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Final Report

SPACE SHUTTLE PROPULSION SYSTEMS ON-BOARD CHECKOUT AND MONITORING SYSTEM DEVELOPMENT STUDY

VOLUME IV - APPENDICES

March 1971

Contract NAS8-25619
DRL No. 187 Rev. A
Line Item No. 3

Prepared for

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

Prepared by

MARTIN MARIETTA
DENVER DIVISION

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Approved by

R. W. VandeKoppel
Program Manager

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FOREWORD

This report was prepared by the Martin Marietta Corporation under Contract NAS8-25619 "Space Shuttle Propulsion Systems On-board Checkout and Monitoring System Development Study," for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The report is comprised of four volumes:

Volume I - Summary

Volume II - Propulsion System Definition and Criteria

Volume III - OCMS Criteria and Concept

Volume IV - Appendices

CONTENTS

NOMENCLATURE

I. Definitions

BIT: A single binary digit. The smallest informational element of a digital system.

BUILT-IN-TEST EQUIPMENT (BITE): An integral part of a functional unit which serves to test and/or provide status on that functional unit, but does not participate in performing the unit's principle function

BYTE: A specified number of BITS.

CHECKOUT: The process of determining whether or not specified physical quantities or operations meet their prescribed criteria. The process can include such functions as data acquisition, processing, storage, display, stimulus generation, etc.

CONTROL: The act or process of initiating, regulating and/or terminating the operation and performance of a functional element in a prescribed manner.

CONTROLLER: A device which governs the state or performance of a particular functional element in a prescribed manner, e.g. engine controller.

DATA BUS: The transmission line(s) along which the system computer(s) communicate with the various Digital Interface Units, controllers, peripheral-equipment, and other computers.

DATA COMPRESSION: The process of screening and selecting data such that only desired information is retained for further processing and/or storage.

DESIGN REFERENCE MODEL: The baseline configuration.

DIAGNOSIS: The determination of the state or condition of an element or parameter through evaluation of available data.

DIGITAL INTERFACE UNIT: An intermediary unit between the computer(s) and another device which formats that device's output for communication to a computer, and accepts and translates a computer's transmissions to the device.

FAULT ISOLATION: The processing of analyzing a malfunction or abnormality to the extent of determining which functional element is defective, where the functional element is ordinarily a Line Replaceable Unit.

NOMENCLATURE (Continued)

FUNCTIONAL ELEMENT: A unit which performs a characteristic action. Parts, components, assemblies, and subsystems are functional elements of increasing complexity.

GAS PATH ANALYSIS: An assessment of engine performance that is made through evaluation of a set of measured values of pressures, temperatures and/or flow rates.

GROUND SUPPORT EQUIPMENT: (for checkout and monitoring) That equipment, in addition to the onboard equipment, which is needed to accomplish the functions of checkout and monitoring.

LINE REPLACEABLE UNIT: A component or group of components that can, as a unit, be removed and replaced in the normal vehicle maintenance area. Such criteria as allowable replacement time spans and degree of complexity of post-replacement calibration form a basis for Line Replaceable Unit selection.

MAINTENANCE: Those functions and activities associated with restoring the vehicle to an operational condition between flights.

MEASUREMENT: A physical quantity or event whose magnitude or time of occurence is of significance.

MONITORING: Repetitive acquisition and evaluation of needed data.

POGO: An oscillatory instability resulting from a dynamic coupling between the fluid and structural elements of the vehicle.

PROCESSING: The manipulations and operations performed on data from the time and place it is acquired to the time and place it is used in its final form.

SELF CHECK: The process by which a functional element assesses its own operational integrity and readiness.

SENSOR: A functional element which responds to a physical quantity or event and converts that response to transmissible data which is proportional to the magnitude of the quantity or indicates occurence of the event.

SINGLE POINT FAILURE: A functional element whose inability to operate within prescribed limits would cause loss of vehicle, crew, and/or mission objectives.

STIMULUS: An excitation or forcing function which is applied from an external source at a prescribed place and time.

NOMENCLATURE (Continued)

TIMELINE: A representation of a sequential series of events which depicts the time of occurence and duration of each event.

TRANSDUCER: Same as sensor.

TREND ANALYSIS: The process of evaluating successive samples of the same data to forecast end of useful life and/or incipient failure as an aid to maintenance operations and to mission or vehicle configuration decisions.

II. Abbreviations and Acronyms

Note: Measurement nomenclature is defined in the measurement section.

A/B	Airbreather or airbreathing
APS	Auxiliary Propulsion System
APU	Auxiliary Power Unit
BITE	Built-In Test Equipment
CC	Combustion Chamber
CCC	Central Computer Complex
CCU	Channel Control Unit
C_f	Thrust Coefficient
C*	Characteristic Exhaust Velocity
DIU	Digital Interface Unit
DRM	Design Reference Model
ΔV	Change in Velocity
EPL	Emergency Power Level
FMEA	Failure Modes and Effects Analysis
FPB	Fuel Preburner
FS_1	Fire Switch #1 (Engine Start Signal)
FS_2	Fire Switch #2 (Engine Shutdown Signal)
GHe	Gaseous Helium
GH_2	Gaseous Hydrogen
GN_2	Gaseous Nitrogen
GOX	Gaseous Oxygen
GSE	Ground Support Equipment
G & N	Guidance and Navigation
HPFTPA	High Pressure Fuel Turbopump Assembly

NOMENCLATURE (Continued)

HPOTPA	High Pressure Oxidizer Turbopump Assembly
Ign	Igniter or Ignition
KSC	Kennedy Space Center
LH_2	Liquid Hydrogen
LO_2	Liquid Oxygen
LOX	Liquid Oxygen
LPFTPA	Low Pressure Fuel Turbopump Assembly
LPOTPA	Low Pressure Oxidizer Turbopump Assembly
LRU	Line Replaceable Unit
MPL	Minimum Power Level
MR	Mixture Ratio
MSFC	Marshall Space Flight Center
NPL	Normal Power Level
OCMS	Onboard Checkout and Monitoring System
OMS	Orbital Maneuvering System
OPB	Oxidizer Preburner
P/L	Payload
RCS	Reaction Control System
TCA	Thrust Chamber Assembly
TPF	Terminal Phase Finalization
TPI	Terminal Phase Initiation
TVC	Thrust Vector Control
VAB	Vertical Assembly Building
WTR	Western Test Range

APPENDIX B - FMEA DATA SHEETS

The objectives of the failure modes and effects analysis (FMEA) were to determine the potential propulsion failure modes and resulting effects on the subsystem, system, crew and mission, and establish the criticality of the failure; and identify candidate failure detection methods for each failure mode to aid in establishing propulsion system measurement requirements. The groundrules and approach used in conducting this analysis are described in Volume II, Chapter III. This appendix contains the FMEA analysis sheets.

