EARTH-TO-ORBIT PROPELLANT TRANSPORTATION OVERVIEW

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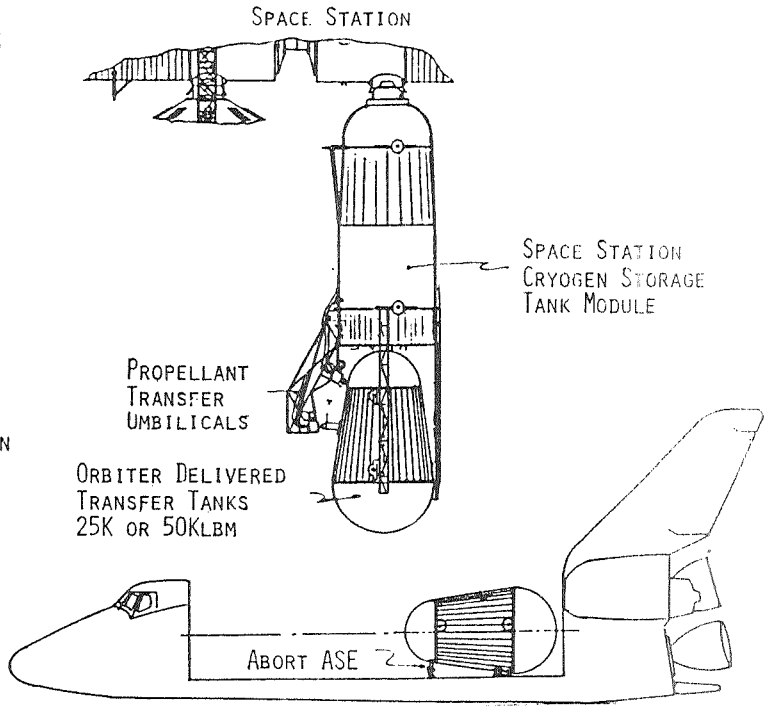
Large quantities of cryogenic propellants are needed to support Space Station/OTV operations. Two ways to get propellants into space are: transporting them in dedicated tankers or scavenging unused STS propellant (which promises significant cost savings). This discussion centers on scavenging propellant, both with and without an aft cargo carrier system. An average of two to four flights per year can be saved by scavenging and manifesting propellant as payload. Addition of an aft cargo carrier permits loading closer to maximum, reduces the required number of flights, and reduces the propellant available for scavenging. Sufficient propellant remains for OTV needs, however.

CRYOGEN PROPELLANT SUPPLY - DEDICATED TANKER

- 70,000 LBM STORAGE ON SS
- RESUPPLIED BY STS
- TWO RESUPPLY TANKS TO AID PAYLOAD SCHEDULING
- COMMON I/F FOR SS STORAGE TANKS AND STS ASE (ABORT DUMP)
- STS TANKS TO USE PRESSURE REGULATED TRANSFER
- SS TANKS TO USE AUTOGENOUS PRESSURIZATION

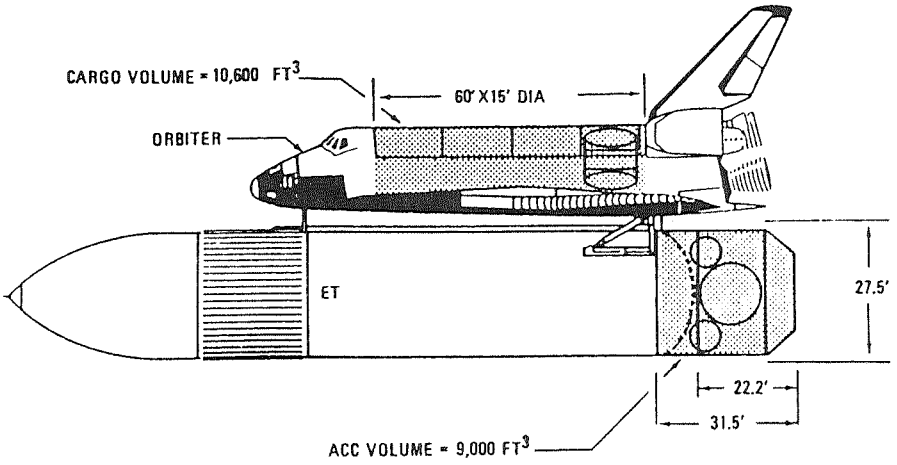


ATTACHED, FREE-FLYING, OR TETHERED DEPOTS ARE BEING CONSIDERED FOR STORAGE OF CRYOGENIC PROPELLANTS AT THE SPACE STATION. ALL HAVE SIMILAR STORAGE REQUIREMENTS. QUANTITIES OF PROPELLANT RANGE FROM 70,000 TO 100,000 LBM STORAGE.

