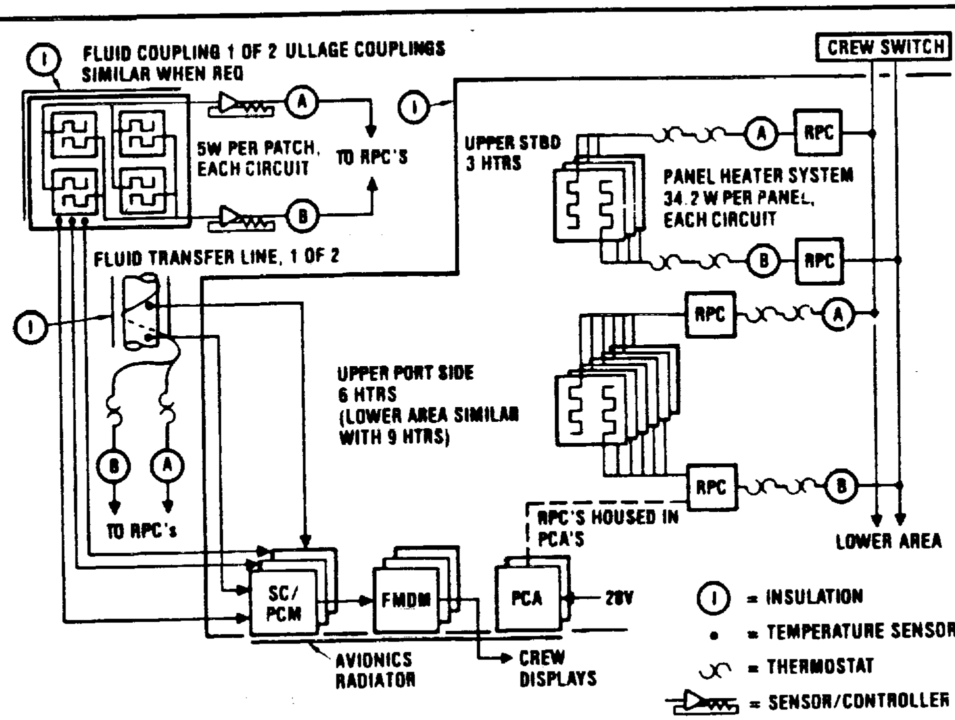


FIGURE 3.2-9

Thermal Subsystem Schematic



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.-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.

The heaters are activated prior to deployment, and deactivated following stowing, since they are stowed in a thermally controlled portion of the OSCRS.

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 3.2-1). 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.

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. Prior to flight, the radiator area is partially insulated, based on the worst hot conditions expected during the mission.

3.2.4.5 Instrumentation

The GRO mission requires 102 temperature sensors. Of these, 65 are required for thermal control purposes, the others being used for safety, gauging, etc.

3.2.4.6 Power Estimate

Peak load for the main compartment is estimated at 616 watts. The standard fluid 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.

3.2.5 Avionics Subsystem Design

An avionics system has been defined for the OSCRS that will provide the capability to safely control the OSCRS fluid systems and protect the receiving spacecraft during resupply operations. The avionics system will also provide OSCRS/spacecraft status and performance data needed by the crew and ground personnel to support on-orbit operations, including system safing if required. The system is comprised of equipment located on the Orbiter AFD and equipment located on the OSCRS tanker module located in the payload bay.

As shown on Figure 3.2-10, 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 3.2-11 gives a detailed view of the avionics system, showing the basic 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 3.2-12 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. Fail-operational is inherent in an active three string system without detection (or intervention). That was a primary reason for chosing such an organization.

Fail-safe (second failure) requires additional data. The Redundant Measurement Concept (Figure 3.2-13 and also incorporated in Avionics Control Concept Figure 3.2-11) shows redundant sensing of valve position available to all FMDM's. Commanded and sensed position are compared and annunciated on the graphic displays. Problems are also sent to the Orbiter caution and warning system and telemetry.

A new concept included in the avionics system, as shown in Figure 3.2-11, is the use of a 2-out-of-3 power voter module. Input commands are provided to the voter module from the three 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 3.2-10, 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 fluid supply 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 (Figure 2.7-2).

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 3.2-13, to assure that adequate data will be available to support safe operations even after two system failures.

