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12P ORBITAL FLUID RESUPPLY ASSESSMENT * 252715
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ABSTRACT

Orbital fluid resupply can significantly increase the cost-effectiveness and operational flexibility of spacecraft, satellites, and orbiting platforms and observatories. Reusable tankers are currently being designed for transporting fluids to space. A number of options exist for transporting the fluids and propellant to the space-based user systems. The fluids can be transported to space either in the Shuttle cargo bay or using expendable launch vehicles (ELVs). Resupply can thus be accomplished either from the Shuttle bay, or the tanker can be removed from the Shuttle bay or launched on an ELV and attached to a carrier such as the Orbital Maneuvering Vehicle (OMV) or Orbital Transfer Vehicle (OTV) for transport to the user to be serviced. A third option involves locating the tanker at the space station or an unmanned platform as a quasi-permanent servicing facility or depot which returns to the ground for recycling once its tanks have been depleted. Current modular tanker designs for monopropellants, bipropellants, and water for space station propulsion are discussed. Superfluid helium tankers are addressed, including trade-offs in tanker sizes, shapes to fit the range of ELVs currently available, and boil-off losses associated with longer-term (greater than 6-month) space-basing. Our study concluded that the mixed fleet approach to on-orbit consumables resupply offers significant advantages to the overall logistics requirements.

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INTRODUCTION

Orbital fluid resupply can significantly increase the cost-effectiveness and operational flexibility of spacecraft, satellites, and orbiting platforms and observations. Potential on-orbit resupply application categories are summarized in Table I. The most likely early applications will consist of resupply operations from the STS Orbiter. Satellites (or other users) in higher orbits can be reached by using an automatic refueling system on an Orbital Maneuvering Vehicle (OMV) and/or an Orbital Transfer Vehicle (OTV). Tankers can also double as space-based depots at either the space station or polar orbiting platforms. Propellant could be supplied to the depots as launch vehicle payload capability is available (i.e. the tanker could be used as a filler payload). Also, it may be more economical to refuel satellites with small fuel requirements from depots because tankers with small fuel capacities are not very efficient.

Refueling could significantly enhance DoD missions by allowing greater maneuvering capability for survival, improved mission performance, (e.g. moving to different orbits in response to changing military or political activities), reduced launch weight of propulsion systems to permit greater payload on growing weight-intensive satellites, and possibly scavenging disabled spacecraft. Another DoD requirement is refueling for Strategic Defense Initiative (SDI) applications.

An increased level of conceptual design work on tankers for storable propellants and fluids occurred in 1986 under the Orbital Spacecraft Consumables Resupply System (OSCRS) contracts with the NASA Johnson Space Center¹⁻³. This initial study focused primarily on monopropellant hydrazine and bipropellant nitrogen tetroxide and monomethylhydrazine resupply performed from the Orbiter cargo bay. The initial servicing would involve astronaut control from the Orbiter Aft Flight Deck (AFD), and Extravehicular Activity (EVA) for umbilical mating and demating operations. Safety was a major design driver, requiring two-fault tolerant, man-rated design approaches to preclude unacceptable risk of hazardous situations in the cargo bay.

The potential of reduced launch capability following the Challenger accident introduced the possibility of using Expendable Launch Vehicles (ELVs), in addition to the Shuttle, in a mixed fleet approach to transporting fluid and propulsion consumables to orbit. The requirement to launch the tankers on ELVs as well as the Shuttle was thus addressed, along with increased emphasis on tanker / OMV interfaces and operations⁴⁻⁵. This became the only approach for polar satellite/platform consumables servicing since the Shuttle was removed from polar launch manifesting out of Vandenberg. An increased emphasis on automatic interfaces and operations accompanied these studies since unmanned, in-site servicing became the only way of implementing the polar orbit servicing mission.

A companion Superfluid Helium Tanker (SFHT) program was conducted in 1987-1988⁶, evaluating the potential of taking superfluid helium to orbit to resupply instruments, observatories, and laboratories with helium at approximately 2 Kelvin. In addition to the above design considerations, a key design driver for this cryogen is the Dewar size and thermal design that can meet environment launch requirements and still minimize the attendant boil-off losses. Ground servicing considerations become much more critical for this category of tanker, especially as ground hold requirements are levied on the design options for the range of launch vehicles considered.

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In the next section tanker interfaces are discussed, including those of the launch vehicles, those of the OMV and those with the space station when the tanker is used as a space-based depot. Storable resupply tankers and the superfluid helium resupply tanker are then discussed in separate sections. The concepts for tanker launch and orbital operations are discussed for each. The aspects of a mixed fleet capability for each category of tanker are emphasized, leading to conclusions regarding mixed fleet concept feasibility and desirability.

TANKER INTERFACES

LAUNCH VEHICLES

A review was made of existing ELV's to determine parameters such as cost, payload capability, and fairing size⁷⁻¹⁰. The results are shown in Table II along with comparable data for the Shuttle¹¹. Published launch costs for all of the vehicles tend to vary widely since they usually are tied to procurement rates. The launch costs shown represent the "best" number we could obtain, sometimes being an average of several published numbers. A wide range of fairing and payload adapter diameters are available. For example, the Titan III provides payload adapters in eleven different diameters. Of the available payload fairings, the Delta II fairing has the smallest diameter (10 feet O.D.) and would present the most difficult packaging problem. However, designing a tanker to fit within this fairing would mean that the tanker could be launched on any of the other ELV's, but would result in a length and weight penalty for a Shuttle launch. Operational aspects such as manifesting flexibility, simplified ground operations, degree of integration required with other payloads manifested to fill up the launch capability, and requirements for on-orbit carrier (e.g., OMV) usage for non-manned automatic operation, become important additional considerations of mixed fleet feasibility. A description of the interface requirements and features of the various launch vehicle, carrier and depot options is helpful in addressing this mixed fleet feasibility.

Tanker/STS Interfaces. The STS can be both the launch vehicle and the base of operations for a resupply tanker. Interfaces required between the resupply tanker and the STS are structural, electrical, and fluid. The tanker can be launched in the STS, removed on-orbit for use as a depot at the Space Station, and then replaced in the cargo bay for return to the ground. Any required interfaces with the Orbiter must therefore be mateable and demateable on-orbit. OSCRS-to-STS interfaces are shown in Fig. 1.

