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Failure Mode, Effects and Criticality Analysis

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16. ABSTRACT

A Failure Mode, Effects and Criticality Analysis was performed on the Space Tug Propulsion System. For purposes of this study the Propulsion System was considered as consisting of the following: (1) Main Engine System, (2) Auxiliary Propulsion System, (3) Pneumatic System, (4) Hydrogen Feed, Fill, Drain and Vent System, (5) Oxygen Feed, Fill, Drain and Vent System, and (6) Helium Reentry Purge System. Each component was critically examined to identify possible failure modes and the subsequent effect on mission success. Each Space Tug mission consists of three phases: Phase A-Launch to Separation from Shuttle; Phase B-Separation to Redocking; Phase C-Redocking to Landing. The analysis considered the results of failure of a component during each phase of the mission.

After the failure modes of each component were tabulated, those components whose failure would result in possible or certain loss of mission or inability to return the Tug to ground were identified as "critical components" and a "criticality number" determined for each. The criticality number of a component denotes the number of mission failures (as defined above) in one million missions due to the loss of that component. A total of 68 components were identified as critical with criticality numbers ranging from 1 to 2990.

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Foreword

This document presents the results of work performed by Teledyne Brown Engineering in support of Program Development of the Marshall Space Flight Center, under Mission Support Contract NAS8-21804. This task was conducted in response to the requirements of Technical Directive D-2-017 "Advanced Rocket Engine Analysis," Amendment No. 2, March 23, 1972.

The NASA technical coordinator for this study was Mr. James F. Thompson, PD-DO-MP, Marshall Space Flight Center, Huntsville, Alabama.

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INTRODUCTION

This report contains a Failure Mode, Effects and Criticality Analysis of the Space Tug Propulsion System. The analysis is broken down into the primary subsystems which comprise the Propulsion System. The results of each of the subsystems analyses are detailed in this report under their individual nomenclatures.

The Space Tug Propulsion System analyzed in this report includes the main propulsion system, the thermal control system and the auxiliary propulsion system. The main propulsion system consists of the main engine, transfer system, propellant conditioning and utilization system. The thermal control system consists of the necessary tank insulation and associated purge system to maintain the propellants in a usable liquid state throughout the mission. The auxiliary propulsion system (APS) consists of sixteen thrusters to perform coast attitude stabilization, rendezvous and docking maneuvers. The APS system also consists of propellant storage tanks and conditioning and feed systems that are necessary to provide the required propellants to the thrusters and for providing re-pressurization of the main engine propellant tanks and for providing propellants for the fuel cell and for the main engine idle mode start sequence.

While it was assumed that monitoring and detection equipment would be required in this system, the analysis does not consider the success probability of these items nor does it consider the success probability of any of the supporting avionic equipment.

The criticality numbers were determined for each critical item of each system. The criticality number of a component denotes the number of mission failures in one million missions due to loss of that component. The loss probability for one mission can be determined by multiplying the criticality number by 10^{-6}.

The current Space Tug is defined in Reference 1.

GROUND RULES AND ASSUMPTIONS

The following ground rules and assumptions were used in the performance of this analysis:

(1) All lines and fittings are brazed and will not leak at the connections without a structural failure.

(2) External leakage past the main engine inducer and turbopump seals is negligible.

(3) Loss of engine idle mode results in loss of the engine function.

(4) All propellant is dumped prior to redocking.

(5) The main engine has isolation valves for the feed lines.

(6) The APS has "thruster out" capability and can perform its mission with one thruster pod disabled.

(7) The system has adequate sensing devices to monitor critical functions and to detect malfunctions.

(8) All valves are "fail safe" in their normal position.

(9) The main engine propellant tanks cannot be re-pressurized from the main engine.

(10) The fill and drain disconnects were analyzed as independent components although they were assumed to be part of an umbilical plate.

(11) Loss of LH_2 and LO_2 multilayer insulation (MLI) purge after launch has no effect on the immediate Tug mission.

(12) Loss of LH_2 and LO_2 tank purge after the Tug returns for redocking creates a hazardous condition.

(13) The following time phases were used in this analysis:

Phase A	Boost and separation of Tug and Shuttle	2.85 hours
Phase B	Tug orbital operations and redocking with Shuttle	136 hours
Phase C	Tug repressurization and return to Earth	16.7 hours

CONCLUSIONS AND RECOMMENDATIONS

The predicted probability of the Space Tug Propulsion System performing for the duration of the Tug mission is 0.969189.

It is recommended that sufficient monitoring and malfunction detection devices be included in the design to assure that redundant systems will be effectively triggered in the event of failure.

More detailed recommendations are included in the analyses of the individual systems where it is deemed appropriate.

MAIN ENGINE SYSTEM FAILURE MODE, EFFECTS AND CRITICALITY ANALYSIS

This section presents a preliminary failure mode, effects and criticality analysis of the Space Tug Main Engine System. This system utilizes a high performance LO_2/LH_2 engine having a nominal specific impulse of 470 seconds and a thrust of 10,000 pounds. A staged-combustion cycle with two preburners in conjunction with coaxial injectors and a nozzle area expansion ratio of 400 is used for high efficiency. The engine has throttle capability to 20 percent and mixture ratio range of 5.5 to 6.5 (6.0 is nominal). No propellants are dumped non-propulsively and a pressure-fed idle mode is utilized for engine chilldown prior to start. The engine is equipped with boost pumps for both propellants which allow NPSH's of 15 feet for LH_2 and 2 feet for LOX without penalty to the main pumps. The nozzle is non-retractable.

The system schematic and the system block diagram are presented in Figures 1 and 2, respectively.

ASSUMPTIONS AND GROUND RULES

1. External leakage past the inducer and turbopump seals is negligible.

2. Loss of engine idle mode results in loss of the engine.

3. All lines and fittings are brazed and will show no appreciable leakage without a structural failure of these components.

4. The following time phases were used for this analysis:

Phase A	Boost and separation of Tug and Shuttle	2.85 hours
Phase B	Tug orbital operations and redocking with Shuttle	136 hours
Phase C	Tug repressurization and return to earth	16.7 hours

CONCLUSIONS AND RECOMMENDATIONS

The predicted probability of this system performing for the duration of a Tug mission is 0.993767.

This analysis did not disclose any areas where a design change would contribute significantly to the reliability of the system.

ENGINE SYSTEM
CRITICAL ITEMS LIST

COMPONENT CODE	ITEM	FAILURE TYPE	CRITICALITY
501	Main LH_2 Valve	Fails to open/remain open	125
		External leakage	66
502	Main LOX Valve	Fails to open/remain open	125
		External leakage	66
503	LH_2 Inducer	Fails to operate/remain in operation	1
504	LOX Inducer	Fails to operate/remain in operation	1
505	Preburner Control Valve LH_2	Fails to open	7
506	Preburner Control Valve LOX	Fails to open	125
		Fails to close/remain closed and internal leakage	7
507	LH_2 Turbopump	Fails to operate/remain in operation	1360
508	Preburner (2 req'd)	Fails to operate/remain in operation	2990
510	LOX Turbopump	Fails to operate/remain in operation	1360

FIGURE 1. SHUTTLE TUG ENGINE SYSTEM SCHEMATIC

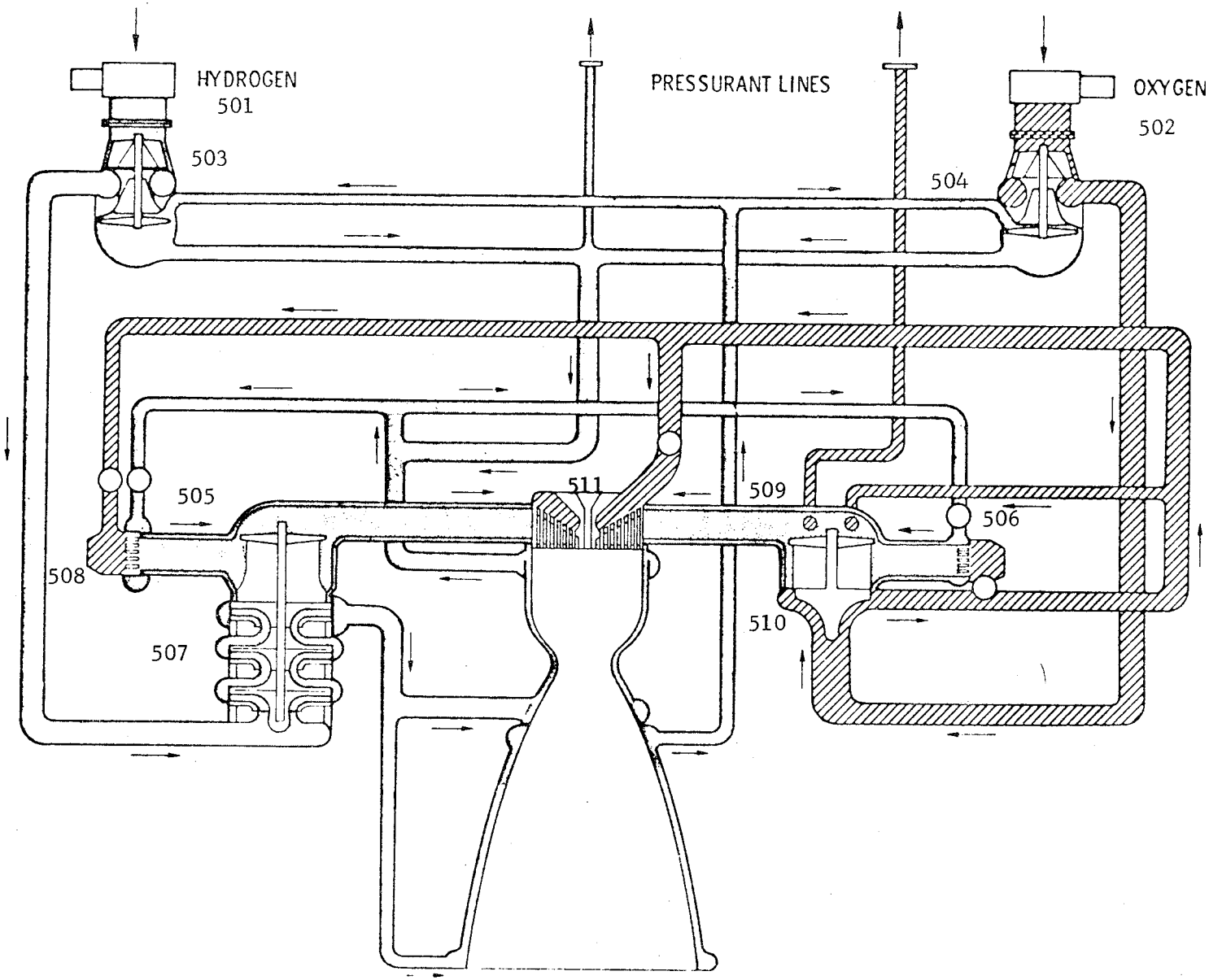
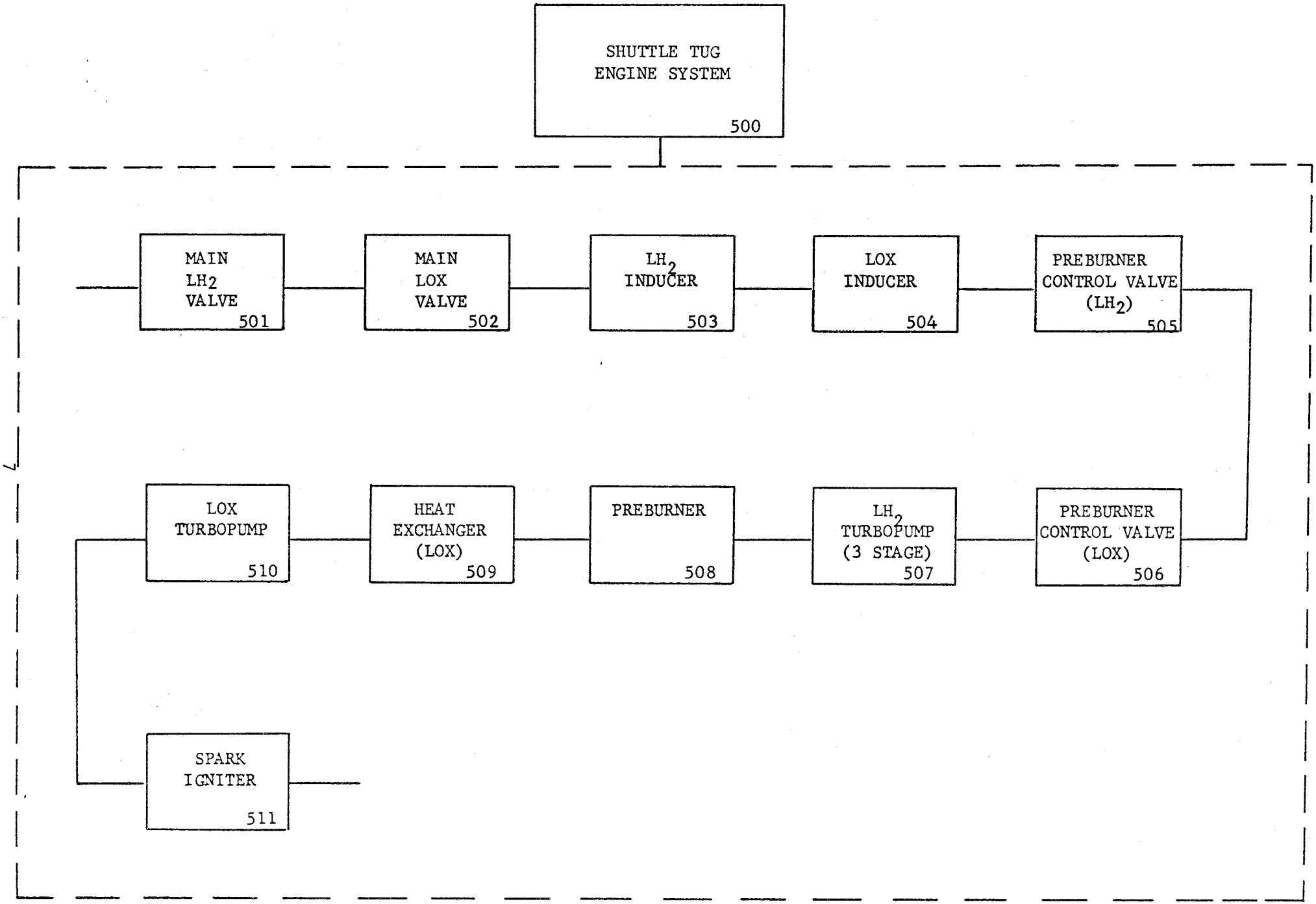


FIGURE 2. SHUTTLE TUG ENGINE SYSTEM BLOCK DIAGRAM



FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
ENGINE SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 501 Main LH_2 Valve This normally closed pneumatically operated poppet valve is opened and closed to control LH_2 flow to the engine. It is assumed that the valve poppet will relieve any pressure caused by fuel entrapment between this valve and the preburner.	Fails to open	A. No effect. Not required to operate during this phase.	A. No effect. Failure mode not applicable.
		B. <u>Actual Loss</u> Unable to operate the engine as required.	B. <u>Actual Loss</u> Inability to operate the tug main engine causes loss of the tug mission.
		C. No effect. Not required to operate during this phase.	C. No effect. Failure mode not applicable.
	Fails to close	A. Not applicable. Valve is closed during this phase.	A. No effect. Failure mode not applicable.
		B. No effect. Redundancy is provided by downstream valves.	B. No effect. Redundancy is provided.
		C. No effect. Valve is closed during this phase.	C. No effect. Failure mode not applicable.
	Fails to remain closed and Internal leakage	A, B, C. No effect. Redundancy provided by downstream valves.	A, B, C. No effect. Redundancy is provided.
	Fails to remain open	A. No effect. The valve is not open during this phase.	A. No effect. Failure mode not applicable.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
ENGINE SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 501			
Main LH_2 Valve (Continued)		B. Actual Loss Unable to operate the engine as required.	B. Actual Loss Inability to operate the tug main engine causes loss of the tug mission. Also, premature closure of this valve could cause a LOX rich shutdown damaging the engine.
		C. No effect. The valve is not open during this phase.	C. No effect. Failure mode not applicable.
	External leakage	A. Possible Loss Hydrogen leaks into the Shuttle bay area.	A. Possible Loss Accumulation of hydrogen in the shuttle bay is a hazard to the mission, vehicle, and crew.
		B. No effect. The amount of leakage past the valve seals will not affect the system.	B. No effect. Leakage past the seals is negligible.
		C. No effect. The propellants are dumped prior to this phase.	C. No effect. Failure mode not applicable.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
ENGINE SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 502			
Main LOX Valve This normally closed pneumatically operated poppet valve is opened and closed to control LOX flow to the engine. It is assumed that the valve poppet will relieve any pressure caused by oxidizer entrapment in the engine	Fails to open	A. No effect. Not required to operate during this phase.	A. No effect. Failure mode not applicable.
		B. Actual Loss Unable to operate the engine as required.	B. Actual Loss Inability to operate the tug main engine causes loss of the tug mission.
		C. Not applicable. Valve is closed during this phase.	C. No effect Failure mode not applicable.
	Fails to close	A. Not applicable. Valve is closed during this phase.	A. No effect. Failure mode not applicable.
		B. No effect. Redundancy is provided by downstream valves.	B. No effect. Redundancy is provided.
		C. No effect. Valve is closed during this phase.	C. No effect. Failure mode not applicable.
	Fails to remain closed and internal leakage	A, B, C. No effect. Redundancy is provided by downstream valves.	A, B, C. No effect. Redundancy is provided.
	Fails to remain open	A. No effect. The valve is not open during this phase.	A. No effect. Failure mode not applicable.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
ENGINE SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 502			
Main LOX Valve (Continued)		B. Actual Loss Unable to operate the engine as required.	B. Actual Loss Inability to operate the tug main engine causes loss of the tug mission.
		C. No effect. The valve is not open during this phase.	C. No effect. Failure mode not applicable
	External leakage	A. Possible Loss Oxygen leaks into the Shuttle bay area.	A. Possible Loss Accumulation of oxygen in the Shuttle bay is hazardous to the crew, vehicle, and mission.
		B. No effect. The amount of leakage past the valve seals will not effect the system.	B. No effect. Leakage past the seals is negligible.
		C. No effect. The propellants are dumped prior to this phase.	C. No effect. Failure mode not applicable.
Component Code: 503			
LH_2 Inducer This pump increases the tank inlet pressure for engine idle mode and main pump NPSH. The pump is operated by gaseous hydrogen tapped from the engine bell.	Fails to operate	A. No effect. Not required to operate in this phase.	A. No effect. Failure mode not applicable.
		B. Actual Loss Loss of the engine main pump NPSH.	B. Probable Loss Loss of main pump NPSH may preclude engine start.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
ENGINE SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 503 LH_2 Inducer (Continued)		C. No effect. Not required to operate in this phase.	C. No effect. Failure mode not applicable.
	Fails to remain in operation	A. No effect. Not required to operate in this phase.	A. No effect. Failure mode not applicable.
		B. Actual Loss Loss of engine main pump NPSH.	B. Possible Loss Loss of main pump NPSH may preclude engine restart or cause a premature shutdown.
		C. No effect. Not required to operate in this phase.	C. No effect. Failure mode not applicable.
	Internal or external leakage	A. No effect. The main engine valve is closed preventing leakage in this phase.	A. No effect. Failure mode not applicable.
		B. No effect. The amount of leakage past the pump seals will not affect the system.	B. No effect. Leakage past the seals is negligible.
		C. No effect. The propellants are dumped prior to this phase.	C. No effect. Failure mode not applicable.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
ENGINE SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 504 LOX Inducer This pump increases the tank inlet pressure for engine idle mode and main pump NPSH. The pump is operated by gaseous hydrogen tapped from the engine bell.	Fails to operate.	A. No effect. Not required operate in this phase.	A. No effect. Failure mode not applicable.
		B. <u>Actual Loss</u> Loss of the engine main pump NPSH.	B. <u>Probable Loss</u> Loss of main pump NPSH may preclude engine start.
		C. No effect. Not required to operate in this phase.	C. No effect. Failure mode not applicable.
	Fails to remain in operation	A. No effect. Not required to operate in this phase.	A. No effect. Failure mode not applicable.
		B. <u>Actual Loss</u> Loss of engine main pump NPSH.	B. <u>Possible Loss</u> Loss of main pump NPSH may preclude engine restart or cause a premature engine shutdown.
		C. No effect. Not required to operate in this phase.	C. No effect. Failure mode not applicable.
	External leakage	A. No effect. The main engine valve is closed preventing leakage in this phase.	A. No effect. Redundancy is provided.
		B. No effect. The amount of leakage past the pump seals will not affect the system.	B. No effect. Leakage past the seals is negligible

