CRYOGENIC SYSTEMS INTEGRATION TECHNOLOGY FOR THE SPACE SHUTTLE

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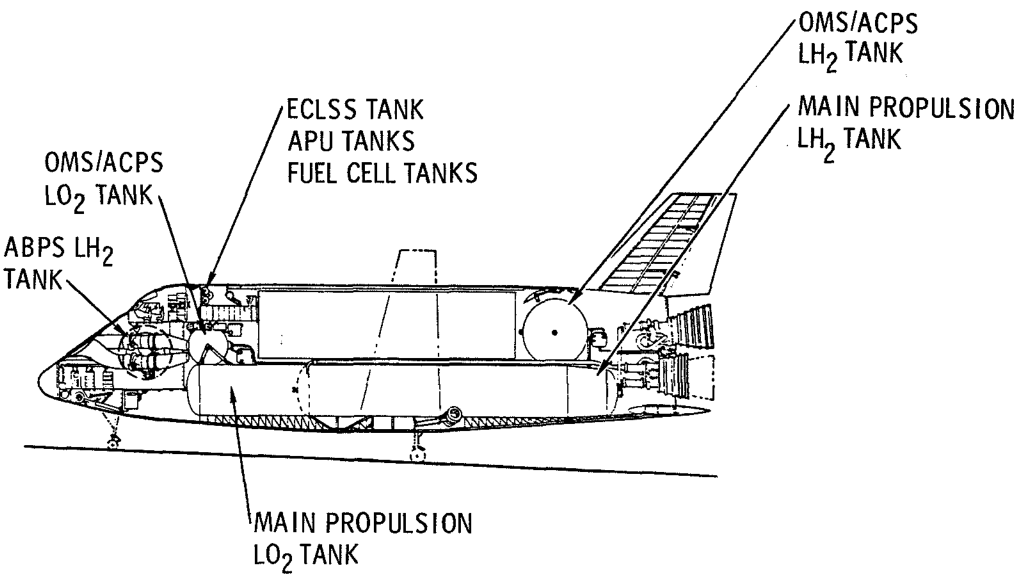
INTRODUCTION

THE NUMBER OF CRYOGENIC TANKS AND THEIR SUPPORTING HARDWARE SHOULD BE MINIMIZED TO REDUCE VEHICLE COMPLEXITY, MAINTAINABILITY, GROUND OPERATIONS AND MAXIMIZE MISSION FLEXIBILITY AND USE OF RESIDUALS. CRYOGENIC TANK INTEGRATION IS NOT A TECHNOLOGY IN ITSELF, BUT IS MADE UP OF A SERIES OF TECHNOLOGY OUTPUTS THAT HAVE BEEN PREVIOUSLY DISCUSSED IN DETAIL. THE RESOLUTION OF THOSE TECHNOLOGY ISSUES WILL AFFECT THE DEGREE OF INTEGRATION. THIS PRESENTATION COVERS THE RANGE OF INTEGRATION FROM THE ONE EXTREME OF ALL PROPELLANTS IN THE BOOST TANKS TO THE OTHER EXTREME OF COMPLETELY SEPARATE TANKS FOR EACH CRYOGENIC SYSTEM. THE ARGUMENT EMPLOYED IS ONE OF FORCING TANK INTEGRATION AS MUCH AS POSSIBLE AND TRYING TO DEFINE A REASONABLE BREAK POINT FOR INTEGRATION BASED ON TECHNOLOGY SIMILARITY.

SHUTTLE CRYOGENIC SYSTEMS

THE SHUTTLE BOOSTER AND ORBITER VEHICLES REQUIRE MANY DIFFERENT CRYOGENIC SYSTEMS TO SUPPORT THE MISSION OBJECTIVES. LARGE, CONVENTIONALLY INSULATED CRYOGENIC HYDROGEN AND OXYGEN TANKS ARE REQUIRED FOR BOOST PROPULSION. LIQUID HYDROGEN AND OXYGEN TANKS ARE REQUIRED FOR THE ATTITUDE CONTROL PROPULSION SYSTEM (ACPS), ORBIT MANEUVERING SYSTEM (OMS), FUEL CELLS, AND AUXILIARY POWER UNITS (APU). OXYGEN TANKAGE FOR THE ENVIRONMENTAL CONTROL AND LIFE SUPPORT (ECLS) AND HYDROGEN TANKAGE FOR THE AIRBREATHING PROPULSION SYSTEM (ABPS) ARE REQUIRED. WITH THE EXCEPTION OF THE BOOST TANKS, ALL OF THESE SYSTEMS REQUIRE HIGH PERFORMANCE INSULATION TO MEET THE MISSION ORBITAL STAY TIME OF 7 TO 30 DAYS.