FIGURE 3.2-10

OSCRS Avionics System Block Diagram

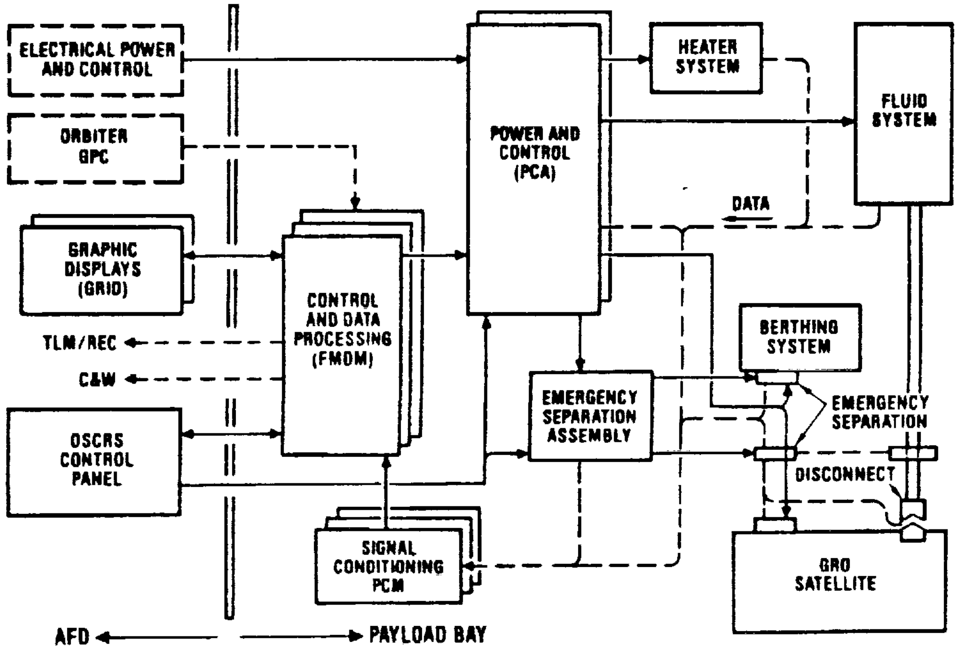


FIGURE 3.2-11 AVIONICS CONTROL CONCEPT

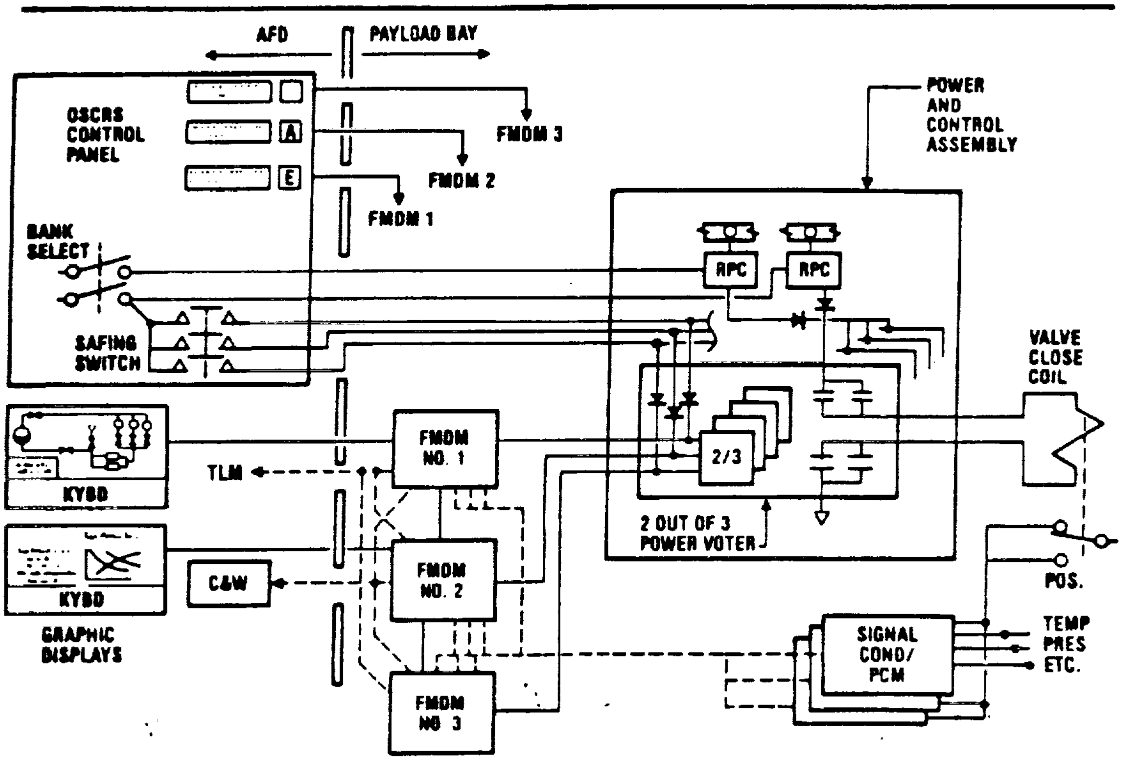


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FIGURE 3.2-12 OSCRS FMDM

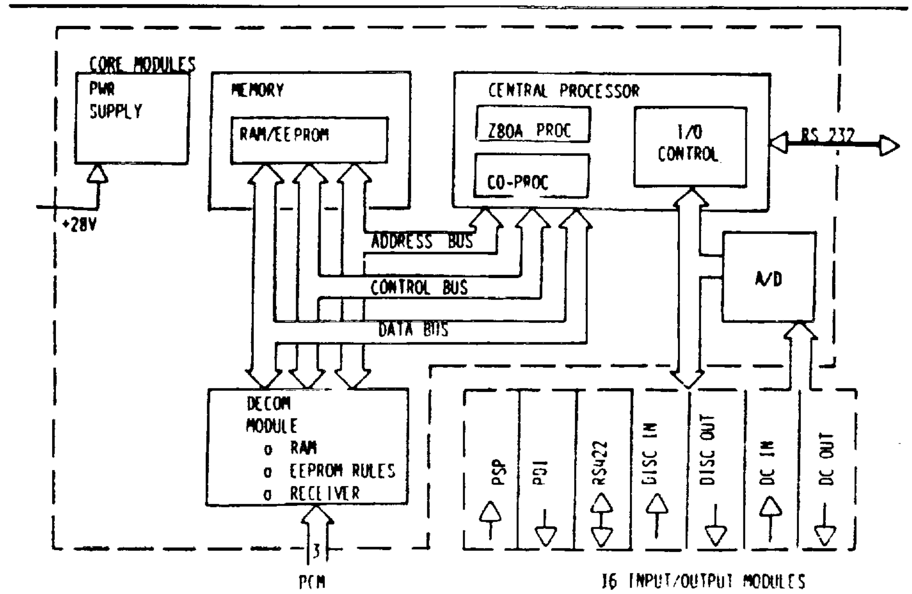
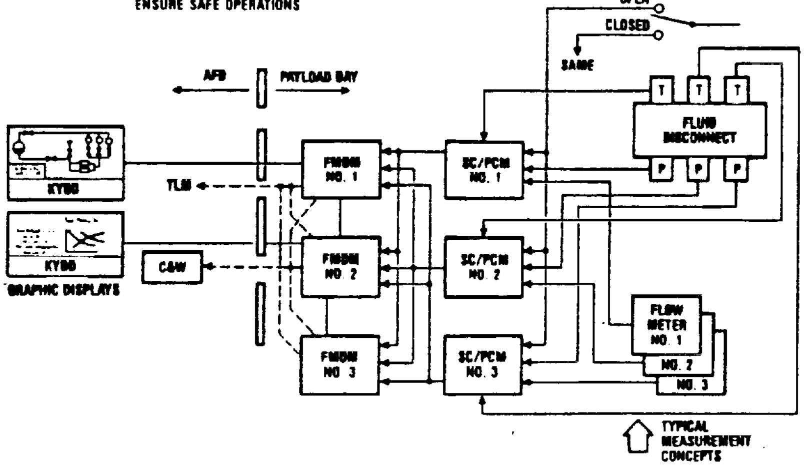


FIGURE 3.2-13

Redundant Measurement Concept

KEY REQUIREMENT THE AVIONICS SYSTEM WILL BE TWO-FAILURE TOLERANT TO PROVIDE CRITICAL DATA TO ENSURE SAFE OPERATIONS



The capabilities of the Orbiter Caution and Warning System are available to the OSCRS through a standard interface. 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 3.2-1.

3.3 AFD Avionics

The AFD avionics (Figure 2.7-2) 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 test 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.