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
ENGINE SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 504			
LOX Inducer (Continued)		C. No effect. The propellants are dumped prior to this phase.	C. No effect. Failure mode not applicable.
	Internal leakage	A. No effect. The main engine valve is closed preventing leakage in this phase.	A. No effect. Failure mode not applicable.
		B. No effect. A helium purge of the pump seals prevents H_2 and O_2 from bleeding into the same cavity.	B. No effect. A purge protects the engine from seal failures.
		C. No effect. The propellants are dumped prior to this phase.	C. No effect. Failure mode not applicable.
Component Code: 505			
Preburner Control Valve (LH_2) 2 Required This valve is opened to allow LH_2 to enter the preburner at start.	Fails to open	A. No effect. The valve remains closed during this phase.	A. No effect. Failure mode not applicable.
		B. <u>Actual Loss</u> Unable to operate the engine during this phase.	B. <u>Actual Loss</u> Loss of the tug engine causes a loss of the tug mission.
		C. No effect. The valve remains closed during this phase.	C. No effect. Failure mode not applicable.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
ENGINE SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 505			
Preburner Control Valve (Continued)	Fails to close	A. No effect. The valve is closed during this phase.	A. No effect. Failure mode not applicable.
		B. No effect. Hydrogen leaks overboard. However, redundancy is provided by the main valve.	B. No effect. Redundancy is provided.
		C. No effect. The valve is closed during this phase.	C. No effect. Failure mode not applicable.
	Fails to remain closed and internal leakage	A & C. No effect. Redundancy is provided by upstream components.	A & C. No effect. Redundancy is provided.
		B. No effect. Some LH_2 is lost overboard. However, redundancy is provided by the main valve.	B. No effect. Redundancy is provided.
	External leakage	A. No effect. Redundancy is provided by upstream components.	A. No effect. Redundancy is provided.
		B. No effect. Leakage past the valve seals is negligible.	B. No effect.
		C. No effect. The LH_2 tanks are purged before this phase.	C. No effect. Failure mode not applicable.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
ENGINE SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 506			
Preburner Control Valve (LOX) 2 Required This valve is opened to allow LOX to enter the preburner at start. During engine operation the valve is modulated by inputs from the engine control package to control the engine mixture valve.	Fails to open	A & C. No effect. The valve remains closed during this phase.	A & C. No effect. Failure mode not applicable.
		B. Actual Loss Unable to operate the engine during this phase.	B. Actual Loss Loss of the tug engine causes a loss of the tug mission.
	Fails to close	A & C. No effect. The valve remains closed during this phase.	A & C. No effect. Failure mode not applicable.
		B. Actual Loss Unable to control the engine mixture ratio as required.	B. Probable Loss Loss of the mixture ratio control can lead to improper performance with resultant loss of mission.
	Fails to remain closed and internal leakage	A & C. No effect. Redundancy is provided by upstream components.	A & C. No effect. Redundancy is provided.
		B. Actual Loss Loss of engine mixture ratio control.	B. Possible Loss Loss of engine mixture ratio control can lead to improper performance with resultant loss of mission.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
ENGINE SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 506			
Preburner Control Valve (Continued)	External leakage	A. No effect. The main engine valve is closed preventing leakage in this phase.	A. No effect.
		B. No effect. Leakage past the valve seals is negligible.	B. No effect.
		C. No effect. The LOX tanks are purged before this phase.	C. No effect. Failure mode not applicable.
Component Code: 507			
LH_2 Turbopump (3^2 stage) Hydrogen from the pump flows around the nozzle and combustion chamber where it is vaporized. The gaseous hydrogen is then used to drive the LH_2 and LOX inducers and provide fuel for preburner and main engine operation.	Fails to operate	A & C. No effect. Not required to operate during this time phase.	A & C. No effect. Failure mode not applicable.
		B. Actual Loss Loss of engine operation.	B. Actual Loss Loss of engine causes loss of tug mission.
	Fails to remain in operation	A & C. No effect. Not required to operate during this time phase.	A & C. No effect. Failure mode not applicable.
		B. Actual Loss Loss of tug engine operation.	B. Actual Loss Loss of tug engine operation causes loss of tug mission.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
ENGINE SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 507			
LH_2 Turbopump (Continued)	External leakage	A. No effect. Redundancy provided by upstream components.	A. No effect. Redundancy is provided.
		B. No effect. Leakage past the pump seals will not affect the system.	B. No effect. Leakage past the seals is negligible.
		C. No effect. The propellants are dumped prior to this phase.	C. No effect. Failure mode not applicable.
Component Code: 508			
Preburner 2 Required These concentric element preburners burn LH_2 and LOX in a very fuel-rich environment to provide power to run the turbopumps.	Fails to operate	A & C. No effect. Not required to operate during this time phase.	A & C. No effect. Failure mode not applicable.
		B. Actual Loss Loss of either preburner would cause loss of the engine.	B. Actual Loss Loss of the engine would cause loss of the tug mission.
	Fails to remain in operation	A & C. No effect. Not required to operate during this time phase.	A & C. No effect. Failure mode not applicable.
		B. Actual Loss Loss of either preburner would cause loss of the engine.	B. Actual Loss Loss of the engine would cause loss of the tug mission.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
ENGINE SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 508			
Preburner (Continued)	External leakage	A. No effect. Redundancy is provided by upstream components.	A. No effect. Redundancy is provided.
		B. No effect. Leakage past the seals would not affect the system.	B. No effect. Leakage past the seals is negligible.
		C. No effect. The propellants are dumped prior to this phase.	C. No effect. Failure mode not applicable.
Component Code: 509			
Heat Exchanger (LOX) This heat exchanger converts LOX to GOX for pressurization of the main LOX tank.	No Applicable Failure Type		
Component Code: 510			
LOX Turbopump This turbopump increases the oxygen pressure for main engine and preburner operation.	Fails to operate	A & C. No effect. Not required to operate during this time phase.	A & C. No effect. Failure mode not applicable.
		B. Actual Loss Loss of engine operation.	B. Actual Loss Loss of engine causes loss of tug mission.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
ENGINE SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 510			
LOX Turbopump (Continued)	Fails to remain in operation	A & C. No effect. Not required to operate during this time phase.	A & C. No effect. Failure mode not applicable.
		B. Actual Loss Loss of engine operation.	B. Actual Loss Loss of engine causes loss of tug mission.
	External leakage	A. No effect. Redundancy is provided by upstream components.	A. No effect. Redundancy is provided.
		B. No effect. Leakage past the pump seals will not affect the system.	B. No effect. Leakage past the seals is negligible.
		C. No effect. The propellants are dumped prior to this phase.	C. No effect. Failure mode not applicable.
Component Code: 511			
Spark Igniter This igniter provides ignition for the engine.	Fails to operate	A & C. No effect. Not required to operate during this time phase.	A & C. No effect. Failure mode not applicable.
		B. No effect. There are two igniters that are redundant for fails to operate.	B. No effect. Redundancy is provided.

PNEUMATIC AND MLI VENT AND BACKFILL SYSTEM FAILURE MODE EFFECTS AND CRITICALITY ANALYSIS

This section presents a preliminary failure mode, effects and criticality analysis of the Space Tug Pneumatic and MLI Vent and Backfill System.

This system provides ambient helium for main engine and multilayer insulation (MLI) purge, and for pneumatic valve and docking latch activation.

The system schematic and the system block diagram are presented in Figures 3 and 4, respectively.

ASSUMPTIONS AND GROUND RULES

1. All lines and fittings have brazed connections and will show no appreciable leakage without a structural failure of these components.

2. Loss of the LH_2 and LOX tank multilayer insulation (MLI) purge after launch has no effect on the immediate tug mission. However, the MLI may be contaminated during reentry and would have to be replaced before the next mission.

3. Loss of LH_2 and LOX tank purge capability after the tug returns to the Shuttle creates a hazardous condition and a decision concerning tug return will be required at that time.

4. The following time phases were used in this analysis:

Phase A	Boost and Separation of Tug and Shuttle	2.85 hours
Phase B	Tug orbital operations and redocking	136 hours
Phase C	Tug repressurization and return to Earth	16.7 hours

CONCLUSIONS AND RECOMMENDATIONS

The predicted probability of this system performing for the duration of a Tug mission is 0.994755.

This analysis did not disclose any areas where a design change would contribute significantly to the reliability of the system.

PNEUMATIC SYSTEM
CRITICAL ITEMS LIST

COMPONENT CODE	ITEM	FAILURE TYPE	CRITICALITY
402	Quick Disconnect	Fails to disconnect	28.5
		Fails to connect	27.2
403	Filter	Clogs	5.5
404	N. C. Solenoid Valve	Fails to open	4.1
		Fails to close/remain closed, internal and external leakage	694.5
405	N. C. Solenoid Valve	Fails to close/remain closed, internal and external leakage	778.0
406	N. C. Solenoid Valve	Fails to close/remain closed, internal and external leakage	778.0
407	Helium Sphere	Burst	12.0
408	Filter	Clogs	51.4
409	Regulator	Regulates high	13.6
		Regulates low	17.0
410	Solenoid Latching Valve	Fails to open/remain open	137.0
		External leakage	2.0

PNEUMATIC SYSTEM
CRITICAL ITEMS LIST
(Concluded)

COMPONENT CODE	ITEM	FAILURE TYPE	CRITICALITY
411	Plenum	Burst	136.8
412	Relief Valve	Fails to close/remain closed internal and external leakage	684.4
413 a-n	Three-Way Solenoid Valve	External leakage	190.4
413 p	Three-Way Solenoid Valve	Fails to open/remain open	625.6
		External leakage	8.0
413 r	Three-Way Solenoid Valve	Fails to open/remain open	625.6
		External leakage	8.0
413 s	Three-Way Solenoid Valve	Fails to open/remain open	625.6
		External leakage	8.0

FIGURE 3. [illegible] PNEUMATIC AND MLI PURGE AND BACKFILL SCHEMATIC

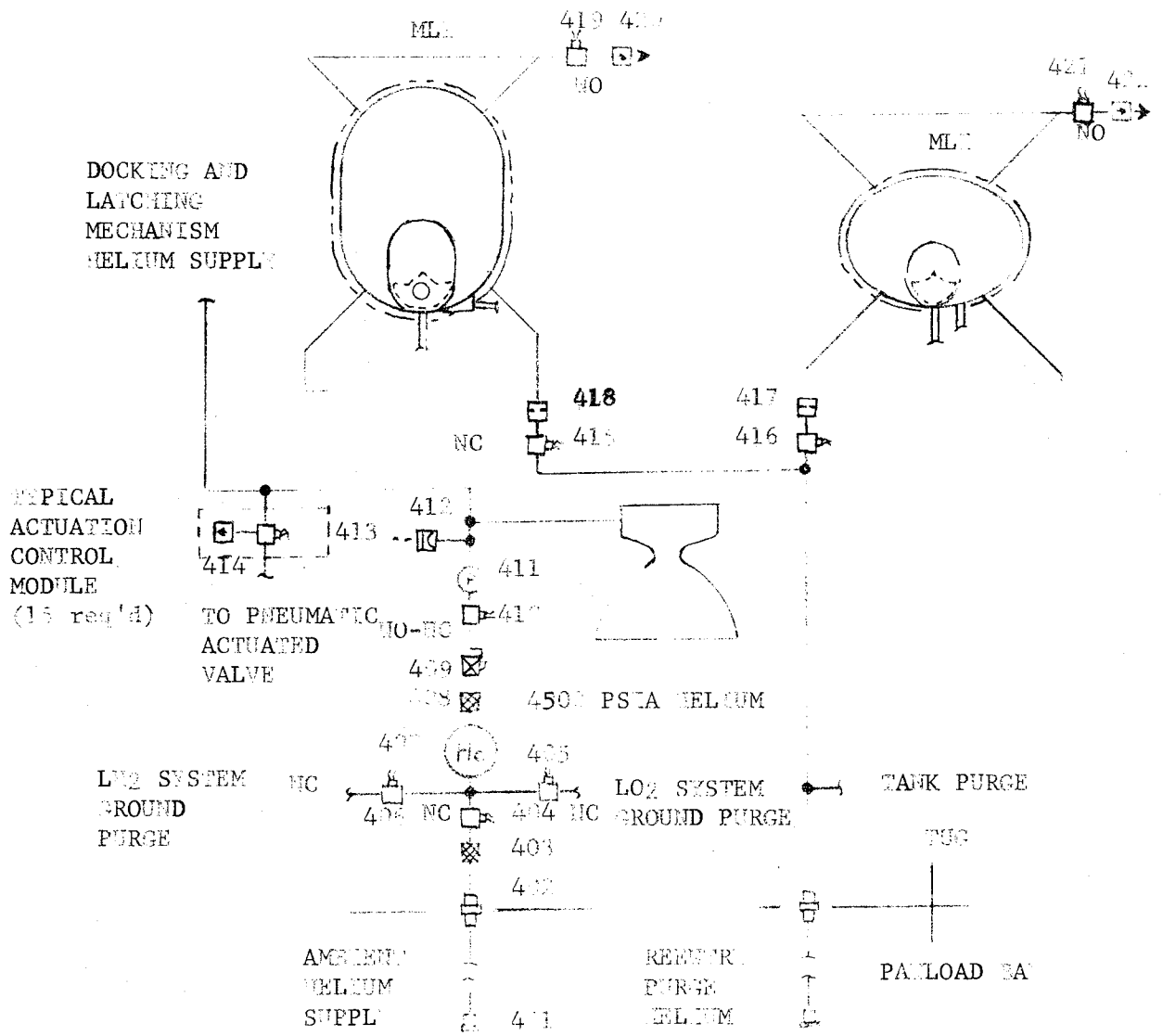
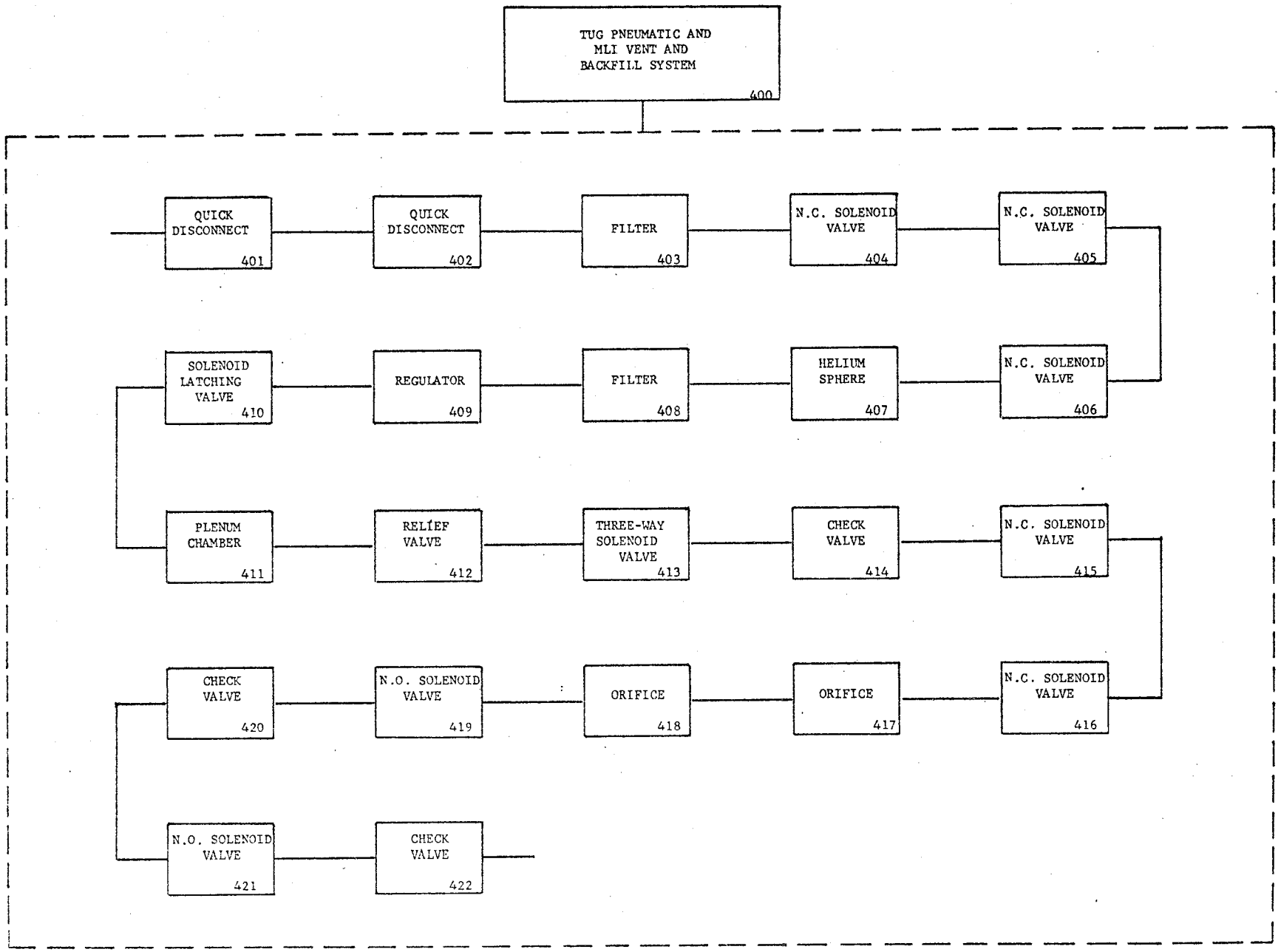


FIGURE 4. TUG PNEUMATIC AND MLI VENT AND BACKFILL SYSTEM BLOCK DIAGRAM



FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
PNEUMATIC SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 401			
Quick Disconnect This quick disconnect provides a connection from the GSE helium supply to the shuttle payload bay.	Fails to disconnect	A, B, & C) No effect. Not required to operate during this time phase.	A, B, & C) No effect. Not required to operate during this time phase.
COMPONENT CODE: 402			
Quick Disconnect This quick disconnect provides a connection between the shuttle payload bay and the tug.	Fails to disconnect	A) Actual loss. Loss of system due to inability to separate from shuttle. B&C) No effect. Not required to perform this function during this time phase.	A) Actual loss. Loss of mission due to inability to separate from shuttle. B&C) No effect. Not required to perform this function during this time phase.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
PNEUMATIC SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 402			
Quick Disconnect (Cont.)	Fails to connect	A) No effect. Not required to perform this function during this time phase.	A) No effect. Not required to perform this function during this time phase.
		B) Actual loss. Unable to purge tug propellant tanks.	B) Possible loss. Being unable to purge the tug propellant tanks creates a hazardous condition to the shuttle and crew.
		C) No effect. Not required to perform this function during this time phase.	C) No effect.
COMPONENT CODE: 403			
Filter This filter removes contaminants from the ambient helium supply line.	Clogs	A) Actual loss. Unable to replenish the tug helium sphere.	A) Possible loss. Possible depletion of the tug helium supply.
		B) No effect. Not required to operate during this time phase.	B) No effect. Not required to operate during this time phase.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
PNEUMATIC SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 403			
Filter (Cont.)		C) Actual loss. Unable to replenish the tug helium sphere.	C) Possible loss. Possible depletion of the tug helium supply.
COMPONENT CODE: 404			
N.C. Solenoid Valve This N.C. solenoid valve shuts off the ambient helium supply.	Fails to open	A) Actual loss. Unable to replenish the tug helium sphere.	A) Possible loss. Possible depletion of the tug helium supply.
		B) No effect. Not required to operate during this time phase.	B) No effect. Not required to operate during this time phase.
		C) Actual loss. Unable to replenish the tug helium sphere.	C) Possible loss. Possible depletion of the tug helium supply.
	Fails to close, remain closed, internal leakage and external leakage	A&B) Actual loss. Loss of helium.	A&B) Actual loss. Loss of helium causes loss of pneumatic valve control.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
PNEUMATIC SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 404 N.C. Solenoid Valve (Cont.)		C) Possible loss. Loss of helium.	C) Possible loss. Loss of helium could cause loss of pneumatic valve control and loss of tug propellant tank purge capability.
COMPONENT CODE: 405 N.C. Solenoid Valve This N.C. solenoid valve shuts off the LOX system ground purge line.	Fails to open	A,B&C) No effect. Not required to perform this function during this time phase.	A,B&C) No effect. Not required to perform this function during this time phase.
	Fails to close, remain closed, internal leakage and external leakage	A,B&C) Actual Loss. Loss of helium.	A,B&C Actual loss. Loss of helium results in loss of pneumatic control and tug propellant tank purge capability.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
PNEUMATIC SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 406			
N.C. Solenoid Valve This N.C. solenoid valve shuts off the LH_2 system ground purge line.	Fails to open	A, B&C) No effect. Not required to perform this function during this time phase.	A, B&C) No effect. Not required to perform this function during this time phase.
	Fails to close remain closed, internal leakage and external leakage	A, B&C) Actual loss. Loss of helium.	A, B&C) Actual loss. Loss of helium results in loss of pneumatic control and tug propellant tank purge capabilities.
COMPONENT CODE: 407			
Helium Sphere This sphere contains helium at 4500 psia.	Burst	A, B&C) Actual loss. Loss of helium and probable damage to surrounding hardware including the LH_2 and LOX tanks.	A, B&C) Actual loss. Burst would cause, at best, loss of the tug and possibly loss of the shuttle (phases A and C only).

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
PNEUMATIC SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 408			
Filter This filter removes contaminants from the pneumatic control and purge helium supply line.	Clogs	A, B&C) Actual loss. Loss of helium supply.	A, B&C) Actual loss. Loss of helium supply results in loss of pneumatic control and tug propellant tank purge capabilitites.
COMPONENT CODE: 409			
Regulator This regulator reduces the 4500 psia helium supply pressure to 750 psia.	Regulates high	A&C) No effect. Operation of valve 10 can keep the plenum chamber within the required pressure range.	A&C) No effect.
		B) Possible loss. Possible depletion of the on-board helium supply due to action of relief valve 412.	B) Possible loss. Depletion of the on-board helium supply would cause loss of tug.
	Regulates Low	A, B&C) Possible Loss. Helium pressure could drop below that required for pneumatic control.	A, B&C) Possible Loss. Possible loss of Tug mission due to loss of pneumatic control.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
PNEUMATIC SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 410 Solenoid Latching Valve This latching valve controls the helium supply to the plenum chamber.	Fails to open/ remain open	A, B&C) Actual loss. Loss of helium supply for pneumatic control, purge and docking and latching.	A) Possible loss. Loss of venting capability could result in structural damage to the propellant tanks. B) Actual loss. Loss of pneumatic control would cause loss of tug. C) Probable loss. Loss of purge capability would result in an unsafe condition and the tug would be brought back at crew discretion.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
PNEUMATIC SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 410			
Solenoid Latching Valve (Cont.)	Fails to close, remain closed and internal leakage	A, B&C) No effect for single failure. If regulator 409 regulates high loss of helium would result	A, B&C) No effect for single failure. Probable loss if regulator 409 regulates high due to loss of helium.
	External leakage	A, B&C) Possible loss. Loss of helium.	A, B&C) Possible loss. Loss of helium could result in loss of pneumatic control.
COMPONENT CODE: 411			
Plenum Chamber This plenum chamber suppresses pressure surges in the helium pneumatic line.	Burst	A, B&C) Actual loss. Burst of the plenum chamber would cause loss of the pneumatic system.	A&B) Actual loss. Loss of the pneumatic system would cause loss of the tug mission. C) Probable loss. Burst of the plenum could damage the shuttle