ORBITER SYSTEM INTERFACE REQUIREMENTS

THE SHUTTLE CRYOGENIC SYSTEMS EACH REQUIRE DIFFERENT PRESSURES, TEMPERATURES, AND FLUID STATE AT THEIR INTERFACES. THE MAIN BOOST AND AIRBREATHING PROPULSION SYSTEMS REQUIRE LIQUID STATE AND LOW INLET PRESSURES. THE PRIMARY REQUIREMENT FOR THESE TWO SYSTEMS IS ONE OF PROVIDING NET POSITIVE SUCTION PRESSURE (NPSP) TO THE LIQUID PUMPS. THE REMAINING SYSTEMS REQUIRE GAS AND HIGHER OPERATING PRESSURES. THE MAIN BOOST PROPELLANT COMPRISES 91 PERCENT OF THE TOTAL HYDROGEN AND OXYGEN LOAD ON THE VEHICLE. THE SECOND LARGEST PROPELLANT SYSTEM IS THE OMS COMPRISING 8 PERCENT WITH THE REMAINING SYSTEMS REQUIRING ONLY ABOUT 1 PERCENT.

		PRESSURE (PSIA)	TEMPERATURE (^{O}R)	NPSP (PSI)	STATE	MASS (LB)
MAIN BOOST	LH_2	20-35		2	LIQUID	58,120
	LO_2	20-350		8		348,720
OMS	LH_2	700	200		GAS	6,870
	LO_2	700	300			26,920
ACPS	LH_2	700	200		GAS	330
	LO_2	700	300			1,670
APU	LH_2	500+	40+		GAS	60
	LO_2	500+	165+			60
FUEL CELLS	LH_2	60+	200+		GAS	60
	LO_2	60+	200+			450
ABPS	LH_2	20+		2	LIQUID	2,200
ECLS	LO_2	100-110	530		GAS	200

WHY INTEGRATE

THERE ARE SEVERAL REASONS FROM A VEHICLE/MISSION OPERATIONAL VIEW THAT DICTATE INTEGRATION OF ALL CRYOGENIC SYSTEMS INTO ONE TANK. INTEGRATION PROVIDES MISSION FLEXIBILITY AS TO HOW PROPELLANTS ARE BUDGETED IN ONE TANK FOR EACH MISSION. THIS REBUDGETING OF PROPELLANT CAN BE TRADED AMONG SYSTEMS AND NOT BE CONFINED BY TANK SIZE AS IT WOULD BE WITH SEPARATE TANKAGE. LAUNCH PREPARATIONS ARE CERTAINLY SIMPLIFIED BY HAVING TO LEAK CHECK AND LOAD ONLY ONE COMMON TANK. THE REDUCED NUMBER OF COMPONENTS, SUCH AS REDUNDANT VENT VALVES, REQUIRED FOR ONLY ONE TANK INSTEAD OF SEVERAL WILL EASE THE MAINTAINABILITY PROBLEM. FINALLY, MANY OF THE SYSTEMS HAVE COMMON FUNCTIONAL REQUIREMENTS SUCH AS LONG TERM ORBITAL STORAGE, PROPELLANT ORIENTATION IN ZERO G, WITH COMPATIBLE PRESSURE, TEMPERATURE AND FLUID STATE INLET CONDITIONS.