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.1.1.1 & 4.1.1.1 Low Pressure Fuel Turbopump *		Boost fuel pressure from engine interface to inlet of high pressure fuel T.P.A. supply coolant flow to extendible nozzle (orbiter only).	Low pressure/flow output during start or steady state, within control range.		Low
			Very low or complete loss of pressure/flow output during steady state.		Low

* Critical component

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 1 0 & 4.0
SUBSYSTEM 1.1 & 4 1

ASSEMBLY 1 1 1 & 4 1 1
SHEET 1 of 1

FAILURE EFFECT ON SUBSYSTEM	FAILURE EFFECT ON SYSTEM	FAILURE EFFECT ON MISSION	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
Limits available range of adjustment for other performance demands	BOOSTER No effect (depends on control range analysis). ORBITER: No effect (depends on control range analysis).	No effect	Pump rpm, inlet and discharge pressure vibration.	Torque check using a controlled gas source at sched. maintenance cycle could add to bearing condition information	Booster A(4) B(4) C(4) Orbiter A(4) B(4) C(4)
Probable cavitation of H.P.F T.P A, premature engine cutoff, possible burn-through of extendible nozzle (orbiter only).	BOOSTER Loss of redundancy. ORBITER Loss of one engine	No effect Possible mission loss.	Vibration, pump rpm, inlet and discharge pressure.		Booster A(4) B(2B) C(4) Orbiter A(4) B(2B) C(2A)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.1 1.2 & 4.1.1.2 High Pressure Fuel T.P A.*		Increase fuel pressure from L.P.F.T.P.A. discharge to provide: 1) Drive fluid for L.P.F.T.P A, 2) High pressure fuel to cool H.P.O.T.P.A. turbine bearings, 3) High pressure fuel for combustion in preburners, and main TCA, 4) High pressure fuel for nozzle/combustion chamber coolant, tank pressurization.	Low pressure/flow output during steady state, but within control range.		Low
			Very low or complete loss of pressure/flow output during start or steady state operation.		Low
			Excessive leakage prior to start.		Medium
			Loss of coolant flow output to H.P.O T.P.A.		Low
* Critical component					

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 1.0 & 4 0

SUBSYSTEM 1 1 & 4 1

ASSEMBLY 1 1 1 & 4 1 1

SHEET 1 of 1

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Limits adaptability to other potential performance irregularities (depends upon control range analysis)	BOOSTER No effect. ORBITER No effect	No effect	Vibration, inlet pressure, outlet pressure, pump rpm, preburner chamber pressure/temp		Booster A(4) B(4) C(4) Orbiter A(4) B(4) C(4)
Premature shutdown.	BOOSTER Loss of redundancy. ORBITER Loss of one engine.	BOOSTER No effect. ORBITER Mission loss.	Vibration, inlet pressure, outlet pressure, pump rpm, preburner chamber pressure/temp		Booster A(4) B(2B) C(4) Orbiter: A(4) B(2B) C(2A)
Excessive leakage to exterior through chamber	Safety hazard.	Possible launch delay.	Vehicle H_2 sensors leak check at maint cycle		Booster A(4) B(3) C(3) Orbiter A(4) B(4) C(3)
OTPA turbine bearing failure, premature engine shutdown	BOOSTER Loss of redundancy ORBITER Loss of one engine.	BOOSTER No effect ORBITER Probable mission loss	Valve position discrete		Booster A(4) B(2B) C(4) Orbiter A(4) B(4) C(2A)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.1.1.3 Low Pressure Oxidizer Turbopump*		Provide pressure boost from engine interface to H.P.O.T.P.A. receives driving force from first stage discharge of H.P.O.T.P.A.	Low pressure/flow output during start or steady state, within control range.		Low
			Very low or no flow output at start or steady state.		Low

*Critical components.

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 1 0 ASSEMBLY 1 1 1

SUBSYSTEM 1 1

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Limits available range of adjustment for other performance demands.	BOOSTER No effect (depends upon control range analysis) ORBITER Same	No effect.	Pump rpm, vibration, inlet and discharge pressure	Torque check using a controlled gas source at sched maint. cycle could add to bearing condition information	Booster A(4) B(3) C(4) Orbiter A(4) B(3) C(4)
Possible cavitation of H P O T.P.A, premature engine cutoff; loss of engine.	BOOSTER, ORBITER: Probable multiple engine loss.	Possible hazard to vehicle/crew	Pump rpm, vibration, inlet and discharge pressure.		Booster A(4) B(2B) C(1) Orbiter A(4) B(4) C(1)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.1.1.4 High Pressure Oxidizer Turbopump*		Increase oxidizer pressure from discharge of LPOTPA to provide: 1) Intermediate pressure output for main comb chamber to drive LPOTPA turbine, to supply oxid to tank pressurization heat exchanger, 2) To supply high pressure oxidizer for preburner combustion	Reduced pump flow/pressure output, within control range		Low
			Low pressure flow output		Low
			Loss of output		Low
			Reduced restriction to seal cavity purge flow		Low
			Excessive leakage of fuel into hot gas manifold prior to launch.		Medium
*Critical component					

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 1 0 & 4 0
SUBSYSTEM 1 1 & 4 1

ASSEMBLY 1 1 1 & 4 1 1
SHEET 1 of 1

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Limits adaptability to other performance degradation	No effect, depending upon control range analysis	No effect	Vibration, shaft displacement, pump RPM inlet pressure discharge pressure (first and second stage) preburner chamber pressure/temp seal cavity oxid vent thrust balance cavity pressure	--	Booster A(4) B(4) C(4) Orbiter A(4) B(4) C(4)
Premature engine shutdown due to low performance	Booster Loss of redundancy Orbiter Loss of one engine	Booster No effect Orbiter Mission loss	Vibration, pump RPM inlet pressure, discharge pressure		Booster A(4) B(2A) C(4) Orbiter A(4) B(4) C(2A)
Loss of engine, possible fire	Engine loss	Loss of mission and possible loss of crew	Same as line 1 above.	--	Booster A(4) B(2B) C(1S) Orbiter A(4) B(4) C(1S)
No effect	Excess usage of GHe (secondary failure)	Potential purging problem must be evaluated in design	Seal cavity pressure	--	Booster A(4) B(3) C(3) Orbiter A(4) B(3) C(3)
Excessive fuel leakage out of nozzle (requires double failure)	Possible safety hazard	Depends upon design and capability of inerting purge May be a launch delay	Leak checks at sched. maint cycle		Booster A(4) B(2B) C(4) Orbiter A(4) B(4) C(3)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.1.1.5 & 4.1.1.5 Fuel Pre-burner		Supply fuel rich hot gas to high pressure fuel turbopump assembly and main combustion chamber.	1) Crack in lox channel with burning upstream of face 2) Orifice plugging		1) Low 2) Low
1 1.1.6 & 4.1.1 6 Oxidizer Preburner		Supply fuel rich hot gas to high pressure oxid. TPA and main combustion chamber.	Same as 1.1.1.5.		Low
1.1.1.7 & 4.1.1.7 Hot Gas Manifold		Support fuel and oxid. TPAs; support fuel and oxid. preburners, support oxid. heat exchanger; transport loads from all gimballed components to gimbal block. Gas plenum ducting fuel rich turbine and heat exchanger hot gas to main combustion chamber.	Structural fatigue.		Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM: 1.0 & 4.0
SUBSYSTEM 1.1 & 4.1