EARLY ON, WE LOOKED AT TWO RESUPPLY TANKS OF 25,000 AND 50,000 LBM CAPACITY TO AID PAYLOAD MANIFESTING. THESE TANKS WOULD BE DELIVERED BY THE ORBITER AND WOULD HAVE A COMMON STS (ABORT DUMP) AND SPACE STATION STORAGE DEPOT INTERFACE. THE RESUPPLY TANKS WOULD USE PRESSURE REGULATED TRANSFER WHILE THE SPACE STATION TANKS WOULD USE AUTOGENOUS PRESSURIZATION TO ASSIST IN REFILLING.

Figure 1

Alternate Locations for Propellant Scavenging Tanks



TWO LOCATIONS ARE SHOWN FOR SCAVENGING TANKS: IN THE ORBITER PAYLOAD BAY AND IN THE ACC. AS WE WILL SEE LATER, VERY FEW OF THE FLIGHTS ARE WEIGHT LIMITED; MANY ARE VOLUME LIMITED. LOCATING SCAVENGING TANKS IN THE PAYLOAD BAY, THEN, DOES NOT APPEAR ATTRACTIVE. IN FACT, MORE CARGO VOLUME IS NEEDED IN MANY INSTANCES, AND THAT IS THE REAL JUSTIFICATION FOR AN ACC -- NOT SCAVENGING. IF AN ACC IS AVAILABLE, THE SCAVENGE TANKS WOULD BE LOCATED THERE.

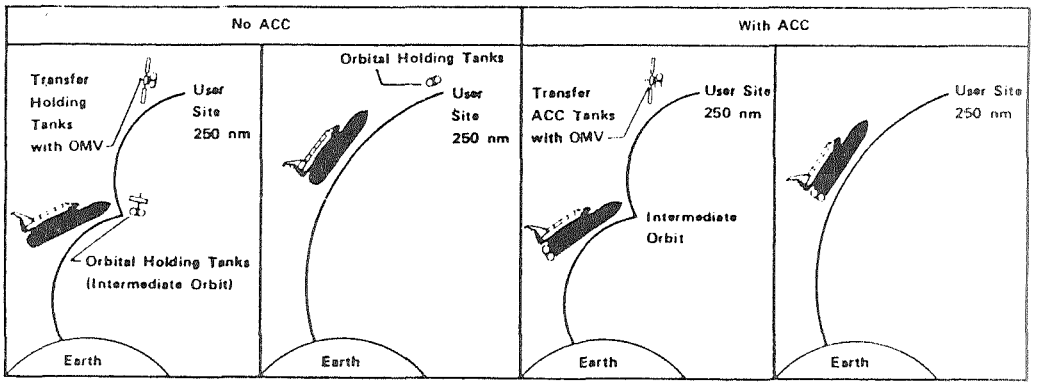
Figure 2

GROUND RULES

1. NASA LOW MISSION MODEL - REVISION G, DATED OCTOBER 1982 (1991 - 2000)
2. WTR AND DOD MISSIONS NOT USED
3. MISSION MODEL MANIFESTED ON GROSS YEARLY BASIS - LOAD FACTORS OBTAINED FROM MSFC MODEL BASED UPON WEIGHT AND/OR VOLUME
4. ALL FLIGHTS LOADED TO MAXIMUM PAYLOAD WEIGHT
5. DIFFERENCE BETWEEN AVERAGE CARGO WEIGHT AND MAXIMUM PAYLOAD CAPABILITY MADE UP BY ADDING PROPELLANT AND TANKAGE AS CARGO
6. SPACE STATION AT 28.5° INCLINATION, 250 NM ALTITUDE
7. OTV PROPELLANT REQUIREMENTS FOR GEO MISSIONS ONLY