Table I On-Orbit Resupply Applications

Refueling Satellites	
- STS (Orbiter) Tanker	
- OMV Servicer	
- OTV/OMV Servicer	
Depots	
- Space Station (SS)	
- Polar Platform	
DoD Mission Enhancements	
- Maneuverability (Survivability)	
- Launch dry to reduce propulsion system weight	
- Improved mission performance capability	
- Scavenging of disabled spacecraft	
Other	
- Cargo bay kit for Orbiter OMS/RCS	
- OMS propellant scavenging	
- Filler payload for the Orbiter	
- Strategic Defense Initiative (SDI).	

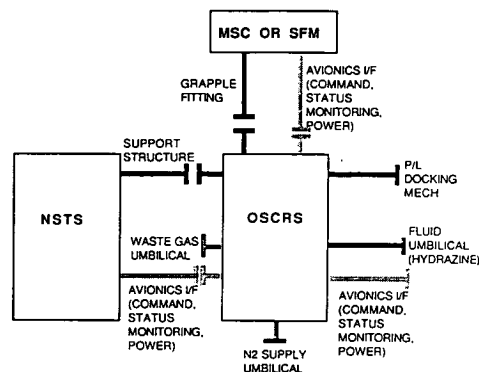


Figure 1 OSCRS-to-STS Interfaces

Table II Launch Vehicle Comparison

PARAMETER	DELTA II	ATLAS/CENTAUR	TITAN III	TITAN IV	STS
LAUNCH COST	\$45M*	\$59M*	\$110M*	\$160M**	\$140-\$245M
PAYLOAD TO 250 NM ORBIT, LBS	8000 (6920) 10000 (7920)	10500	29500	-39000	48000***
DOLLARS PER POUND (TO ABOVE ORBIT)	5625	5619	3729	4103	2917-5104
PAYLOAD FAIRING I.D., IN.	110	115,143.7	143.7	180.0	180.0
PAYLOAD ADAPTER INTERFACE DIAMETER, IN.	32.5,60	32.5	32.8-70.0	111.77	N/A

*FROM DATA SUPPLIED BY NASA LARC FOR COLD-SAT PROGRAM

** HARDWARE COSTS ONLY, NO MISSION SUPPORT/ INTEGRATION INCLUDED

***WITH PERFORMANCE UPGRADES

Structural interfaces consist of the standard trunnion and keel fittings located on the tanker cradle. An active keel mechanism is required to permit berthing and unberthing of the tanker while on-orbit. Also, a minimum of two standard remote manipulator system (RMS) grapple fixtures will be required to permit the Shuttle RMS to perform the berthing/unberthing process and to pass off the tanker to the Space Station Mobile Servicing Center (MSC) or a Service Facility Manipulator (SFM). The electrical interface between the tanker and the Shuttle will be used to provide power, monitoring, and control to the tanker. This interface will also require a mateable/demateable electrical coupler for those missions where the Shuttle is serving only as the launch vehicle and not the base of operation of the tanker.

Tanker/ELV Interfaces. Launch of the resupply tanker on an ELV requires interfaces similar to those required for a Shuttle launch. An interface to the ELV payload adapter to react launch loads, and an electrical interface for power and telemetry, will be required. Additionally, interfaces with the GSE during the ground processing flow will require access holes in the ELV payload fairing to allow for servicing, and power and monitoring via the tanker GSE. Also, as in the Shuttle launch case, vent interfaces with the fairing are required for both normal and emergency venting of cryogenic tankers such as the SFHT. These interfaces should be located to use the same ground service panel on the SFHT as during Shuttle launch processing. The tanker/ELV structural interface is a deployable interface requiring the use of explosive bolts to allow the tanker to be ejected on-orbit.

OMV INTERFACES.

Interfacing the tanker and the OMV for transport in-orbit will require both structural and electrical interfaces. The OMV, shown in Fig. 2, can provide payloads with three types of structural interfaces¹². The Three Point Docking Mechanism (TPDM) interfaces with standard FSS type latches and consists of three coordinated latches mounted on a structural ring, with redundant TV cameras, lights, and electrical umbilicals. The RMS Grapple Docking Mechanism (RGDM) interfaces with a standard RMS grapple fixture and incorporates three snare wires with retracting mechanism, cameras and lights, and an integral electrical connector. Both of these interfaces are intended for orbital operations and are therefore limited in the loads they can withstand. Payloads can be bolted to the front face of the OMV using a 135-inch diameter circular interface capable of 10000 ft-lbs cantilevered moment for Shuttle launch. This bolted interface can be mated or demated by an astronaut via EVA on-orbit.

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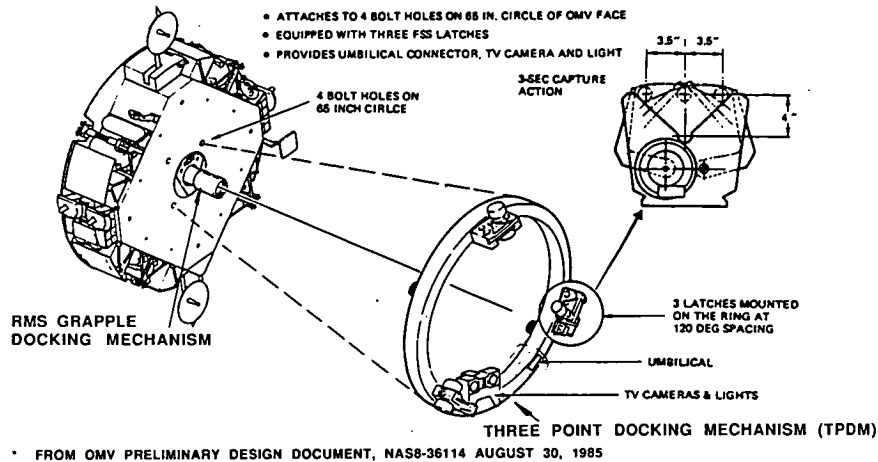


Figure 2 OMV Payload Accommodations Equipment (PAE)

In addition to a structural interface, an electrical interface for power and telemetry will be required. The OMV provides 5 kwh total power to a payload (with 1 kw peak), and the Fairchild data system for payload use. The tanker has to provide the necessary hardware for pass-through of OMV utilities to the user spacecraft being serviced. The tanker/OMV electrical interface would be a part of the TPDM or RGDM mechanisms. Additional equipment will be required by the tanker to operate while attached to the OMV even though this equipment is not a direct physical interface with the OMV. A docking target visible to the camera package on the OMV's TPDM will be required to ease mating of the tanker and OMV on-orbit. Once attached, a camera and light package would be attached to the front face of the tanker to allow viewing for mating to a user spacecraft. An automatic coupler mating mechanism on the front face of the tanker would also be required to mate fluid and electrical couplers to the user along with an FSS or similar interface to mate with the user spacecraft.