ASSEMBLY: 1.1.1 & 4.1.1

SHEET 1 of 1

FAILURE EFFECT ON: SUBSYSTEM	FAILURE EFFECT ON: SYSTEM	FAILURE EFFECT ON: MISSION	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
1) Loss of performance; loss of engine, premature shutdown 2) No effect	1) Booster: Loss of redundancy Orbiter: Loss of one engine 2) No effect	1) Booster: No effect Orbiter: Mission loss 2) No effect	1) Preburner lox flow Preburner chamber pressure Preburner temperature 2) No effect		Booster: A(4) B(4) C(4) Orbiter: A(4) B(4) C(4)
Same as above.	Same as above.	Same as above.	Same as above.		Booster: A(4) B(4) C(4) Orbiter: A(4) B(4) C(4)
Premature engine cutoff and structural failures of other components, particularly inter-connecting lines which would in turn result in cross leakages of hot gas, fuel, and oxidizer; fire-explosion hazard.	Possible severe thermal or mechanical damage to neighboring engine and other systems.	Booster: Loss of vehicle and crew Orbiter: Loss of vehicle and crew	Failure would be reflected principally in main combustion chamber pressure. The engine controller would command an emergency shutdown, but extensive damage would result before zero thrust condition. Recommend postflight inspection.		Booster: A(4) B(1S) C(1) Orbiter: A(4) B(4) C(1)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.1.1 8 & 4.1.1.8 Fuel Main Valve*		Provides on-off control of fuel flow from 3rd stage of high pressure fuel TPA to engine systems.	Fails to open at start.		Low
			Closes prematurely after engine reaches NPL		Low
			Failure to close at shutdown		Low
			Opens slowly.		Low
			Closes slowly.		Low
			Internal and external leakage beyond spec. limit.		
* Critical component					

FAILURE EFFECT ON SUBSYSTEM	FAILURE EFFECT ON SYSTEM	FAILURE EFFECT ON MISSION	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
Engine fails to start	Booster Loss of redundancy Orbiter Loss of one engine	Booster No effect Orbiter Mission loss	Valve position discrete.	Interlock with other engine sequences.	Booster. A(4) B(2B) C(4) Orbiter A(4) B(4) C(2A)
Engine cutoff with severe engine damage Possible shrapnel	Possible multiple engine damage	Possible vehicle/crew loss	Valve position discrete	This requires a double failure, based on parts analysis Valve is designed to fail open	Booster A(4) B(2B) C(4) Orbiter A(4) B(4) C(2A)
No effect	No effect - prevalve redundancy	No effect	Valve position discrete	—	Booster A(4) B(4) C(4) Orbiter A(4) B(4) C(4)
Delay in start, or possible sequence shutdown	Booster Possible loss of redundancy Orbiter Possible loss of one engine	Booster No effect Orbiter Possible mission loss	Valve position analog, valve position discrete	Redundancy recommended in drive motor windings	Booster A(4) B(3) C(4) Orbiter A(4) B(4) C(2A)
Fuel rich shutdown - no effect	No effect	No effect	Valve position analog	—	Booster A(4) B(4) C(4) Orbiter A(4) B(4) C(4)
See text	No effect	No effect			Booster A(4) B(4) C(4) Orbiter A(4) B(4) C(4)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.1.1.9 & 4.1.1.9 Oxidizer Main Valve*		Provides on-off control of oxid. flow from first stage output of H.P.O.T.P.A. to main injector and oxid. heat exchanger. Valve is powered on & off, no power for maintenance. Fails open on loss of power & will close on ΔP.	Failure to open at start.		Low
			Closes prematurely after engine reaches NPL.		Low
			Failure to close at shutdown.		Low
			Opens slowly.		Low
			Closes slowly.		Low
* Critical component			Excessive leakage in closed position beyond spec. limits.		

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 1 0 & 4 0 | SUBSYSTEM 1 1 & 4.1 | ASSEMBLY 1.1.1 & 4.1.1 | SHEET 1 of ___

FAILURE EFFECT ON: SUBSYSTEM	FAILURE EFFECT ON: SYSTEM	FAILURE EFFECT ON: MISSION	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
Engine fails to start.	Booster Loss of redundancy Orbiter Loss of one engine	Booster No effect. Orbiter Mission loss	Valve position discrete	Interlock with start sequence Redundant control circuits here? Why not interlock with shutdown sequence.	Booster: A(4) B(2B) C(4) Orbiter A(4) B(4) C(2A)
Premature engine cutoff. Engine damage due to shrapnel.	Possible multiple engine loss.	Possible loss of vehicle/crew.	Valve position discrete	Requires double failure based on parts analysis. Valve is designed to fail open	Booster. A(4) B(2B) C(4) Orbiter: A(4) B(4) C(2A)
Engine shutdown is ox-rich, damage to main C. chamb. extended shutdown impulse	No effect.	Possible loss of vehicle/crew.	Valve position discrete	Engine postfire purge should be linked with ox valve closure Requires stage or prevalve to close Redundancy provided by this valve	Booster: A(4) B(4) C(1) Orbiter: A(4) B(4) C(1)
Delay in start, or possible sequence shutdown.	Booster Possible loss of redundancy. Orbiter Possible loss of one engine.	Booster No effect. Orbiter Possible loss of mission	Valve position discrete Valve position analog.	Redundancy recommended in drive motor Why?	Booster. A(4) B(3) C(4) Orbiter. A(4) B(4) C(2A)
Oxid. rich at shutdown - possible main C.C. damage Possible extended shutdown impulse.	No effect	Possible loss of vehicle/crew	Valve position analog.	Use stage ox prevalve for redundancy	Booster: A(4) B(4) C(1) Orbiter: A(4) B(4) C(1)
See text			System leak checks at scheduled maintenance cycle.		Booster: A( ) B( ) C( ) Orbiter. A( ) B( ) C( )