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
PNEUMATIC SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 412			
Relief Valve This relief valve prevents over-pressurization in the pneumatic system.	Fails to open.	A, B&C) No effect for single failure. Possible damage to pneumatic system hardware due to overpressurization if regulator 409 regulates high.	A, B&C) No effect for single failure.
	Fails to close/ remain closed internal leakage and external leakage	A, B&C) Actual loss. Loss of pneumatic pressure.	A, B&C) Actual loss. Loss of pneumatic pressure results in loss of the tug mission.
COMPONENT CODE: 413 a.			
Three-Way Solenoid Valve This valve is one of fifteen identical valves which control pneumatically operated valves in the feed, fill, drain, vent and reentry purge system. This valve and valve 413b control the two in flight LH_2 vent and relief valves.	Fails to open/ remain open	A&C) No effect. Not required to operate during this time phase.	A&C) No effect.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
PNEUMATIC SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 413 a. Three-Way Solenoid Valve (Cont.)		B) No effect for single failure. The inflight LH_2 vent and relief valves are redundant for fails to open.	B) No effect for single failure. If valve 413b fails to operate properly or if the other vent and relief valve fails to open/ remain open this would result in a loss of venting capability for the LH_2 tank.
	Fails to close/ remain closed and internal leakage	A, B&C) No effect for single failure. Redundancy is provided by parallel/ upstream components.	A, B&C) No effect for single failure.
	External leakage	A, B&C) Possible loss. Loss of pneumatic pressure could result in loss of pneumatic control.	A, B&C) Possible loss. Loss of pneumatic control would result in loss of tug mission.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
PNEUMATIC SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 413b. Three-Way Solenoid Valve This valve operates in conjunction with valve 413b.	Fails to open/ remain open	A&C) No effect. Not required to operate during this time phase.	A&C) No effect.
		B) No effect for single failure. The inflight LH_2 vent and relief valves are redundant for fails to open.	B) No effect for single failure. If valve 413b fails to operate properly or if the other vent and relief valve fails to open/remain open this would result in a loss of venting capability for the LH_2 tank.
	Fails to close/ remain closed and internal leakage	A,B&C) No effect for single failure. Redundancy is provided by parallel/upstream components.	A,B&C) No effect for single failure.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
PNEUMATIC SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 413b. (Cont.)			
Three-Way Solenoid Valve This valve operates in conjunction with valve 413a.	External leakage	A,B&C) Possible loss. Loss of pneumatic pressure could result in loss of pneumatic control.	A,B&C) Possible loss. Loss of pneumatic control would result in loss of tug mission.
COMPONENT CODE: 413 c or d.			
Three-Way Solenoid Valve These valves control the two inflight LOX vent and relief valves.	Fails to open/ remain open	A&C) No effect. Not required to operate during this time phase. B) No effect for single failure. The inflight LOX vent and relief valves are redundant for fails to open.	A&C) No effect. B) No effect for single failure.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
PNEUMATIC SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 413c or d.			
Three-Way Solenoid Valve (Cont.)	Fails to close/ remain closed and internal leakage	A, B&C) No effect for single failure. Redundancy is provided by upstream components.	A, B&C) No effect for single failure.
	External leakage	A, B&C) Possible loss. Loss of pneumatic pressure could cause loss of pneumatic control.	A, B&C) Possible loss. Loss of pneumatic control would cause loss of tug mission.
COMPONENT CODE: 413 e or f.			
Three-Way Solenoid Valves These valves control the two LH_2 tank vent and relief valves.	Fails to open/ remain open	A&C) No effect. Not required to operate during this time phase.	A&C) No effect.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
PNEUMATIC SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 413 e or f. Three-Way Solenoid Valve (Cont.)		B) No effect for single failure. Loss of venting capability if both valves 413e and 413f fail to open.	B) No effect for single failure. Loss of venting capability could cause structural damage to the LH_2 tank.
	Fails to close/ remain closed and internal leakage	A, B&C) No effect. Redundancy is provided by down-stream components.	A, B&C) No effect.
	External leakage	A, B&C) Possible loss. Loss of pneumatic pressure could result in loss of pneumatic control.	A, B&C) Possible loss. Loss of pneumatic control means loss of tug mission.
COMPONENT CODE: 413 g or h. Three-Way Solenoid Valve These valves control the two LOX tank vent and relief valves.	Fails to open	A&C) No effect. Not required to operate during this time phase.	A&C) No effect.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
PNEUMATIC SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 413 g or h. Three-Way Solenoid Valves (Cont.)		B) No effect for single failure. Loss of venting capability if both valves 413g and 413h fail to open.	B) No effect for single failure. Loss of venting capability could cause structural damage to the LOX tank.
	Fails to close/ remain closed and internal leakage	A, B&C) No effect. Redundancy is provided by down-stream components.	A, B&C) No effect.
	External leakage	A, B&C) Possible loss. Loss of pneumatic pressure which could result in loss of pneumatic control.	A, B&C) Possible loss. Loss of pneumatic control means loss of tug mission.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
PNEUMATIC SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 413 j or k.			
Three-Way Solenoid Valve These valves control the two LH_2 tank vent and relief valves.	Fails to open/ remain open	A&C) No effect for single failure. Loss of venting capability if both valves 413j and 413k fail to open.	A&C) No effect for single failure.
		B) No effect. Not required to operate during this time phase.	B) No effect.
	Fails to close/ remain closed and internal leakage	A&C) No effect. Not required to perform this function during this time phase.	A&C) No effect.
		B) No effect. Redundancy provided by downstream components.	B) No effect.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
PNEUMATIC SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 413 j or k.			
Three-Way Solenoid Valve (Cont.)	External leakage	A, B&C) Possible Loss. Loss of pneumatic pressure could cause loss of pneumatic control.	A, B&C) Possible loss. Loss of pneumatic control would result in loss of tug mission.
COMPONENT CODE: 413 l or n.			
Three-way solenoid valves These valves control the two LOX tank vent and relief valves.	Fails to open/ remain open	A&C) No effect for single failure. Loss of venting capability if both valves 4131 and 413n fail to open.	A&C) No effect for single failure.
		B) No effect. Not required to operate during this time phase.	B) No effect.
	Fails to close/ remain closed and internal leakage	A&C) No effect. Not required to perform this function during this time phase.	A&C) No effect.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
PNEUMATIC SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 413 1 or n.			
Three-Way Solenoid Valve (Cont.)		B) No effect. Redundancy is provided by downstream components.	B) No effect.
	External leakage	A, B&C) Possible loss. Loss of pneumatic pressure which could cause loss of pneumatic control.	A, B&C) Possible loss. Loss of pneumatic control would result in loss of tug mission.
COMPONENT CODE: 413 p.			
Three-Way Solenoid Valve This valve controls the N.C. LH_2 main tank feed line valve.	Fails to open/ remain open	A&C) No effect. Not required to perform this function during this time phase.	A&C) No effect.
		B) Actual loss. Loss of LH_2 to tug engine.	B) Actual loss. Loss of tug engine.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
PNEUMATIC SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 413 p.			
Three-Way Solenoid Valve (Cont.)	Fails to close. remain closed and internal leakage	A, B&C) No effect. Multiple redundancy is provided.	A, B&C) No effect.
	External leakage	A, B&C) Possible loss. Loss of helium pressure.	A, B&C) Possible loss. Loss of helium pressure results in loss of pneumatic control.
COMPONENT CODE: 413 r.			
Three-Way Solenoid Valve This valve controls the tug engine LH_2 feed line valve.	Fails to open/ remain open	A&C) No effect. Not required to operate during this time phase.	A&C) No effect.
		B) Actual loss. Loss of LH_2 to tug engine	B) Actual loss. Loss of tug engine.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
PNEUMATIC SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 413 r. (Cont.)			
Three-Way Solenoid Valve	Fails to close/ remain closed and internal leakage	A, B&C) No effect. Multiple redundancy is provided.	A, B&C) No effect.
	External leakage	A, B&C) Possible loss. Loss of helium pressure.	A, B&C) Possible loss. Loss of helium pressure results in loss of pneumatic control.
COMPONENT CODE: 413 s.			
Three-Way Solenoid Valve This valve controls the tug engine LOX feed line valve.	Fails to open/ remain open	A&C) No effect. Not required to operate during this time phase.	A&C) No effect.
		B) Actual loss. Loss of LOX to tug engine.	B) Actual loss. Loss of tug engine.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
PNEUMATIC SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 413 s. (Cont.)			
Three-Way Solenoid Valve	Fails to close/ remain closed and internal leakage	A, B&C) No effect. Multiple redundancy is provided.	A, B&C) No effect.
	External leakage	A, B&C) Possible loss. Loss of helium pressure.	A, B&C) Possible loss. Loss of helium pressure results in loss of pneumatic control.
COMPONENT CODE: 414			
Check Valves 15 required These check valves prevent cryopumping of air while the tug is on the ground. There is one check valve associated with each of the 15 three-way solenoid valves.	Fails to open/ remain open	A, B&C) No effect for single failure. Multiple redundancy is provided.	A, B&C) No effect.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
PNEUMATIC SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 414 (Cont.)			
Check Valves 15 required	Fails to close/ remain closed, internal leakage and external leakage	A, B&C) No effect. Not required to perform this function during this time phase.	A, B&C) No effect.
COMPONENT CODE: 415			
N. C. Solenoid Valve This valve controls the flow of helium to the MLI on the LH_2 tank.	Fails to open/ remain open	A, B&C) Actual loss. Loss of MLI purge.	A, B&C) No effect. Loss of MLI purge after launch has no effect on the immediate tug mission. However, the MLI may be contaminated during reentry and would have to be replaced before the next mission.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
PNEUMATIC SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 415 (Cont.)			
N. C. Solenoid Valve	Fails to close/ remain closed and internal leakage	A, B&C) No effect. Redundancy is provided.	A, B&C) No effect.
	External leakage	A, B&C) Possible loss. Possible loss of MLI purge.	A, B&C) No effect. No effect on immediate tug mission.
COMPONENT CODE: 416			
N. C. Solenoid Valve This valve controls the flow of helium to the MLI on the LH_2 tank.	Fails to open/ remain open	A, B&C) Actual loss. Loss of MLI purge.	A, B&C) No effect. Loss of MLI purge after launch has no effect on the immediate tug mission. However, the MLI may be contaminated during reentry and would have to be replaced before the next mission.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
PNEUMATIC SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 416 (Cont.)			
N. C. Solenoid Valve	Fails to close/ remain closed and internal leakage	A, B&C) No effect. Redundancy is provided.	A, B&C) No effect.
	External leakage	A, B&C) Possible loss. Possible loss of MLI purge.	A, B&C) No effect. No effect on immediate tug mission.
COMPONENT CODE: 417			
Orifice This orifice provides the proper flow and pressure to the MLI on the LOX tank.	No applicable failure type		
COMPONENT CODE: 418			
Orifice This orifice provides the proper flow and pressure to the MLI on the LH_2 tank.			

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
PNEUMATIC SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 419			
N. O. Solenoid Valve This valve is cycled to maintain the proper pressure in the MLI on the LH_2 tank.	Fails to open/ remain open	A, B&C) Actual loss. Loss of MLI purge.	A, B&C) No effect. No effect on the immediate tug mission.
	Fails to close/ remain closed, internal leakage and external leakage	A, B&C) Possible loss. Valve is normally open. Failure to close causes loss of MLI purge.	A, B&C) No effect. No effect on the immediate tug mission.
COMPONENT CODE: 420			
Check Valve This check valve prevents back flow to the MLI on the LH_2 tank.	Fails to open/ remain open	A, B&C) Actual loss. Loss of MLI purge	A, B&C) No effect. No effect on the immediate tug mission.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
PNEUMATIC SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 420 (Cont.)			
Check Valve	Fails to close/ remain closed, internal leakage and external leakage	A, B&C) No effect. Redundancy is provided by upstream valve.	A, B&C) No effect.
COMPONENT CODE: 421			
N. O. Solenoid Valve This valve is cycled to maintain the proper pressure in the MLI on the LOX tank.	Fails to open/ remain open	A, B&C) Actual loss. Loss of MLI purge.	A, B&C) No effect. No effect on the immediate tug mission.
	Fails to close/ remain closed, internal leakage and external leakage	A, B&C) Possible loss. Valve is normally open. Failure to close causes loss of MLI purge.	A, B&C) No effect. No effect on the immediate tug mission.
COMPONENT CODE: 422			
Check Valve This check valve prevents backflow to the MLI on the LOX tank.	Fails to open/ remain open	A, B&C) Actual loss. Loss of MLI purge.	A, B&C) No effect. No effect on the immediate tug mission.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
PNEUMATIC SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 422 (Cont.) Check Valve	Fails to close/ remain closed internal leakage and external leakage	A, B&C) No effect. Redundancy is provided by upstream valve.	A, B&C) No effect.

HYDROGEN FEED, FILL, DRAIN, VENT AND REENTRY PURGE SYSTEM FAILURE MODE, EFFECTS AND CRITICALITY ANALYSIS

This section presents a preliminary failure mode, effects and criticality analysis of the Space Tug Hydrogen Feed, Fill, Drain, Vent and Reentry Purge System. This system performs the following functions:

(a) The feed system is comprised of the ducting and associated valving which is required to route the propellants from the tank to the engine system.

(b) The fill and drain lines are provided to allow the LH_2 tank to be filled on the ground. Ground draining of propellants may be accomplished through the fill line.

(c) The vent and relief system is provided to insure that tank pressures are maintained within structural design limits during ground and inflight operation.

(d) The reentry purge system provides conditioning of the main and APS LH_2 tank for reentry by the use of a helium purge and pressurization of the tanks.

The system schematic and the system block diagram are presented in Figures 5 and 6, respectively. Figure 7 presents the block diagram for the helium reentry purge system.

ASSUMPTIONS AND GROUND RULES

1. The quick-disconnects in the hydrogen feed, fill, drain, and vent system are part of one umbilical plate. The quick-disconnect in the helium reentry purge system is part of the same umbilical plate. However, an analysis has been performed on each quick-disconnect as if it were a single component.

2. There is no propellant in the LH_2 tank at time of redocking.

3. Engine cannot operate without proper operation of the idling mode.

4. There are valves within the engine which are not shown on the schematic, but are used as isolation valves for the engine feed line.

5. Loss of mission means loss of Tug mission. Loss of crew and vehicle means loss of Space Shuttle crew and vehicle.

6. The following time phases were used in this analysis:

Phase A	Boost and separation of Tug and Shuttle	2.85 hours
Phase B	Tug orbital operations and redocking with Shuttle	136 hours
Phase C	Tug repressurization and return to Earth	16.7 hours

CONCLUSIONS AND RECOMMENDATIONS

1. The predicted probability of no primary mission loss due to failure of the hydrogen feed, fill, drain and vent system is 0.998585.

2. The predicted probability of no loss of the shuttle crew or vehicle due to failure of the hydrogen feed, fill, drain and vent system is 0.999998.

3. The predicted probability of no primary mission loss due to failure of the helium reentry purge system is 0.999200.

4. The predicted probability of no loss of the shuttle crew or vehicle due to failure of the helium reentry purge system is 0.999994.

5. For some missions it is recommended that the helium reentry purge supply be placed on the tug instead of in the shuttle payload bay. This would reduce the criticality of the quick-disconnect involved in this system.

6. It is recommended that a check valve be added between the reentry purge valves (Component Code 116) and the oxygen system purge line. This would provide added safety in the event of double failure of internal leakage, and failure to remain closed. It is a preventative measure to keep hydrogen and oxygen from mixing in the event of internal leakage of purge valves.

HYDROGEN FEED, FILL, DRAIN, AND VENT SYSTEM
CRITICAL ITEMS LIST

COMPONENT CODE	COMPONENT	FAILURE MODE	CRM	CRC	CRV
101	Quick-Disconnect 1 required	Fails to disconnect	163.00		
		Leakage	.82	.82	.82
102	Quick-Disconnect 1 required	Fails to disconnect	163.00		
		Leakage	.82	.82	.82
104	Valve, Pneumatically Operated, N.C. 2 required	Fails to close	4.28		
		Fails to remain closed and internal leakage	42.85		
		External leakage	.21	.02	.02
105	Valve, Pneumatically Operated, N.C. 1 required	Fails to open	77.50		
		Fails to remain open	77.50		
		External leakage	.02	.01	.01
108	Solenoid Valve, N.O. 1 required	Fails to open	6.25		
		Fails to remain open	0.62		
		Fails to remain closed and internal leakage	17.30		
		External leakage	.02	.01	.01

HYDROGEN FEED, FILL, DRAIN, AND VENT SYSTEM
CRITICAL ITEMS LIST
(Continued)

COMPONENT CODE	COMPONENT	FAILURE MODE	CRM	CRC	CRV
109	Solenoid Valve, N.C. 1 required	Fails to open	62.50		
		Fails to close	6.25		
		Fails to remain open	6.25		
		Fails to remain closed and internal leakage	62.50		
		External leakage	.08	.01	.01
110	Solenoid Valve, N.C. 1 required	Fails to remain closed and internal leakage	79.80		
		External leakage	.08	.01	.01
111	Solenoid Valve, N.C. 2 required	Fails to close	3.46		
		Fails to remain closed and internal leakage	34.60		
		External leakage	.15	.01	.01
112	Solenoid Valve, N.C. 2 required	Fails to close	12.50		
		Fails to remain closed and internal leakage	159.52		
		External leakage	.15	.01	.01

HYDROGEN FEED, FILL, DRAIN AND VENT SYSTEM
CRITICAL ITEMS LIST
(Continued)

COMPONENT CODE	COMPONENT	FAILURE MODE	CRM	CRC	CRV
113	Valve, Pneumatically Operated, N.C. 2 required	Fails to close	15.50		
		Fails to remain closed and internal leakage	197.75		
		External leakage	.21	.02	.02
114	Valve, Pneumatically Operated, N.C. 1 required	Fails to open and remain open	155.00		
		External leakage	.01	.01	.01
106	Solenoid Valve, N.C. 1 required	Fails to open and remain open	2.15		
		Fails to close and internal leakage	62.50		
		External leakage	.08	.01	.01
116	Solenoid Valve, N.C. 2 required	External leakage	.15	.01	.01
		Final Totals:	1415.38	1.77	1.77

HELIUM REENTRY PURGE SCHEMATIC
CRITICAL ITEMS LIST

COMPONENT CODE	COMPONENT	FAILURE MODE	CRM	CRC	CRV
317	Quick-Disconnect 1 required	Fails to connect	154.88		
		Fails to disconnect	163.00		
318	Solenoid Valve, N.C. 2 required	Fails to remain closed and internal leakage	124.92		
		External leakage	.13		
320	Sphere 2 required	Burst	277.70	6.02	6.02
321	Solenoid Valve, N.C. 1 required	Fails to remain closed and internal leakage	79.80		
		Final Totals:	800.43	6.02	6.02

FIGURE 5. HYDROGEN FEED, FILL, DRAIN, VENT AND REENTRY PURGE SCHEMATIC

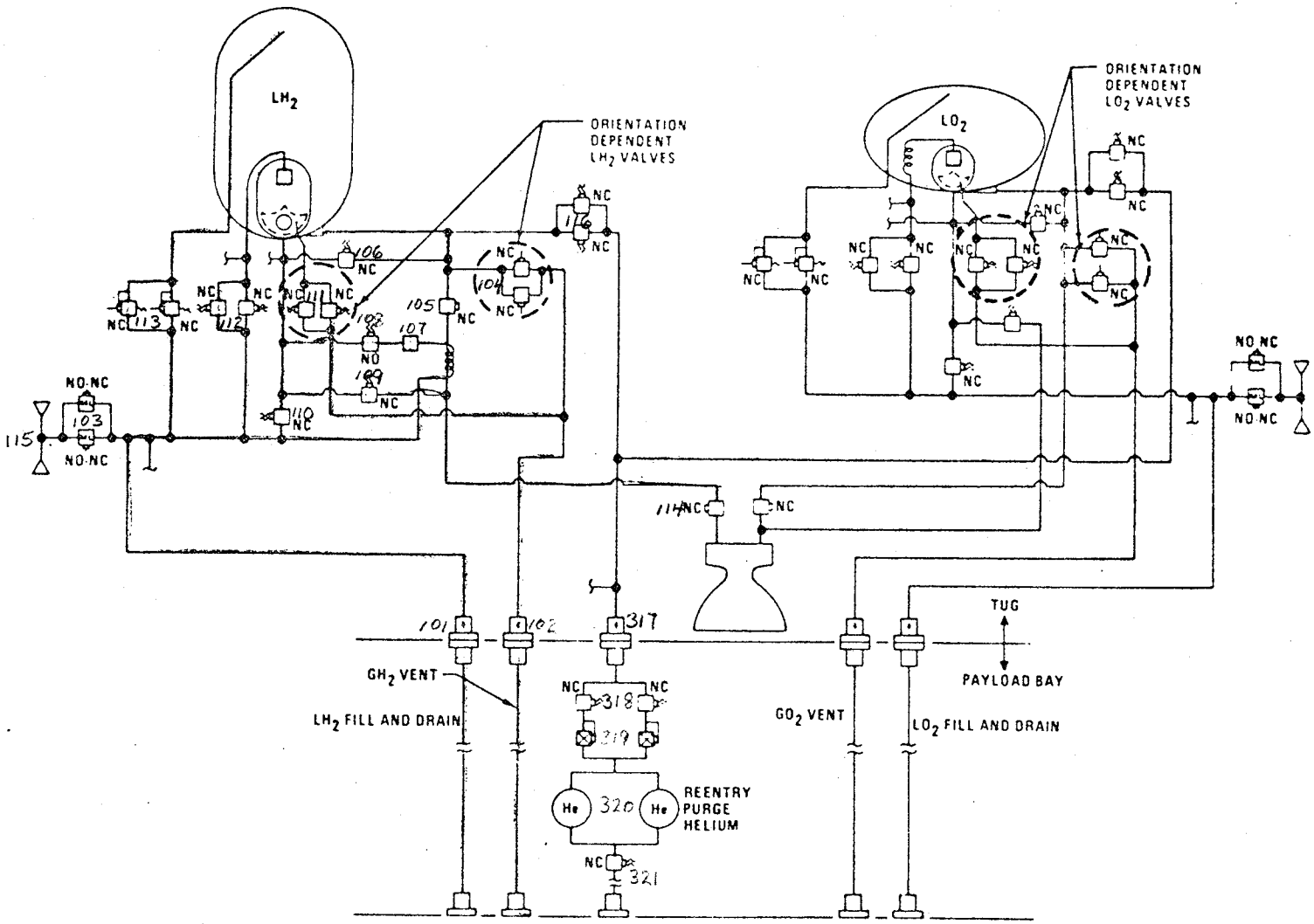


FIGURE 6. HYDROGEN FEED, FILL, DRAIN, VENT AND REENTRY PURGE SYSTEM BLOCK DIAGRAM

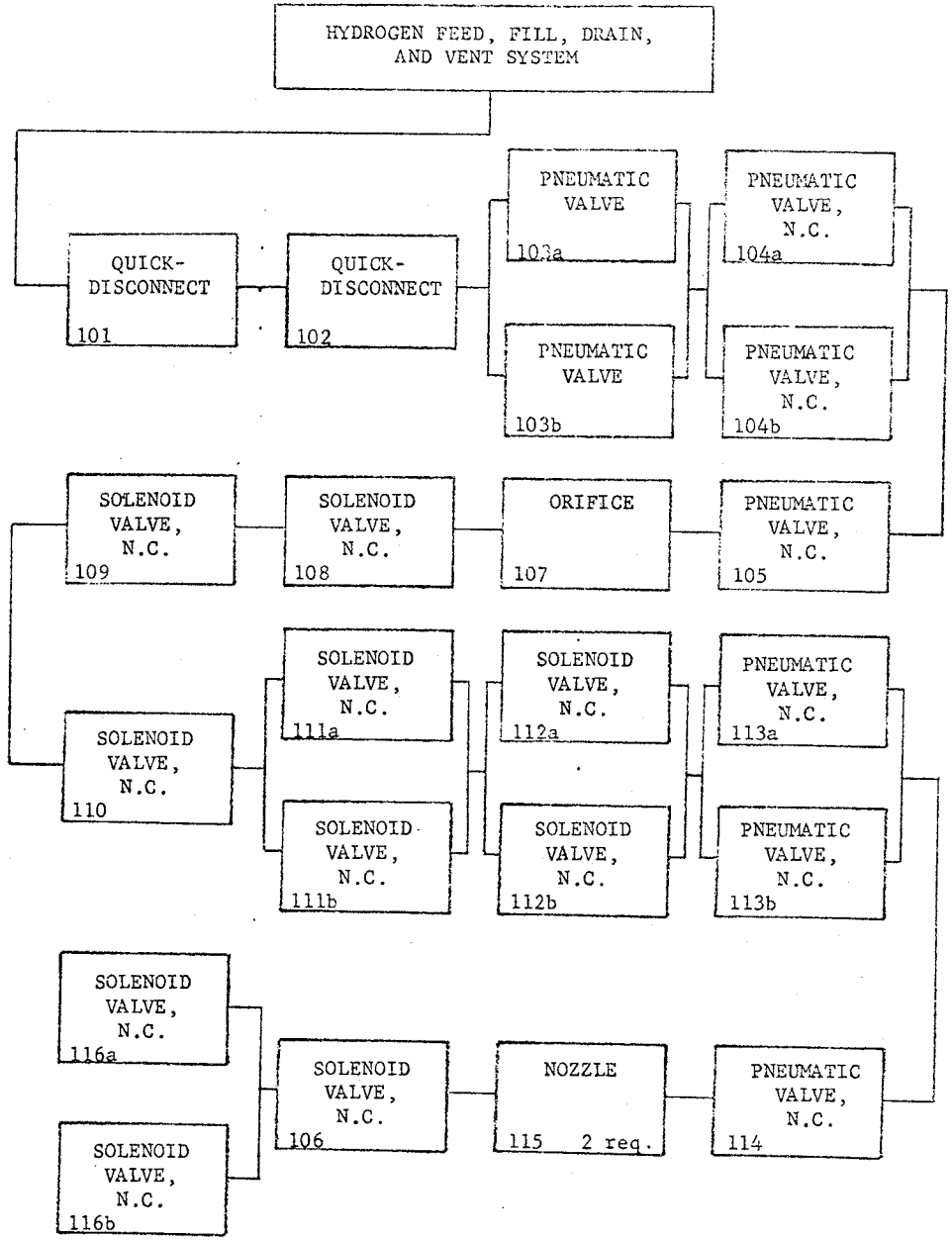
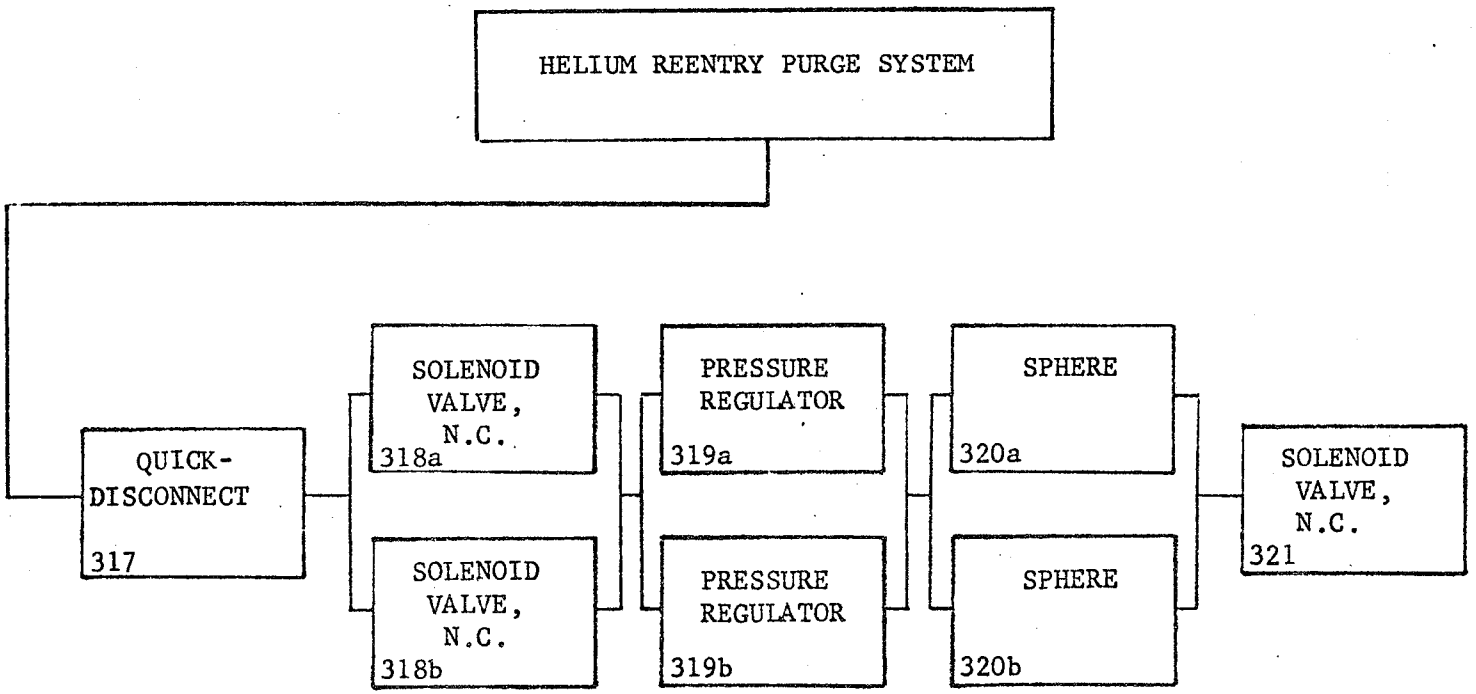