MISSION FLEXIBILITY

LAUNCH PREPARATIONS

MAINTAINABILITY

FUNCTIONAL COMMONALITY

DESIGN/TECHNOLOGY CONSIDERATIONS

THIS MATRIX EXPANDS THE ADVANTAGES AND DISADVANTAGES OF INTEGRATED VERSUS SEPARATE TANKS FOR THE OPERATIONAL CONSIDERATIONS. THIS CHART POINTS OUT THE REQUIREMENT FOR AN ADDITIONAL TECHNOLOGY ADVANCE IF SEPARATE TANKS ARE USED WITH INTERCONNECTING PLUMBING TO TRANSFER PROPELLANT FROM ONE SYSTEM TO ANOTHER. PROPELLANT TRANSFER UNDER A ZERO G ENVIRONMENT IS A TECHNOLOGY ISSUE REQUIRING RESOLUTION IF EMPLOYED. HOWEVER, IF THE TANKS ARE INTEGRATED THIS RESOLUTION WOULD NOT BE REQUIRED FOR THE SHUTTLE VEHICLE.

CONSIDERATION	INTEGRATED	SEPARATE
REDUNDANCY	NO LOW-G PROPELLANT TRANSFER	REQUIRES TANK-TO-TANK COMMUNICATION TO TRANSFER PROPELLANT. TRANSFER IS A PROBLEM AT LOW-G LEVEL
VERSATILITY	SMALL INCREASES IN SYSTEM REQUIREMENTS ACCOMMODATED	CAN ACCOMMODATE LARGE SIZE CHANGES WITH MINIMUM IMPACT ON OTHER SYSTEMS
MAINTAINABILITY-SERVICEABILITY-REUSEABILITY	SINGLE LOCATION FOR ALL CRYOGENIC STORAGE - TANK DIAMETER LITTLE LARGER THAN OMS TANK ALONE	LARGE NUMBER OF UNITS EACH REQUIRING THE SAME ATTENTION AS A SINGLE LARGE ONE
RELIABILITY-FAILURE MODES	MINIMUM TANK PENETRATIONS/ LEAK POINTS	LARGE NUMBER OF TANK PENETRATIONS INCREASING LEAK SOURCES

BOOSTER PROPELLANT TIME LINE

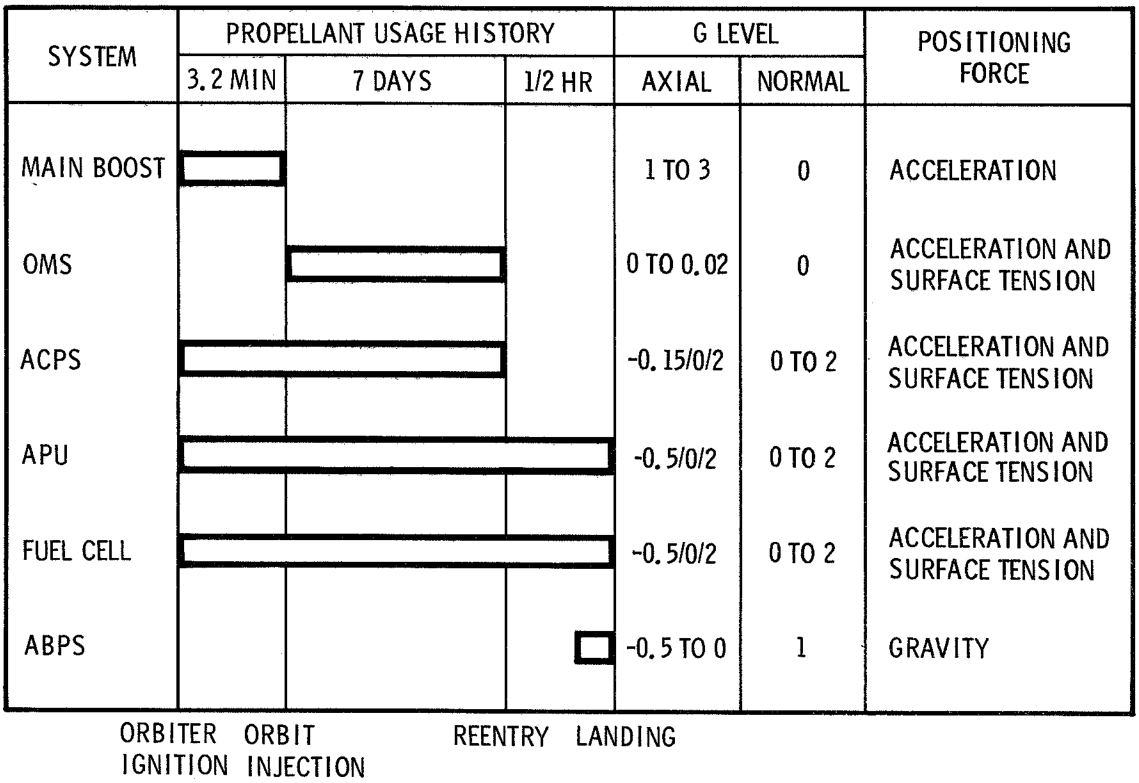
THE PROPELLANT USAGE HISTORY THROUGH THE MISSION TIME FROM LIFT-OFF TO BOOSTER CRUISE BACK AND LANDING IS SHOWN IN THIS CHART. THE AXIAL AND NORMAL G LEVELS ACTING ON THE BOOSTER DURING THESE TIMES SHOW THAT THE CRYOGENIC SYSTEMS HAVE TO WORK FROM A MINUS ONE G TO A PLUS THREE G AXIAL LEVEL AS WELL AS OPERATE APPROXIMATELY SEVEN MINUTES IN A ZERO G ENVIRONMENT. PROPELLANT POSITIONING MUST BE SATISFACTORILY ACCOMPLISHED THROUGH THIS WIDE RANGE OF G LEVEL AND DIRECTION. PROPELLANT STORAGE TIME IS RELATIVELY SHORT FOR THE BOOSTER WITH THE ABPS HAVING THE LARGEST REQUIREMENT OF 1.5 HOURS.