SPACE-BASED DEPOT (SPACE STATION INTERFACES).

Resupply tankers will be designed to be stored at the Space Station to perform periodic resupply for a variety of users. Since a specifically configured Servicing Facility is not currently part of the Space Station baseline configuration¹³, interfaces were defined assuming the tanker is attached to the truss assembly only. These interfaces consist of structural, electrical, and fluid interfaces. Fig. 3 shows a servicing facility concept as an unpressurized structure attached to the transverse boom adjacent to the pressurized modules.

The tanker could be attached to the truss assembly using a standard docking mechanism such as the multi-mission spacecraft Flight Servicer System (FSS) latches, or alternately, could be attached to the truss via the trunnion and keel fittings. An additional structural interface requirement, although not directly a part of the tanker structure, is for meteoroid and space debris protection. This protection is required since the tanker may spend up to 12 months attached to the Station. The amount and configuration of this protection depends on the location of the tanker on the Station and how much it is shielded by other elements of the Station. Regardless of particular location of the tanker at the Space Station, the debris protection would be left on the Station and not incorporated in the tanker structure to save weight. The meteoroid and space debris protection would consist of an aluminum

panel 0.08-cm (0.03-in) to 0.19-cm (0.075-in) thick configured with hinges to allow it to be folded away so that the tanker could be removed or replaced.

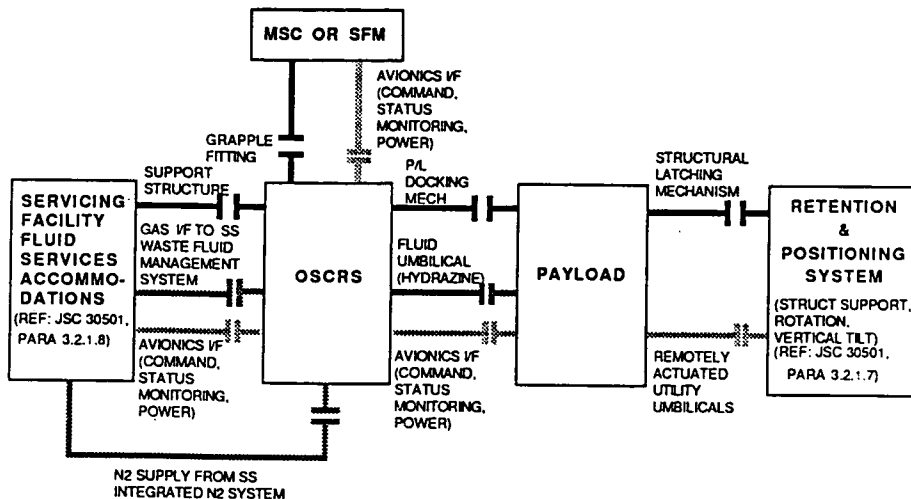


Figure 3 OSCRS-to-Station Servicing Facility/Payload Interfaces

An electrical interface provides power, command, and data handling from the Space Station avionics. The Space Station avionics replaces the Shuttle Aft Flight Deck control system for controlling and monitoring the tanker during all phases of its mission. This interface must also be mateable and demateable. An electrical interface between the tanker and the Station MRMS would not be required unless it was desired to perform replenishment operations while attached to the MRMS.

STORABLE FLUID RESUPPLY TANKERS

MONOPROPELLANT TANKER

Martin Marietta's original approach to the design of a monopropellant hydrazine OSCRS tanker is shown in Fig. 4. The tanker was designed to be carried to space in the Shuttle with an option to be removed from the Shuttle for use as a space station depot or carried by the OMV to a user for in-situ servicing. The tanker utilized a modular design approach where storage tanks could be added or removed to match the capacity of hydrazine required to be resupplied to the user. Excess tank capacity was thus not launched, thereby maximizing the mass fraction of propellant mass-to-dry mass on each servicing mission.

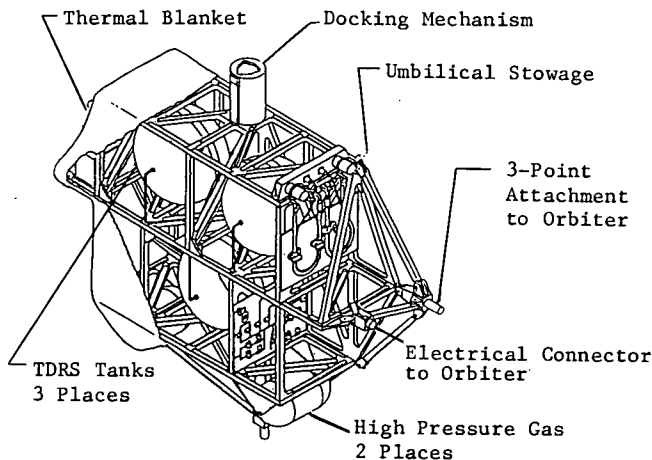


Figure 4 OSCRS Basic Monopropellant Configuration

The baseline monopropellant fluid subsystem used a pressure fed system approach to expel the propellants. The monopropellant hydrazine OSCRS schematic is shown in Fig. 5. A catalytic vent system to allow overboard venting of residual propellants and propellant-contaminated pressurants was also included. Three Tracking and Data Relay Satellite System (TDRSS) tanks were used to provide a total propellant load of 1323 kg (2910 lb), enough to resupply the Gamma Ray Observatory (GRO) spacecraft, at a mass fraction of 0.60. Provisions were included for two additional TDRSS tanks in an add-on propellant module, additional pressurant tanks for propellant expulsion, and an add-on module for pressurant resupply. The propellant tanks were plumbed to allow

expulsion individually or in combinations up to all tanks simultaneously. These add-on features allowed a maximum monopropellant load of 2205 kg (4850 lb) at a tanker mass fraction of 0.66.