3.4 Bipropellant Tanker Conceptual Design

The bipropellant tanker concept (Figure 3.4-1) utilizes the monopropellant tanker structure, and basic avionics and thermal subsystems, and incorporates a bipropellant fluid storage and distribution system in place of the monopropellant hydrazine system. The fluid system also incorporates high and low pressure pressurant resupply sources, 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 an area 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.

3.4.1 Common Structure with Monopropellant Tanker

The Generic vs. Dedicated Tanker Structure study (paragraph 2.3.2) concluded that the weight penalty (87 lbs) to increase the carrying capacity of the baseline GRO tanker from 2450 lbs of N_2H_4 to 8545 lbs of bipropellants was a good trade off for the increased flexibility gained with a common structure. Based on that conclusion, the bipropellant tanker primary structure is identical in design to the monopropellant tanker structure.

3.4.2 Fluid Subsystem Similar to Monopropellant Tanker

The modular fluid system concept developed for the monopropellant tanker provides an excellent basis for a generic fluid system, monopropellant, or bipropellant. The six propellant tank bays can be used to house three fuel and three oxidizer tanks arranged as shown in Figure 3.4-1 to achieve good c.g. control around the longeron and keel trunnions. The two bays reserved for pressurant gases can be used to store up to 28 lbm of deliverable GHe at 4200 psia and/or as storage areas for other spacecraft supply fluids or effluents. The major difference from the monopropellant tanker is the two fluid systems (fuel and oxidizer) required in the bipropellant tanker.

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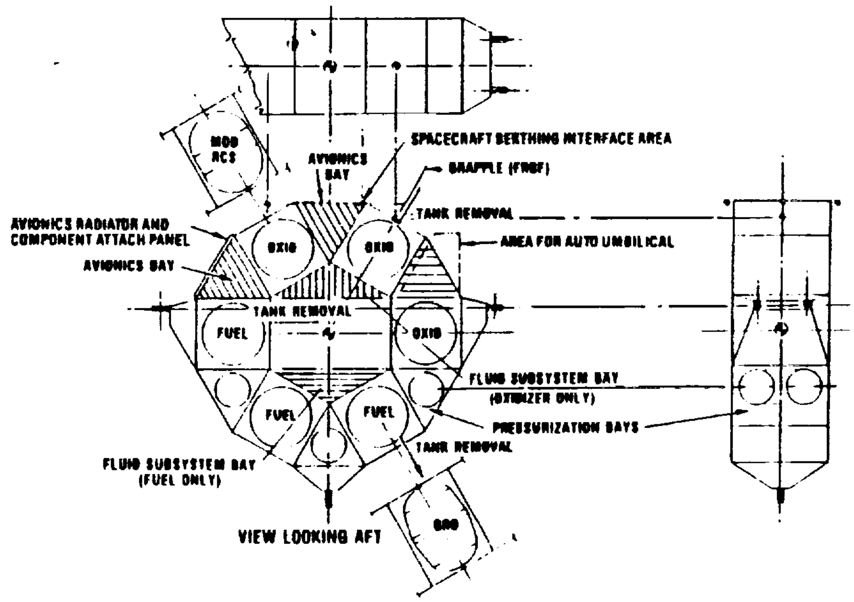
FIGURE 3.4-1

OSCRS Bipropellant Tanker Configuration



3.4.2.1 Fuel System Nearly Identical to Monopropellant Feed System

The feed system designed for the monopropellant tanker can be used for the fuel system in the bipropellant tanker. Compare the similarity of Figures 3.4-2 and 3.2-6. This includes propellant and ullage tanks and associated control components, flowmeters, pumps, service and checkout couplings, and instrumentation. Some differences may be required in the overboard vent system, since the catalyst used for N_2H_4 may have a short life when used with MMH or A-50 fuels due to carbon poisoning of the catalyst beds. A TBD alternative would be to use other catalyst materials and/or an ignitor system.

3.4.2.2 Oxidizer System Similar to Fuel Systems

The basic design of the oxidizer system is the same as is used for fuels. It is completely independant of the fuel system (Figure 3.4-3). Because of NTO compatibility issues, it is anticipated that some components will require alternative materials, both metallic and non-metallic.

A different propellant tank is required to handle oxidizer, since at present no diaphragm material is qualified for NTO. Therefore, a tank providing some other propellant acquisition device must be selected or developed.

3.4.2.3 Pressurant Resupply System Identical to Monopropellant Growth System

The pressurant storage and spacecraft resupply system (Figure 3.4-3) is identical to the system used as the monopropellant tanker, except independent transfer manifold couplings may be required for the fuel and oxidizer pressurant systems.

3.4.2.4 Spacecraft Ullage Disposal

Because the bipropellant spacecraft ullage cannot be easily and safely decomposed via a catalytic reactor, and because complete separation of NTO liquid and vapor cannot be assured, the ullage must be handled by other means.

The ullage exchange method is preferred wherever the spacecraft can support this method. Spacecraft ullage is transferred from the spacecraft to OSCRS tanks as the spacecraft tanks fill. If venting is required and the receiver tanks do not have ullage control capability, residual propellant should first be transferred to the tanker. The vapor should then be disposed of using a chemical reactor. For NTO, some development work is necessary to develop an adequate solid fuel reactor.

3.4.3 Thermal Control Subsystem (TCS) Similar to Monopropellant Tanker

With the exception of the fluid transfer interface TCS, the thermal subsystem is the same as is used for the monopropellant design. The bipropellant fluids are less sensitive to temperature extremes than hydrazine. Since the thermal design utilizes heating and control over the tanker volume rather than on a component-by-component basis, no additional TCS is required for the added fluid subsystem components.