FIGURE 7. HELIUM REENTRY PURGE SYSTEM BLOCK DIAGRAM



FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 101			
Quick Disconnect 1 required This quick disconnect with check valve provides connection to the payload bay of the space shuttle orbiter. It enables filling and draining of the main and APS LH_2 tanks.	Fails to connect	A) No effect. Quick disconnect is not required to connect during this time.	A) No effect. Not applicable.
		B) No effect. The LH_2 tank will be drained before redocking.	B) No effect. Not applicable.
		C) No effect. Quick disconnect is not required to connect during this time.	C) No effect. Not applicable.
	Fails to disconnect	A) Actual loss. System cannot be disconnected from shuttle orbiter.	A) Actual loss. Tug cannot leave orbiter to carry out assigned mission.
		B & C) No effect. Quick disconnect is not required to disconnect during this time.	B & C) No effect. Not applicable.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 101 Quick Disconnect (Cont)	Leakage	A) Possible loss. System could be lost due to loss of hydrogen into payload bay.	A) Possible loss. Escape of hydrogen into payload bay could cause loss of tug mission, and could create a hazard to the shuttle crew.
		B) No effect. Upstream valves can shut off pressure to line, and hydrogen leaks only into space.	B) No effect. Not applicable.
		C) No effect. Leakage is not applicable since LH_2 tank will be drained prior to redocking.	C) No effect. Not applicable.
COMPONENT CODE: 102 Quick Disconnect 1 required This quick disconnect with check valve provides connection to the payload bay of the space shuttle orbiter. It enables venting of GH_2.	Fails to connect	A) No effect. Quick disconnect is not required to connect during this time.	A) No effect. Not applicable.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 102 Quick Disconnect (Cont)		B) Possible loss. Loss of capability to vent GH_2 from the tank would mean that the reentry helium purge could not take place.	B) Possible loss. Vehicle cannot be made safe for reentry with residual hydrogen aboard.
		C) No effect. Quick disconnect is not required to connect during this time.	C) No effect. Not applicable.
	Fails to disconnect	A) Actual loss. System cannot be disconnected from shuttle orbiter.	A) Actual loss. Tug cannot leave orbiter to carry out assigned mission.
		B & C) No effect. Quick disconnect is not required to disconnect during this time.	B & C) No effect. Not applicable

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 102 Quick Disconnect (Cont)	Leakage	A) Possible loss. System could be lost due to loss of hydrogen into payload bay.	A) Possible loss. Escape of hydrogen into payload bay could cause loss of tug mission, and could create a hazard to the shuttle crew.
		B) No effect. Upstream valves can shut off pressure in line, and hydrogen leaks only into space.	B) No effect. Not applicable.
		C) No effect. GH_2 leakage would be negligible, and would be diluted by helium.	C) No effect. Not applicable.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 103 Valve, Pneumatically Operated 2 required These valves are used to provide on-off capability to two non-propulsive nozzles for venting of the LH_2 tanks during flight of the space tug. They are pneumatically operated valves which remain in the last commanded position. They are redundant for failure to open, and failure to remain open. The valves also provide venting for flow of hydrogen from the APS tank through the heat exchanger for main tank propellant conditioning.	Fails to open	A) No effect. Valve is not required to open during this time. B) No effect for single failure. If both valves fail to open, venting of the LH_2 tank during tug flight cannot be achieved. C) No effect. Valve is not required to open during this time.	A) No effect. Not applicable. B) No effect for single failure. Preconditioning of main tank propellants cannot take place without proper in-orbit venting. Loss of tug mission could occur in the event of double failure. C) No effect. Not applicable.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 103 Valve, Pneumatically Operated (Cont)	Fails to close	A) No effect. Valve is closed during this time.	A) No effect. Not applicable.
		B) No effect. Valve is not required to close during this time.	B) No effect. Not applicable.
		C) No effect. Valve is closed during this time.	C) No effect. Not applicable.
	Fails to remain open	A) No effect. Valve is closed during this time.	A) No effect. Not applicable.
		B) No effect for single failure. Double failure would cause loss of venting. Flow through LH_2 heat exchanger would be stopped, and liquid could not be maintained at the engine interface.	B) No effect for single failure. Double failure could cause premature loss of venting, causing possible loss of tug mission.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 103 Valve, Pneumatically Operated (Cont.)		C) No effect. Valve is closed during this time.	C) No effect. Not applicable.
	Fails to remain closed and leakage	A) No effect for single failure. If upstream valve fails to remain closed also, hydrogen will escape into payload bay. This double failure would cause loss of system.	A) No effect for single failure. Double failure causes leakage of hydrogen into payload bay creating a hazard to shuttle crew and mission.
		B) No effect. Valve is not required to remain closed since venting must be provided for flow of GH_2 through hydrogen heat exchanger.	B) No effect. Not applicable.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 103 Valve, Pneumatically Operated (Cont.)		C) No effect for single failure. If upstream valve fails to remain closed also, helium pressurization would be lost and tank could collapse during reentry.	C) No effect for single failure. Double failure could cause loss of tug mission.
COMPONENT CODE: 104 Valve, Pneumatically Operated, N.C. 2 required These valves provide on-off capability to the GH_2 vent line. Before orbital operations begin, GH_2 will be vented through one of these valves from the main propellant tank. The valve will also be used to vent the main tank during the reentry purge process.	Fails to open	A) No effect for single failure. Double failure causes inability to vent through GH_2 vent line. B) No effect. Valve is not required to open during this time.	A) No effect for single failure. Double failure may cause pressure in tank to exceed structural limits. B) No effect. Not applicable.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 104 Valve, Pneumatically Operated, N.C. (Cont.)		C) No effect for single failure. Double failure causes inability to purge residual hydrogen gas from tank.	C) No effect for single failure. Double failure would cause inability to make vehicle safe for reentry.
	Fails to close	A) Actual Loss The GH_2 vent line could not be shut off, and venting could not be stopped.	A) Possible loss. Inability to stop venting may cause sufficient propellant loss for loss of tug mission.
		B) No effect. Valve is closed during this time.	B) No effect. Not applicable.
		C) Actual loss. Helium pressurization will be lost.	C) Possible loss. Loss of helium pressurization could cause main tank to collapse during reentry.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 104 Valve, Pneumatically Operated, N.C. (Cont.)	Fails to remain open	A) No effect for single failure. Double failure would cause premature shut-off of LH_2 venting.	A) No effect for single failure. Double failure could cause pressure in tank to exceed structural limits.
		B) No effect. Valve is closed during this time.	B) No effect. Not applicable.
		C) No effect for single failure. A double failure of premature closing of valve would prohibit complete residual gas purge.	C) No effect for single failure. Double failure could cause inability to make vehicle safe for reentry.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 104 Valve, Pneumatically Operated, N.C. (Cont.)	Fails to remain closed and internal leakage	A) Possible loss. Premature venting could cause excessive loss of hydrogen. B) No effect for single failure. Redundancy is provided by check valve in quick-disconnect. Double failure would cause loss of hydrogen to space. C) Actual loss. Helium pressurization would be lost.	A) Possible loss. Loss of hydrogen could cause loss of tug mission. B) No effect for single failure. Double failure could cause loss of tug mission due to excessive hydrogen loss. C) Possible loss. Loss of helium pressurization could cause tank to collapse during reentry.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 104 Valve, Pneumatically Operated, N.C. (Cont.)	External Leakage	A) Possible loss. System could be lost due to loss of hydrogen.	A) Possible loss. Escape of hydrogen could cause loss of tug mission, and could create a hazard to the shuttle crew.
		B) Possible loss. System could be lost due to loss of hydrogen.	B) Possible loss. Excessive leakage could cause loss of propellant causing loss of tug mission.
		C) Possible loss. Helium pressure could be lost.	C) Possible loss. Loss of helium pressurization could cause main tank to collapse during reentry.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 105 Valve, Pneumatically Operated, N.C. 1 required This valve provides on-off capability between the LH_2 tank and the engine feed line.	Fails to open	A) No effect. Valve is not required to open during this time.	A) No effect. Not applicable.
		B) Actual loss. Liquid hydrogen cannot be supplied to engine.	B) Actual loss. Inability to feed LH_2 to engine causes loss of tug mission.
		C) No effect. Valve is not required to open during this time.	C) No effect. Not applicable.
	Fails to close	A) No effect. Valve is closed throughout this time.	A) No effect. Not applicable.
		B) No effect for single failure. Redundancy is provided by downstream valve. In the event of double failure, hydrogen will bleed through engine.	B) No effect for single failure. Hydrogen bleed in the event of a double failure will not affect tug.
		C) No effect. Valve is closed throughout this time.	C) No effect. Not applicable.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 105 Valve, Pneumatically Operated, N.C. (Cont.)	Fails to remain open.	A) No effect. Valve is closed throughout this time.	A) No effect. Not applicable.
		B) Actual loss. Engine would be prematurely shut off.	B) Actual loss. Engine shut-off would cause loss of tug mission.
		C) No effect. Valve is closed throughout this time.	C) No effect. Not applicable.
	Fails to remain closed and internal leakage	A) No effect. Redundancy is provided by downstream valve, and valves within engine.	A) No effect. Not applicable.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
_____ SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 105 Valve, Pneumatically Operated N.C. (Cont.)		B) No effect. Valve is not required to remain closed during this time. Engine is in operation.	B) No effect. Not applicable.
		C) No effect. Redundancy is provided by downstream valve, and valves within engine.	C) No effect. Not applicable.
	External leakage	A) Possible loss. System could be lost due to loss of hydrogen.	A) Possible loss. Escape of hydrogen could cause loss of tug mission and could create a hazard to the shuttle crew.
		B) No effect. Valve is open during this time, and hydrogen leakage into space is not critical.	B) No effect. Not applicable.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 105 Valve, Pneumatically Operated N. C. (Cont)		C) Possible loss. Helium pressure could be lost.	C) Possible loss. Loss of helium pressurization could cause main tank to collapse during reentry.
COMPONENT CODE: 107 Orifice 1 required This orifice controls the flow of hydrogen from the APS tank through the heat exchanger for proper main tank propellant conditioning.	No applicable failure modes		

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 108			
Solenoid Valve, N.O. 1 required This valve enables hydrogen to pass from the APS tank and through the heat exchanger during tug orbital operations. It remains open during tug orbital operations so that the main tank propellant may be properly conditioned. It will be closed intermittently during orbital operations while the main and APS tanks are being vented.	Fails to open	A) No effect. Valve is not required to open during this time.	A) No effect. Not applicable.
		B) Actual loss. Loss of flow through hydrogen heat exchanger causes loss of main tank propellant conditioning process.	B) Possible loss. Engine may not function properly due to improper conditioning of main tank propellant. This could lead to loss of tug mission.
		C) No effect. Valve is not required to open during this time.	C) No effect. Not applicable.
	Fails to close	A) No effect. Valve is closed during this time.	A) No effect. Not applicable.
		B) No effect. Valve is not required to close during this time.	B) No effect. Not applicable.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 108 (Cont.) Solenoid Valve, N.O. 1 required		C) No effect. Valve is closed during this time.	C) No effect. Not applicable.
	Fails to remain open	A) No effect. Valve is closed during this time.	A) No effect. Not applicable.
		B) Actual loss. Propellant conditioning process would be lost.	B) Possible loss. Inability to condition main tank propellant could cause loss of tug mission.
		C) No effect. Valve is closed during this time.	C) No effect. Not applicable.
	Fails to remain closed and internal leakage	A) Actual loss. Hydrogen would be drained from APS tank.	A) Possible loss. Hydrogen drainage from APS tank could cause loss of tug mission.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 108 (Cont.) Solenoid Valve, N.O. 1 required		B) No effect. Valve is open during this time.	B) No effect. Not applicable.
		C) Actual loss. Helium pressurization would be lost from APS tank.	C) Possible loss. Loss of helium pressurization could cause tank to collapse during reentry.
	External leakage	A) Possible loss. Excessive hydrogen leakage could cause loss of use of APS tank.	A) Possible loss. Excessive loss of propellant could cause loss of tug mission, and leakage of hydrogen into payload bay could create a hazard to the shuttle crew.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 108 (Cont.) Solenoid Valve		B) No effect. Valve is open during this time, and hydrogen leakage into space is not critical. C) Possible loss. Excessive leakage could cause loss of helium pressurization.	B) No effect. Not applicable. C) Possible loss. Loss of helium pressurization could cause tank to collapse during reentry.
COMPONENT CODE: 109 Solenoid Valve, N.C. 1 required This valve provides on-off capability between the APS tank and the engine. It is opened so that the engine may be placed in idle mode prior to start of main tank feed.	Fails to open	A) No effect. Valve is not required to open during this time. B) Actual loss. Engine cannot be placed in idle mode.	A) No effect. Not applicable. B) Actual Loss Inability to use idle mode would prevent starting of engine, leading to loss of mission.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 109 (Cont.) Solenoid Valve, N.C. 1 required		C) No effect. Valve is not required to open during this time.	C) No effect. Not applicable.
	Fails to close.	A) No effect. Valve is closed during this time.	A) No effect. Not applicable.
		B) Possible loss. Inability to shut off idle mode could cause excessive hydrogen loss from the APS tank.	B) Possible loss. Excessive loss of hydrogen from APS tank could cause loss of tug mission.
		C) No effect. Valve is closed during this time.	C) No effect. Not applicable.
	Fails to remain open	A) No effect. Valve is closed during this time.	A) No effect. Not applicable.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 109 (Cont.) Solenoid Valve, N.C. 1 required		B) Possible loss. Premature closing of valve would cause loss of engine mode.	B) Possible loss. Inability to use idle mode could prevent starting of engine, leading to loss of tug mission.
		C) No effect. Valve is closed during this time.	C) No effect. Not applicable.
	Fails to remain closed and internal leakage	A) No effect. Redundancy is provided by downstream valve, and by valves within engine.	A) No effect. Not applicable.
		B) Possible loss. Inability to shut off idle mode could cause excessive hydrogen loss from the APS tank.	B) Possible loss. Excessive loss of hydrogen from APS tank could cause loss of tug mission.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 109 Cont.) Solenoid Valve, N.C. 1 required		C) No effect. Redundancy is provided by downstream valve, and by valves within engine.	C) No effect. Not applicable.
	External leakage	A) Possible loss. Excessive hydrogen leakage could cause loss of use of APS tank.	A) Possible loss. Excessive loss of propellant could cause loss of tug mission, and leakage of hydrogen into payload bay could create a hazard to the shuttle crew.
		B) Possible loss. Excessive hydrogen leakage could cause loss of use of APS tank.	B) Possible loss. Excessive loss of propellant could cause loss of tug mission.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
		C) Possible Loss. Excessive leakage could cause loss of helium pressurization.	C) Possible Loss Loss of helium pressurization could cause tank to collapse during reentry.
COMPONENT CODE: 110			
Solenoid Valve, N. C. 1 required This valve is used during ground operations for filling the APS LH_2 tank. It is also available for use in case of abort dump of tug propellants.	Fails to open and remain open	A, B, & C) No effect. Valve is not required to open after liftoff.	A, B, & C) No effect. Not applicable.
	Fails to close	A, B, & C) No effect. Valve is closed throughout these times.	A, B, & C) No effect. Not applicable.
	Fails to remain closed and internal leakage	A & B) Possible Loss. Propellant would be lost from APS tank.	A & B) Possible Loss. Excessive loss of propellant from APS tank could cause loss of tug mission.
		C) Possible Loss. Helium pressurization could be lost from APS tank.	C) Possible Loss. Loss of helium pressurization could cause tank to collapse during reentry.
	External Leakage	A) Possible Loss. Excessive hydrogen leakage causes loss of LH_2 from APS tank.	A) Possible Loss. Leakage of APS propellant could cause loss of tug mission, and could create a hazard to the shuttle crew.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 110			
Solenoid Valve, N. C. (Contd)		B) Possible Loss. Excessive hydrogen leakage causes loss of LH_2 from APS tank.	B) Possible Loss. Loss of APS propellant would cause loss of tug mission.
		C) Possible Loss. Excessive leakage would cause loss of helium pressurization.	C) Possible Loss. Loss of helium pressurization could cause tank to collapse during reentry.
COMPONENT CODE: 111			
Solenoid Valve, N. C. 2 required These valves provide on-off capability to the GH_2 vent line. Before orbital operations begin, GH_2 will be vented through these valves from the APS tank. The valves will also be used to vent the APS tank during the reentry purge process. They are redundant for fails to open and remain open.	Fails to open and remain open	A) No effect for single failure. Double failure causes inability to vent through GH_2 vent line.	A) No effect for single failure. Double failure may cause pressure in tank to exceed structural limits.
		B) No effect. Valve is not required to open during this time.	B) No effect. Not applicable.
		C) No effect for single failure. Double failure causes inability to purge residual hydrogen gas from tank.	C) No effect for single failure. Double failure would cause inability to make vehicle safe for reentry.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 111			
Solenoid Valve, N. C. (Contd)	Fails to close	A) Actual Loss. The GH_2 vent line could not be shut off, and venting could not be stopped.	A) Possible Loss. Inability to stop venting may cause sufficient propellant loss for loss of tug mission.
		B) No effect. Valve is closed during this time.	B) No effect. Not applicable.
		C) Actual Loss. Helium pressurization would be lost.	C) Possible Loss. Loss of helium pressurization could cause APS tank to collapse during reentry.
	Fails to remain closed and internal leakage	A) Possible Loss. Premature venting could cause loss of hydrogen.	A) Possible Loss. Loss of hydrogen could cause loss of tug mission.
		B) No effect for single failure. Redundancy is provided by check valve in quick-disconnect. Double failure would cause loss of hydrogen to space.	B) No effect for single failure. Double failure could cause loss of tug mission due to excessive hydrogen loss.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 111 Solenoid Valve, N: C. (Contd)		C) Actual Loss. Helium pressurization would be lost.	C) Possible Loss. Loss of helium pressurization could cause APS tank to collapse during reentry.
	External leakage	A) Possible Loss. Excessive hydrogen leakage could cause loss of system.	A) Possible Loss. Escape of hydrogen could cause loss of tug mission, and could create a hazard to the shuttle crew.
		B) Possible Loss. Excessive hydrogen leakage could cause loss of system.	B) Possible Loss. Excessive leakage could cause loss of propellant causing loss of tug mission.
		C) Possible Loss. Excessive leakage could cause loss of helium pressurization.	C) Possible Loss. Loss of helium pressurization could cause APS tank to collapse during reentry.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 112 Solenoid Valve, N. C. 2 required These valves provide on-off capability to the LH_2 fill and drain line for in-flight venting of the APS tank during tug orbital operation. They are redundant for failure to open and remain open.	Fails to open and remain open	A) No effect. Valve is not required to open during this time.	A) No effect. Not applicable.
		B) No effect for single failure. Double failure causes inability to vent during tug operation.	B) No effect for single failure. Double failure could cause APS tank to exceed structural limits.
		C) No effect. Valve is not required to open during this time.	C) No effect. Not applicable.
	Fails to close	A) No effect. Valve is closed throughout this time.	A) No effect. Not applicable.
		B) Possible Loss. Inability to stop venting could cause excessive hydrogen loss.	B) Possible Loss. Excessive hydrogen loss from APS tank could cause loss of tug mission.
		C) No effect. Valve is closed throughout this time.	C) No effect. Not applicable.
	Fails to remain closed and internal leakage	A & B) Possible Loss. Inability to stop venting could cause excessive hydrogen loss.	A & B) Possible Loss. Excessive hydrogen loss from APS tank could cause loss of tug mission.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 113			
Valve, Pneumatically Operated, N. C., Position-Indicating (Contd)	Fails to remain closed and internal leakage	A & B) Possible Loss. Inability to stop venting could cause excessive hydrogen loss.	A & B) Possible Loss. Excessive hydrogen loss from main tank could cause loss of tug mission.
		C) Possible Loss. Inability to shut off fill and drain line could cause loss of helium pressurization.	C) Possible Loss. Loss of helium pressurization could cause main tank to collapse during reentry.
	External leakage	A) Possible Loss. Excessive leakage of hydrogen causes loss of LH_2 from main tank.	A) Possible Loss. Leakage of main tank propellant could cause loss of tug mission, and could create a hazard to the shuttle crew.
		B) Possible Loss. Excessive leakage of hydrogen causes loss of LH_2 from main tank.	B) Possible Loss. Leakage of main tank propellant could cause loss of tug mission.
		C) Possible Loss. Excessive leakage would cause loss of helium pressurization.	C) Possible Loss. Loss of helium pressurization could cause tank to collapse during reentry.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 114 Valve, Pneumatically Operated, N. C. 1 required This valve provides on-off capability between the main tank, APS tank, and the engine. It must be open for engine idle mode and main engine operation.	Fails to open and remain open	A) No effect. Valve is not required to open during this time.	A) No effect. Not applicable.
		B) Actual Loss. Engine cannot operate.	B) Actual Loss. Loss of tug engine causes loss of tug mission.
		C) No effect. Valve is not required to open during this time.	C) No effect. Not applicable.
	Fails to close	A) No effect. Valve is closed during this time.	A) No effect. Not applicable.
		B) No effect. Redundancy is provided by upstream valve, and valves within engine.	B) No effect. Not applicable.
		C) No effect. Valve is closed during this time.	C) No effect. Not applicable.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 114			
Valve, Pneumatically Operated, N. C. (Contd)	Fails to remain closed and internal leakage	A) No effect. Redundancy is provided by upstream valve, and valves within engine.	A) No effect. Not applicable.
		B) No effect. Valve is not required to remain closed during this time.	B) No effect. Not applicable.
		C) No effect. Redundancy is provided by upstream valve, and valves within engine.	C) No effect. Not applicable.
	External leakage	A) Possible Loss. Leakage of hydrogen could cause excessive loss of propellant.	A) Possible Loss. Leakage of hydrogen could cause loss of tug mission, and could create a hazard to the shuttle crew.
		B) No effect. Valve is open during this time, and hydrogen leaks only into space.	B) No effect. Not applicable.
		C) No effect for single failure. Upstream valve would prevent leakage of helium except in the event of double failure.	C) No effect for single failure. Double failure could cause tank to collapse during reentry.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 115			
Nozzle 2 required These are non-propulsive nozzles which allow in-flight venting during tug operations.	No applicable failure modes.		
COMPONENT CODE: 106			
Solenoid Valve, N. C. 1 required This valve is opened to enable helium to enter the APS tank for pressurization prior to reentry.	Fails to open and remain open	A & B) No effect. Valve is not required to open during this time. C) Actual Loss. APS tank cannot be pressurized.	A & B) No effect. Not applicable. C) Possible Loss. Inability to pressurize APS tank could cause it to collapse during reentry.
	Fails to close	A & B) No effect. Valve is closed during this time. C) No effect. Valves in the vent and feed lines provide redundancy.	A & B) No effect. Not applicable. C) No effect. Not applicable.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 106			
Solenoid Valve, N. C. (Contd)	Fails to remain closed and internal leakage	A) No effect. Valves in the vent and feed lines provide redundancy.	A) No effect. Not applicable.
		B) Possible Loss. Hydrogen supply in APS tank could be too rapidly depleted.	B) Possible Loss. Loss of APS causes loss of tug mission.
		C) No effect. Valves in the vent and feed line provide redundancy.	C) No effect. Not applicable.
	External leakage	A) Possible Loss. Excessive leakage could cause rapid depletion of APS supply.	A) Possible Loss. Loss of APS supply causes loss of tug mission, and hydrogen leakage could create a hazard to shuttle crew.
		B) Possible Loss. Excessive leakage could cause rapid depletion of APS supply.	B) Possible Loss. Loss of APS supply could cause loss of tug mission.
		C) Possible Loss. Excessive leakage would cause APS helium pressurization to be lost.	C) Possible Loss. Loss of helium pressurization could cause APS tank to collapse upon reentry.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 116 Solenoid Valve, N. C. 2 required These valves provide on-off capability between the LH_2 tanks, and the reentry purge helium system. They are opened to allow the LH_2 tanks to be pressurized with helium prior to reentry. They are redundant for failure to open and remain open.	Fails to open and remain open	A & B) No effect. Valves are closed during this time.	A & B) No effect. Not applicable.
		C) No effect for single failure. If both valves fail to open, helium pressurization will be lost.	C) No effect for single failure. Double failure would lead to possibility of tanks collapsing during reentry.
	Fails to close	A & B) No effect. Valves are closed during this time.	A & B) No effect. Not applicable.
		C) No effect for single failure. Upstream valves can shut off pressurization. Double failure causes loss of system.	C) No effect for single failure. Double failure of upstream valve would lead to possibility of tanks collapsing during reentry.
	Fails to remain closed and internal leakage	A) No effect for single failure. Upstream valves can shut off pressurization. Double failure causes premature pressurization.	A) No effect for single failure. Double failure could cause premature pressurization, which could lead to loss of tug mission.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HYDROGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 116 Solenoid Valve, N. C. (Contd)		B) No effect for single failure. Check valve in quick-disconnect provides redundancy. Double failure could cause loss of hydrogen.	B) No effect for single failure. Double failure could cause loss of tug mission.
		C) No effect for single failure. Upstream valve can shut off pressurization. Double failure causes loss of pressurization.	C) No effect for single failure. Double failure could cause tanks to collapse during reentry.
	External leakage	A) Possible Loss. Excessive leakage could cause loss of LH_2 supply.	A) Possible Loss. Loss of LH_2 supply causes loss of tug mission, and leakage could create a hazard to shuttle crew.
		B) Possible Loss. Excessive leakage could cause hydrogen supply to be rapidly depleted.	B) Possible Loss. Rapid hydrogen depletion would cause loss of tug mission.
		C) Possible Loss. Excessive leakage could cause loss of helium pressurization.	C) Possible Loss. Loss of helium pressurization could cause tanks to collapse during reentry.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HELIUM SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 317			
Quick-Disconnect 1 required This quick disconnect with check valve provides connection to the payload bay of the space shuttle orbiter. It enables the LH_2 tanks to be purged and pressurized with helium prior to reentry.	Fails to connect	A) No effect. Quick-disconnect is not required to connect during this time.	A) No effect. Not applicable.
		B) Actual Loss. Inability to purge and pressurize prior to reentry would result.	B) Possible Loss. Loss of purge and pressurization causes inability to make vehicle safe for reentry.
		C) No effect. Quick-disconnect is not required to connect during this time.	C) No effect. Not applicable
	Fails to disconnect	A) Actual Loss. System cannot be disconnected from shuttle orbiter.	A) Actual Loss. Tug cannot leave orbiter to carry out assigned mission.
		B & C) No effect. Quick-disconnect is not required to disconnect during this time.	B & C) No effect. Not applicable.
	Leakage	A) No effect for single failure. Double failure could cause loss of hydrogen.	A) No effect for single failure. Double failure could cause a hazard to shuttle crew, and could cause loss of tug mission.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HELIUM SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 317			
Quick-Disconnect (Contd)		B) No effect for single failure. Double failure could cause loss of hydrogen.	B) No effect for single failure. Double failure could cause loss of tug mission.
		C) No effect for single failure. Double failure could cause loss of helium pressurization.	C) No effect for single failure. Double failure could cause tanks to collapse during reentry.
COMPONENT CODE: 318			
Solenoid Valve, N. C. 2 required These valves provide on-off capability between the reentry purge helium supply and the purge line. They are opened in order to purge and pressurize the LH_2 tanks prior to reentry. They are redundant for failure to open and remain open.	Fails to open and remain open	A & B) No effect. Valves are not required to open during this time.	A & B) No effect. Not applicable.
		C) No effect for single failure. Double failure causes inability to use helium purge system.	C) No effect for single failure. Double failure causes inability to make vehicle safe for reentry.
	Fails to close	A & B) No effect. Valves are closed during this time.	A & B) No effect Not applicable.
		C) No effect for single failure. Double failure could cause loss of helium purge system.	C) No effect for single failure. Double failure could cause inability to make vehicle safe for reentry.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HELIUM SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 318			
Solenoid Valve, N. C. (Contd)	Fails to remain closed and internal leakage	A) No effect for single failure. Double failure could cause premature pressurization.	A) No effect for single failure. Double failure could cause loss of tug mission due to premature pressurization.
		B) Possible Loss. Failure to contain helium supply would cause loss of helium purge system.	B) Possible Loss. Loss of helium supply would cause inability to make vehicle safe for reentry.
		C) No effect for single failure. Double failure could cause inability to use helium system.	C) No effect for single failure. Double failure could cause inability to make vehicle safe for reentry.
	External leakage	A & B) Possible Loss. Excessive leakage could cause loss of helium supply.	A & B) Possible Loss. Loss of helium supply would cause inability to make vehicle safe for reentry.
		C) No effect for single failure. Double failure could cause loss of helium pressurization.	C) No effect for single failure. Double failure could cause tanks to collapse during reentry.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HELIUM SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 319			
Pressure Regulator 2 required These regulators are provided so that the pressure from the helium supply spheres can be reduced for purging and pressurization prior to reentry. They are redundant for regulates high or low.	Regulates high or low	A & B) No effect. Regulators do not affect purge and pressurization system during this time. C) No effect. Redundant regulator is provided.	A & B) No effect. Not applicable. C) No effect. Not applicable.
COMPONENT CODE: 320			
Spheres 2 required These spheres provide storage for the reentry purge helium supply.	Burst	A, B, & C) Actual Loss. Loss of helium system results.	A, B, & C) Actual Loss. Loss of helium system causes loss of tug mission. Burst of helium sphere could create a hazard to shuttle crew.
COMPONENT CODE: 321			
Solenoid Valve, N. C. 1 required This valve provides on-off capability between the helium sphere fill line and ground equipment. It is opened during ground operations only.	Fails to open and remain open	A, B, & C) No effect. Valve is not required to open during this time.	A, B, & C) No effect. Not applicable.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
HELIUM SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 321			
Solenoid Valve, N. C. (Contd)	Fails to close	A, B, & C) No effect. Valve is closed during this time.	A, B, & C) No effect. Not applicable.
	Fails to remain closed and leakage	A, B, & C) Possible Loss. Excessive loss of helium causes loss of purge system.	A, B, & C) Possible Loss. Loss of purge system causes inability to make vehicle safe for reentry.