Figure 3

Mission Concepts

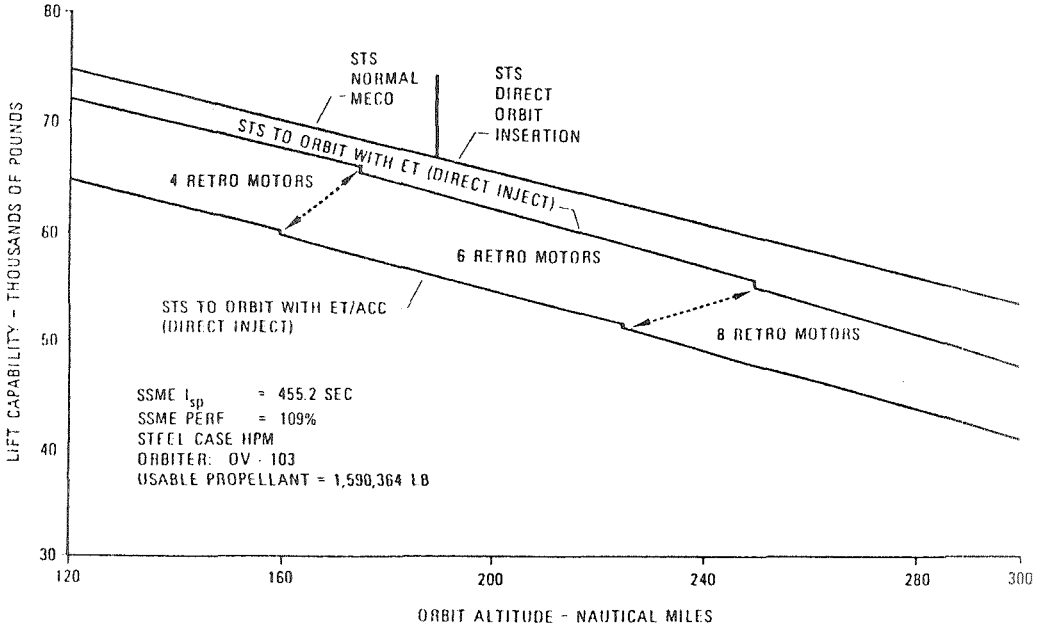


SCENARIOS WITH AND WITHOUT AN ACC ARE SHOWN. WITH NO ACC, ORBITAL HOLDING TANKS ARE FILLED AT LEO AND TRANSFERRED TO THE USER SITE WITH AN OMV. THE SAME IS TRUE OF THE SCAVENGING TANKS WITH AN ACC.

IN ALL CASES, THE ET IS TAKEN TO ORBIT, EITHER TO LEO OR TO THE SPACE STATION (DIRECT INJECTION), TO PROVIDE SUFFICIENT TIME (HOURS) FOR SCAVENGING. ON A DIRECT ORBIT INSERTION FLIGHT WITH THE ET DROPPED INTO THE OCEAN, INSUFFICIENT TIME EXISTS FOR OMV RENDEZVOUS AND DOCKING.

Figure 4

STS Lift Capability for 28.5 Degree Inclination



FOR THE STS CRITERIA LISTED, LIFT CAPABILITY IS SHOWN AS A FUNCTION OF ORBIT ALTITUDE. THE LOWER CURVES ARE FOR THE CASES OF STS AND ET TO ORBIT (DIRECT INJECT) WITH AND WITHOUT AN ACC.

WITH THIS SCENARIO, A SYSTEM IS REQUIRED TO DE-ORBIT THE ET FOR ORING PROPELLANT SCAVENGING. SOLID MOTORS WITH HYDRAZINE ATTITUDE CONTROL WOULD BE USED. MORE RETRO MOTORS WOULD BE REQUIRED AT HIGHER ORBITS, ACCOUNTING FOR THE SMALL STEP DECREMENTS IN LIFT CAPABILITY.

Figure 5

Propellant Scavenging Definitions

RESIDUAL PROPELLANT	=	UNUSABLE + FLIGHT PERFORMANCE RESERVE + FUEL BIAS
SURPLUS PROPELLANT	=	PROPELLANT LEFT AT MECO MINUS RESIDUAL (NOT USED DUE TO LESS THAN MAXIMUM PAYLOAD)
PAYLOAD PROPELLANT	=	"SURPLUS" LOADED INTO SCAVENGING TANKS BEFORE LAUNCH

ACC ENVIRONMENT ASSUMED EQUIVALENT TO ORBITER CARGO BAY

SINCE THE ET IS ALWAYS LOADED FULL, SURPLUS PROPELLANT EXISTS WITH LESS THAN MAXIMUM PAYLOAD. SOME OF THIS SURPLUS PROPELLANT COULD BE LOADED INTO SCAVENGING TANKS BEFORE LAUNCH IF A CHANGE IN LOADING PHILOSOPHY OCCURRED.