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.1.1.10 & 4.1.1.10 Fuel Control Valve, Oxidizer Preburner*		Initiates, controls, and terminates fuel flow to the oxidizer preburner. Provides mixture ratio and thrust control. Fails static on loss of power.	Failure to open at start.		Low
			Premature closure.		Low
			Failure to close at shutdown.		Low
			Slow response; Erratic action, no response to commands at steady state. Shift in position for given power demand.		Low
			Internal and external leakage beyond spec limits.		Low

* Critical component

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.1.1.11 & 4.1.1.11 Oxidizer Control Valve, Oxidizer Pre-burner*		Controls oxidizer flow to the oxid. preburner. One circuit controls flow to approx. MPL, the second controls above MPL. provides on-off as well as continuous flow control. Fail close on loss of power.	Fails to open at start		Low
			Closes prematurely.		Low
			Failure to close at shutdown.		Low
			Slow response, erratic operation.		Low
			Internal and external leaks beyond spec. limits.		

* Critical component

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 1.0 & 4.0
SUBSYSTEM 1.1 & 4.1

ASSEMBLY· 1.1.1 & 4.1.1

SHEET 1 of 1

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Engine fails to start.	Booster Loss of redundancy Orbiter Loss of one engine	Booster No effect Orbiter Mission loss	Valve position discrete	Redundant motor windings should be considered.	Booster A(4) B(2B) C(4) Orbiter: A(4) B(4) C(2A)
Premature engine shutdown. Possible preburner, TPA, injector damage due to high M R.	Booster: Loss of redundancy Orbiter: Loss of one engine	Booster No effect Orbiter. Mission loss	Valve position analog.	This valve is designed to fail static. Premature closure requires a structural failure internally which would affect pressure balance, not now identified, plus a second failure in valve.	Booster. A(4) B(2B) C(4) Orbiter A(4) B(4) C(2A)
Continued fuel flow until fuel main valve closes	No effect	No effect.	Valve position analog.	--	Booster. A(4) B(4) C(4) Orbiter. A(4) B(4) C(4)
Failure to follow M.R./thrust commands. Possible premature shutdown due to out-of-spec. engine.	Booster. Loss of redundancy Orbiter Loss of one engine	Booster No effect Orbiter Mission loss	Valve position analog preburner chamber pressure.	Same as above.	Booster. A(4) B(3A) C(4) Orbiter A(4) B(4) C(2A)
See text.			Same as above.		Booster A(4) B(4) C(4) Orbiter: A(4) B(4) C(4)

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 1.0 & 4.0
SUBSYSTEM 1 1 & 4.1
ASSEMBLY 1.1.1 & 4 1 1
SHEET 1 of 1

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Engine fails to start	Booster Loss of redundancy. Orbiter Loss of one engine.	Booster No effect. Orbiter Mission loss.	Valve position discrete	Recommend considering redundant motor winding.	Booster A(4) B(2B) C(4) Orbiter A(4) B(4) C(2A)
Premature engine cutoff	Booster Loss of redundancy Orbiter Loss of one engine	Booster No effect. Orbiter Mission loss	Valve position analog.	Same as above	Booster A(4) B(2B) C(4) Orbiter A(4) B(4) C(2A)
Extended burn time - increased shutdown impulse, internal engine damage due to high M.R. in preburner.	No effect, thrust not terminated properly.	Booster. Possible vehicle separation difficulty. Orbiter No effect due to OMS and RCS operation.	Valve position analog	Same as above	Booster A(4) B(4) C(1) Orbiter A(4) B(4) C(4)
Engine fails to respond to M.R./thrust commands - out of spec condition with premature shutdown (possible).	Booster Possible loss of redundancy Orbiter Possible loss of one engine	Booster No effect. Orbiter Possible mission loss.	Valve position analog Preburner chamber pressure	--	Booster A(4) B(3) C(4) Orbiter A(4) B(4) C(3)
See text.					

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.1 1.12 & 4.1.1.12 Oxidizer Control Valve, Fuel Preburner		Controls flow of oxidizer to fuel preburner. Provides on-off as well as continuous control. One circuit provides for flow up to MPL, and a second provides control above MPL. Valve is powered open, powered for main stage and powered to close, OR will close on loss of power.	Fails to open at start.		Low
			Closes prematurely.		Low
			Failure to close at shutdown.		Low
			Slow response, erratic operation, shift in position for a given power demand.		Low
			Leakage, internal and external, beyond spec limits.		

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 1.0 & 4.0

SUBSYSTEM 1.1 & 4.1

ASSEMBLY 1.1.1 & 4.1.1

SHEET 1 of 1

FAILURE EFFECT ON: SUBSYSTEM	FAILURE EFFECT ON: SYSTEM	FAILURE EFFECT ON: MISSION	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
Engine fails to start.	Booster No effect Orbiter Loss of one engine	Booster No effect Orbiter Mission loss	Valve position discrete, in start sequence.	Recommend redundant motor windings be considered.	Booster A(4) B(2B) C(4) Orbiter: A(4) B(4) C(2A)
Premature engine shutdown.	Booster. No effect Orbiter. Loss of one engine	Booster No effect Orbiter Mission loss	Valve position discrete, valve position analog.	--	Booster A(4) B(2B) C(2A) Orbiter: A(4) B(4) C(2A)
Extended burn time - increased shutdown impulse, internal engine damage due to high M R. in preburner	Thrust not terminated properly.	Booster Possible vehicle separation difficulty Orbiter. No effect - OMS and RCS compensate	Valve position analog.	--	Booster: A(4) B(2B) C(1) Orbiter: A(4) B(4) C(4)
Engine fails to respond to M.R./ thrust commands. Out-of-spec condition with possible premature shutdown.	Booster Possible loss of redundancy Orbiter Possible loss of one engine	Booster No effect Orbiter Possible mission loss	Valve position analog, Preburner chamber pressure, Preburner chamber temperature.	Recommend redundant motor windings be considered.	Booster: A(4) B(3) C(3) Orbiter. A(4) B(4) C(3)
See text.					