OXYGEN FEED, FILL, DRAIN, VENT AND REENTRY PURGE SYSTEM FAILURE MODE, EFFECTS AND CRITICALITY ANALYSIS

This section presents a preliminary failure mode, effects and criticality analysis of the Space Tug Oxygen Feed, Fill, Drain, Vent and Reentry Purge System. This system performs the following functions:

(a) The feed system is comprised of the ducting and associated valving which is required to route the propellants from the tank to the engine system.

(b) The fill and drain lines are provided to allow the LO_2 tank to be filled on the ground. Ground draining of propellants may be accomplished through the fill line.

(c) The vent and relief system is provided to insure that tank pressures are maintained within structural design limits during ground and inflight operation.

(d) The reentry purge system provides conditioning of the main and APS LO_2 tank for reentry by the use of a helium purge and pressurization of the tanks.

The system schematic and the system block diagram are presented in Figures 8 and 9, respectively.

ASSUMPTIONS AND GROUND RULES

1. The quick disconnects were analyzed as if they were independent components, although they are part of an umbilical plate.

2. Failure of the idle mode operation results in loss of ability to start the main engines.

3. There are valves within the main engine which provide redundancy for the isolation valve.

4. The following time phases were used for this analysis:

Phase A	Boost and separation of Tug and Shuttle	2.85 hours
Phase B	Tug orbital operations and redocking with Shuttle	136 hours
Phase C	Tug repressurization and return to Earth	16.7 hours

CONCLUSIONS AND RECOMMENDATIONS

The predicted probability of this system performing for the duration of a Tug mission is 0.998777.

A check valve could be provided downstream of valves 211 to prevent flow of LO_2 into the LH_2 system. If one of the redundant valves were to fail open or leak then a hazardous situation exists.

OXYGEN FEED, FILL, DRAIN, VENT AND REENTRY PURGE SYSTEM
CRITICAL ITEMS LIST

COMPONENT CODE	ITEM	FAILURE MODE	CRITICALITY
201	Quick Disconnect	Fails to disconnect	163.07
		Leakage	8.15
202	Quick Disconnect	Fails to connect	163.07
		Leakage	8.15
204	Pneumatic Valve 2 required	Fails to close	4.28
		Internal leakage and fails to remain closed	42.89
205	Solenoid Valve	External leakage	.78
		Internal Leakage	55.89
		Fails to open and remain open	125.12
		Fails to close and remain closed	6.88
206	Solenoid Valve	External leakage	.78
		Internal leakage and fails to remain closed	17.3
207	Solenoid Valve 2 required	External leakage	1.59
		Internal leakage and fails to remain closed	3.4
		Fails to close	1.3

OXYGEN FEED, FILL, DRAIN, VENT AND REENTRY PURGE SYSTEM
CRITICAL ITEMS LIST
(Continued)

COMPONENT CODE	ITEM	FAILURE MODE	CRITICALITY
208	Solenoid Valve 2 required	External leakage	1.59
		Internal leakage and fails to remain closed	159.51
		Fails to close	12.49
209	Pneumatic Valve 2 required	External leakage	1.59
		Internal leakage and fails to remain closed	159.51
		Fails to close	12.49
210	Solenoid Valve	External leakage	.78
		Internal leakage and fails to remain closed	62.56
		Fails to open	1.07
		Fails to remain open	1.07
211	Solenoid Valve 2 required	External leakage	1.59
		Internal leakage and fails to remain closed	138.
		Fails to close	2.15
212	Pneumatic Valve	External leakage	.78
		Fails to open	62.56
		Fails to remain open	6.256

FIGURE 8. OXYGEN FEED, FILL, DRAIN, VENT AND REENTRY PURGE SCHEMATIC

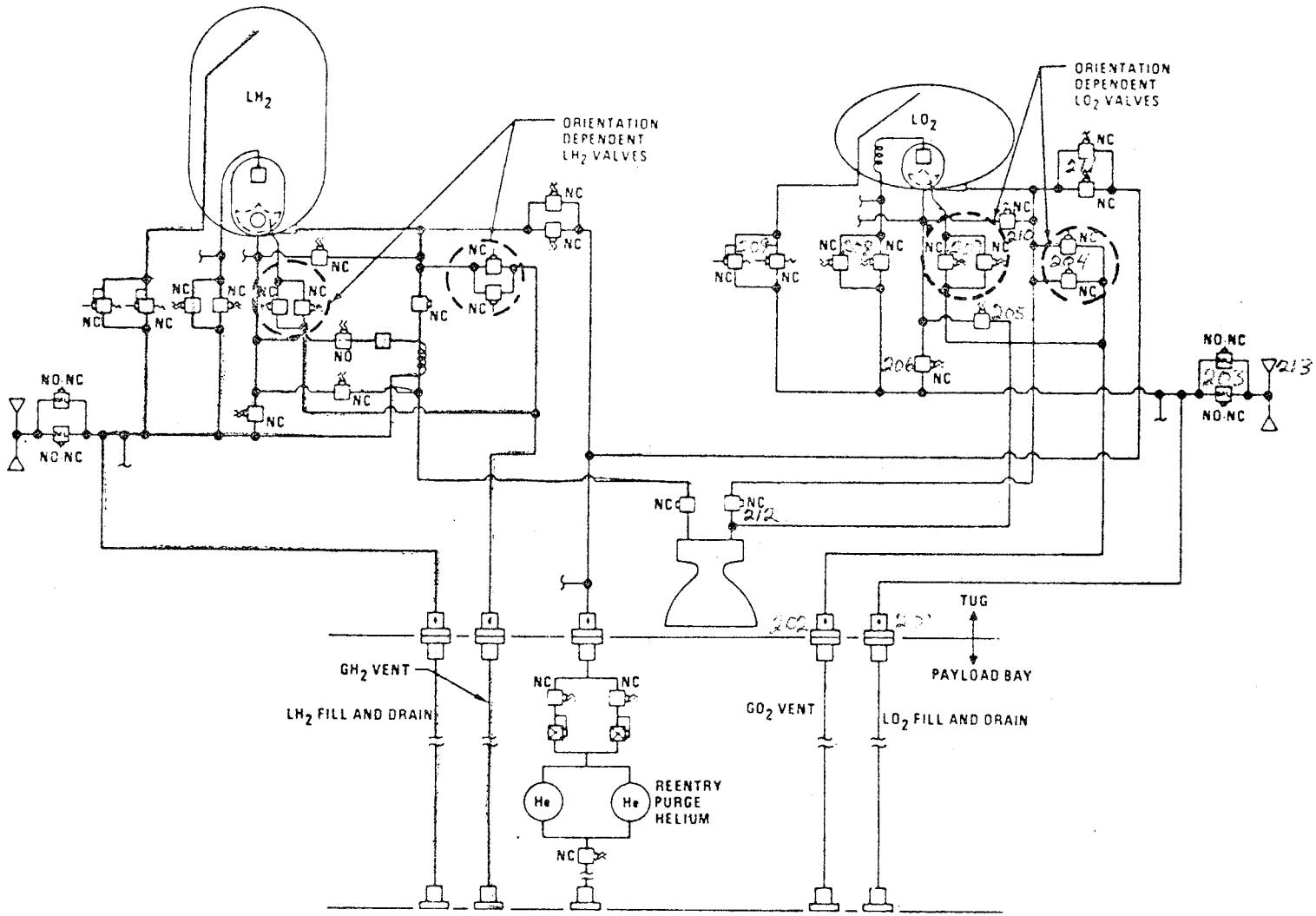
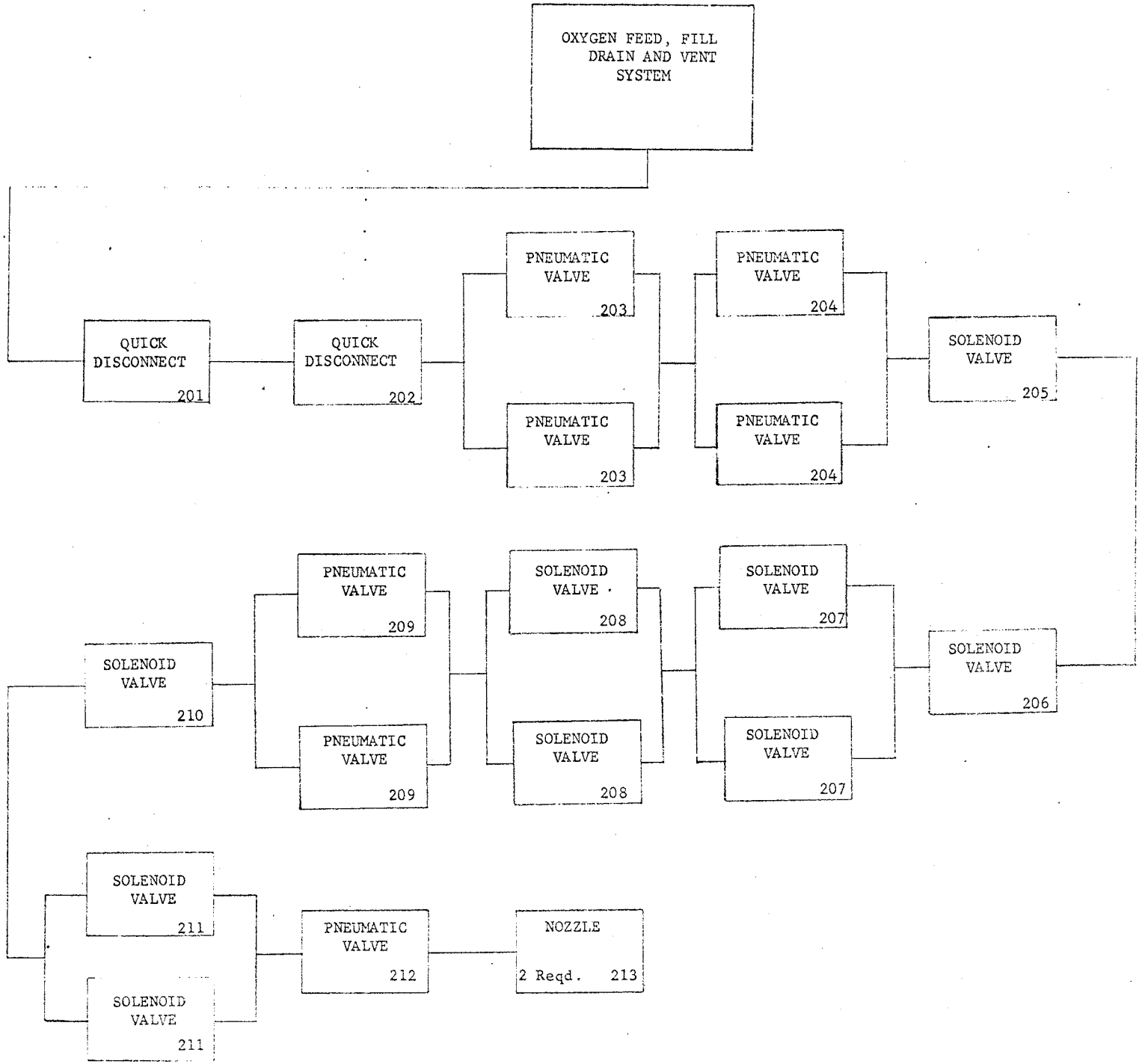