SYSTEM	PROPELLANT USAGE HISTORY			G LEVEL		POSITIONING FORCE
	3.5 MIN	7 MIN	1.5 HRS	AXIAL	NORMAL	
MAINBOOST				1 TO 3	0	ACCELERATION
ACPS				-1 TO 0	0 TO 4	ACCELERATION AND SURFACE TENSION
APU				-1/0/3	0 TO 4	ACCELERATION AND SURFACE TENSION
ABPS				0 TO 1	1	GRAVITY

LIFT OFF BOOSTER BURNOUT REENTRY LANDING

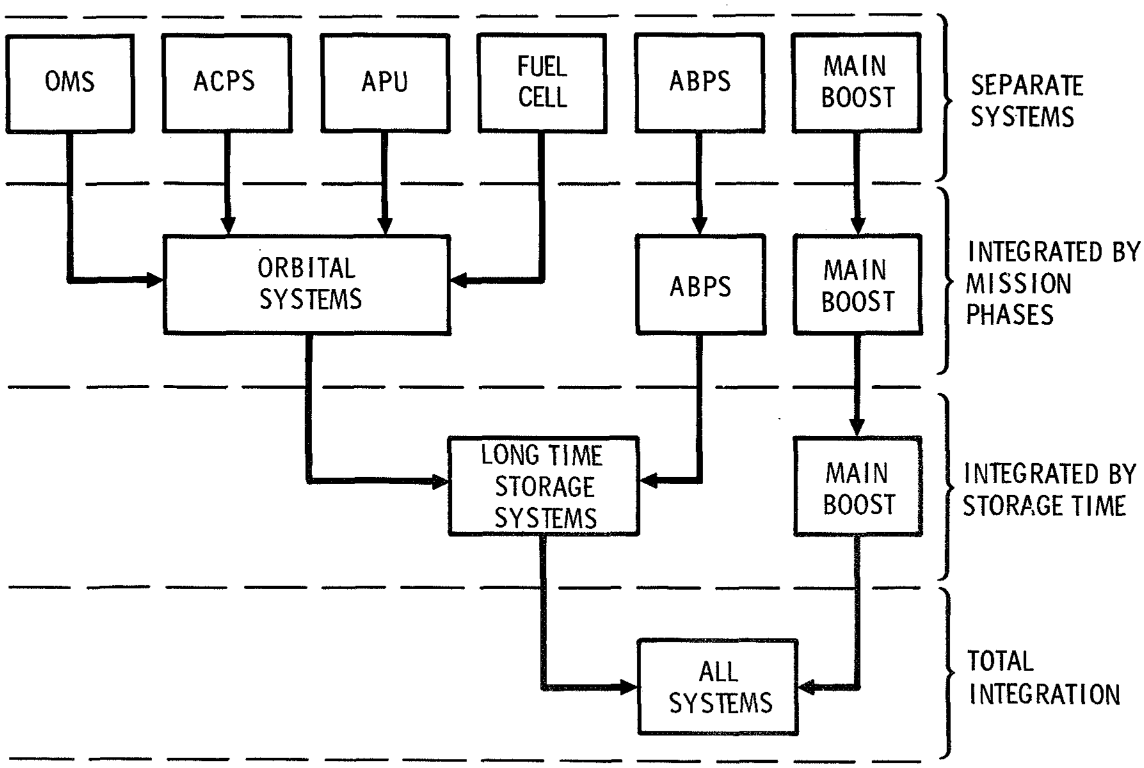
ORBITER PROPELLANT TIME LINE

THIS CHART SHOWS THE SAME TYPE OF INFORMATION FOR THE ORBITER AS WAS SHOWN FOR THE BOOSTER. THE MAJOR DIFFERENCES ARE THE SEVEN DAY STORAGE TIME IN ORBIT AND THE EXTENDED PERIOD AT ZERO G. THIS EXTENDED ORBITAL STORAGE TIME REQUIRES TECHNOLOGY IMPROVEMENTS IN REUSABLE HIGH PERFORMANCE INSULATION AND PROPELLANT ORIENTATION CONCEPTS COMPATIBLE WITH CRYOGENIC PROPELLANTS.



CANDIDATE SYSTEM INTEGRATION

THE DEGREE OF CRYOGENIC SYSTEM INTEGRATION IS CATEGORIZED FROM COMPLETELY SEPARATE SYSTEMS TO TOTALLY INTEGRATED SYSTEMS. TWO INTERMEDIATE CONSIDERATIONS BEING AN INTEGRATION BY MISSION PHASE; I.E., MAIN BOOST, ORBITAL OPERATION AND RE-ENTRY, AND POWERED LANDING, AND INTEGRATION BY LENGTH OF STORAGE TIME.



TOTAL SYSTEM INTEGRATION CONSIDERATIONS