THE ACC ENVIRONMENT IS ASSUMED EQUIVALENT TO THE ORBITER CARGO BAY. THIS IS A DESIGN REQUIREMENT FOR THE ACC. THE ACC SHROUD IS JETTISONED FOLLOWING SRB SEPARATION.

Figure 6

Cryogenic Propellant Scavenging Concepts

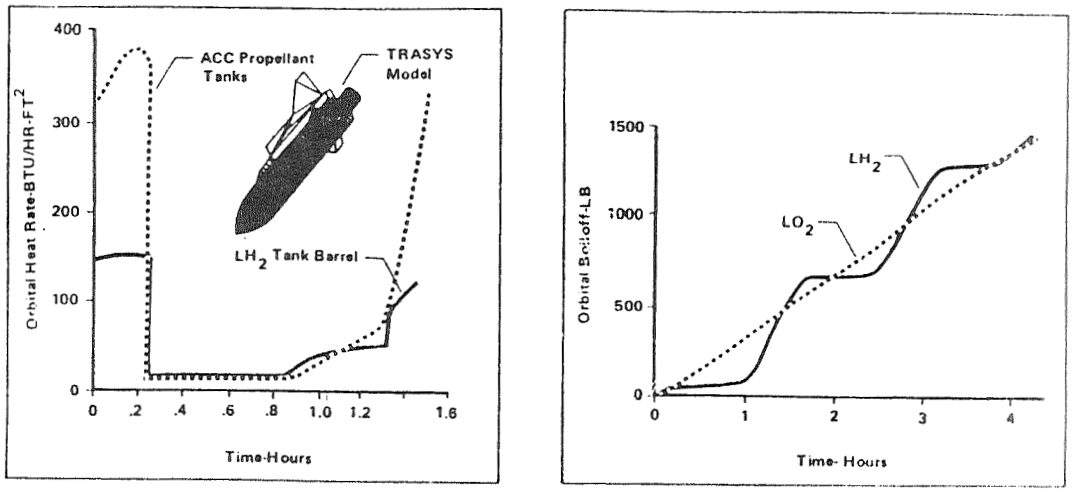
BASIC MISSION CONCEPTS	OPERATIONS			
	PROPELLANT TRANSFER	PROPELLANT SETTLING	OMV OPERATIONS	OTHER CONSIDERATIONS
TRANSFER TO STORAGE TANKS AT SPACE STATION	SPACE STATION 250 NM	• ET TRAP • THRUSTERS - RCS - ULLAGE GASES - GO2/GH2 ENGINES • TETHER	PROPELLANT SETTLING	DEORBIT ET
TRANSFER TO ORBITAL HOLDING TANKS IN LEO	LEO ≈ 160 NM		• PROPELLANT SETTLING • HOLDING TANK TRANSPORT	
TRANSFER TO HOLDING TANKS IN ACC PAYLOAD BAY	~~POST MECO SUBORBITAL~~	• THRUSTERS - RCS - ULLAGE GASES - GO2/GH2 ENGINES	HOLDING TANK TRANSPORT	
	POST MECO ORBITAL			DEORBIT ET/ACC
	PRE MECO	NOT REQUIRED		• SURPLUS AND FPR ONLY • ET QUANTITY MEASUREMENT • DEORBIT ET/ACC
	PRELAUNCH			• SURPLUS ONLY • DEORBIT ET/ACC

THE BASIC MISSION CONCEPTS AND ASSOCIATED OPERATIONS ARE SHOWN. PROPELLANT TRANSFER POST-MECO BUT SUBORBITAL IS NOT FEASIBLE BECAUSE INSUFFICIENT TIME IS AVAILABLE FOR OMV RENDEZVOUS (DISCUSSED EARLIER). PROPELLANT MUST BE MAINTAINED IN THE SETTLED CONDITION FOR ALL CASES WHERE PROPELLANT IS TRANSFERRED ON ORBIT. WITH AN ACC, SURPLUS PROPELLANT CAN BE LOADED IN THE SCAVENGING TANKS PRIOR TO LAUNCH OR SURPLUS AND FLIGHT PERFORMANCE RESERVE CAN BE TRANSFERRED PRE-MECO; SETTLING WOULD NOT BE REQUIRED FOR THESE CASES.