FIGURE 3.4-2 BASELINE BIPROPELLANT FLUID SUBSYSTEM SCHEMATIC

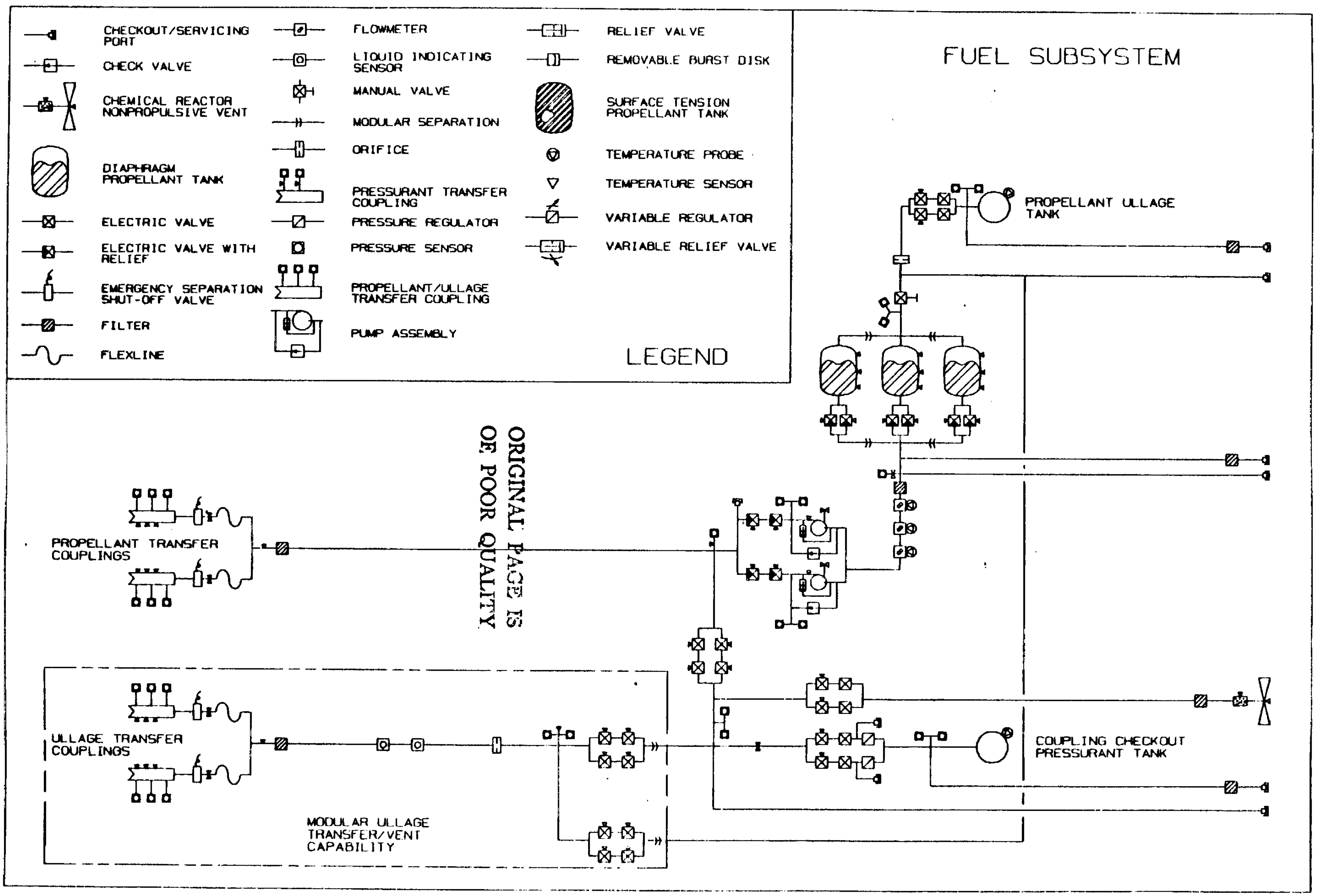
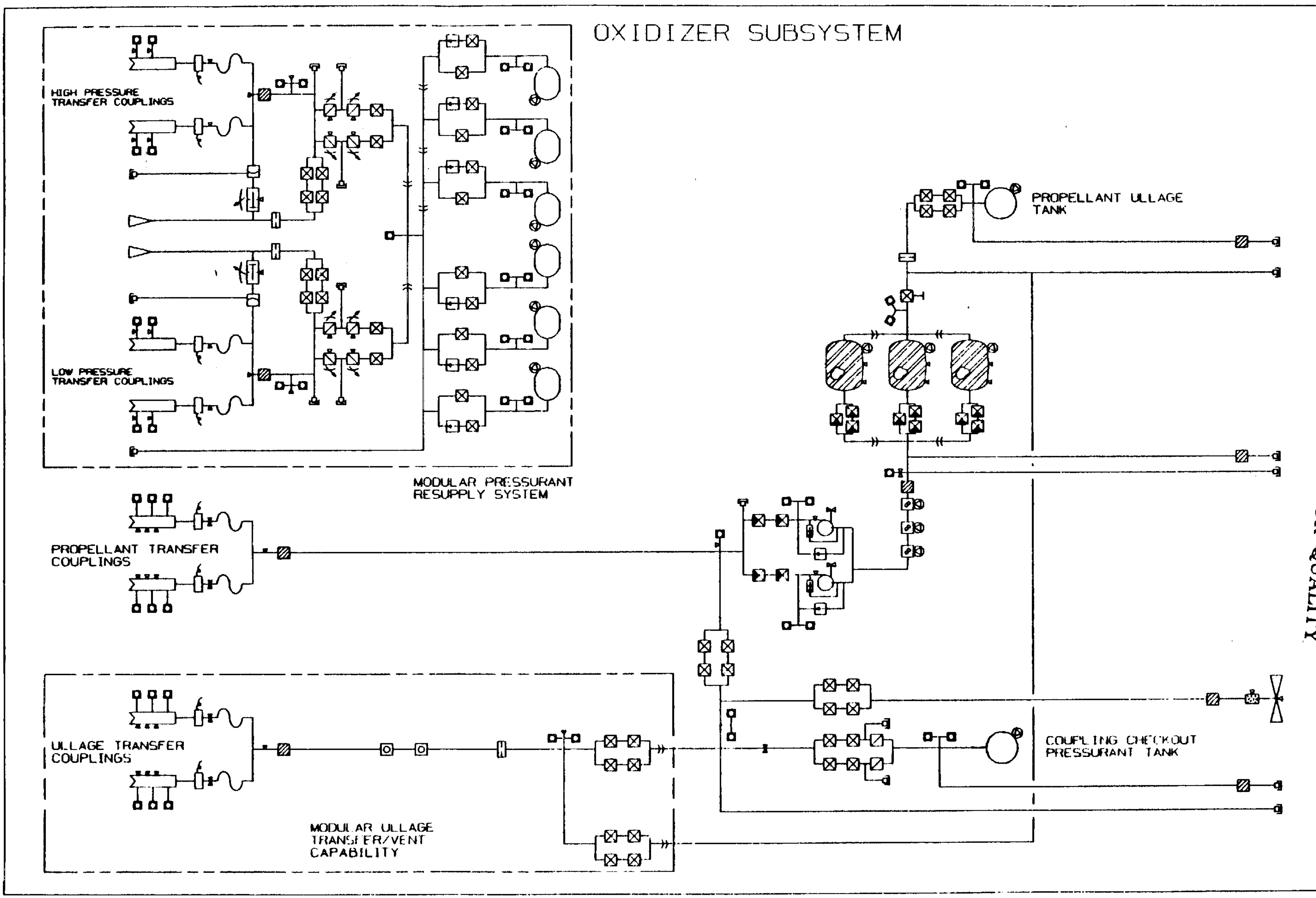


FIGURE 3.4-3 BASELINE BIPROPELLANT FLUID SUBSYSTEM SCHEMATIC



The bipropellant interface assembly is expected to be new, and should have an integrated thermal design.