TO INTEGRATE ALL CRYOGENIC SYSTEMS INTO THE BOOST TANKS REQUIRES THAT THE BOOST TANKS BE CAPABLE OF STORAGE TIMES OF SEVEN DAYS. CONSEQUENTLY, THE BOOST TANKS WOULD HAVE TO BE INSULATED WITH HIGH PERFORMANCE INSULATION AND BE REUSABLE FOR 100 MISSIONS. BECAUSE OF THE SIZE OF THE BOOST TANKS, THE GROUND AND RE-ENTRY PURGES OF THE INSULATION WOULD BE GREATLY INCREASED. CONTROL OF HEAT SHORTS TO MINIMIZE HEAT LEAKS TO SUCH A LARGE STRUCTURALLY INTEGRAL TANK WOULD BE VERY DIFFICULT. PROPELLANTS FOR ORBITAL, RE-ENTRY AND LANDING OPERATIONS ONLY TAKE UP APPROXIMATELY 9 PERCENT OF THE TOTAL TANK VOLUME. FOR THIS REASON AN UNDESIRABLE LARGE TANK SURFACE AREA TO USABLE PROPELLANT EXISTS AFTER ASCENT. A PROPELLANT ORIENTATION DEVICE MUST BE INCORPORATED WHICH CANNOT INTERFERE WITH THE FEED SYSTEM FOR THE MAIN BOOST ENGINES. THE HOT PRESSURANT GAS USED DURING ASCENT TO PRESSURIZE THE TANK MUST BE VENTED OVERBOARD AFTER ORBITAL INJECTION WITHOUT DISRUPTING THE PROPELLANT ORIENTATION SYSTEM. AT MAIN ENGINE SHUTDOWN, PROPELLANT IN THE FEED DUCTS WILL SURGE BACK INTO THE TANK AND THE PROPELLANT ORIENTATION DEVICE MUST BE PROTECTED FROM THIS. THE OMS REQUIRES MULTIPLE STARTS WHICH REQUIRES PRESSURIZATION OF THE OVERSIZED TANKS. IN SHORT, THE INTEGRATED LARGE BOOST TANK COMPLICATES ALREADY SEVERE EXISTING TECHNOLOGY PROBLEMS.