THE OMV IS ALWAYS USED TO TRANSPORT SCAVENGE OR ORBITAL HOLDING TANKS TO THE SPACE STATION. DE-ORBIT OF THE ET WITH OR WITHOUT THE ACC SUPPORT STRUCTURE IS REQUIRED FOR ALL MISSION CONCEPTS.

Figure 7

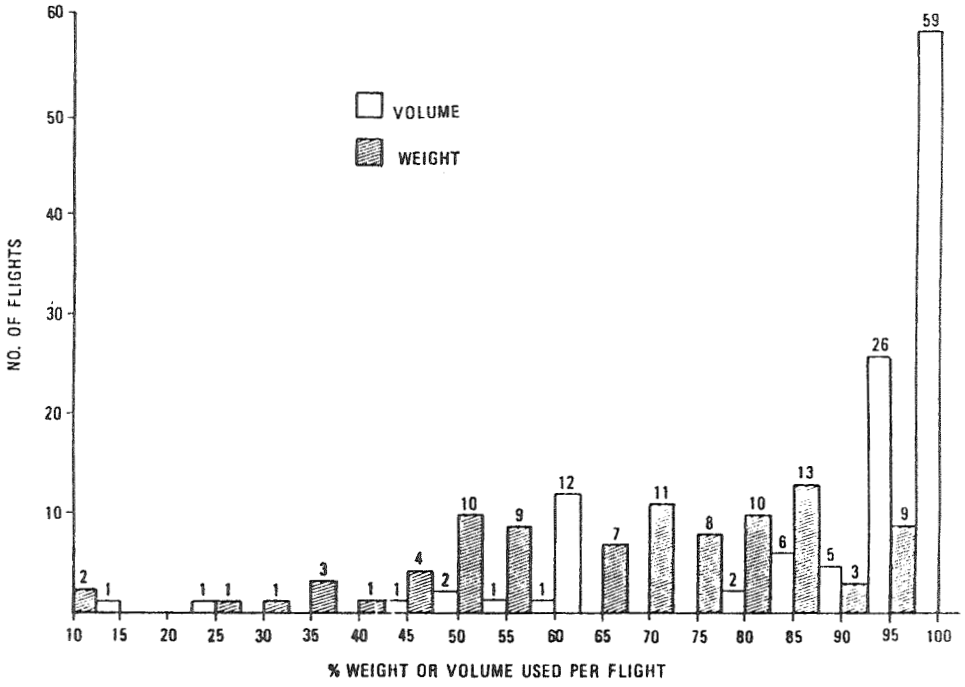
Orbital Heating Rates and Propellant Boiloff



PREDICTED ORBITAL HEATING RATES AND RESULTING PROPELLANT BOILOFF ARE SHOWN AS A FUNCTION OF TIME. THESE DATA PROVIDE FURTHER VERIFICATION THAT THE SCAVENGING OPERATION MUST BE ACCOMPLISHED IN THE SHORTEST TIME POSSIBLE. PRELIMINARY ASSESSMENT HAS SHOWN THAT OMV RENDEZVOUS IS THE TIME-CONSUMING OPERATION, NOT SCAVENGING.