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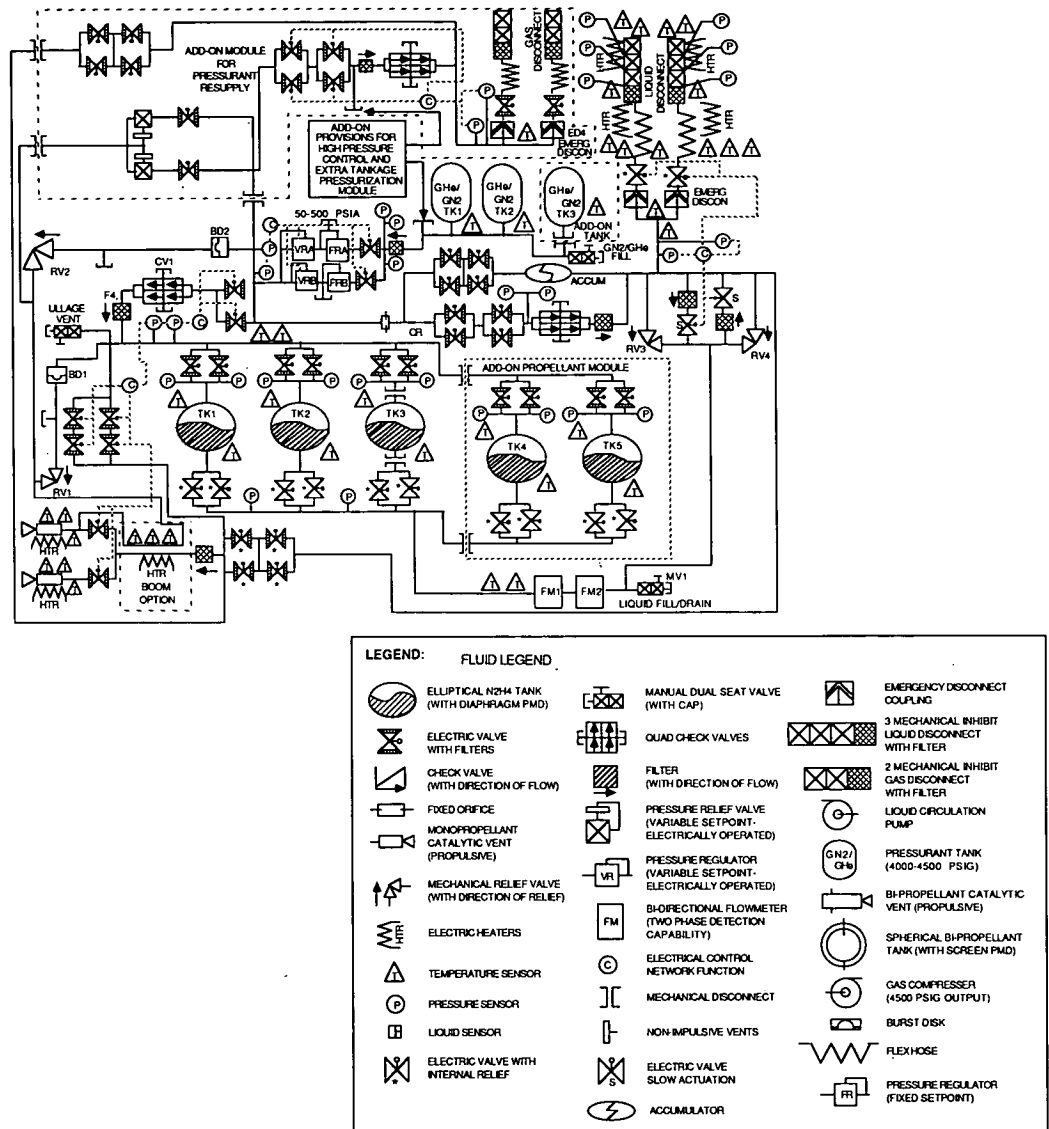


Figure 5 Monopropellant Fluid Subsystem Schematic

The shuttle Challenger accident, with the accompanying tightening of launch vehicle resources, opened the possibility of launch of some logistic-type payloads using Expendable Launch Vehicles. The potential launch compatibility of the OSCRS tankers with ELVs resulted in the identification of design changes to provide a number of operating options, such as:

- 1) Modularizing the OSCRS subsystems (primarily the avionics subsystem and the fluid subsystem) to allow elements to be based on the Space Station, thereby substantially increasing the up/down mass fraction;
- 2) Reconfiguring the OSCRS structure to allow easy interfacing with the OMV structure, since this is a necessity for payloads launched on an ELV;
- 3) Repackaging the OSCRS structure to accommodate launch on ELV's with payload fairings of 143.7-inch inner diameter or greater;
- 4) Incorporating into the OSCRS structure the ability to accept an automatic coupler/docking mechanism.

The above changes resulted in a new baseline OSCRS shown in Fig. 6. To provide the dual capability of Shuttle and ELV launches, and Shuttle on-orbit retrieval of the OSCRS, the trunnion and keel fittings and their attachment structure are designed to be removable or deployable. The main OSCRS structure would remain within a 143.7 inch diameter static envelope of the Atlas Centaur and Titan ELV payload fairings. The revised

structure also allows attachment to the OMV and Space Station via the planned structural attachment mechanisms. In order to achieve the reduction in diameter while maintaining the same propellant load as the original baseline, different propellant tanks are used. After a review of existing tanks, the tanks used in the Gamma Ray Observatory were selected. This allows the same propellant load with fewer tanks, since the GRO tanks have a greater capacity than the TDRSS tanks of the baseline configuration.