HIGH PERFORMANCE INSULATED BOOST TANKS

- REUSABILITY
- LARGE PURGE REQUIREMENTS
- HEAT SHORTS
- LARGE SURFACE AREA TO USABLE PROPELLANT

PROPELLANT ORIENTATION DEVICE

HOT PRESSURANT GAS FROM BOOST

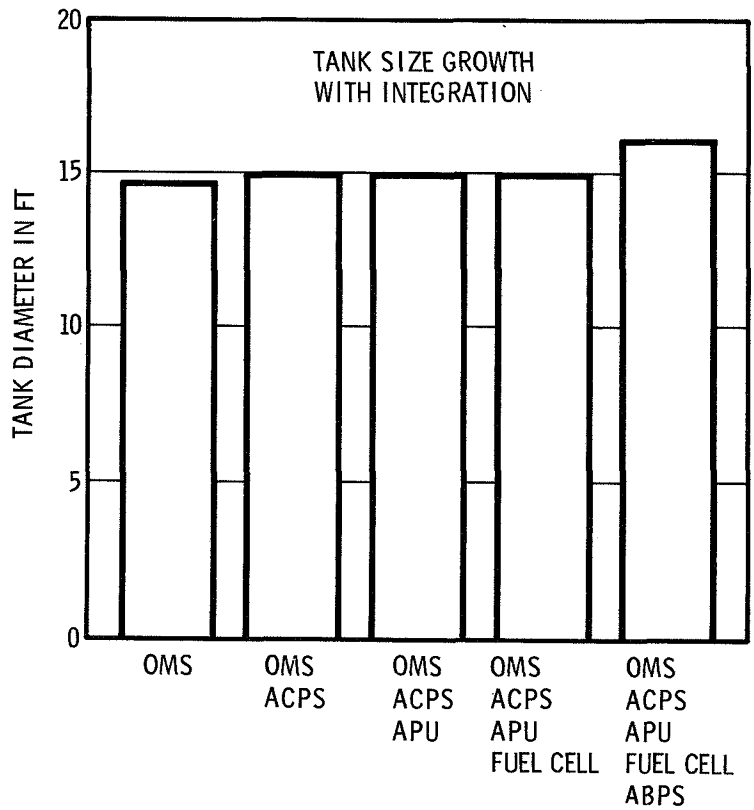
MAIN ENGINE SHUTDOWN PROPELLANT DYNAMICS

MULTIPLE START REPRESSURIZATION

LARGE TANK SIZE COMPLICATES EXISTING TECHNOLOGY PROBLEMS

LONG TERM STORAGE INTEGRATION

IF THE BOOST PROPELLANT IS KEPT SEPARATE FROM THE LONG TERM STORAGE PROPELLANTS, THE ADDITIONAL SYSTEMS CAN BE ADDED TO THE OMS TANKAGE WITH VERY LITTLE GROWTH IN TANK SIZE. CONSEQUENTLY, THE TANK VOLUME TO PROPELLANT MASS IS VERY FAVORABLE AND ELIMINATES MANY OF THE PROBLEMS ASSOCIATED WITH TOTAL INTEGRATION. CONSTRAINTS THAT MAY LIMIT THE INTEGRATION OF ALL OF THE LONG TERM STORAGE SYSTEMS ARE PROPELLANT PURITY FOR THE FUEL CELLS (HELIUM CONTAMINATION) AND MULTIPLE TANK OUTLETS TO BYPASS THE PROPELLANT ORIENTATION SYSTEM FOR THE AIRBREATHING PROPULSION SYSTEM.