FIGURE 9. OXYGEN FEED, FILL, DRAIN AND VENT SYSTEM BLOCK DIAGRAM



FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
OXYGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 201 Quick Disconnect 1 required This quick disconnect connects the LO_2 fill and drain line of tug to payload bay. It has an internal check valve which prevents LO_2 backflow.	Fails to connect	A) No effect. Not required to connect during this phase.	A) No effect. Not applicable.
		B) No effect. Oxygen is vented through the GO_2 vent line.	B) No effect. Oxygen is vented through the GO_2 vent line.
		C) No effect. System is connected prior to this phase.	C) No effect. Not applicable.
	Fails to disconnect	A) Actual loss. Loss of ability to separate the system from the payload bay.	A) Actual loss. Loss of ability to separate the space tug from the shuttle.
		B,C) No effect. Failure does not apply during these phases.	B,C) No effect. Failure does not apply during these phases.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
OXYGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 201 (Cont.)			
Quick Disconnect	Leakage	A) Possible loss. Oxygen would leak into the payload bay creating a fire hazard.	A) Possible loss. Oxygen would leak into the payload creating a fire hazard and danger to crew.
		B) No effect. Even if the upstream valve opens, the amount of leakage into space is not critical.	B) No effect. No critical effect.
		C) No effect. The oxygen is dumped prior to docking.	C) No effect. The oxygen is dumped prior to docking.
COMPONENT CODE: 202			
Quick Disconnect 1 required This quick disconnect connects the GO_2 vent line of the tug to the payload bay. It has an internal check valve.	Fails to connect	A) No effect. Not required to connect during this phase.	A) No effect. This failure does not apply.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
OXYGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 202 (Cont.) Quick Disconnect		B) Possible loss. Loss of ability to perform GO_2 vent.	B) Possible loss. Loss of capability to safe the tug. Residual oxygen could make the tug a safety hazard.
		C) No effect. The disconnect has already been connected prior to this phase.	C) No effect. This failure does not apply.
	Fails to disconnect	A) Actual loss. Loss of ability to separate the system from the payload bay.	A) Actual loss. Loss of ability to separate the space tug from the shuttle.
		B,C) No effect. This failure does not apply during these phases.	B,C) No effect. This failure does not apply during these phases.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
OXYGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 202 (Cont.)			
Quick Disconnect	Leakage	A) Possible loss. Oxygen could leak into the payload by creating a fire hazard.	A) Possible loss. Oxygen could leak into the payload by creating a fire hazard.
		B) No effect. Even if the upstream valve opens, the amount of leakage into space is not critical.	B) No effect. No critical effect.
		C) No effect. Oxygen is dumped prior to docking.	C) No effect. Oxygen is dumped prior to docking.
COMPONENT CODE: 203			
Valve, Pneumatically Operated 2 required These pneumatic valves provide on-off capability to vent through the non-propulsive nozzles. These valves remain in the last commanded position. They are redundant for fails to open.	Fails to open.	A) No effect. Not required to open during this phase.	A) No effect. Not applicable.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
OXYGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPPONENT CODE: 203 (Cont.) Valve, Pneumatically Operated 2 required		B) No effect for single failure. Failure of both valves results in loss of capability to vent space tug during orbital operations.	B) No effect for single failure. Failure of both valves results in loss of ability to maintain proper NPSH.
		C) No effect. Not required to operate during this phase.	C) No effect. Not applicable.
	Fails to close	A) No effect. Valve is already in closed position during this phase.	A) No effect. Not applicable.
		B) No effect for single failure. Failure of upstream valve would result in loss of ability to stop orbital venting.	B) No effect for single failure. A double failure results in loss of tug mission due to loss of ability to control tug venting.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
OXYGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE: 203 (Cont.) Valve, Pneumatically Operated 2 required		C) No effect. Valve already in closed position.	C) No effect. Not applicable.
	Fails to remain open	A) No effect. Valve is closed during this phase.	A) No effect. Not applicable.
		B) No effect for single failure. Failure of both valves results in loss of capability to vent space tug during orbital operations.	B) No effect for single failure. Failure of both valves results in loss of ability to maintain proper NPSH.
		C) No effect. Valve is closed during this phase.	C) No effect. Not applicable.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
OXYGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
COMPONENT CODE 203 (Cont.) Valve, Pneumatically Operated 2 required	Fails to remain closed and leakage	A) No effect for single failure. If upstream vent valve also fails, then oxygen will leak into the payload bay creating a safety hazard. B) No effect. These valves are normally open in this phase. C) No effect for single failure. If one of the upstream vent valves also fails, then the ability to maintain tug pressure requirements will be lost.	A) No effect for single failure. If upstream vent valve also fails, then oxygen will leak into the payload bay creating a fire hazard. B) No effect. These valves are normally open in this phase. C) No effect for single failure. If one of the upstream vent valves also fails, then the loss of ability to maintain pressure would result in loss of structural integrity of space tug for reentry.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
OXYGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 204			
Valve, Pneumatically Operated 2 Required These normally closed orientation dependent LO_2 valves provide on-off capability to the GO_2 vent line. These valves allow the LO_2 tank to be vented prior to orbital operations. After redocking one of these valves must open to allow the tank and system to be purged.	Fails to open	A. No effect for single failure. If both valves fail, the ability to vent through the GO_2 vent line will be lost.	A. No effect for single failure. Failure of both valves results in loss of ability to maintain tank pressure within structural limits.
		B. No effect. Valves are not required to open during this phase.	B. No effect. Failure does not apply.
		C. No effect for single failure. If both valves fail, the ability to purge the LO_2 tank will be lost.	C. No effect for single failure. Failure of both valves results in loss of ability to purge LO_2 and residual oxygen would remain in the tug.
	Fails to close	A. Actual Loss Loss of ability to control GO_2 vent. Venting of LO_2 tank cannot be stopped.	A. Possible Loss Depletion of oxygen supply could result in early mission termination of space tug.
		B. No effect. Valve is already closed prior to this phase.	B. No effect. Failure does not apply.
		C. Actual Loss Loss of ability to pressurize space tug.	C. Possible Loss Inability to pressurize the tug would result in loss of structural integrity during reentry.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
OXYGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 204			
Valve, Pneumatically Operated (Continued)	Fails to remain open	A. No effect for single failure. If both valves fail, the ability to vent LO_2 tank would be lost.	A. No effect for single failure. Double failure results in loss of ability to maintain pressure requirements in LO_2 tank.
		B. No effect. Failure does not apply.	B. No effect. Failure does not apply.
		C. No effect for single failure. If both valves fail, the ability to complete LO_2 purge would be lost.	C. No effect for single failure. Double failure results in incomplete purge. The tug could not be made completely safe for reentry.
	Fails to remain closed and internal leakage	A. Actual Loss Loss of ability to control GO_2 venting. Venting of LO_2 tank cannot be stopped.	A. Possible Loss Depletion of oxygen supply could result in early mission termination of space tug.
		B. No effect for single failure. Redundancy is provided by the check valve in the disconnect. Double failure would result in loss of oxygen overboard.	B. No effect for single failure. Double failure could result in early mission termination due to depletion of oxygen supply.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
OXYGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 204 Valve, Pneumatically Operated (Continued)		C. Actual Loss Loss of ability to pressurize space tug.	C. Possible Loss Inability to pressurize the tug would result in loss of structural integrity during reentry.
Component Code: 205 Solenoid Valve 1 required This normally closed idle mode valve provides on-off capability from the APS tank to the engine. It is opened during idle mode operation to cool the main engine turbopump.	External leakage	A. Possible Loss Leakage of LO_2 into payload bay which could result in loss of APS.	A. Possible Loss Leakage of LO_2 into payload bay resulting in a safety hazard and loss of the APS.
		B. Possible Loss Leakage of LO_2 overboard resulting in depletion of APS supply.	B. Possible Loss Depletion of APS supply could lead to early mission termination.
		C. Possible Loss Loss of APS tank pressurization.	C. Possible Loss Loss of APS pressure results in loss of structural integrity of the tug APS tank during reentry.
	Internal leakage	A. No effect. Engine valves downstream provide multiple redundancy.	A. No effect. Engine valves downstream provide multiple redundancy.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
OXYGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 205 Solenoid Valve (Continued)		B. <u>Possible Loss</u> This valve closes after idle mode operation. Leakage could result in depletion of APS supply.	B. <u>Possible Loss</u> Depletion of APS supply could result in early mission termination.
		C. No effect. Engine valves downstream provide multiple redundancy.	C. No effect. Engine valves downstream provide multiple redundancy.
	Fails to open and remain open	A. No effect. Failure does not apply.	A. No effect. Failure does not apply.
		B. <u>Actual Loss</u> Loss of ability to provide idle mode operation.	B. <u>Actual Loss</u> Loss of capability to start the main engines due to loss of idle mode operation.
		C. No effect. Failure does not apply.	C. No effect. Failure does not apply.
	Fails to close and remain closed	A. No effect. Failure does not apply.	A. No effect. Failure does not apply.
		B. <u>Actual Loss</u> Premature depletion of APS supply.	B. <u>Possible Loss</u> Depletion of APS supply could lead to early mission termination.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
OXYGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 205 Solenoid Valve (Continued)		C. No effect. Engine valves downstream provide multiple redundancy.	C. No effect. Engine valves downstream provide multiple redundancy.
Component Code: 206 Solenoid Valve 1 required This normally closed solenoid valve is opened to allow the APS tank to be filled prior to launch. Inflight, it can be opened to allow the APS tank to be vented through the non-propulsive nozzles.	External leakage	A. Possible Loss Leakage of LO_2 into the payload bay APS supply could be depleted.	A. Possible Loss LO_2 in payload bay could create a safety hazard. Depletion of APS supply could lead to early mission termination.
		B. Possible Loss Leakage of LO_2 overboard resulting in depletion of APS supply.	B. Possible Loss Depletion of APS supply could lead to early mission termination.
		C. Possible Loss Loss of APS tank pressurization.	C. Possible Loss Loss of APS pressure results in loss of structural integrity of the tug APS tank during reentry.
	Internal leakage and fails to remain closed	A. Possible Loss Leakage of oxygen overboard resulting in depletion of APS tank supply.	A. Possible Loss Depletion of APS tank supply could lead to early mission termination.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
OXYGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 206 Solenoid Valve (Continued)		B. No effect for single failure. A check valve is provided downstream, a double failure results in premature depletion of APS tank supply. C. Possible Loss Loss of APS tank pressurization.	B. No effect for single failure. A double failure results in depletion of APS tank supply which could lead to early mission termination. C. Possible Loss Loss of APS pressure results in loss of structural integrity of the tug APS tank during reentry.
	Fails to close, fails to open and fails to remain open	A, B, C. No effect. Failure does not apply.	A, B, C. No effect. Failure does not apply.
Component Code: 207 Solenoid Valve 2 required These normally closed orientation dependent LO_2 valves provide on-off capability to the GO_2 vent line for the APS tank. These valves are opened to vent the APS tank to required pressure limits.	External leakage	A. Possible Loss Leakage of LO_2 into the payload bay. APS tank supply could be depleted.	A. Possible Loss Leakage of LO_2 into the payload bay could create a safety hazard. Excess depletion of APS tank could lead to early mission termination.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
OXYGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 207 Solenoid Valve (Continued)		B. Possible Loss Premature depletion of APS tank supply.	B. Possible Loss Depletion of APS tank supply could lead to early mission termination.
		C. Possible Loss Loss of APS tank pressurization.	C. Possible Loss Loss of APS pressure results in loss of structural integrity of the tug APS tank during reentry.
	Internal leakage and fails to remain closed	A. Possible Loss Leakage of oxygen overboard resulting in depletion of APS tank supply.	A. Possible Loss Depletion of APS tank supply could lead to early mission termination.
		B. No effect for single failure. A check valve is provided downstream, a double failure results in premature depletion of APS tank supply.	B. No effect for single failure. A double failure results in depletion of APS tank supply which could lead to early mission termination.
		C. Possible Loss Loss of APS tank pressurization.	C. Possible Loss Loss of APS pressure results in loss of structural integrity of the tug APS tank during reentry.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
OXYGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 207			
Solenoid Valve (Continued)	Fails to close	A. Actual Loss Loss of ability to shut off venting of the APS tank.	A. Possible Loss Premature depletion of the APS tank leading to early mission termination.
		B & C. No effect. Failure does not apply.	B & C. No effect. Failure does not apply.
	Fails to open and remain open	A. No effect for single failure. Failure of both valves would result in loss of ability to vent the APS tank.	A. No effect for single failure. Failure of both valves results in loss of ability to maintain pressure requirements in the APS tank due to loss of vent capability.
		B & C. No effect. Failure does not apply.	B & C. No effect. Failure does not apply.
Component Code: 208			
Solenoid Valve 2 required These normally closed vent and relief valves provide on-off capability to the tug vent line. These valves are used during tug orbital operations to maintain APS tank pressure requirements and to dump the residual LO_2 prior to redocking.	External leakage	A. Possible Loss Leakage of LO_2 into the payload bay.	A. Possible Loss Leakage of LO_2 into the payload bay creating a safety hazard and premature depletion of the APS tank.
		B. Possible Loss Leakage of LO_2 overboard.	B. Possible Loss Loss of LO_2 overboard could result in premature depletion of LO_2 in APS tank.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
OXYGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 208 Solenoid Valve (Continued)		C. Possible Loss Loss of APS tank pressurization.	C. Possible Loss Loss of APS tank pressure could result in loss of structural integrity of APS tank during reentry.
	Internal leakage and fails to remain closed	A. Possible Loss Leakage of oxygen overboard through the fill and drain line.	A. Possible Loss Leakage of oxygen overboard could result in premature depletion of LO_2 in the APS tank which could lead to early mission termination.
		B. Possible Loss Loss of ability to shut off venting of the APS tank.	B. Possible Loss Continuous venting of the APS tank could result in depletion of LO_2 and early mission termination.
		C. Possible Loss Loss of APS tank pressurization.	C. Possible Loss Loss of APS tank pressure results in loss of structural integrity during reentry.
	Fails to close	A. No effect. Failure does not apply.	A. No effect. Failure does not apply.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
OXYGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 208 Solenoid Valve (Continued)		B. Possible Loss Loss of ability to shut off venting of the APS tank.	B. Possible Loss Continuous venting of the APS tank could result in depletion of LO_2 and early mission termination.
		C. No effect. Failure does not apply.	C. No effect. Failure does not apply.
	Fails to open and fails to remain open	A. No effect. Failure does not apply.	A. No effect. Failure does not apply.
		B. No effect for single failure. If both valves fail, then the ability to maintain pressure requirements in the APS tank will be lost.	B. No effect for single failure. Failure of both valves results in loss of ability to maintain pressure requirements of APS tank.
		C. No effect. Failure does not apply.	C. No effect. Failure does not apply.
Component Code: 209 Valve, Pneumatically Operated 2 Required These normally closed vent and relief valves provide on-off capability to LO_2 tank vent line. These valves are used during tug orbital operations to maintain proper pressure in the main LO_2 tank.	External leakage	A. Possible Loss Leakage of LO_2 into the payload bay.	A. Possible Loss Leakage of LO_2 into the payload bay creating a safety hazard and premature depletion of the APS tank.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
OXYGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 209 Valve, Pneumatically Operated (Continued)		B. Possible Loss Leakage of LO_2 overboard.	B. Possible Loss Loss of LO_2 overboard could result in premature depletion of LO_2 in APS tank.
		C. Possible Loss Loss of APS tank pressurization.	C. Possible Loss Loss of APS tank pressure could result in loss of structural integrity of APS tank during reentry.
	Internal leakage and fails to remain closed	A. Possible Loss Leakage of oxygen overboard through the fill and drain line.	A. Possible Loss Leakage of oxygen overboard could result in premature depletion of LO_2 in the main LO_2 tank which could lead to early mission termination.
		B. Possible Loss Loss of ability to shut off venting of the main LO_2 tank.	B. Possible Loss Continuous venting of the main LO_2 tank could result in depletion of LO_2 and early mission termination.
		C. Possible Loss Loss of main LO_2 tank pressurization.	C. Possible Loss Loss of LO_2 tank pressure results in loss of structural integrity of main tank during reentry.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
OXYGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 209			
Valve, Pneumatically Operated (Continued)	Fails to close	A. No effect. Failure does not apply.	A. No effect. Failure does not apply.
		B. Possible Loss Loss of ability to shut off venting of the main LO_2 tank.	B. Possible Loss Continuous venting of the main LO_2 tank could result in depletion of LO_2 and early mission termination.
		C. No effect. Failure does not apply.	C. No effect. Failure does not apply.
	Fails to open and fails to remain open	A. No effect. Failure does not apply.	A. No effect. Failure does not apply.
		B. No effect for single failure. If both valves fail, then the ability to maintain pressure requirements in the main LO_2 tank will be lost.	B. No effect for single failure. If both valves fail, then the ability to maintain pressure requirements in the main LO_2 tank will be lost.
		C. No effect. Failure does not apply.	C. No effect. Failure does not apply.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
OXYGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 210			
Solenoid Valve 1 required This normally closed solenoid valve is opened after redocking to allow the APS tank to be pressurized before reentry.	External leakage	A. Possible Loss Leakage of LO_2 tank into the payload bay.	A. Possible Loss Leakage of LO_2 into the payload bay creating a safety hazard and premature depletion of APS tank.
		B. Possible Loss Leakage of LO_2 overboard.	B. Loss of LO_2 overboard could result in premature depletion of LO_2 in APS tank.
		C. Possible Loss Loss of ability to maintain pressure in the APS tank.	C. Possible Loss Loss of pressure in the APS tank results in loss of structural integrity of the tank during reentry.
	Internal leakage and fails to remain closed	A. No effect. Multiple redundancy is provided.	A. No effect. Multiple redundancy is provided.
		B. Possible Loss Premature depletion of the LO_2 in the APS tank.	B. Possible Loss Premature depletion of LO_2 in APS tank could lead to early mission termination.
		C. No effect. Multiple redundancy.	C. No effect. Multiple redundancy.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
OXYGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 210			
Solenoid Valve (Continued)	Fails to close	A & B. No effect. Failure does not apply.	A & B. No effect. Failure does not apply.
		C. No effect. Multiple redundancy provided.	C. No effect. Multiple redundancy provided.
	Fails to open	A & B. No effect. Failure does not apply.	A & B. No effect. Failure does not apply.
		C. Actual Loss Loss of ability to pressurize APS tank.	C. Possible Loss Loss of APS tank pressurization results in loss of structural integrity of APS tank during reentry.
	Fails to remain open	A & B. No effect. Failure does not apply.	A & B. No effect. Failure does not apply.
		C. Possible Loss Loss of ability to adequately pressurize APS tank.	C. Possible Loss Loss of ability to adequately pressurize APS tank could result in loss of structural integrity of APS tank during reentry.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
OXYGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 211			
Solenoid Valve 2 required These normally closed LO_2 purge valves provide on-off capability between the LO_2 tank and the helium purge system. They are opened after redocking to pressurize the LO_2 tank.	External leakage	A. Possible Loss Leakage of LO_2 could result in premature depletion of LO_2 supply.	A. Possible Loss Leakage of LO_2 into payload bay resulting in a safety hazard. Premature depletion of LO_2 could lead to early termination of tug mission.
		B. Possible Loss LO_2 supply could be prematurely depleted.	B. Possible Loss Depletion of LO_2 supply could lead to early termination of tug mission.
		C. Possible Loss Loss of ability to maintain proper pressure in the LO_2 tank.	C. Possible Loss Loss of pressurization would result in loss of structural integrity of the LO_2 tank during reentry.
	Internal leakage and fails to remain closed	A & B. Possible Loss LO_2 would leak into the hydrogen side of the tug purge system.	A & B. Possible Loss LO_2 leakage to the hydrogen side of the tug purge system could result in loss of the shuttle and tug as well as shuttle crew. If the LO_2 would come in contact with the LH_2, then a catastrophic effect would result.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
OXYGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 211			
Solenoid Valve (Continued)		C. No effect. Multiple redundancy provided.	C. No effect. Multiple redundancy provided.
	Fails to close	A & B. No effect. Failure does not apply.	A & B. No effect. Failure does not apply.
		C. Possible Loss Loss of ability to maintain pressure in LO_2 tank.	C. Possible Loss Loss of ability to maintain pressure in LO_2 tanks would result in loss of structural integrity of the tanks during reentry.
	Fails to open	A & B. No effect. Failure does not apply.	A & B. No effect. Failure does not apply.
		C. No effect for single failure. Loss of ability to pressurize the LO_2 tanks if double failure occurs.	C. No effect for single failure. Inability to pressurize LO_2 tanks results in loss of structural integrity of the tanks during reentry if double failure occurs.
	Fails to remain open	A & B. No effect. Failure does not apply.	A & B. No effect. Failure does not apply.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
OXYGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 211			
Solenoid Valve (Continued)		C. No effect for single failure. Loss of ability to pressurize LO_2 tanks to required pressure if double failure occurs.	C. No effect for single failure. Improper pressure in LO_2 tanks could result in loss of structural integrity of LO_2 tanks during reentry if double failure occurs.
Component Code: 212			
Valve, Pneumatically Operated 1 Required This normally closed feedline isolation valve provides on-off capability between the engine and LO_2 tanks. It is opened during the idle mode phase and remains open during tug orbital operations.	External leakage	A. Possible Loss Leakage of LO_2 into the payload and depletion of LO_2 in the main tank.	A. Possible Loss Leakage of LO_2 into the payload bay creates a safety hazard.
		B. Possible Loss Excessive leakage could result in premature depletion of LO_2 in the main tank.	B. Possible Loss Premature depletion of LO_2 supply could result in early mission termination.
		C. Possible Loss Loss of ability to maintain pressure in main LO_2 tank.	C. Possible Loss Loss of LO_2 tank pressure could result in loss of tank structural integrity during reentry.
	Internal leakage and fails to remain closed	A. No effect. Multiple redundancy provided.	A. No effect. Multiple redundancy provided.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
OXYGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 212 Valve, Pneumatically Operated (Continued)		B. No effect. Failure does not apply.	B. No effect. Failure does not apply.
		C. No effect. Multiple redundancy provided.	C. No effect. Multiple redundancy provided.
	Fails to close	A & B. No effect. Failure does not apply.	A & B. No effect. Failure does not apply.
		C. No effect. Multiple redundancy provided.	C. No effect. Multiple redundancy provided.
	Fails to open	A. No effect. Failure does not apply.	A. No effect. Failure does not apply.
		B. Actual Loss Loss of ability to supply LO_2 to the main engine.	B. Actual Loss Inability to provide LO_2 to main engine results in loss of tug mission.
		C. No effect. Failure does not apply.	C. No effect. Failure does not apply.
	Fails to remain open	A. No effect. Failure does not apply.	A. No effect. Failure does not apply.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
OXYGEN SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 212 Valve, Pneumatically Operated (Continued)		B. Actual Loss Loss of ability to provide flow of LO_2 to the main engines.	B. Possible Loss The flow of LO_2 to the main engines is cut off. This could result in turbopump cavitation and loss of mission and vehicle due to fire and explosion.
		C. No effect. Failure does not apply.	C. No effect. Failure does not apply.
Component Code: 213 Nozzle 2 Required These nozzles provide the capability for a non-propulsive vent during tug orbital operations.	No Applicable Failure Modes		

AUXILIARY PROPULSION SYSTEM FAILURE MODE, EFFECTS AND CRITICALITY ANALYSIS

This section presents a preliminary failure mode, effects and criticality analysis of the Space Tug Auxiliary Propulsion System. This system provides the necessary thrust to perform the following functions:

(a) Maintain Tug Vehicle attitude control throughout the coast phases of the mission.

(b) Perform stage $\triangle V$ maneuvers for mid-course corrections.

(c) Perform transverse and lateral translation maneuvers during rendezvous and docking.

(d) Perform vehicle and sensor pointing and alignment as required.

The APS system schematic and the APS system block diagram are presented in Figures 10 and 11, respectively. Figures 12, 13 and 14 present block diagrams for the APS and Main Tank Pressurization Subsystem, the APS LH_2 Conditioning and Feed Subsystem and the APS LO_2 Conditioning and Feed Subsystem, respectively.

ASSUMPTIONS AND GROUND RULES

1. The APS has "thruster out" capability and can perform its mission with one thruster pod disabled.

2. The system has adequate sensing devices to monitor critical functions and to detect malfunctions.

3. All valves are "fail safe" in their normal position.

4. The APS system analyzed by this FEA does not have the capability to re-pressurize the main engine propellant tanks from the main engines.

5. The following time phases were used for this analysis:

Phase A	Boost and separation of Tug and Shuttle	2.85 hours
Phase B	Tug orbital operations and redocking with Shuttle	136 hours
Phase C	Tug repressurization and return to Earth	16.7 hours

CONCLUSIONS AND RECOMMENDATIONS

The predicted probability of the APS system performing for the duration of a Tug mission is 0.983002.

Approximately 36 percent of the criticality associated with the Tug APS System is caused by the gas generator bi-propellant valves, items 45 and 46. This criticality results from the possibility of a failure to close, failure to remain closed and leakage of these valves. The inclusion of shutoff valves in the portion of the propellant feed lines which serves only the bi-propellant valves would eliminate this criticality and increase the mission success probability from 0.983002 to 0.989288.