When remote operations are considered, TCS changes may be necessary to reduce the peak power levels designed into the Orbiter in-bay system.

3.4.4 Avionics Subsystem Similar to Monopropellant Tanker

The avionics system conceptual design for a bipropellant OSCRS system is virtually the same as that of the monopropellant OSCRS avionics system.

The generic avionics system concept was purposely 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.

In the bipropellant resupply system, an automated umbilical assembly is recommended for fluid and electrical lines connecting the tanker module to the receiving spacecraft. 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 spacecraft. Emergency disconnect pyros would still be required for the TBD berthing mechanism, however.

The number of FMDM units and SC/PCM units would remain the same, three of each. 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 is expected to increase from two in the baseline monopropellant tanker to six in the bipropellant tanker.

The major change to the AFD avionics will be on the dedicated switch panel (Figure 3.4-4) which will have considerably fewer hardwired pyro actuator (PIC) switches. As noted above, emergency disconnect pyro's may still be required as shown in Figure 3.4-4.

3.5 Weight and Center of Gravity

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 analyses 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 valves. 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.

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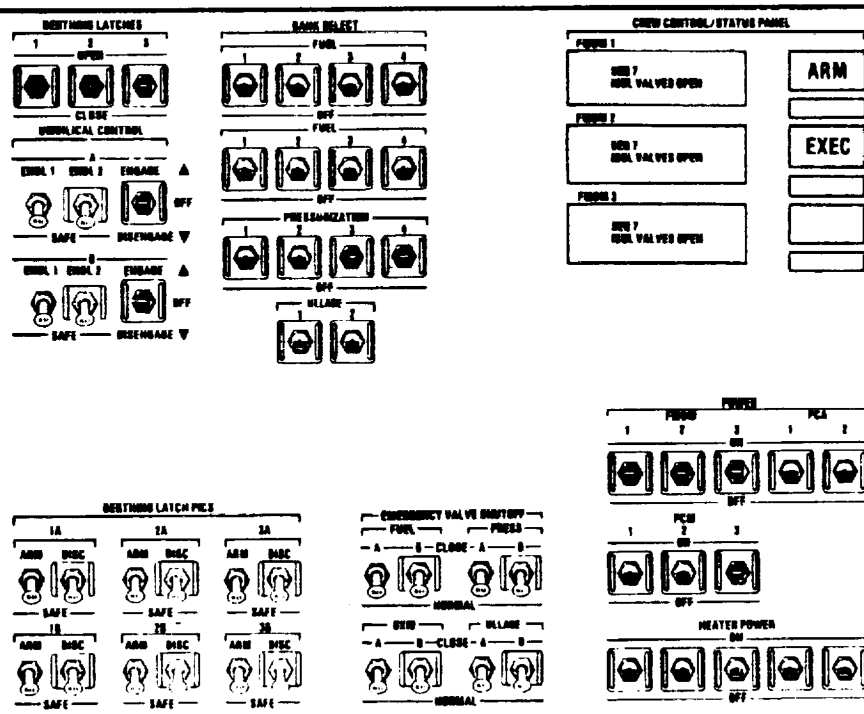
FIGURE 3.4-4

Bipropellant Resupply Control Panel



3.5.1 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 3.5-1 (GRO Tanker) and 3.5-2 (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.

3.5.2 Bipropellant Tanker Mass Properties

The dry and wet lift-off weights and centers of gravity of the fully loaded bipropellant tanker are shown in Table 3.5-3.

TABLE 3.5-1 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 3.5-2 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 3.5-3

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.

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4.0 Operation Considerations

An extensive analysis of the ground and flight operations was conducted during the study. There were no significant ground operations limitation identified with the existing KSC facilities nor with the existing or planned VAFB facilities. OSCRS unique GSE required to support the ground operations were identified and conceptual design requirements were prepared for all identified GSE.

4.1 KSC Operations

It was concluded that a dedicated OSCRS facility should be established to perform inspections; maintenance, refurbishment and reconfigurations; checkouts; fluid servicing (propellants and pressurants); and for storage of the tanker during non-use periods. Cryogenic building number 2 (M7-1410) is recommended for the monopropellant tanker dedicated facility.

An analysis of the turnaround operation indicates the monopropellant tanker can be processed between flight within the normal Orbiter turnaround timelines (Figure 4.1-1).

4.2 VAFB Operations

The turnaround processing flow of the OSCRS tanker at VAFB can perform with existing or planned facilities within the Orbiter turnaround timelines (Figure 4.2-1).

4.3 Orbital Operations

Analysis of the orbital operations during the GRO resupply mission indicates the resupply can be achieved in a single EVA (Table 4.3-1). If however, the orbital mission operations include EVA activities to support tanker relocation, at least 2 EVA's will be required.

4.4 Operational Constraints

Once developed and verified by a well planned certification program, the resupply mission should be achieved with very few operational constraints. The study did however identify some recommended or potential constraints or operations.

It is recommended that all hazardous fluids servicing should be performed in the hazardous processing facility (HPF) to avoid launch schedule impacts which would be incurred if servicing is performed at the launch pad.

The GRO resupply timelines depicted in Table 4.3-1 are based on conservative ullage recompression time/temperatures profiles performed by Rockwell. The GRO contractor has to date recommended even more conservative resupply times. To accept these more conservative resupply times will require two EVA's instead of the single proposed EVA.