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1 1.1.14-1 & 4.1.1.14-1 Interconnect Articulating Lines. Low Pressure Fuel TPA Discharge Line		Duct fuel from LPFTPA to inlet of HPFTPA. Provide flexibility for gimballing and misalignment. Vacuum jacketed to control fuel quality, prevent formation of liquid air.	Loss of vacuum due to rupture may be a line or bellows jacket.		Low
1.1.1.14-3 & 4.1 1.14-3 Low Pressure Fuel Turbopump Turbine Drive Lines		Duct fuel from HPFTPA 1st and 3rd stages to turbine drive inlets on LPFTPA. Vacuum jacketed to control fuel quality and prevent formation of liquid air.	Loss of vacuum due to rupture may be a line or bellows		Low
1.1.1.14-2 & 4.1.1.14-2 Low Pressure OTPA Discharge Line		Duct oxidizer from L P. OTPA to inlet of H.P OTPA. Provide flexibility for gimballing and misalignment. Bellows are vacuum jacketed to prevent ice formation in convolutions	Loss of vacuum jacket, ice formation, with potential line rupture at gimballing cycle		Low
1.1 1.14-4 & 4.1.1.14-4 Low Pressure OTPA Turbine Drive Line		Duct oxidizer from first stage discharge of H.P. OTPA to Turbine inlet of L.P OTPA Provide flexibility for gimballing and misalignment. Bellows are vacuum jacketed to prevent ice formation in convolutions	Same as above.		Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 1 0 & 4 0

SUBSYSTEM 1 1 & 4 1

ASSEMBLY 1 1 1 & 4.1.1

SHEET 1 of 1

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Booster Possible failure to start Liquid air formation-safety hazard, possible effect on molded cables, hydraulic lines Orbiter Liquid air formation-safety hazard, possible effect on molded cables, hydraulic lines Beyond some altitude, problem no longer exists	Booster Safety hazard loss of redundancy Orbiter Safety hazard	Depends upon analysis of safety aspects Possible launch delay	Surface temperature measurement on each vacuum section, or direct vacuum areas (Latter preferred due to desirability to know conditions prior to loading)	Test vacuum at scheduled maintenance cycle Compartment purge may be adequate Launch delay may be necessary	Booster A(4) B(2B) C(4) Orbiter A(4) B(2B) C(4)
Same as above	Same as above	Same as above	Same as above	Same as above	Booster A(4) B(2B) C(4) Orbiter A(4) B(2B) C(4)
Premature shutdown (Small leak A large rupture could result in major damage) Pre-valve closure would prevent further loss	Booster Loss of redundancy Orbiter Loss of one engine	Booster No effect Orbiter Possible mission loss	Surface temp meas or direct vacuum meas (latter preferred)	Check vacuum at sched maint cycle and after delivery to pad. Launch delay may be necessary Compartment purge may preclude ice formation Frost would have no effect	Booster A(4) B(2B) C(4) Orbiter A(4) B(4) C(2A)
Same as above	Same as above	Same as above	Same as above	Same as above	Booster A(4) B(2B) C(4) Orbiter A(4) B(4) C(2A)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.1.1.15-2a & 4.1.1.15-2a Fuel Suction Line		Duct fuel from eng./veh. interface to LPF TPA. Protect fuel quality via a vacuum jacket. Prevent form. of liq. air.	Loss of vacuum.		Low
1.1.1.15, 1.1.2.6, 1.1.3.2, 1.1.6.4, 1.1.7.2, 1.1.8.4 & 4.1.1.15, 4.1.2.6, 4.1.3.2, 4.1.6.4, 4.1.7.2, 4.1.8.4 All Other Lines as Identified in Component Listing		As described in component listings.	Structural fatigue failure only.		Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 1.0 & 4.0

SUBSYSTEM 1.1 & 4.1

ASSEMBLY 1.1.1 & 4.1.1

SHEET 1 of 1

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Booster engine may fail to start	Loss of redundancy.	None.	Vacuum checks at scheduled maintenance cycle. Fuel suction temperature at start	--	Booster: A(4) B(3) C(4) Orbiter A(4) B(3) C(4)
--	--	--	--	--	--

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.1 1.16 & 4 1.1.16 Oxidizer Recirculation Select Valve		Provide recirculation prior to engine start, and flow oxid. from first stage H.P.O.TPA to LPO TPA turbine. Must be in turbine position prior to start. Fails to turbine position on power failure.	Failure to shuttle to recirc. position prior to loading.		Low
			Failure to shuttle to turbine position at start.		Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM: 1.0 & 4.0
SUBSYSTEM: 1.1 & 4.1

ASSEMBLY: 1.1.1 & 4.1.1
SHEET 1 of 1

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Propellant loading hold.	--	Probable mission launch delay.	Valve position discrete.	--	Booster: A(4) B(3) C(4) Orbiter: A(4) B(3) C(4)
Engine fails to start	Flow disruption in oxid. feedline.	Mission termination.	Valve position discrete.	Interlock with start sequence.	Booster: A(4) B(2B) C(4) Orbiter: A(4) B(2B) C(2A)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.1.1.17 & 4.1.1.17 Fuel Re-circ. Select Valve		Provide on-off select of fuel recirc. line to tank or to L.P.F. TPA for start-assist Flows from third stage of H P.F. TPA must be in turbine position prior to start.	Failure to shuttle to recirc. position prior to loading.		Low
			Failure to shuttle to turbine position at start.		Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 1.0 & 4.0
SUBSYSTEM 1.1 & 4.1

ASSEMBLY: 1.1.1 & 4.1.1
SHEET 1 of 1

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Propellant loading hold.	--	Probable launch delay	Valve position discrete.	Interlock with loading-ready sequence.	Booster: A(4) B(3) C(4) Orbiter: A(4) B(3) C(2A)
Fails to start.	Disruption of fuel flow in the fuel feed line.	Mission termination.	Valve position discrete.	Interlock with start sequence.	

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.1.1.18 & 4.1.1.18 Fuel Re-circ. Control Valve		Provide start transient control of fuel to L.P. TPA turbine to assist in bootstrap period. Fails to off position. Shutoff not required. Fails to closed position on loss of power. Required to be open during recirculation and loading operation.	Fails to open for recirculation and start-up.		Low
			Fails to close to minimum flow position after start.		Low

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Possible inadequate bleed-in, failure to start.	Booster Loss of redundancy Orbiter. Possible loss of one engine	Booster: No effect Orbiter: Possible mission loss	Valve position discrete.	Interlock with propellant loading sequence, and start sequence.	Booster: A(4) B(2B) C(4) Orbiter: A(4) B(2B) C(4)
Possible L.P F TPA overspin, cavitation, with premature engine shutdown (depends upon bootstrap system design and regulator performance). Pressure regulation redundancy lost.	Booster· Loss of redundancy Orbiter· Loss of one engine	Booster No effect Orbiter Possible mission loss	Valve position discrete.	--	Booster: A(4) B(2B) C(4) Orbiter: A(4) B(4) C(2A)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1 1.1.19 & 4.1.1.19 Fuel Re-circ. Regulator		Limit the pressure in the recirc. line ahead of the bellows, select valve, and turbine drive/tank press. system. (See 1.1.1.19 Recirc. Control Valve.) Provides redundant pressure regulation.	Fails to regulate pressure.		Low
					Low
			Fails to open during recirculation.		Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 1.0 & 4.0
SUBSYSTEM 1.1 & 4.1