AUXILIARY PROPULSION SYSTEM
CRITICAL ITEMS LIST

COMPONENT CODE	ITEM	FAILURE TYPE	CRITICALITY
01	Quick Disconnect	Fail to disengage	1556
06	Solenoid Valve, N. C.	Fail to close, fail to remain closed and major leakage	1289
		Minor leakage	102
08	Solenoid Valve, N. C.	Fail to close, fail to remain closed and major leakage	1289
		Minor leakage	102
39	Quick Disconnect	Fail to disengage	1556
40	Quick Disconnect	Fail to disengage	1556
44	Thruster	Burn-Thru	2372
45	Bi-Propellant Valve	Fail to close, fail to remain closed and major leakage	2855
		Minor leakage	228
46	Bi-Propellant Valve	Fail to close, fail to remain closed and major leakage	2855
		Minor leakage	228
47	Filter	Clogs	408

AUXILIARY PROPULSION SYSTEM
CRITICAL ITEMS LIST

COMPONENT CODE	ITEM	FAILURE TYPE	CRITICALITY
48	Filter	Clogs	408
49	Solenoid Valve, N. C.	Fail to open	63
		Fail to close, fail to remain closed and major leakage	34
50	Solenoid Valve, N. C.	Fail to open	63
		Fail to close, fail to remain closed and major leakage	34
		TOTAL	16,998

FIGURE 10. SPACE TUG AUXILIARY PROPULSION SYSTEM SCHEMATIC

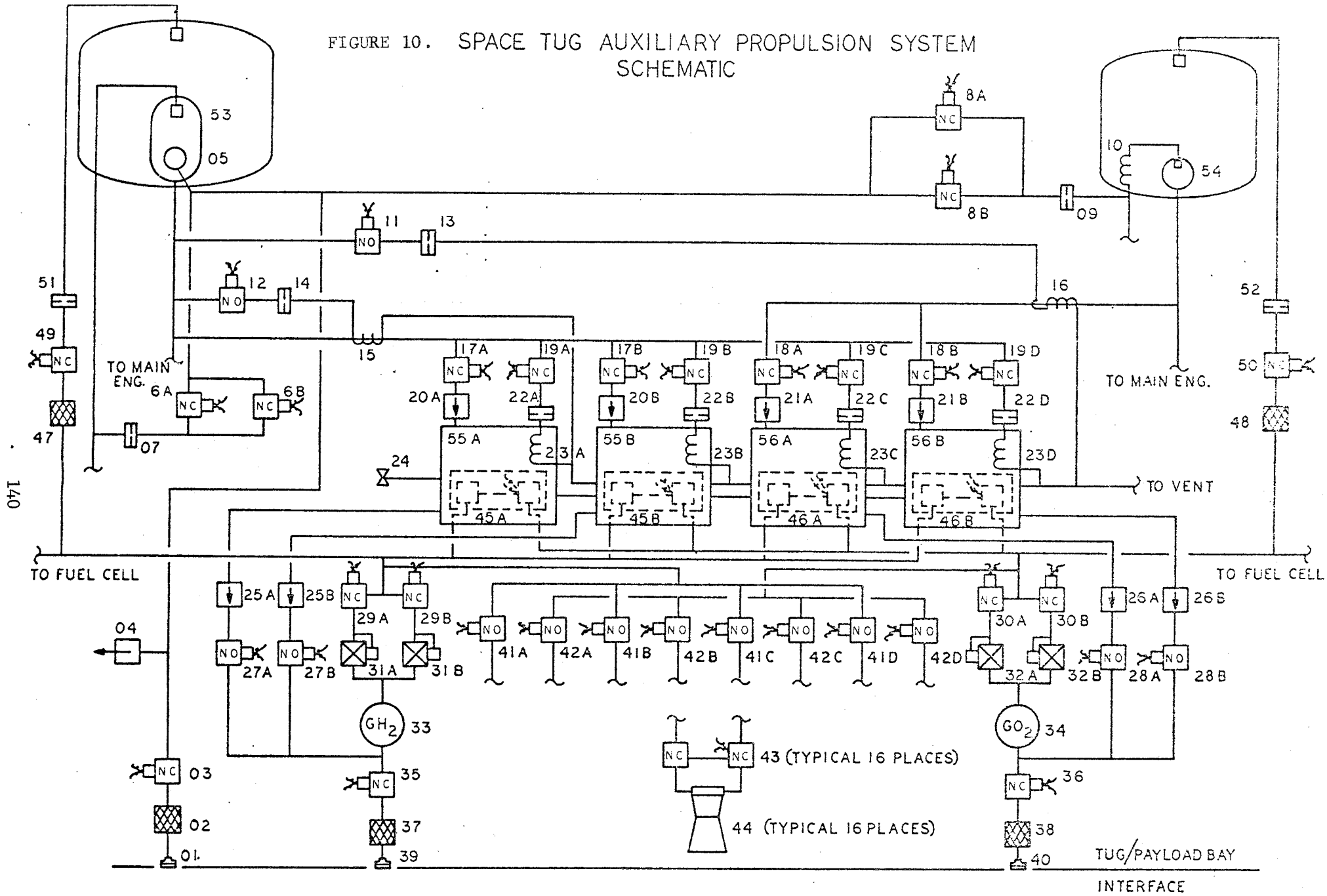


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FIGURE 11. SPACE TUG AUXILIARY PROPULSION SYSTEM (APS) BLOCK DIAGRAM

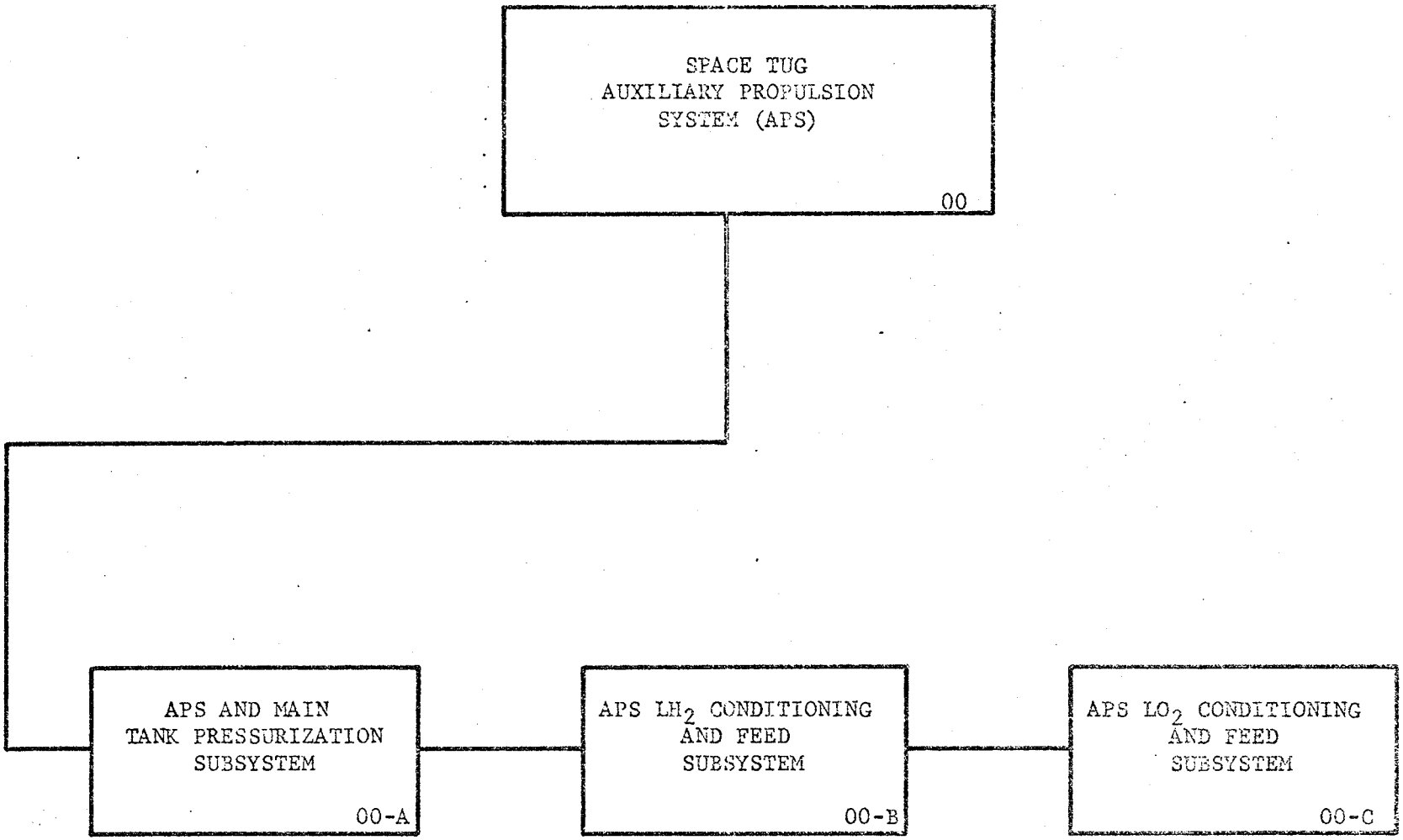


FIGURE 12. APS AND MAIN TANK PRESSURIZATION SUBSYSTEM BLOCK DIAGRAM

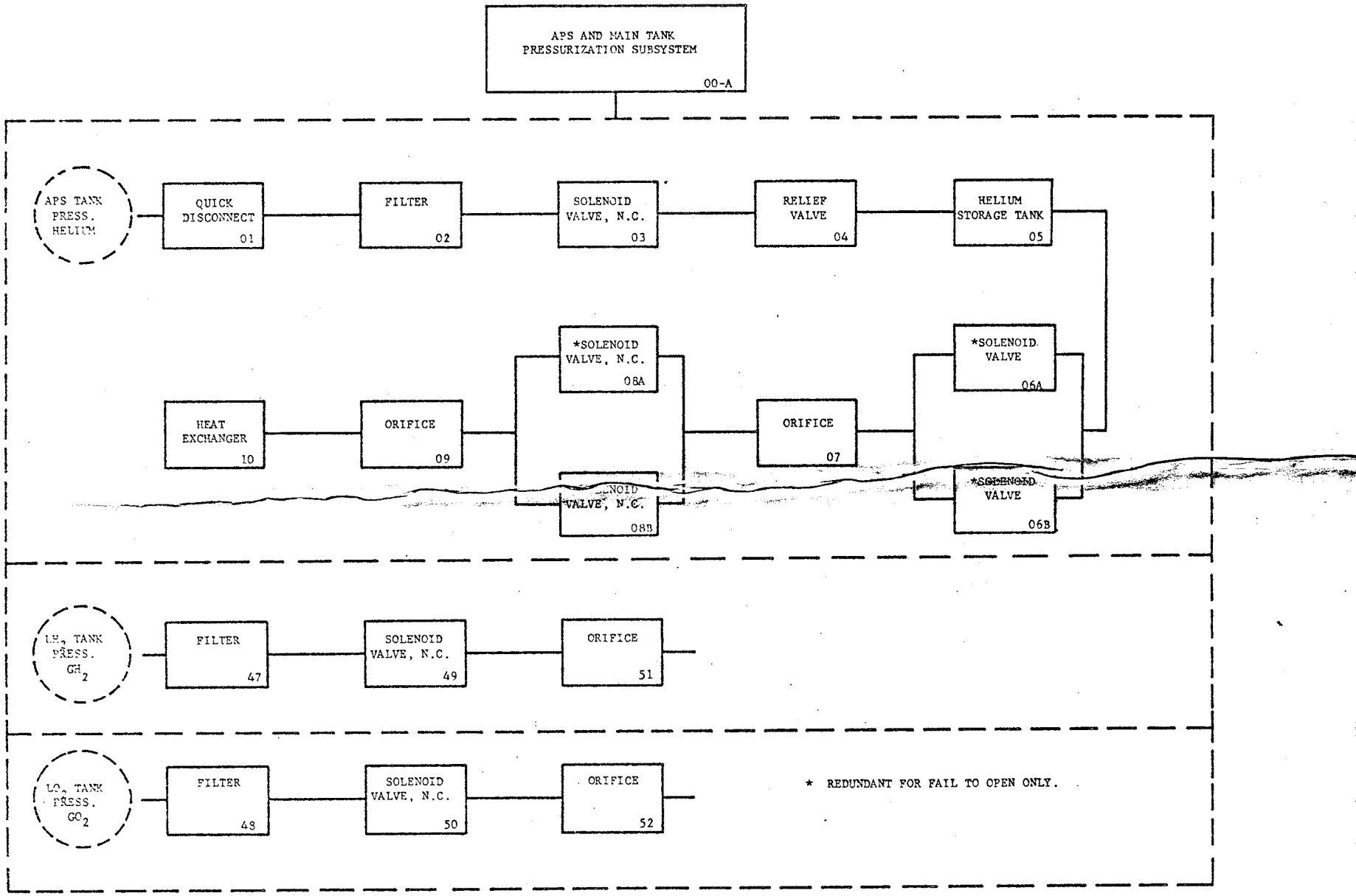


FIGURE 13. APS LH_2 CONDITIONING AND FEED SUBSYSTEM BLOCK DIAGRAM

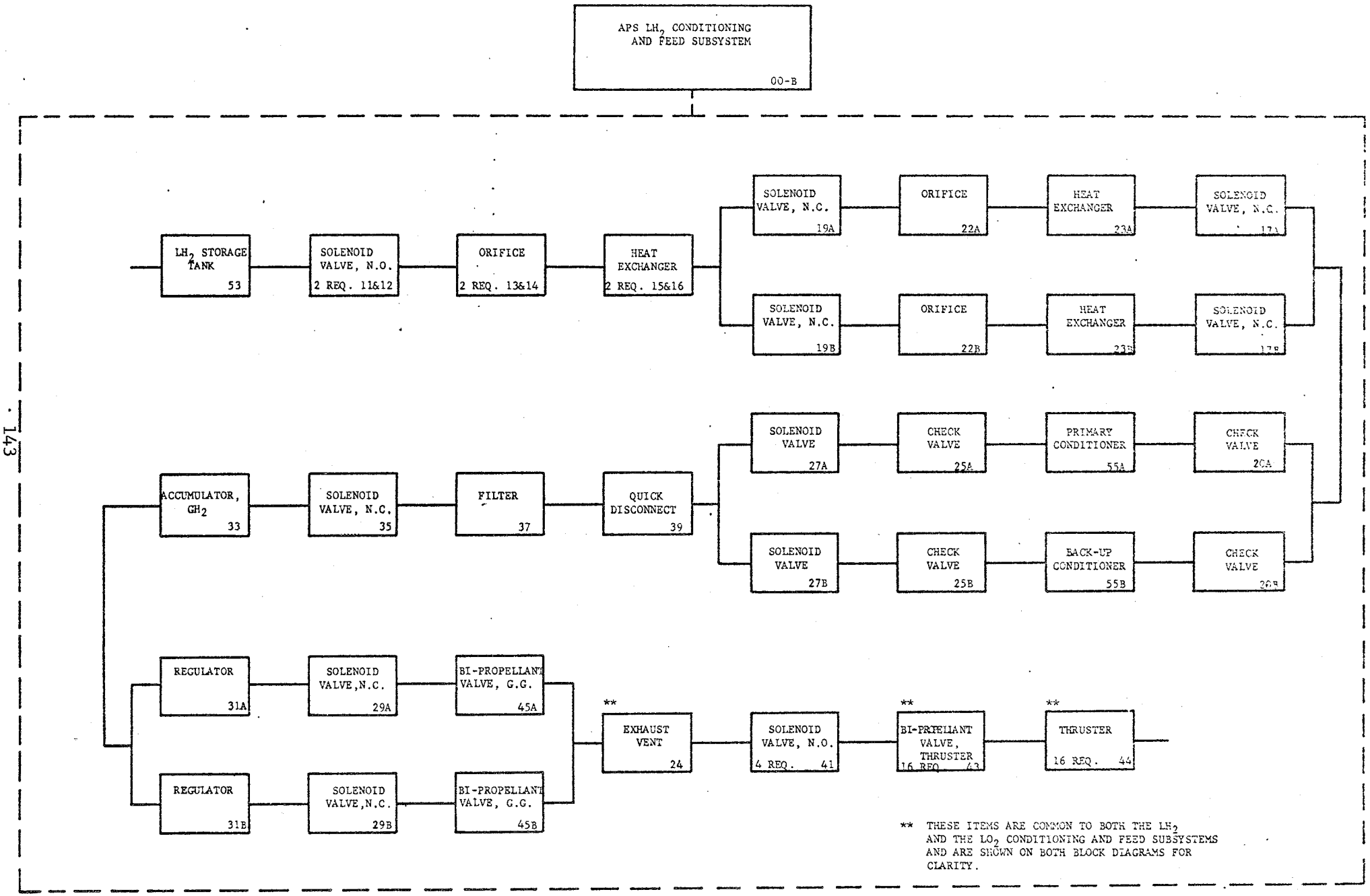
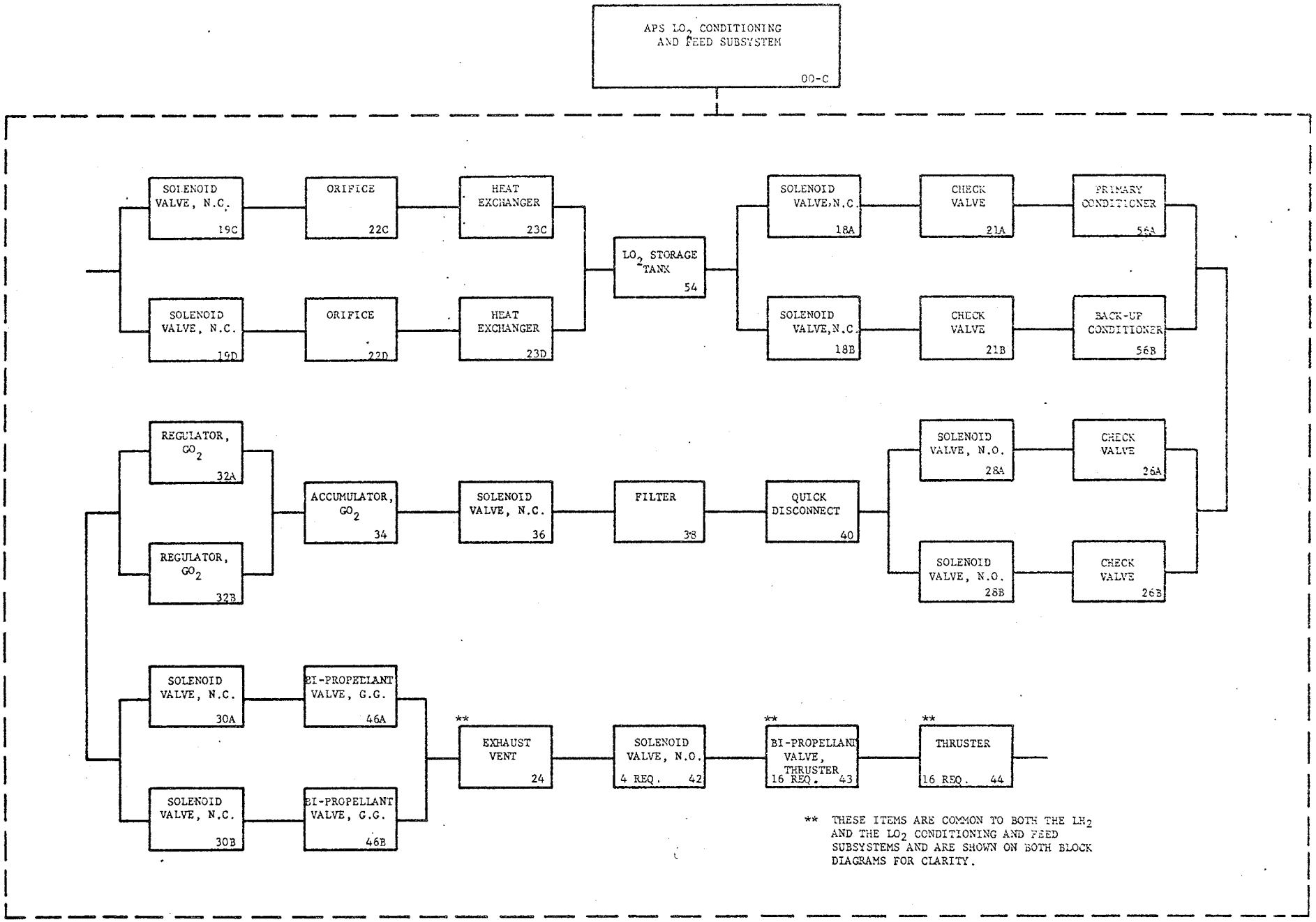


FIGURE 14. APS LO_2 CONDITIONING AND FEED SUBSYSTEM BLOCK DIAGRAM



FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
AUXILIARY PROPULSION SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 01			
Quick Disconnect 1 Required Provides a connection at the tug/payload bay interface for the helium fill operation.	Fail to engage	A & C. No effect. Disconnect is already engaged during these phases. B. No effect. After the tug completes its mission and returns to the orbiter, all propellants and pressurants are dumped overboard prior to docking. In addition, the solenoid shut-off valves at the fill lines will be closed prior to storing the tug in the orbiter for return to earth.	A & C. No effect. Disconnect is already engaged during these phases. B. No effect.
	Fail to disengage	A & C. No effect. Failure mode not applicable during these phases. B. Actual Loss The failure of the tug disconnects to disengage at the tug/payload bay interface will cause the tug to remain docked to the orbiter and unable to perform its mission.	A & C. No effect. Not applicable during these phases. B. Actual Loss

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
AUXILIARY PROPULSION SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 01			
Quick Disconnect (Continued)	Leakage	A, B, & C. No effect. Redundancy provided by solenoid shutoff valves.	A, B, & C. No effect.
Component Code: 02			
Filter 1 Required Removes contaminants from the helium supply during ground fill operation.	Clogs	A, B, & C. No effect. Filter is not used during these phases. Any problem encountered during the fill operation would be corrected prior to lift off.	A, B, & C. No effect. Not applicable during
Component Code: 03			
Solenoid Valve, N. C. 1 Required Controls the flow of helium to the helium storage tank during ground filling operation.	Fail to open	A, B, & C. No effect. Valve is not required to operate during these phases.	A, B, & C. No effect. Valve is not required to operate during these phases.
	Fails to close	A, B, & C. No effect. Valve is not required to operate during these phases.	A, B, & C. No effect. Valve is not required to operate during these phases.
	Fails to remain closed and leakage	A, B, & C. No effect. Redundancy is provided by disconnect, component code 01.	A, B, & C. No effect. Redundancy is provided by disconnect, component code 01.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
AUXILIARY PROPULSION SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 04			
Relief Valve 1 Required Protects the helium storage tank against over-pressurization during filling.	Fail to open	A, B, & C. No effect. Not required to operate during these phases.	A, B, & C. No effect. Not required to operate during these phases.
	Fail to remain closed and leakage	A, B, & C. No effect. Valve is burst disc/relief type and therefore provides redundancy for this failure mode.	A, B, & C. No effect. Valve is burst disc/relief type and therefore provides redundancy for this failure type.
Component Code: 05			
Helium Storage Tank 1 Required Stores the helium used to pressurize the APS propellant tanks.	No Applicable Failure Modes	N/A	N/A
Component Code: 06			
Solenoid Valve, N. C. 2 Required Controls the flow of helium to the APS LH_2 tank for pressurization.	Fail to open	A & B. No effect. Redundancy provided. C. No effect. Valve is not required to operate during this phase.	A & B. No effect. Redundancy provided. C. No effect.

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
AUXILIARY PROPULSION SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 06			
Solenoid Valve, N. C. (Continued)	Fail to close, fail to remain closed and leakage	A & C. No effect. Failure mode is not applicable during these phases.	A & C. No effect.
		B. Probable Loss The continuous flow of helium to the APS tank will cause the tank to be over-pressurized and the helium will be vented overboard. Unscheduled venting will cause premature depletion of the helium supply.	B. Probable Loss Premature depletion of helium supply will cause loss of mission.
Component Code: 07			
Orifice 1 Required Provides damping for the initial helium surge and provides flow control of the helium used to pressurize the APS LH_2 tank.	No Applicable Failure Modes	N/A	N/A

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
AUXILIARY PROPULSION SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 08			
Solenoid Valve, N. C. 2 Required Controls the flow of helium to the APS LO_2 tank for pressurization.	Fail to open	A & B. No effect. Redundancy provided.	A & B. No effect. Redundancy provided.
		C. No effect. Valve is not required to operate during this phase.	C. No effect. Not applicable during this phase.
	Fail to close, fail to remain closed and leakage	A & C. No effect. Failure mode is not applicable during phases.	A & C. No effect.
		B. Probable Loss The continuous flow of helium to the APS LO_2 tank will cause the tank to be overpressurized and the helium will be vented overboard. Unscheduled venting will cause premature depletion of the helium supply.	B. Probable Loss Premature depletion of helium supply will cause loss of mission.
Component Code: 09			
Orifice 1 Required Provides damping for the initial helium surge and provides flow control of the helium used to pressurize the APS LO_2 tank.	No Applicable Failure Modes	N/A	N/A

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Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 10			
Heat Exchanger 1 Required Provides a means of equalizing the temperature of the helium and the LO_2 prior to pressurizing the APS LO_2 tank.	No Applicable Failure Modes	N/A	N/A
Component Code: 11			
Solenoid Valve, N. O. 1 Required Controls the flow of LH_2 to Heat Exchanger, Component Code 16, for conditioning the LO_2 feed line.	Fail to open	A, B, & C. No effect. Valve remains open during these phases unless venting is required.	A, B, & C. No effect.
	Fail to close	A & C. No effect. Valve is open during these phases.	A & C. No effect.
		B. No effect. If venting occurs while this valve is open, some propellant will be lost. Because scheduled venting occurs at the end of this phase, loss of some propellant will not cause any problems.	B. No effect. Loss of propellant at the end of this phase will not affect the mission.
	Fails to remain closed and leakage	A & C. No effect. Valve is open during these phases.	A & C. No effect.