FIGURE 4.1-1

OSCRS Processing Timeline (KSC)

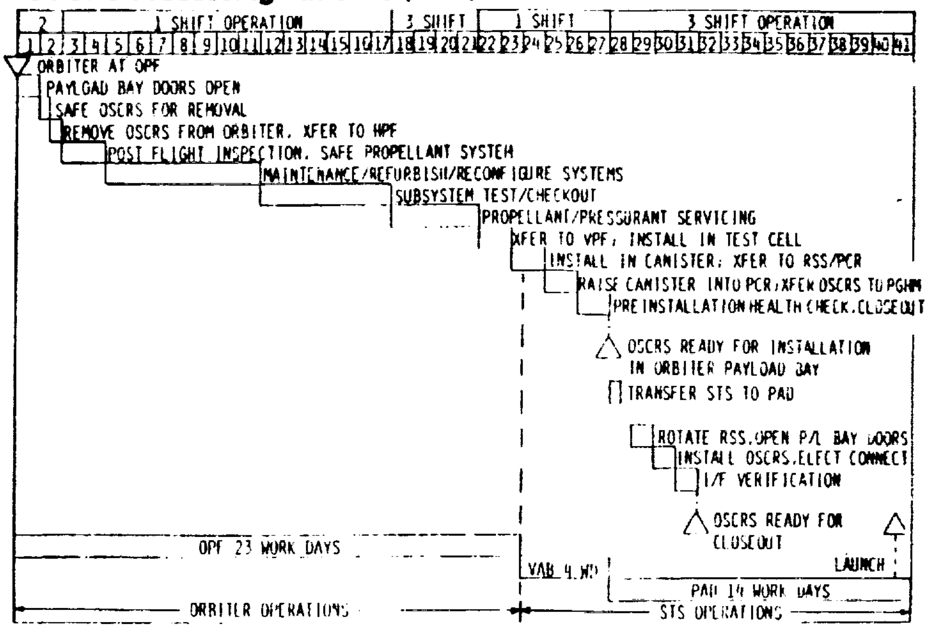

FIGURE 4.2-1

OSCRS Processing Timeline (VAFB)

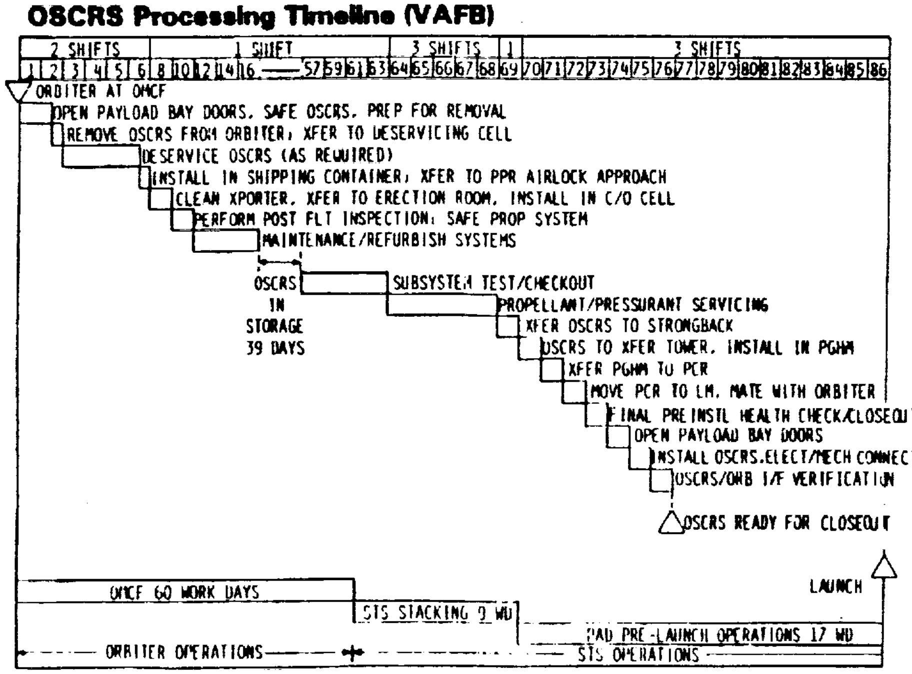

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TABLE 4.3-1 TRANSFER OPERATION TIMELINE

o 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

The berthing interface baselined herein for the GRO resupply tanker, has the FSS latch configuration permanently fixed to the tanker upper (+Z) structure. The fluid coupling interface, berthing CCTV, mass properties, and associated orbital resupply timelines are all based on the tanker mounted berthing interface. To incorporate the FSS A' cradle as the primary berthing mechanism will increase OSCRS launch weight and volume (cost) and require changes to the normal mate and emergency demate of the fluid and electrical umbilicals. It will also necessitate modification of the FSS A' cradle latches to accommodate emergency seperation without EVA. The orbital operations timelines may also be extended requiring a second EVA.

If tanker relocation is required during on-orbit operations several constraints may arise. A system safety status may be temporarily lost during the relocation process if Orbiter electrical umbilicals must be disconnected to achieve the relocation. A fully loaded OSCRS may alter the c.g., location required to ensure an acceptable Orbiter entry/landing c.g., if an emergency abort has to be performed prior to relocation to the launch position. Finally, the relocation process will extend the EVA timelines, thus requiring a second EVA.

The tanker cannot be ferry flown in the Orbiter vehicle aboard the SCA. The payload bay temperature and air flow are uncontrolled and the tanker thermal control system (which is optimized for the vacuum of space) will not keep the hydrazine components, lines, and propellant tanks above freezing. Thawing of propellant after freezing can cause lines and components to structurally fail. Freezing of the propellant tank diaphragms would cause loss of very expensive and costly to replace hardware.

4.5 GSE

A thorough evaluation of the necessary GSE required to support ground operations was performed. Sixteen (16) pieces of equipment were identified to support the monopropellant tanker operations. Twelve (12) are fluid/mechanical, four (4) are avionics/electrical. GSE item identification sheets (GIIS) were created and GSE concepts developed. Figures 4.5-1 and 4.5-2 show typical equipment.

The GSE developed for the monopropellant tanker can also be used to support fuel system operations of the bipropellant tanker. Six unique pieces of GSE were also developed for the oxidizer system of the bipropellant tanker.