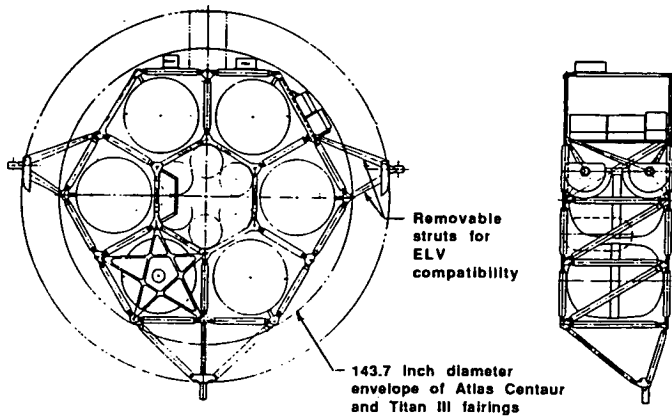


Figure 6 Modular Monopropellant OSCRS Design

The structure itself consists of three machined panels attached to each other by nine graphite/epoxy composite struts. The center of the structure is left open to facilitate attachment to the OMV and installation of an automatic umbilical mating mechanism. The estimated weight savings of this structure compared to the baseline is approximately 15%. The resulting configuration provides the flexibility of launch on an ELV or Shuttle, and a common structure and tanks for water, monopropellant, and bipropellant tankers. Flexibility in both launch manifesting and operations is thus provided in the tanker systems to accommodate different users and resupply scenarios with a minimum number of tanker designs.

BIPROPELLANT TANKER

A bipropellant OSCRS tanker for resupplying monomethyl hydrazine (MMH) and nitrogen tetroxide (NTO) is shown in Fig. 7 with the major subsystems and subsystems elements identified. The same simple pressure-fed approach adopted for the monopropellant tanker to expel propellants into user tankage was also selected for the baseline bipropellant design. Six L-SAT-type propellant tanks with screen-type propellant management devices, and six pressurant bottles, make up the basic fluids capability. Features of the basic bipropellant fluid subsystem design are shown schematically in Fig. 8. The bipropellant tanks are plumbed so that they can be depleted individually, in combinations up to all three at the same time or in a series arrangement. The oxidizer and fuel tanks are identical. Two of the tanks (one each oxidizer and fuel) are used as receiver "catch" tanks. They are used to dump the residual propellant remaining in the receiver tanks so they can be vented with a minimum of liquid in the vented gas. This configuration provides 3428 kg (7540 lb) of usable bipropellants. Propellant storage tanks can be loaded to 98% full and have a maximum expected operating pressure (MEOP) of 1035 kPa (150 psia). This basic propellant configuration achieves a mass fraction of 0.70.

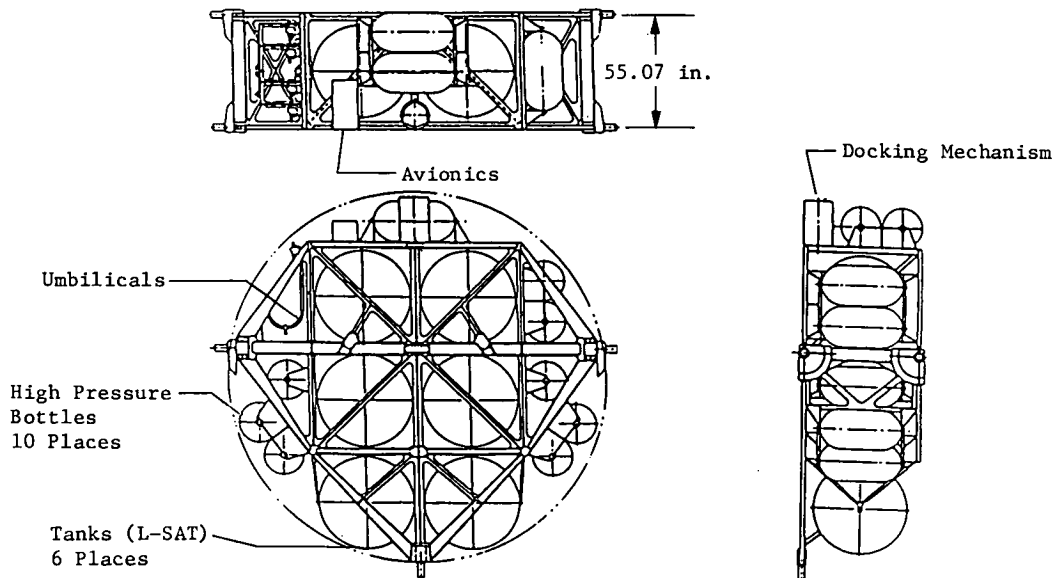


Figure 7 Basic Bipropellant OSCRS

The basic bipropellant OSCRS configuration can be reconfigured with only four L-SAT tanks to meet lower propellant requirements and increase the mass fraction. Also, the basic design may have all six tanks loaded with propellant if no catch tanks are required for resupply operations. The basic bipropellant structural configuration has been designed to allow for the increased propellant load, and all associated subsystem changes are incorporated to permit higher and lower propellant capacities. The full capacity six-loaded-tank option can provide a resupply quantity of 5182 kg (11,400 lb) with a mass fraction of 0.76. With tank changeout a bipropellant configuration with two loaded tanks achieves a mass fraction of 0.55.

The bipropellant OSCRS can accommodate future growth, particularly with regard to the supply of high pressure pressurant gases. Gas compressors (not shown in Fig. 8) can be added to supply spacecraft users with up to 123 kg (270 lb) of gaseous nitrogen at up to 31 mPa (4500 psia). Variable set-point regulators provide pressurant control in the 20.7 mPa (3000 psia) and below range. Pressure relief valves and variable set-point relief valves plumbed in parallel provide overpressure protection against regulator failure for both the OSCRS and a user spacecraft.