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Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 11			
Solenoid Valve, N. O. (Continued)		B. No effect. Because the valve is open except during venting, failure to remain closed or leakage may cause loss of some of propellant at the end of this phase.	B. No effect. Loss of propellant at the end of this phase will not affect the mission.
Component Code: 12			
Solenoid Valve, N. O. 1 Required Controls the flow of LH_2 to Heat Exchanger; Component Code 15, for conditioning the LH_2 feed line.	Fail to open	A, B, & C. No effect. Valve remains open during these phases unless venting is required.	A, B, & C. No effect.
	Fail to close	A & C. No effect. Valve is open during these phases.	A & C. No effect.
		B. No effect. If venting occurs while this valve is open, some propellant will be lost. Because scheduled venting occurs at the end of this phase, loss of some propellant will not cause any problems.	B. No effect. Loss of propellant at the end of this phase will not affect the mission.
	Fail to remain closed and leakage	A & C. No effect. Valve is open during these phases.	A & C. No effect.

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Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 12			
Solenoid Valve, N. O. (Continued)		B. No effect. Because the valve is open except during venting, failure to remain closed or leakage may cause some loss of propellant.	B. No effect. Loss of propellant at the end of this phase will not affect the mission.
Component Code: 13			
Orifice 1 Required Provides flow control of the LH_2 used to condition the LO_2 line.	No Applicable Failure Modes	N/A	N/A
Component Code: 14			
Orifice 1 Required Provides flow control of the LH_2 used to condition the LH_2 line.	No Applicable Failure Modes	N/A	N/A
Component Code: 15			
Heat Exchanger 1 Required Provides a means of conditioning the LH_2 line prior to the LH_2 entering the conditioners/gas generators.	No Applicable Failure Modes	N/A	N/A

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Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 16			
Heat Exchanger 1 Required Provides a means of conditioning the LO_2 line prior to the LO_2 entering the conditioners/gas generators.	No Applicable Failure Modes	N/A	N/A
Component Code: 17			
Solenoid Valve, N. C. 2 Required Controls the flow of LH_2 to the primary and backup LH_2 conditioners/ gas generators for gasification of the LH_2 and storage as GH_2 in the GH_2 accumulator.	Fail to open	A & C. No effect. Valve is not required to operate during these, phases.	A & C. No effect.
		B. No effect. Redundancy provided.	B. No effect. Redundancy provided.
	Fail to close, fail to remain closed and leakage	A, B, & C. No effect. Redundancy provided by closing valve 27 and using the back-up conditioner.	A, B, & C. No effect.
Component Code: 18			
Solenoid Valve, N. C. 2 Required Controls the flow of LO_2 to the primary and backup conditioners/ gas generators for gasification and storage as GO_2 in the GO_2 accumulator.	Fail to open	A & C. No effect. Valve is not required to operate during these phases.	A & C. No effect. Not applicable during these phases.
		B. No effect. Redundancy is provided.	B. No effect. Redundancy is provided.

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Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 18			
Solenoid Valve, N. C. (Continued)	Fail to close, fail to remain closed and leakage	A, B, & C. No effect. Redundancy provided by closing valve 28 and using back-up conditioner.	A, B, & C. No effect.
Component Code: 19			
Solenoid Valve, N. C. 4 Required Controls the flow of LH_2 over the turbopumps, located in the conditioners, to maintain the pumps in a chilled condition.	Fail to open	A & C. No effect. Valve is not required to operate during these phases.	A & C. No effect. Not applicable during these phases.
		B. No effect. Redundancy provided.	B. No effect. Redundancy provided.
	Fail to close	A. No effect. Failure mode is not applicable during this phase.	A. No effect. Not applicable during this phase.
		B. No effect. Valve is required to be open during this phase.	B. No effect. Valve is required to be open during this phase.
		C. No effect. All propellants are dumped overboard prior to re-docking.	C. No effect.
	Fail to remain closed and leakage	A & B. No effect. Valve required to be open during these phases.	A & B. No effect

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Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 19 Solenoid Valve, N. C. (Continued)		C. No effect. All propellants are dumped overboard prior to re-docking.	C. No effect.
Component Code: 20 Check Valve 2 Required Prevents propellant vapor backflow from the LH_2 conditioner to the LH_2 feed line.	Fail to open	A & C. No effect. Failure mode is not applicable during these phases.	A & C. No effect. Not applicable during these phases.
		B. No effect. Redundancy provided.	B. No effect. Redundancy provided.
	Fail to close, fail to remain closed and leakage	A, B, & C. No effect. Redundancy provided by solenoid shutoff valves.	A, B, & C. No effect. Redundancy provided.
Component Code: 21 Check Valve 2 Required Prevents propellant vapor backflow from the LH_2 conditioners to the LO_2 feed line.	Fail to open	A & C. No effect. Failure mode is not applicable during these phases.	A & C. No effect. Not applicable during these phases.
		B. No effect. Redundancy provided.	B. No effect. Redundancy provided.

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Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 21			
Check Valve (Continued)	Fail to close, fail to remain closed and leakage	A, B, & C. No effect. Redundancy provided by solenoid shutoff valves.	A, B, & C. No effect. Redundancy provided.
Component Code: 22			
Orifice 4 Required Provides flow control of the LH_2 used to chill the turbopumps.	No Applicable Failure Modes	N/A	N/A
Component Code: 23			
Heat Exchanger 4 Required Provides a means of cooling the gas generator turbopump during operation of LH_2 and LO_2 propellant conditioner.	No Applicable Failure Modes	N/A	N/A
Component Code: 24			
Exhaust Vent 1 Required Vents the residual exhaust gases created during gas generator burn.	No Applicable Failure Modes	N/A	N/A

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Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 25			
Check Valve 2 Required Prevents backflow of gaseous H_2 from the GH_2 accumulator to the LH_2 propellant conditioners.	Fail to open	A & C. No effect. Failure mode is not applicable during these phases.	A & C. No effect. Not applicable during these phases.
		B. No effect. Redundancy provided.	B. No effect. Redundancy provided.
	Fail to close, fail to remain closed and leakage	A, B, & C. No effect. This line can be isolated by closing valves, Component Codes 17 and 27 and using redundant conditioner.	A, B, & C. No effect. Redundancy provided
Component Code: 26			
Check Valve 2 Required Prevents backflow of gaseous O_2 from the GO_2 accumulator to the LO_2 propellant conditioners.	Fail to open	A & C. No effect. Failure mode is not applicable during these phases.	A & C. No effect. Not applicable during these phases.
		B. No effect. Redundancy provided.	B. No effect. Redundancy provided.
	Fail to close, fail to remain closed and leakage	A, B, & C. No effect. This line can be isolated by closing valves, Component Codes 18 and 28 and using redundant conditioner.	A, B, & C. No effect. Redundancy provided.

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Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 27			
Solenoid Valve, N. O. 2 Required Controls the flow of GH_2 from the LH_2 propellant conditioners to the GH_2 accumulator.	Fail to open, fail to remain open	A & C. No effect. Failure mode is not applicable during these phases.	A & C. No effect. Not applicable during these phases.
		B. No effect. Redundancy provided.	B. No effect. Redundancy provided.
	Fail to close, fail to remain closed and leakage	A, B, & C. No effect. Redundancy provided by check valves, Component Code 25.	A, B, & C. No effect. Redundancy provided.
Component Code: 28			
Solenoid Valve, N. O. 2 Required Controls the flow of GO_2 from the LO_2 conditioners to the GO_2 accumulators.	Fail to open, fail to remain open	A & C. No effect. Failure mode is not applicable during these phases.	A & C. No effect. Not applicable during these phases.
		B. No effect. Redundancy provided.	B. No effect. Redundancy provided.
	Fail to close, fail to remain closed and leakage	A, B, & C. No effect. Redundancy provided by check valves, Component Code 26.	A, B, & C. No effect. Redundancy provided.

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Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 29			
Solenoid Valve, N. C. 2 Required Controls the flow of GH_2 from the GH_2 accumulator to the gas generators, the main LH_2 tank and the thruster pods.	Fail to open	A & C. No effect. Failure mode is not applicable during these phases.	A & C. No effect. Not applicable during these phases.
		B. No effect. Redundancy provided.	B. No effect. Redundancy provided.
	Fail to close, fail to remain closed and leakage	A, B, & C. No effect. Redundancy provided by the bi-propellant valve in the gas generator and by the shutoff valves on the thruster pods.	A, B, & C. No effect. Redundancy provided.
Component Code: 30			
Solenoid Valve, N. C. 2 Required Controls the flow of GO_2 from the GO_2 accumulators to the gas generators, the main LO_2 tank and the thruster pods.	Fail to open	A & C. No effect. Failure mode not applicable during these phases.	A & C. No effect. Not applicable during these phases.
		B. No effect. Redundancy provided.	B. No effect. Redundancy provided.

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Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 30			
Solenoid Valve, N. C. (Continued)	Fail to close, fail to remain closed and leakage	A, B, & C. No effect. Redundancy provided by the bi-propellant valves in the gas generator and by the shutoff valves on the thruster pods.	A, B, & C. No effect. Redundancy provided.
Component Code: 31 .			
Regulator 2 Required Regulates the flow of GH_2 from the GH_2 accumulator to the thrusters, gas generators, fuel cell and to the main propellant tank for pressurization.	Regulates high	A & C. No effect. Failure mode is not applicable during these phases.	A & C. No effect. Not applicable during these phases.
		B. No effect. Redundancy provided.	B. No effect. Redundancy provided.
	Regulates low	A & C. No effect. Failure mode is not applicable during these phases.	A & C. No effect. Not applicable during these phases.
		B. No effect. Redundancy provided.	B. No effect. Redundancy provided.

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Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 32			
Regulator 2 Required Regulates the flow of GO_2 from the GO_2 accumulator to the thrusters, gas generators, fuel cell and to the main GO_2 tank for pressurization	Regulates high	A & C. No effect. Failure mode is not applicable during these phases.	A & C. No effect. Not applicable during these phases.
		B. No effect. Redundancy provided.	B. No effect. Redundancy provided.
	Regulates low	A & C. No effect. Failure mode is not applicable during these phases.	A & C. No effect. Not applicable during these phases.
		B. No effect. Redundancy provided.	B. No effect. Redundancy provided.
Component Code: 33			
GH_2 Accumulator 1 Required Stores GH_2 for use by the thrusters, fuel cells, gas generators and for pressurizing the main LH_2 tank.	No Applicable Failure Modes	N/A	N/A
Component Code: 34			
GO_2 Accumulator 1 Required Stores GO_2 for use by the thrusters, fuel cells, gas generators and for pressurizing the main LO_2 tank.	No Applicable Failure Modes	N/A	N/A

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Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 35			
Solenoid Valve, N. C. 1 Required Controls the flow of GH_2 to the GH_2 accumulator during the ground fill operation.	Fail to open	A, B, & C. No effect. Failure mode is not applicable during these phases.	A, B, & C. No effect. Not applicable during these phases.
	Fail to close, fail to remain closed and leakage	A, B, & C. No effect. Redundancy provided by disconnect, Component Code 39.	A, B, & C. No effect. Redundancy provided.
Component Code: 36			
Solenoid Valve, N.C. 1 Required Controls the flow of GO_2 to the GO_2 accumulator during the ground fill operation.	Fail to open	A, B, & C. No effect. Failure mode is not applicable during these phases.	A, B, & C. No effect. Not applicable during these phases.
	Fail to close, fail to remain closed and leakage	A, B, & C. No effect. Redundancy provided by disconnect, Component Code 40.	A, B, & C. No effect. Redundancy provided.
Component Code: 37			
Filter 1 Required Removes contaminants from the GH_2 supply during ground fill of the GH_2 accumulator.	Clogs	A, B, & C. No effect. Filter is not used during these phases. Any problem encountered during the fill operation would be corrected prior to liftoff.	A, B, & C. No effect. Not applicable during these phases.

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Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 38			
Filter 1 Required Removes contaminants from the GO_2 supply during the ground fill of the GO_2 accumulator.	Clogs	A, B, & C. No effect. Filter is not used during these phases. Any problem encountered during the fill operation would be corrected prior to liftoff.	A, B, & C. No effect. Not applicable during these phases.
Component Code: 39			
Quick Disconnect 1 Required Provides a separable connection at the tug/payload bay interface for the GH_2 fill operation.	Fail to engage	A & C. No effect. Not applicable during these phases. B. No effect. After the tug completes its mission and returns to the orbiter, all pressurants and propellants are dumped overboard prior to docking. In addition, the solenoid valves on the fill lines are closed prior to storing the tug in the orbiter for return to earth.	A & C. No effect. Not applicable during these phases. B. No effect.
	Fail to disengage	A & C. No effect. Failure mode is not applicable during these phases.	A & C. No effect. Not applicable during these phases.

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Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 39			
Quick Disconnect (Continued)		B. Actual Loss The failure of the tug disconnects to disengage at the tug/payload bay interface will cause the tug to remain docked to the orbiter and unable to perform its mission.	B. Actual Loss
	Leakage	A, B, & C. No effect. Redundancy provided by solenoid shutoff valve 39.	A, B, & C. No effect.
Component Code: 40			
Quick Disconnect 1 Required Provides a separable connection at the tug/payload bay interface for the GO_2 fill operation.	Fail to engage	A & C. No effect. Failure mode is not applicable during these phases.	A & C. No effect. Not applicable during these phases.
		B. No effect. After the tug completes its mission and returns to the orbiter, all pressurants and propellants are dumped overboard prior to docking. In addition, the solenoid valves in the fill lines are closed prior to storing the tug in the orbiter for return to earth.	B. No effect.

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Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 40			
Quick Disconnect (Continued)	Leakage	A, B, & C. No effect. Redundancy provided by solenoid shutoff valve 40.	A, B, & C. No effect.
	Fail to disengage	A & C. No effect. Failure mode is not applicable during these phases.	A & C. No effect. Not applicable during these phases.
		B. Actual Loss The failure of the tug disconnects to disengage at the Tug/Payload bay interface will cause the tug to remain docked to the orbiter and unable to perform its mission.	B. Actual Loss
Component Code: 41			
Solenoid Valve, N. O. 4 Required Controls the flow of GH_2 from the GH_2 accumulator to the thruster pods.	Fail to open	A & C. No effect. Failure mode is not applicable during these phases.	A & C. No effect. Not applicable during these phases.
		B. No effect. Valve is normally open during this phase.	B. No effect. Valve is normally open during this phase.

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Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 41			
Solenoid Valve, N. O. (Continued)	Fail to close	A & C. No effect. Valve is normally open during this phase.	A & C. No effect.
		B. No effect. Flow control of propellants to the thrusters is obtained by using valves 29, 30, and 43.	B. No effect.
	Fail to remain closed and leakage	A, B, & C. No effect. Redundancy provided by valves 29, 30, and 43.	A, B, & C. No effect. Redundancy provided.
Component Code: 42			
Solenoid Valve, N. O. 4 Required Controls the flow of GO_2 from the GO_2 accumulator to the thruster pods.	Fail to open	A & C. No effect. Failure mode is not applicable during these phases.	A & C. No effect. Not applicable during these phases.
		B. No effect. Valve is normally open during this phase.	B. No effect. Valve is normally open during this phase.
	Fail to close	A & C. No effect. Valve is normally open during these phases.	A & C. No effect.

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Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 42			
Solenoid Valve, N.O. (Continued)		B. No effect. Flow control of propellants to the thrusters is obtained by using valves 29, 30, and 43.	B. No effect.
	Fail to remain closed and leakage	A, B, & C. No effect. Redundancy provided by valves 29, 30, and 43.	A, B, & C. No effect. Redundancy provided.
Component Code: 43			
Thruster Bi-Propellant Valve, Solenoid Operated, N. C. 16 Required Controls the flow of GH_2 and GO_2 to the thruster.	Fail to open	A & C. No effect. Failure mode is not applicable during these phases.	A & C. No effect. Not applicable during these phases.
		B. No effect. Tug has one thruster out capability.	B. No effect. Loss of one thruster will not prevent the tug from performing its mission.
	Fail to close, fail to remain closed and leakage	A & C. No effect. Failure mode is not applicable during these phases.	A & C. No effect. Not applicable during these phases.

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Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 43 Thruster Bi-Propellant Valve, Solenoid Operated, N. C. (Continued)		B. Actual Loss GH_2 and GO_2 supply to each thruster pod can be controlled by valves 41 and 42. This would cause loss of one thruster pod.	B. No effect. The loss of one thruster pod may affect the response time for maneuvering, but will not cause loss of mission.
Component Code: 44 APS Thruster Assembly 16 Required Provides a nominal thrust of 30 pounds for attitude control of the space tug during mission coast phases, mid-course correction, lateral and transverse maneuvers during rendezvous and docking and to perform vehicle and sensor pointing as required.	Burn-Thru	A & C. No effect. Not required to operate during these phases. B. Actual Loss Engine burn-thru could result in fire and explosion and destroy the APS system and damage the tug.	A & C. No effect. Not applicable during these phases. B. Actual Loss Mission loss would result from fire and explosion.
Component Code: 45 Bi-Propellant Valve, LH_2 Conditioner 2 Required Controls the flow of GH_2 and LO_2 from the accumulators to the LH_2 conditioners.	Fail to open	A & C. No effect. Failure mode is not applicable during these phases. B. No effect. Redundancy provided by back-up conditioner.	A & C. No effect. Not applicable during these phases. B. No effect. Redundancy provided.

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Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 45			
Bi-Propellant Valve, LH_2 Conditioner (Continued)	Fail to close, fail to remain closed and leakage	A & C. No effect. The propellant flow to the bi-propellant valves is shut off by the accumulator solenoid valves, Component Code 29, during these phases.	A & C. No effect.
		B. Probable Loss Any flow or leakage through the bi-propellant valves would result in uncontrolled burning in the gas generator, or, in the case of only one propellant leaking, the leakage would result in abnormal usage of the propellant gas and could prematurely deplete the propellant supply.	B. Probable Loss Premature depletion of propellant could cause termination of mission.
Component Code: 46			
Bi-Propellant Valve, LO_2 Conditioner 2 Required Controls the flow of GH_2 and LO_2 from the accumulators to the LO_2 conditioner.	Fail to open	A & C. No effect. Failure mode is not applicable during these phases.	A & C. No effect. Not applicable during these phases.
		B. No effect. Redundancy provided by back-up conditioner.	B. No effect. Redundancy provided.

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Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 46 Bi-Propellant Valve, LO_2 Conditioner (Continued)	Fail to close, fail to remain closed and leakage	A & C. No effect. The propellant flow to the bi-propellant valves is shut off by the accumulator solenoid valves, Component Code 30, during these phases. B. Probable Loss Any flow or leakage through the bi-propellant valves would result in uncontrolled burning in the gas generator if both propellant were leaking, or in the case of only one propellant leaking, the leakage would be vented overboard by the by the gas generator exhaust vent and could prematurely deplete the propellant supply.	A & C. No effect. B. Probable Loss Premature depletion of propellants could cause termination of mission.
Component Code: 47 Filter 1 Required Removes contaminants from the GH_2 supply used to pressurize the main LH_2 tank.	Clogs	A & C. No effect. Failure mode is not applicable during these phases.	A & C. No effect. Not applicable during these phases.

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Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 47			
Filter (Continued)		B. Actual Loss Unable to pressurize the main LH_2 tank. The loss of pressurization capability will cause the main engine to shut down.	B. Actual Loss Loss of the main engine on the tug will cause loss of mission.
Component Code: 48			
Filter 1 Required Removes contaminants from the GO_2 supply used to pressurize the main LO_2 tank.	Clogs	A & C. No effect. Failure mode is not applicable during these phases.	A & C. No effect. Not applicable during these phases.
		B. Actual Loss Unable to pressurize the main LO_2 tank. The loss of pressurization capability will cause the main engine to shut down.	B. Actual Loss Loss of the main engine on the tug will cause loss of mission.
Component Code: 49			
Solenoid Valve, N. C. 1 Required Controls the flow of GH_2 from the GH_2 accumulator to the main LH_2 tank for pressurization.	Fail to open	A & C. No effect. Failure mode is not applicable during these phases.	A & C. No effect.

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Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 49			
Solenoid Valve, N. C. (Continued)		B. Actual Loss Unable to pressurize the LH_2 tank. The loss of pressurization capability will cause the main engine to shut down.	B. Actual Loss Loss of the main engine on the tug will cause loss of mission.
	Fail to close, fail to remain closed and major leakage	A & C. No effect. Failure mode is not applicable during these phases.	A & C. No effect.
		B. Probable Loss The continuous flow of GH_2 to the main LH_2 tank will cause the tank to be over-pressurized and the GH_2 will be vented overboard. This venting may cause premature depletion of APS propellants.	B. Probable Loss The premature depletion of APS propellants will cause loss of mission. The severity of the effect will depend on the time of occurrence in the mission time frame.
Component Code: 50			
Solenoid Valve, N. C. 1 Required Controls the flow of GO_2 from the GO_2 accumulator to the main LO_2 tank for pressurization.	Fail to open	A & C. No effect. Failure mode is not applicable during these phases.	A & C. No effect.

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Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 50			
Solenoid Valve, N. C. (Continued)		B. Actual Loss Unable to pressurize the main LO_2 tank. The loss of pressurization capability will cause the main engine to shut down.	B. Actual Loss Loss of main engine on tug will cause loss of mission.
	Fail to close, fail to remain closed and major leakage	A & C. No effect. Failure mode is not applicable during these phases.	A & C. No effect.
		B. Probable Loss The continuous flow of GO_2 to the main LO_2 tank will cause the tank to be overpressurized and the GO_2 will be vented overboard. This venting may cause premature depletion of APS propellants.	B. Probable Loss The premature depletion of APS propellants will cause loss of mission. The severity of the effect will depend on the time of occurrence in the mission time frame.
Component Code: 51			
Orifice 1 Required Provides flow control of the GH_2 used to pressurize the LH_2 main tank from the APS GH_2 accumulator.	No Applicable Failure Modes	N/A	N/A

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
AUXILIARY PROPULSION SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 52 Orifice 1 Required Provides flow control of the GO_2 used to pressurize the GO_2 main tank from the APS GO_2 accumulator.	No Applicable Failure Modes	N/A	N/A
Component Code: 53 LH_2 Storage Tank, APS 1 Required Stores LH_2 for use as propellant by the APS thrusters and for use by the main engine during the idle mode start sequence. The tank also stores LH_2 for conversion to gases for pressurizing the main engine LH_2 tank and for supplying GH_2 to the fuel cell.	No Applicable Failure Modes	N/A	N/A
Component Code: 54 LO_2 Storage Tank, APS 1 Required Stores LO_2 for use as propellant by the APS thrusters and for use by the main engine during the idle mode start sequence. The tank also stores LO_2 for conversion to gases for pressurizing the main engine LO_2 tank and for supplying GO_2 to the fuel cell.	No Applicable Failure Modes	N/A	N/A

FAILURE MODE EFFECTS ANALYSIS
ON SPACE TUG MISSION
AUXILIARY PROPULSION SYSTEM

Component Identification	Failure Mode	Failure Effect on System	Failure Effect on Vehicle, Mission, Crew
Component Code: 55			
LH_2 Conditioners 2 Required Converts the LH_2 to GH_2 for use as propellant and pressurization gases. The conditioners contain a gas generator, a turbopump, a heat exchanger and bi-propellant valves to control the flow of propellant to the gas generator burner. The bi-propellant valves are analyzed as Component Code 45.	Fail to operate	A & C. No effect. Not required to operate during these phases. B. No effect. Redundancy provided by back-up conditioner.	A & C. No effect. B. No effect.
Component Code: 56			
LO_2 Conditioners 2 Required Converts the LO_2 to GO_2 for use as propellant and pressurization gases. The conditioners contain a gas generator, a turbopump, a heat exchanger and bi-propellant valves to control the flow of propellant to the gas generator burner. The bi-propellant valves are analyzed as Component Code 46.	Fail to operate	A & C. No effect. Not required to operate during these phases. B. No effect. Redundancy provided by back-up conditioners.	A & C. No effect. B. No effect. Redundancy provided by back-up conditioners.

REFERENCES

1. Baseline Tug Definition Document, Preliminary Design Office Program Development, National Aeronautics and Space Administration, George C. Marshall Space Flight Center, Huntsville, Alabama, dated March 15, 1972.