Figure 8

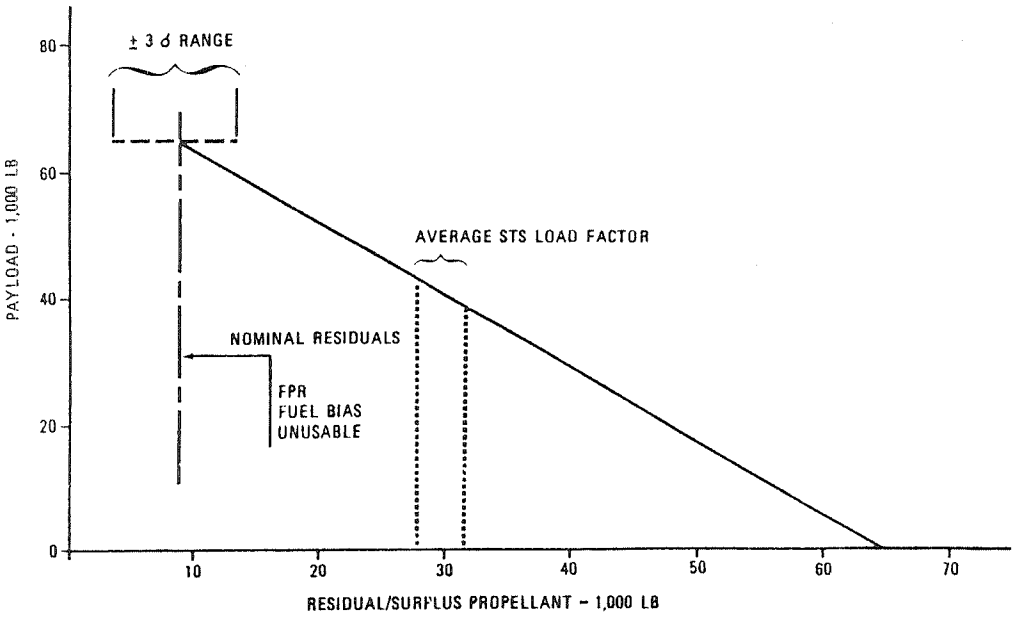
Weight Volume Utilization for STS Non-DOD ETR Flights



OF THE OVER 200 FLIGHTS SHOWN FOR THE NEXT 10 YEARS, NEARLY HALF ARE VOLUME LIMITED, WHILE ONLY A FEW (LESS THAN 10 PERCENT) ARE WEIGHT LIMITED, INDICATING AN ADVANTAGE OF USING AN ACC.

Figure 9

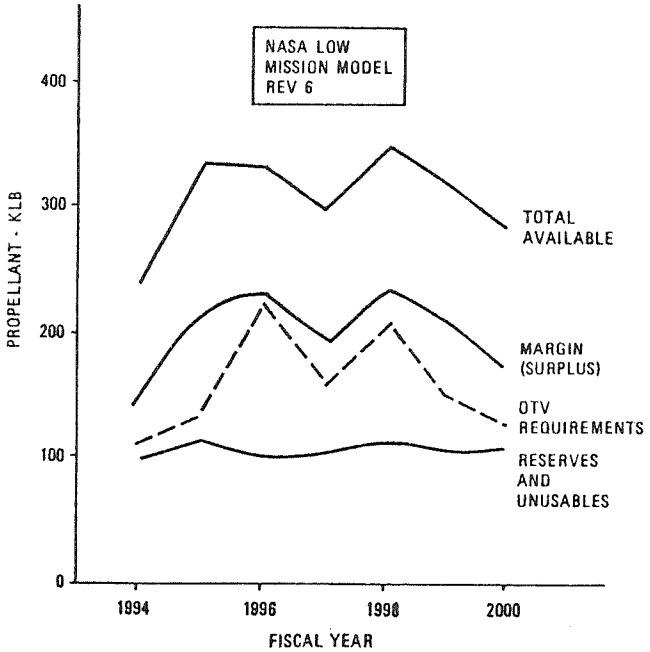
Payload vs Residual/Surplus Propellant



NOMINAL RESIDUALS OF 9000 LBM ARE SHOWN FOR THE FULLY WEIGHT LOADED SITUATION. HOWEVER, THE AVERAGE LOAD FACTOR IS ABOUT 40,000 LBM WHICH RESULTS IN ABOUT 21,000 LBM OF SURPLUS PROPELLANT IN ADDITION TO THE 9000 LBM OF RESIDUALS.