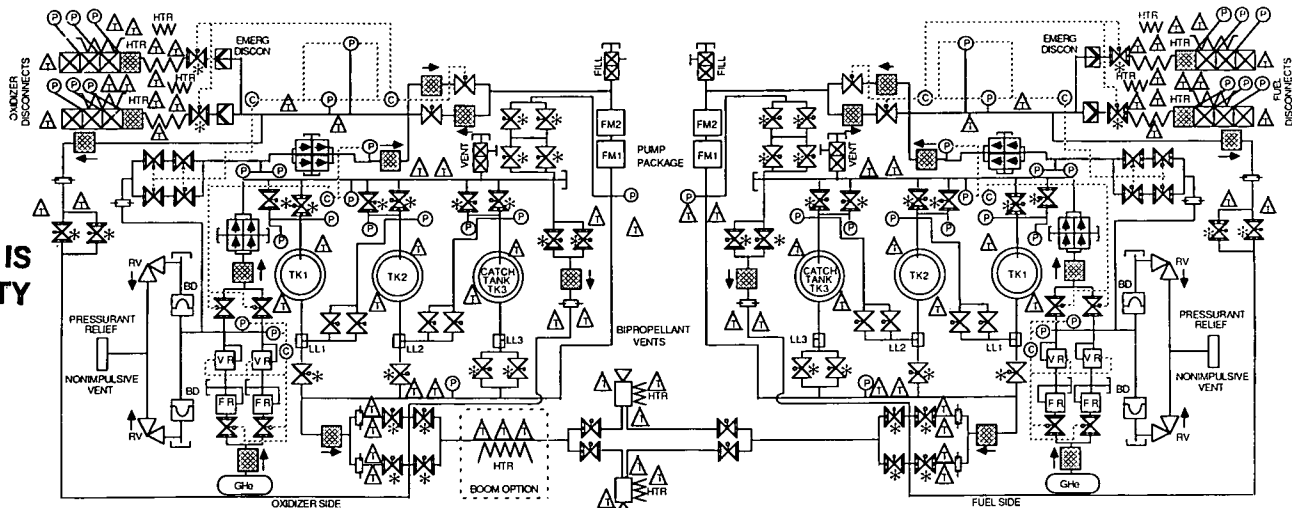


Figure 8 Bipropellant Fluid Subsystem Schematic

WATER TANKER

When the space station selected gaseous oxygen/gaseous hydrogen propulsion, using electrolysis of water, an alternate configuration of the monopropellant hydrazine OSCRS was investigated for the transport of water to the Space Station. We found that the basic monopropellant OSCRS can be greatly simplified for use with water due in part to the reduced safety concerns and elimination of some of the redundancy associated with safety fault tolerance, and the potential of going to an augmented blowdown system, such as shown in Fig. 9. Simplification of the fluid plumbing also allowed a corresponding simplification of the avionics. Since the water OSCRS is used only at the Station, the avionics would be station-based and the station's power and data handling and control system used for processing.

SUPERFLUID HELIUM RESUPPLY TANKER

Replenishment of superfluid helium (SFHe) will extend the on-orbit life of observatories, satellite instruments, sensors and laboratories which operate in the 2 Kelvin temperature range. Technology development associated with SFHe resupply has been progressing both within NASA and industry over the past several years to provide timely data for design interfaces with anticipated user systems now nearing hardware development. This technology data base was used as a starting point to produce a conceptual design of a superfluid helium tanker (SFHT) for orbital resupply.

REQUIREMENTS

Time-phased helium requirements were compiled based on the results of a user literature search. Because of the uncertainty involved with many of the users, particularly their likelihood of being funded in the time schedule currently planned, a reduced user complement was defined to determine the sensitivity of the helium resupply requirements. This was done by considering those users that are the best defined and furthest along in their development phase. These users were the Advanced X-Ray Astrophysics Facility (AXAF), Space Infrared Telescope Facility (SIRTF), Astromag, and Microgravity and Materials Processing Sciences Facility/Critical Point Phenomena Facility (MMPS/CPFF). The MMPS/CPFF was considered since it is representative of a payload designed to be placed inside the U.S. Laboratory Module on the Space Station. The time-phased helium resupply required for the reduced user complement is shown in Fig. 10. SIRTF is the major design driver due to its large capacity. These representative helium resupply requirements were used in fluid subsystem sizing trades to allow the selection of a capacity for the SFHT.

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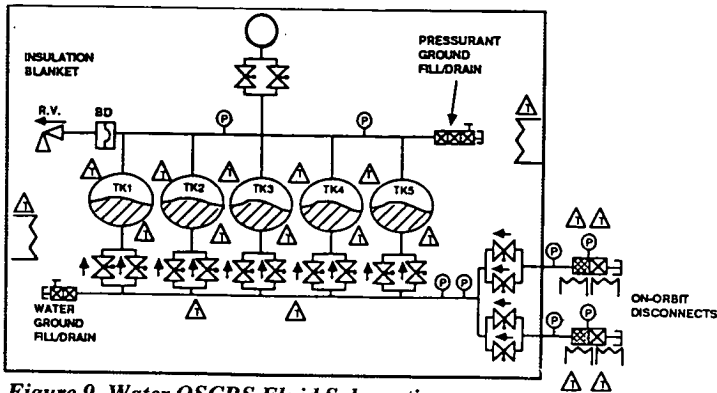


Figure 9 Water OSCRS Fluid Schematic

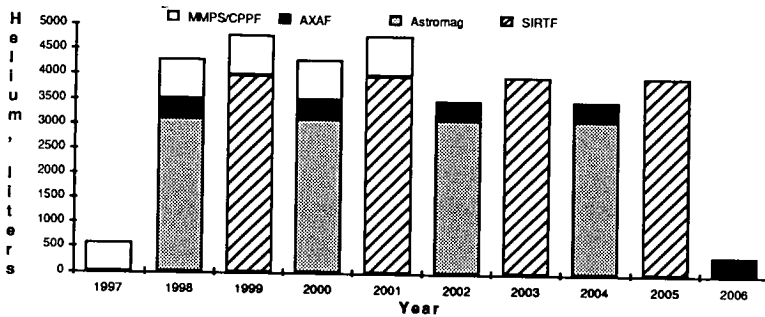


Figure 10 Time-Phased Helium Requirements

DESIGN TRADES

Tanker packaging studies were conducted to examine all of the issues associated with the SFHT Dewar design. These issues include geometrical constraints associated with both Shuttle and ELV launch, location in the Shuttle bay and the limitations of the venting interface and cg location constraints, and the effect of Dewar geometry on heat leak. Many of the design requirements for the SFHT are conflicting when assessing tank packaging and the final design is necessarily a compromise.

The first issue examined was the geometrical constraint imposed by the Shuttle cargo bay and the ELV payload fairings. When launching the SFHT on the Shuttle, it is desirable to have a compact Dewar design in order to minimize the overall length of the tanker, since launch costs are calculated either by weight or length depending on which is the more significant. This dictates using the entire 15-foot payload diameter and configuring the SFHT with a compact Dewar. However, this is in conflict with the desirability to be ELV compatible, unless the Titan IV vehicle is used exclusively. Packaging the SFHT to be launched on vehicles such as the Delta or Atlas necessitates decreasing the overall tanker diameter and increasing the length.