ASSEMBLY 1.1.1 & 4.1.1

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
No effect - redundancy provided by recirc. control valve.	No effect	No effect	Pressure, regulator output.	--	Booster A(4) B(4) C(4) Orbiter: A(4) B(4) C(4)
If double failure occurs, the L P.F TPA would overspin, and potentially the bellows section would fail. Engine loss Possible fire. (Depends upon design of bellows - if it can withstand full pressure, the only effect is premature engine shutdown.)	Both Engine loss.	Both Possible hazardous condition. Mission termination.	Pressure, regulator output.	Low pressure portion should be designed to take full pressure. L P.F. TPA overspin trip should be utilized.	Booster: A(4) B(2B) C(1) Orbiter: A(4) B(4) C(1)
Improper chill down - failure to start is possible.	Booster Loss of redundancy Orbiter Loss of one engine	Booster. No effect Orbiter Possible mission loss	Bleed point temperature, possibly in recirculation line.	--	Booster: A(4) B(4) C(4) Orbiter A(4) B(4) C(2A)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.1.2.1 & 4.1.2.1 Main Injector		Uniformly distribute TPA exhaust gases flowing from gas distribution plate and oxygen discharged from H.P.O.T.P.A. first stage, into combustion chamber.	1) Crack in lox channel with burning upstream of face 2) Oxid. torus crack or rupture 3) Orifice plugging (secondary failure)		Low Low Low
1.1.2.2 & 4.1.2.2 Main Combustion Chamber		Contain internal pressures and transmits thermal loads from combustion gases to fuel regenerative coolant. Contains side loads. Transmits loads from nozzle to main injector, and provides forward support of nozzle extension drive mechanism.	1) Crack internally with fuel loss into chamber 2) Inter-channel leakage (Both of above would result in loss of cooling efficiency)		Low Low
1.1.2.3 Booster Nozzle		Remove heat from combustion gas by regen. cooling. Transmit thrust, side, and thermal loads to combustion chamber. Condition coolant for fuel tank pressurization.	Same as above.		Low
4.1.2.4 Orbiter Nozzle		Same as 1 1.2.3. Transmit forces from extendible nozzle to combustion chamber.	Same as above.		Low
1.1.2.5 & 4.1.2.5 Gas Distribution Plate		Uniformly distribute high pressure TPA turbine exhaust gases flowing from the hot gas manifold to the main injector.	Cracking or deformation with nonuniform flow distribution to injector.		Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 1.0 & 4.0
SUBSYSTEM 1.1 & 4.1

ASSEMBLY 1.1.2 & 4.1.2
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FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
1) Loss of engine-premature shutdown 2) Abrupt engine loss 3) Premature shutdown	1) Booster. Loss of redundancy. Orbiter: Loss of one engine. 2) Multiple engine loss 3) Booster: No effect Orbiter: Loss of one engine	1) Booster. No effect Orbiter: Mission loss 2) Possible loss of vehicle/crew 3) Booster No effect Orbiter: Loss of mission	1) Oxid flow, C*; I_{sp}, M.R 2) -- 3) M.R , chamber pressure	Inspection and leak checks at scheduled maint cycle	Booster: A(4) B(2B) C(1) Orbiter. A(4) B(4) C(1)
Loss of performance with premature shutdown	Booster. Loss of redundancy Orbiter· Loss of one engine	Booster No effect Orbiter Mission loss	Mixture ratio, C*	Same as above	Booster· A(4) B(2B) C(4) Orbiter: A(4) B(4) C(2A)
Same as above	Same as above	Same as above	Same as above	Same as above.	Booster: A(4) B(2B) C(4) Orbiter A(4) B(4) C(2A)
Same as above.	Same as above.	Same as above.	Same as above	Same as above.	Booster: A(4) B(2B) C(4) Orbiter A(4) B(4) C(2A)
Loss of performance - may be sufficient to cause out of spec performance short of total structural collapse.	Booster Loss of redundancy Orbiter· Possible loss of one engine	Booster: No effect Orbiter: Possible mission loss	Chamber pressure, C*, I_{sp}	Visual inspection not very practical. Run-to-run performance comparisons by trend analysis is recommended	Booster A(4) B(2B) C(4) Orbiter: A(4) B(4) C(2A)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.1.3.1 & 4.1.3.1 Igniter, Main Combustion Chamber*		Provides ignition source for main combustion chamber	Fails to ignite		Low
			Continues to burn.		Low
			Hard start.		Low

* Critical components

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Engine fails to start	Booster Loss of redundancy Orbiter Loss of one engine	Booster No effect Orbiter Mission loss	Valve position discrete, ignition detector, igniter current main conbustion chamber pressure	--	Booster A(4) B(2B) C(4) Orbiter A(4) B(4) C(2A)
Main TCA Burnout, loss of performance, premature shutdown	Booster Loss of redundancy Orbiter Loss of one engine	Booster No effect Orbiter Mission loss	Same as above, plus leak checks at maintenance cycle	Recommend redundant valves be considered	Booster A(4) B(2B) C(4) Orbiter A(4) B(4) C(2A)
Capable of withstanding hard start	No effect	No effect	Leak check at maintenance cycle, main C C pressure	--	Booster A(4) B(4) C(4) Orbiter A(4) B(4) C(4)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1 1 3.2 & 4.1.3.2 Fuel Preburner Igniter*		Provide ignition source for fuel preburner at start. Operates from oxidizer and fuel propellant inlet, valve command, and 28 vdc.	Fails to ignite or premature loss of ignition.		Low
			Continues to burn.		Low
			Hard start due to leakage in oxidizer valve beyond spec. limit.		Low
* Critical component					

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 1 0 & 4 0
SUBSYSTEM 1 1 & 4 1
ASSEMBLY 1 1 3 & 4 1 3
SHEET 1 of 1