Figure 10

OTV Requirements vs Scavenged Propellant Available

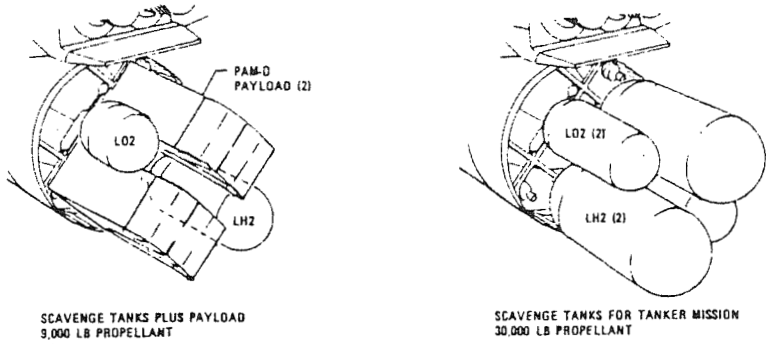


QUANTITIES OF PROPELLANTS AVAILABLE FOR SCAVENGING ARE SHOWN FOR THE YEARS 1994 TO 2000. OTV REQUIREMENTS WERE ESTABLISHED BY ROUTING ALL OTV MISSIONS TO GEO, ASSUMING APPROXIMATELY 45,000 LBM OF PROPELLANTS. RESERVES AND UNUSABLES AMOUNT TO ABOUT 100,000 LBM PER YEAR AND SURPLUS IS ABOUT 200,000 LBM PER YEAR, RESULTING IN A TOTAL OF ABOUT 300,000 LBM PER YEAR.

NO LOSSES HAVE BEEN INCLUDED IN THIS ASSESSMENT. HOWEVER, THESE CURSORY RESULTS SHOW THAT THE SURPLUS ALONE COULD MEET THE OTV NEEDS.

Figure 11

Typical Propellant Tank Installations in ACC



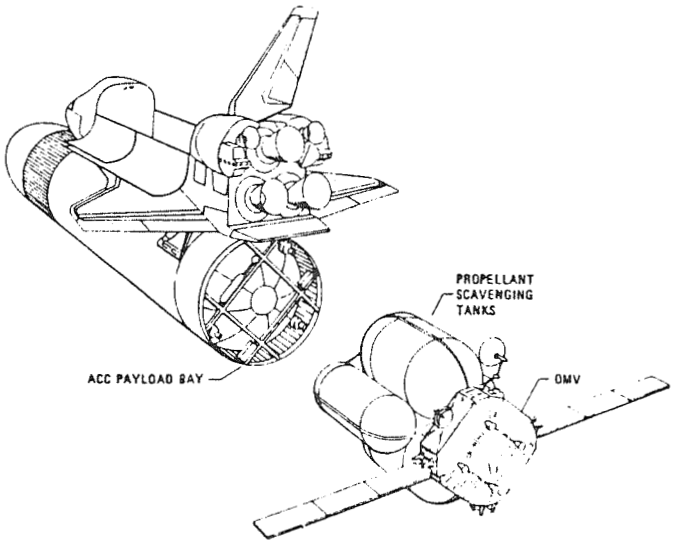
SCAVENGE TANKS PLUS PAYLOAD
9,000 LB PROPELLANT

SCAVENGE TANKS FOR TANKER MISSION
30,000 LB PROPELLANT

TWO POSSIBLE INSTALLATIONS ARE SHOWN. ONE INCLUDES TWO PAM-D PAYLOADS PLUS TANKS FOR 9000 LBM PROPELLANT AND THE OTHER HAS SCAVENGE TANKS ONLY TO ACCOMODATE 30,000 LBM PROPELLANT.

Figure 12

Propellant Tank Transfer with OMV



THE OMV HAS PICKED UP THE SCAVENGE TANKS FOR TRANSFER TO THE SPACE STATION DEPOT. THE ET DEORBIT MOTORS CAN BE SEEN ATTACHED TO THE ACC STRUCTURE.

Figure 13

SUMMARY

- AN AVERAGE OF 2 TO 4 STS FLIGHTS PER YEAR CAN BE SAVED BY SCAVENGING AND MANIFESTING PROPELLANT AS PAYLOAD TO SUPPORT SPACE-BASED OTV OPERATIONS.
- STS FLIGHTS SHOULD BE MANIFESTED TO CARRY MAXIMUM PAYLOAD WEIGHT.
- ADDITION OF AN ACC PERMITS LOADING CLOSER TO MAXIMUM AND REDUCES PROPELLANTS AVAILABLE FOR SCAVENGING (162 VS. 172 FLIGHTS). OTV NEED STILL MET.
- ET RESIDUAL PROPELLANTS HAVE AN OXIDIZER/FUEL RATIO FROM 2 TO 4.

Figure 14