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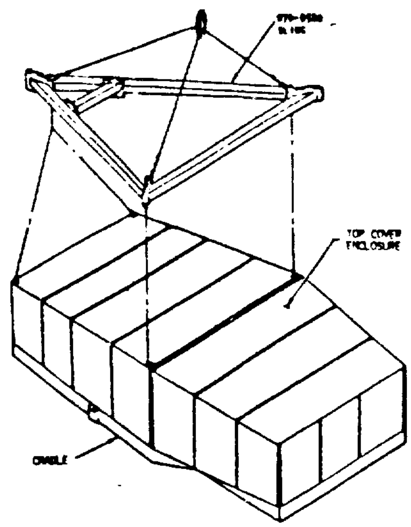
FIGURE 4.5-1 TYPICAL HANDLING GSE CONCEPT

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



TOP COVER - CONTAINER ASSY

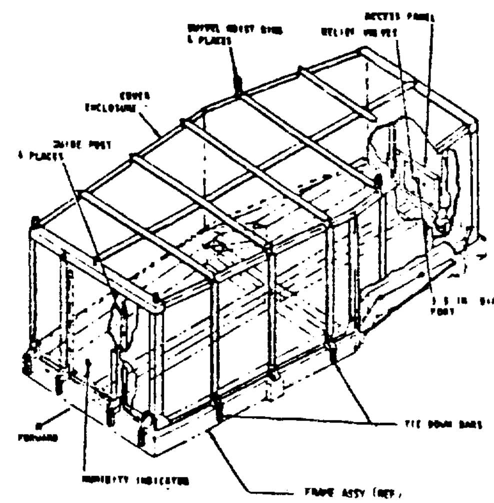
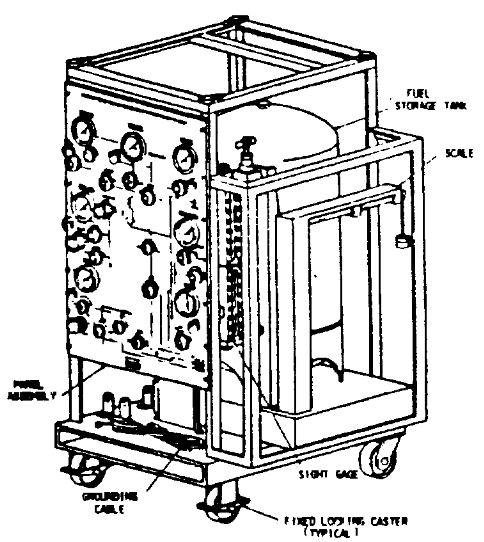
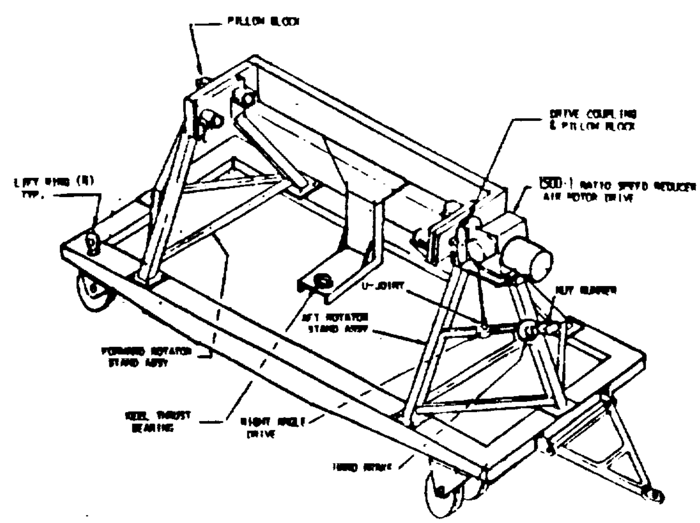


FIGURE 4.5-2 TYPICAL FLUID/MECHANICAL GSE CONCEPTS

FUEL SERVICING/DESERVICING UNIT



TANKER SUPPORT STAND



5.0 Program Cost Estimates

Cost analyses were performed for both a monopropellant OSCRS program and a bipropellant OSCRS program. The cost estimates were based on the monopropellant baseline tanker and its associated control avionics being developed, fabricated, qualified for limited flight usage, and delivered to the NASA within 41 months from authority to proceed (ATP). In consonance with the study SOW, ATP was assumed to be in October 1987. The costs also include the required GSE and those contractor costs associated with support of first flight operations. The baseline tanker was assumed to be developed and qualified for the GRO mission only.

5.1 Cost Optimization Efforts

The basic OSCRS tanker philosophy maximizes commonality between the baseline monopropellant tanker required to resupply GRO with less than 2500 lbm of N_2H_4 and the future earth storable fluids resupply tanker which will be required to resupply over 7000 lbm of bipropellants. This commonality was optimized by use of the hybrid tanker concept which has a common structure for all earth storable propellant tankers, and modularizes all subsystems so that only mission essential elements need to be certified in the baseline tanker and flown in any future mission scenarios. The hybrid structure is incorporated into the baseline tanker (GRO) at a weight penality of 87 lbs. The subsystem tare weight for unused modules is kept essentially nil by proper planning and good design practices.

The tradeoff of program cost savings associated with developing and producing a generic hybrid tanker versus the increased operations costs associated with the hybrid structure weight impact (87 lbs) on GRO resupply quantities ($\sim$ 2500 lbm) is complicated by future mission uncertainties. However, the overall programatic gains from a hybrid earth storables fluids tanker should be more economical than dedicated tanker concept for each fluid capacity range (e.g., 1000-2500 lbm, 2500-5000 lbm, and 5000-8500 lbm).

Unique program features which aid in low schedule risks (always a large cost influence) and optimization of the commonality features of the hybrid tanker include:

- o Initial development of a baseline monopropellant tanker to satisfy the GRO mission keeps front end costs low and schedule risks minimal.
- o Monopropellant and bipropellant fuel systems are of a common design.
    - o Common development and qualification
    - o Monopropellant qualification system used for fuel system in bipropellant qualification test program.
- o Pump fed system is common to the monopropellant and bipropellant tankers.
- o Blowdown pump fed system minimizes components and complexity.
- o Avionics hardware design is common for all tanker configurations.
    - o Modular add-ons used as fluid subsystems growth

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- Modularized software provides commonality for all mission scenarios.
  - Mission constants in core
  - Mission unique requirements in replaceable modules
- Cascade Pressurant resupply simplifies design and reduces technology development.
- Engineering mockup doubles as design aid and crew interface tool, including wet tank operations (simulated zero-g).
- Bread board tests initialize system/component characteristic early-on.
- Limited life qual on flight article reduces first article qualification and production costs.

5.2 Costing Approach

Cost estimating can be done by Analogy, Grassroots using expert judgement, or by Algorithmic models. The estimates performed under this study used the algorithmic model to determine the monopropellant OSCRS program costs. The bipropellant OSCRS program costs were estimated by Engineering using an Analogy comparison to the monopropellant system.