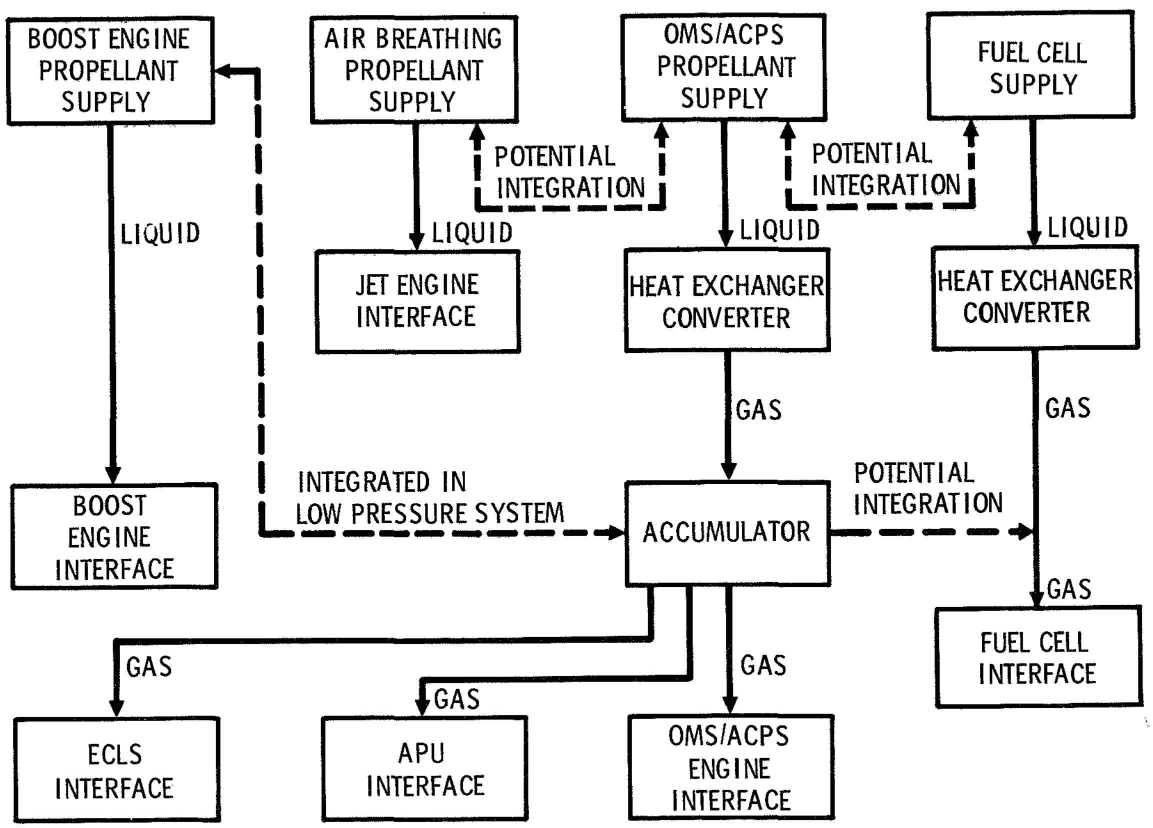


CONSTRAINTS

- PURITY (FUEL CELL)
- MULTIPLE TANK OUTLET

CRYOGENIC SYSTEM INTEGRATION SUMMARY

THIS SUMMARIZES THE CRYOGENIC SYSTEMS THAT CAN BE INTEGRATED. POTENTIAL INTEGRATION OF THE FUEL CELLS AND ABPS IS SHOWN IF THE PROBLEMS ASSOCIATED WITH PURITY AND MULTIPLE TANK OUTLETS CAN BE OVERCOME. THE PRESSURE, TEMPERATURE AND STATE INTERFACE REQUIREMENTS ARE COMPATIBLE AND THE TECHNOLOGY REQUIREMENTS FOR LONG TERM STORAGE AND ZERO G OPERATION ARE THE SAME FOR ALL SYSTEMS.



CONCLUSION

THE RESOLUTION OF IDENTIFIED TECHNOLOGIES IN LONG TERM CRYOGENIC STORAGE WITH A REUSABLE INSULATION SYSTEM AND OPERATION OF A PROPELLANT ORIENTATION SYSTEM IN A ZERO G ENVIRONMENT WILL SATISFY THE DESIRE TO INTEGRATE THE LONG TERM STORAGE SYSTEMS ON THE SPACE SHUTTLE. THIS DEGREE OF INTEGRATION WILL REDUCE LAUNCH PREPARATIONS AND VEHICLE COMPLEXITY, ENHANCE MAINTAINABILITY, AND WILL PROVIDE MISSION FLEXIBILITY. THE INTEGRATION BY STORAGE TIME DOES NOT PENALIZE THE ORBITAL SYSTEMS. THE ADDITIONAL COMPLICATIONS TO ALREADY TOUGH TECHNOLOGY PROBLEMS ASSOCIATED WITH INTEGRATION OF THE ORBITAL PROPELLANT IN THE LARGE BOOST TANKS CAN BE ELIMINATED.