A key factor examined in Dewar sizing was the penalty associated with on-orbit boiloff. Boiloff was estimated assuming a loss rate of 1.5 percent per month. Cumulative boiloff losses were compared with the cumulative resupply requirements for the various tanker sizes. As an example of sensitivity to a wide range of Dewar size, Fig. 11 shows the results for both a 15000 liter capacity tanker and a 6000 liter capacity tanker, assuming the same user requirements of Fig. 10. The boiloff losses for the 15000 liter capacity tanker approach the total capacity requirement of the users. Ideally, the amount of transported helium should be as close to the user requirements as possible for the most efficient resupply system. A 6000-liter size was selected as the preferred capacity.

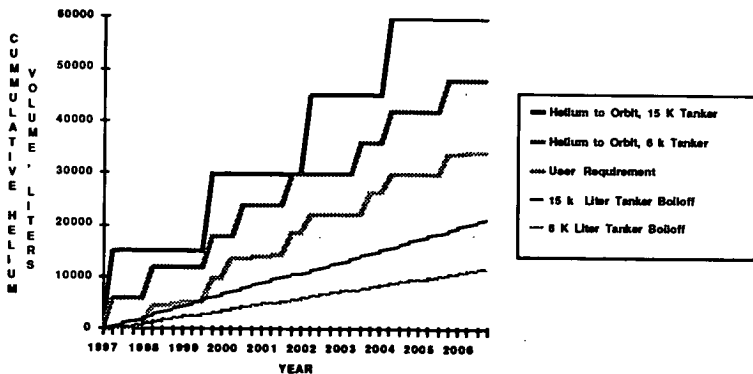


Figure 11 Tanker Capacity Sensitivity to Boiloff Losses in Meeting a Specified User Resupply Scenario

Possible scenarios for ground processing flows for the SFHT were also evaluated. A schematic diagram of the SFHT, which includes an isolated open loop cooling system to condition the liquid helium from its initial loaded condition of about normal boiling point (4.22 K) to superfluid at about 1.6 K or below, is shown in Fig. 12. Normal helium is loaded into the vented tanker at about one atmosphere until the desired fill condition is reached (including fill levels as high as 100 percent). All valves are then closed and the independent cooling system is placed into operation to cool the fluid to the superfluid state, and reduce its temperature to the desired launch condition. The independent cooling system is an open loop refrigerator. The schematic shows dual redundant and quad redundant hardware arrangements required to meet the fail-operational, fail-safe mandated requirements. This includes redundant orbiter vents to a generic overboard vent interface. This is required assuming the potential for loss of vacuum jacket integrity on the ground during launch processing. A liquid acquisition device (LAD) is used to feed a thermomechanical pump for accomplishing the transfer to the user Dewar. Total dry weight of this tanker, including the STS support cradle, structural and avionics subsystems, and instrumentation and thermal control hardware, is 2320 kg. (5105 lb). The 6000 liter (approximately 884 kg) of superfluid helium carried by the tanker results in a mass fraction of 0.28.

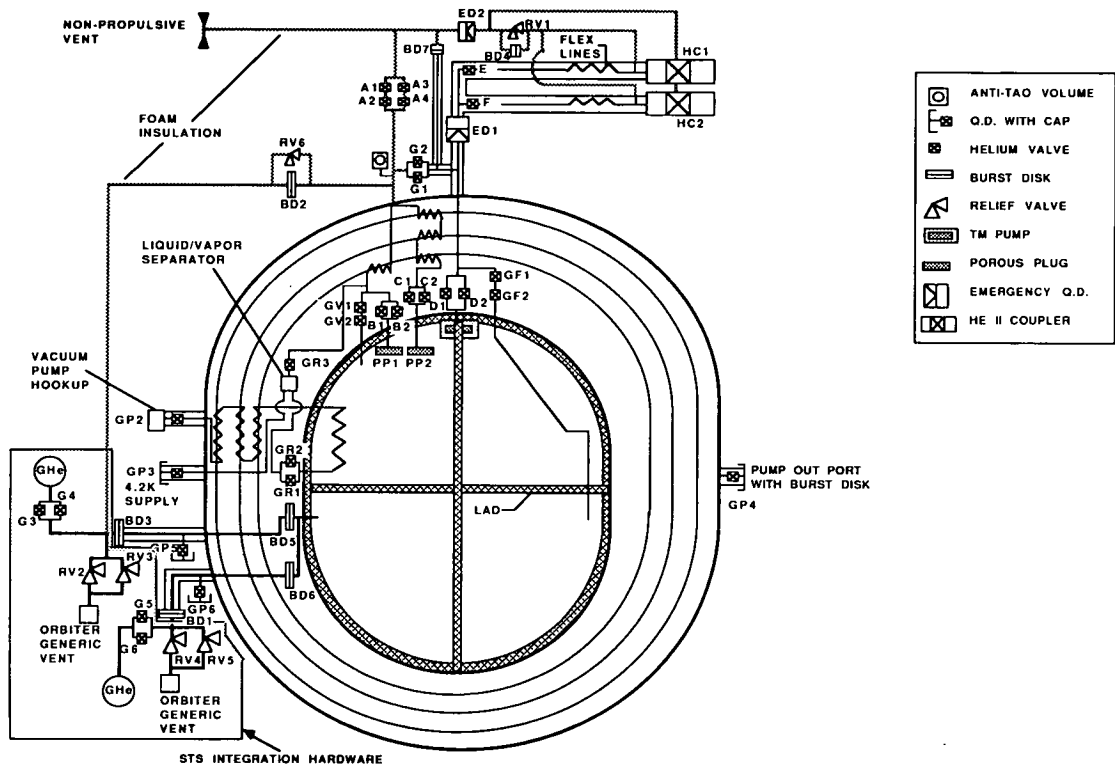


Figure 12 Schematic of Baseline Superfluid Helium Tanker

MIXED FLEET ASSESSMENT

A benefit of the selection of the relatively smaller capacity of 6000 liters for the SFHT is that it provides easier packaging within the smaller payload fairings. Designing the SFHT to a nine foot diameter to package within the Delta II payload fairing results in a longer length tanker which penalizes it for a Shuttle launch. This penalty is minimized, however, by the smaller capacity tanker. Therefore, due to the selection of the 6000 liter SFHT, we chose to maximize compatibility and design the SFHT to fit within the Delta II fairing. The length penalty associated with this design diameter for a Shuttle launch is 0.7 - 1.0 m (2-3 ft). The packaging of the nine foot diameter, 6000 liter SFHT in the various ELV fairings is shown in Fig. 13 for comparison. The SFHT uses most of the payload fairing volume for the Delta II and Atlas/Centaur vehicles. Packaging in the Titan vehicles, however, results in significant payload weight and volume margins, indicating that to make the SFHT launch cost effect it would need to be part of a multiple payload launch for these vehicles. The SFHT tanker configuration is shown in Fig. 14, along with its ELV mounting adaptor.