The major strength of using algorithmic models is they are not biased by subjective factors such as desire to win or please. They also present repeatable results. To further remove subjectivity from the review, the analysis was subcontracted to an outside company (ECON, Inc.).

The analysis was performed using the RCA PRICE H & S models.

Since the fluid subsystem is potentially hazardous to the Orbiter, spacecraft and the crew who will interface with the OSCRS, it was man rated in the analysis. On the other hand, since the structure, mechanism, thermal control system and avionics are all relatively benign, they were all rated as unmanned.

5.3 Estimated Costs

The estimated cost through DDT&E for the monopropellant system is $45.1 M. Production costs for the first article are estimated at $17.1 M. Operations support costs through the first mission (GRO resupply) including post flight checkout, modification and data analysis and reporting, is $1.0 M. The total cost estimate for the monopropellant OSCRS DDT&E, Production and Operation support is $63.2 M (Figure 5.3-1).

The estimated cost for the bipropellant OSCRS through DDT&E and first unit production is $62.8 M (Figure 5.3-2).

The combined program funding to support concurrent monopropellant and bipropellant development and production programs (parallel but bipropellant lags by 12 months) is shown in Figure 5.3-3.

FIGURE 5.3-1

PHASE C/D MONOPROPELLANT OSCRS PROGRAM COSTS

TOTAL PHASE C/D COSTS = $63.2 M

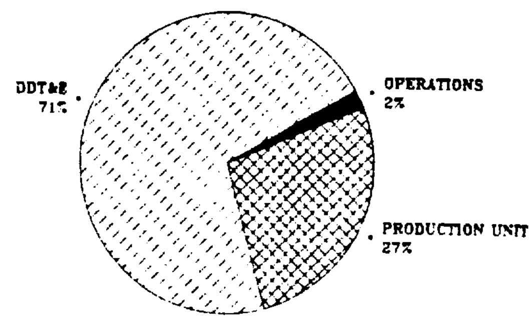


FIGURE 5.3-2

PHASE C/D BIPROPELLANT OSCRS PROGRAM COSTS

TOTAL PHASE C/D COSTS = $ 62.8 M

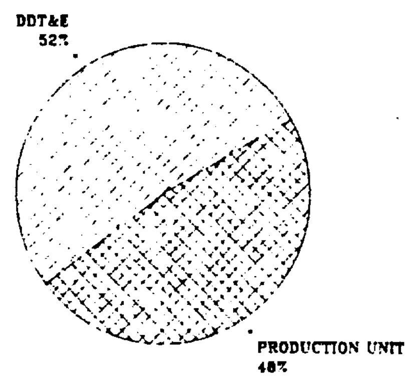
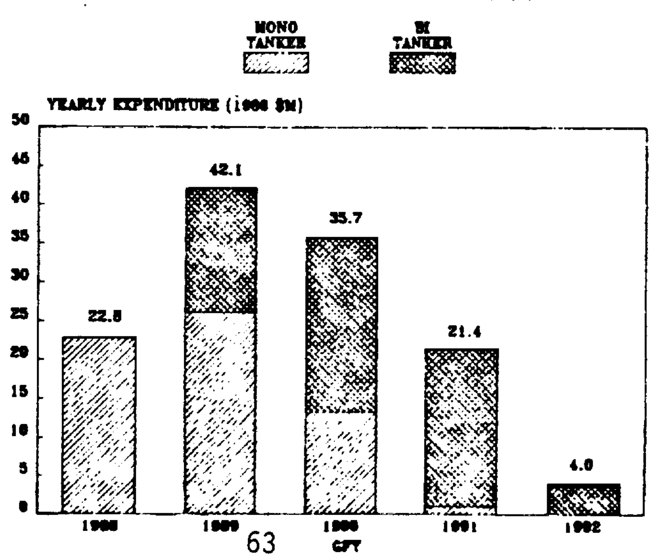


FIGURE 5.3-3

EXPENDITURE PROFILE

FOR A MONO & BIPROPELLANT TANKER



6.0 Conclusion and Recommendations

The study resulted in some significant conclusions and recommendations which should aid the NASA in directing the OSCRS program objective.

6.1 Significant Conclusions

- o There is wide interest and need for earth storable fluids resupply within the next decade.
  - o GRO is committed to resupply of N 2450 lbm of N_2H_4 in the early 1990's.
  - o Space Station will require periodic resupplies of 2300 lbm of N_2H_4 and other fluids in the early-mid 1990's.
  - o DOD will require up to 7000 lbm bipropellant and pressurant gas resupplies in the early 1990's.
- o A hybrid-generic tanker can be economically developed to meet the initial (GRO) resupply requirements yet retain the features which allows growth into a bipropellant tanker concept.
  - o Structures sized for over 7000 lbs of fluids penalize the baseline GRO tanker 87 lbs.
  - o Modularization of subsystem elements limits scar weights to mission essentials only.
- o Development of the uncomplicated ullage blowdown pump fed system will provide commonality between the monopropellant and bipropellant tanker systems.
- o Future needs for pressurant resupply can most easily and economically be achieved by cascade blowdown.
  - o Avoids the need to develop space rated compressors.
  - o Simplifies remote operations.
- o A three-string avionics system will provide commonality to manned in-bay FO/FS operations and remote automatic operations.
  - o Redundant commands will assure continuous operations.
  - o 2-out-of-3 voter prevents inadvertant operations.
  - o Avoids extensive and often inconclusive single string verification tasks.
- o It will take approximately $62 M and 41 months lead time to design, develop, qualify, produce and deliver the first (GRO) resupply tanker and associated avionics, and the supporting GSE.
  - o The fluid subsystem should be man rated.
  - o Structures, Thermal Control and Avionics can be unmannned rated.
- o Future resupply scenarios will require more sophisticated unmanned/automatic spacecraft/tanker interface capabilities.
  - o Remote/automatic berthing.
  - o Remote/automatic fluid and electrical umbilical mate/demate.

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6.2 Recommendations

The following recommendations are made to guide the NASA in establishing the design, development, and first article production phase of the OSCRS program.

- Develop a hybrid earth storable tanker to meet the GRO resupply commitment and future needs of 7000 lbm of bipropellants.
- Develop a pump fed system which can be used in both the monopropellant and bipropellant tankers.
- Baseline a three-string avionics control system.
- Plan $62 M and 41 months leadtime to develop, qualify and deliver the first monopropellant tanker.
- Continue technology to develop remote/automatic spacecraft servicing.