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Engine fails to start, possible high M.R and internal engine damage	Booster Loss of redundancy. Orbiter Loss of one engine.	Booster No effect. Orbiter Mission loss.	Oxid valve position discrete pre-burner chamber pressure ignition detector	Redundant oxidizer valve should be considered	Booster A(4) B(2B) C(4) Orbiter A(4) B(4) C(2A)
Premature shut down of engine due to loss of power.	Booster Loss of redundancy. Orbiter Loss of one engine	Booster No effect. Orbiter Mission loss	Oxidizer valve position discrete.	--	Booster A(4) B(2B) C(4) Orbiter A(4) B(4) C(2A)
Engine capable of withstanding limited hard start	Booster No effect Orbiter. No effect	Booster No effect Orbiter No effect	Leak checks at maintenance cycle, preburner chamber pressure	--	Booster A(4) B(4) C(4) Orbiter A(4) B(4) C(4)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.1 3 3 & 4.1.3.3 Oxidizer Preburner Igniter		Provides ignition source for oxidizer preburner at start. Operates from oxidizer and fuel propellant inlet, valve command and 28 vdc.	Fails to ignite or premature loss of ignition.		Low
			Continues to burn.		Low
			Hard start due to leakage in oxidizer valve beyond spec limit.		Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 1 0 & 4 0

SUBSYSTEM 1 1 & 4 1

ASSEMBLY 04.1.3 & 4.1 3

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FAILURE EFFECT ON: SUBSYSTEM	FAILURE EFFECT ON: SYSTEM	FAILURE EFFECT ON: MISSION	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
Engine fails to start.	Booster Loss of redundancy Orbiter Loss of one engine.	Booster No effect Orbiter Mission loss	Oxidizer valve position discrete, preburner chamber pressure ignition detector	Redundant oxidizer valve should be considered.	Booster A(4) B(2B) C(4) Orbiter A(4) B(4) C(2A)
Premature shutdown of engine due to loss of power.	Booster Loss of redundancy Orbiter Loss of one engine	Booster No effect Orbiter Mission loss.	Oxidizer valve position discrete	--	Booster A(4) B(2B) C(4) Orbiter. A(4) B(4) C(2A)
Engine capable of withstanding limited hard start	Booster No effect Orbiter No effect.	Booster No effect Orbiter No effect.	Leak checks at maintenance cycle. Preburner chamber pressure	--	Booster A(4) B(4) C(4) Orbiter A(4) B(4) C(4)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.1.4 1 & 4 1 4 1 Gimbal Block		Transfer loads from all gimballed components to vehicle.	Bearing failure.		Low
1.1 4.2 & 4 1 4 2 Gimbal Actuator and Power Pack *		Positions the rocket engine for thrust vector control	Actuator goes hardover and remains there.		Low
			No response of actuator to command (remains at null).		Low
			Unstable actuator position (oscillation)		Low
			Unmodulated actuator position (full extend or full retract positions only).		Low
			Slow response		Medium

* Critical components

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 1 0 & 4 0

SUBSYSTEM 1 1 & 4 1

ASSEMBLY 1 1 4 & 4 1 4

FAILURE EFFECT ON: SUBSYSTEM	FAILURE EFFECT ON: SYSTEM	FAILURE EFFECT ON: MISSION	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
Requires excessive torque to move engine	Possible sluggish engine position response	None	Actuator position as compared to command (rate)	Install ΔP transducer across actuator piston, utilize in ground testing with ramp current measurement	Booster A(4) B(4) C(4) Orbiter A(4) B(4) C(4)
Possible Structural Damage	Booster Loss of TVC on one engine Orbiter Unable to control vehicle Engine shutdown required	Booster No effect (compensated by flight control system) Orbiter Mission loss, fail safe, increased burn time of remaining engine	Actuator position measurement compared to command		Booster A(4) B(3) C(4) Orbiter A(4) B(3) C(2A)
--	Loss of TVC on one engine	No effect (compensated by flight control system)	Same as above		Booster A(4) B(3) C(4) Orbiter A(4) B(3) C(4)
--	Oscillation of engine thrust vector	Oscillatory excitation of vehicle (until actuator can be locked in null, then no effect)	Actuator position measurement analyzed for oscillation	Lock actuator in null position when this failure mode is detected	Booster A(4) B(3) C(4) Orbiter A(4) B(3) C(4)
Possible Structural Damage	Unstable thrust vector in one plane	Possible vehicle flight instability (until actuator can be locked in null, then no effect)	Actuator position measurement compared to command	Lock actuator in null position when this failure mode is detected	Booster A(4) B(3) C(4) Orbiter A(4) B(3) C(4)
--	Poor TVC	No effect (assume compensation by flight control system)	Same as above		Booster A(4) B(4) C(4) Orbiter A(4) B(4) C(4)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
			Excessive null shift.		Medium
			Loss of position accuracy (hysteresis).		Low
			Actuator fails to lock at null when engine is shut down.		Low
			Actuator fails to lock at null when commanded (to correct for mission effects of other failure modes)		Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 1 0 & 4 0

SUBSYSTEM 1 1 & 4 1

ASSEMBLY 1 1 4 & 4 1 4

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FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
--	Poor TVC	No effect	Same as above		Booster A(4) B(4) C(4) Orbiter A(4) B(4) C(4)
--	Poor TVC	Loss of flight control stability margin (until actuator can be locked in null, then no effect)	Same as above	Lock actuator in null position when this failure mode is detected	Booster A(4) B(3) C(4) Orbiter A(4) B(3) C(4)
Possible Structural Damage	--	--	Actuator null position switch		Booster A(4) B(3) C(4) Orbiter A(4) B(3) C(4)
--	--	One engine shutdown necessary to correct for vehicle oscillation Booster No effect Orbiter Mission loss, fail safe, increased burn time of remaining engine	Actuator null position switch		Booster A(4) B(3) C(4) Orbiter A(4) B(3) C(2A)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.1.5.1 & 4.1 5 1 Engine Controller		Provides power distribution, management of data from vehicle and engine, and data processing. Provides interface to enable engine to respond to vehicle commands and for receipt and distribution of electrical power. Performs start and stop sequencing of engine. Provides thrust, mixture ratio, and TVC in response to vehicle commands. Aids in POGO suppression. Provides checkouts necessary to respond to vehicle with engine-ready signal. Automatic nulling and locking the engine on shutdown. Initates shutdown based on checks and monitoring.	First failure in any module results in: a) Loss of one data input channel redundancy, b) Loss of one 16 channel module; c) Loss of one total channel; d) Loss of channel switching		Medium
			Second failure of like-module (excludes C.C.U. - only one module).		Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM: 1.0 & 4.0