The Space Station configuration does not currently include a Servicing Facility; therefore, the current plans are to perform servicing from the Orbiter. An example of this kind of servicing includes the baseline SIRTf resupply mission which calls for a dedicated Shuttle flight. The Orbiter would transport the SFHT, and A' cradle, and a fully fueled OMV to a 500 km orbit. The OMV would then be used to retrieve the SIRTf from its 900 km orbit and transport it to the Shuttle orbit. With the flexible, mixed fleet approach, the option does exist to resupply SIRTf in-situ using automated operations. Such operations would be performed while the SFHT is attached to the OMV. This requires the SFHT to incorporate structural and utility connections for attaching to both the OMV and the user spacecraft, as illustrated in Fig. 15.

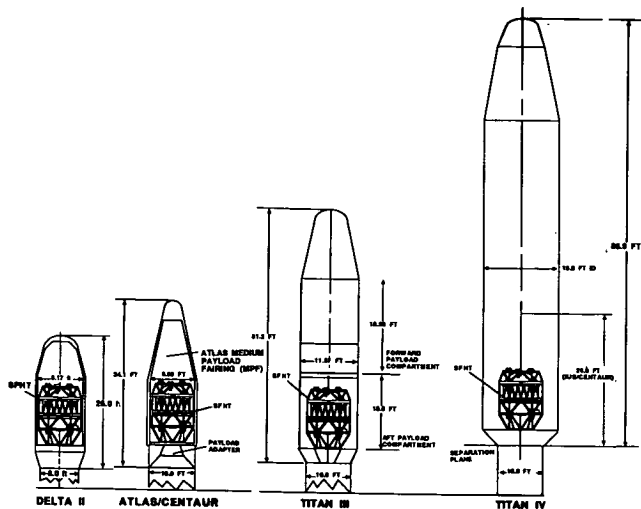


Figure 13 ELV Payload Fairing Comparison

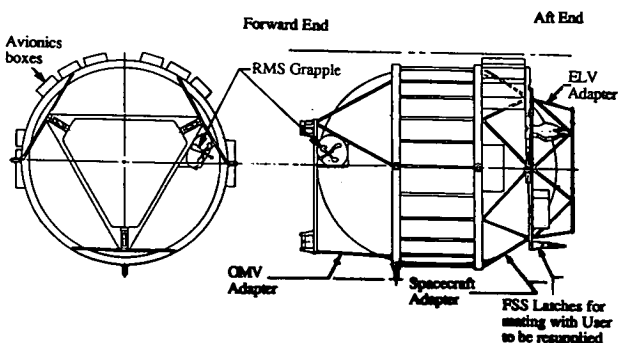


Figure 14 SFHT Configuration for ELV Launch (or Placement in Transport Cradle for STS Launch)

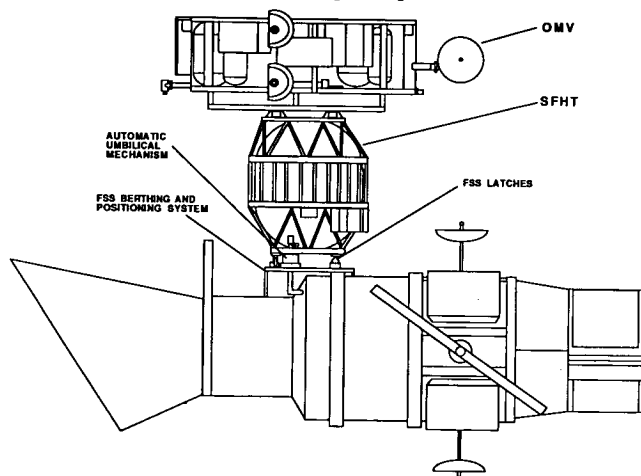


Figure 15 SFHT/SIRTF In-Situ Automatic Resupply Interfaces

The SFHT would require a mechanism to dock to the user spacecraft and an automatic coupler mating mechanism to attach the fluid and electrical couplers. The front face of the SFHT would be equipped with a structural docking interface such as the FSS latches. A television camera and light system would be required to perform the docking procedure. Once docking is complete, the active half of the automated coupler mating mechanism would mate the fluid and electrical couplers. Two electrical connectors and two fluid couplers would satisfy mission success requirements. Power and command and data handling would be fed to the user spacecraft from the OMV via the SFHT with the resupply process being monitored and controlled if necessary from the ground. Upon completion of the replenishment operations, the SFHT would be detached from the user spacecraft and returned either to the Space Station or to the STS.

CONCLUSIONS

Our study concluded that the mixed fleet approach to logistics offers significant advantages to the overall logistics requirements. An optimized storable tanker capable of accommodating monopropellants, bipropellants and water was configured with commonality of structure, avionics and tankage. This modular configuration is compatible with STS, Space Station and OMV operations as well as providing a dual STS/ELV launch capability. For the superfluid helium tanker, a 6000 liter capacity was selected as an optimum size to handle a wide range of user capacities, to permit launching on a diverse mixed fleet of expendable launch vehicles and the Shuttle, and to minimize ground handling and fluid conditioning requirements. Operating the superfluid helium tanker in the mixed fleet mode was found to be cost competitive to the exclusive use of the STS as the launch mode at its advertised cost.

Station or platform-basing major subsystems was found to be the most versatile and efficient approach for an on-orbit logistics servicing facility. Meteoroid and space debris protection must be provided for the tankers while they are at the logistics depots. Space-basing these elements, as well as many of the other subsystems such as avionics and thermal control, significantly reduces structural up/down weight, thus also contributing to lower usable fluid costs-per-pound for resupply to on-orbit users.

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