SUBSYSTEM: 1.1 & 4.1

ASSEMBLY: 1.1.5 & 4.1.5

SHEET 1 of ___

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Loss of redundancy.	No effect.	Booster/Orbiter: Possible launch delay.	Internal checks reveal status of modules.		Booster: A(4) B(2B) C(4) Orbiter: A(4) B(2B) C(2A)
Premature engine shutdown.	Booster: Loss of redundancy Orbiter: Loss of one engine.	Booster: No effect Orbiter: Possible mission loss.	Same as above.		Booster: A(4) B(2B) C(4) Orbiter: A(4) B(2B) C(2A)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.1.5.2-1 & 4.1.5.2-1 Ignition Control Harness (Excluding Ignition Valve Control) Fuel Preburner Oxid Preburner, Main Combustion Chamber		Conduct 28 vdc from engine controller to spark exciter on command.	Loss of continuity, or high resistance in primary harness, or loss of conduction due to short.		Low
			Loss of redundant harness		Low
1.1.5.2-2 & 4.1.5.2-2 Valve Control Harness (All Electric Valves)		Conduct dc and ac power from controller to valves	See individual valves - Failure mechanisms of harness result in loss of power conduction, which is a fail-to-operate or premature closure mode included under each electric valve.		Low
* Critical components					

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM: 1 0 & 4 0
SUBSYSTEM 1.1 & 4.1

ASSEMBLY: 1.1.5 & 4.1.5

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FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Loss of redundancy in ignition system	None	None.	Igniter current	--	Booster: A(4) B(4) C(4) Orbiter: A(4) B(4) C(4)
Engine fails to reach NPL	Booster· Loss of redundancy Orbiter Loss of one engine	Booster No effect Orbiter: Mission loss	Igniter current		Booster: A(4) B(2B) C(4) Orbiter: A(4) B(4) C(2A)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.1.5.3 & 4.1 5.3 Harness (Control Instrumentation)		Provide electrical connection between transducers and engine controller inputs (primary signal path).	Open circuit. Short circuit.		Low
			Loss of insulation resistance		Medium
		Secondary signal path.	Same as above.		Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 1 0 & 4 0

SUBSYSTEM 1.1 & 4 1

ASSEMBLY 1.1.5 & 4 1.5

SHEET 1 of 1

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Loss of redundancy	No effect	If detected prior to engine start - possible launch delay.	Shunt calibrations, plus comparison of redundant channels	--	Booster A(4) B(3) C(4) Orbiter A(4) B(4) C(4)
Loss of redundancy	No effect	If detected prior to engine start - possible launch delay	Shunt calibrations, plus comparison of redundant channels	--	Booster: A(4) B(2B) C(4) Orbiter A(4) B(4) C(2A)
Premature engine shutdown	Booster Loss of redundancy Orbiter Loss of one engine	Booster No effect Orbiter Possible mission loss	--	--	Booster: A(4) B(2B) C(4) Orbiter A(4) B(4) C(2A)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1 1.5.4 & 4.1.5.4 Sensors - Pressure (continued)		Provide pressure data for control loops (primary).	Change of output sensitivity with pressure.		Medium
1 1.5.4 & 4.1.5.4 Sensors - Pressure		Provide pressure data for control loops (primary). (Backup)	Loss of signal; reduction of sensitivity; zero offset (appears as a change in sensitivity during operation); change of output sensitivity with pressure.		Low
1.1.5.4 & 4.1.5.4 Sensors - Temperature		Provide temperature data for mixture ratio control loop (primary).	Sensitivity change.		Low
			Open circuit.		Low
1.1.5.4 & 4 1.5.4 Sensors - Temperature		Provide temperature data for mixture ratio control loop (primary). (Backup)	Sensitivity change; open circuit.		Low

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Loss of redundancy - minor increase in error band of mixture ratio control	No effect	No effect	Comparison of redundant data.		Booster: A(4) B(4) C(4) Orbiter A(4) B(4) C(4)
Loss of control, premature shutdown.	Booster Loss of redundancy Orbiter Loss of one engine	Booster No effect Orbiter Possible mission loss	Requires comparison within controller of at least a third parameter		Booster A(4) B(2B) C(4) Orbiter: A(4) B(4) C(2A)
Loss of redundancy - minor increase in error band of mixture ratio control	No effect.	If detected prior to engine start, launch delay possible	Comparison of redundant data		Booster A(4) B(4) C(4) Orbiter. A(4) B(4) C(4)
Same as above.	Same as above	Same as above	Same as above		Booster. A(4) B(4) C(4) Orbiter. A(4) B(4) C(4)
Loss of control Premature shutdown.	Booster Loss of redundancy Orbiter· Loss of one engine	Booster No effect. Orbiter. Possible mission loss	Requires comparison with at least a third parameter		Booster A(4) B(2B) C(4) Orbiter. A(4) B(4) C(2A)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.1 5.4 & 4.1 5.4 Sensors - Flow (turbine meters)		Provide volumeric flow data for mixture ratio control loop.	Loss of signal, one coil.		Low
			Erratic output signal, loss of signal (in both coils simultaneously); or loss of output from second coil after loss from first coil.		Low
1.1.5.4 & 4.1.5.4 Sensors - Pressure		Provide pressure data for control loops (primary).	Loss of signal.		Low
			Zero offset.		Medium
			Reduction of sensitivity.		Low
			Improper output from shunt steps.		Medium

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 1 0 & 4.0
SUBSYSTEM 1.1 & 4 1

ASSEMBLY 1.1 5 & 4 1.5

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Loss of redundancy - minor increase in error band of mixture ratio control	No effect.	If detected prior to engine start - launch delay possible	Continuity check Comparison with redundant coil output		Booster A(4) B(3) C(4) Orbiter: A(4) B(4) C(4)
Loss of redundant flow meas. Use of backup system results in an increased error band in M R. control	Booster No effect. Orbiter No effect.	Booster. No effect Orbiter No effect.	Comparison of both coils		Booster: A(4) B(2B) C(4) Orbiter. A(4) B(4) C(4)
Loss of redundancy, minor increase in error band of mixture ratio control.	No effect	If detected prior to engine start, launch delay possible	Comparison of redundant data channels, shunt calib check may be used on ground tests.		Booster. A(4) B(2B) C(4) Orbiter: A(4) B(4) C(4)
Same as above	Same as above	Same as above	Same as above		Booster· A(4) B(2B) C(4) Orbiter A(4) B(4) C(4)
Same as above	Same as above.	Same as above	Same as above		Booster: A(4) B(2B) C(4) Orbiter A(4) B(4) C(4)
Same as above	Same as above	Same as above	Same as above		Booster A(4) B(2B) C(4) Orbiter A(4) B(4) C(4)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.1.6 1 Fuel Tank Pressurant Check Valve		Prevent backflow of tank GH_2 into engine.	Failure to open.		Low
			Failure to close at shutdown.		Medium
1 1 6.2 Oxidizer Tank Pressurant Check Valve.		Prevent backflow of tank gox into engine	Failure to open.		Low
			Failure to close		Medium
1.1.6 3 Oxidizer Heat Exchanger		Heat oxidizer to desired thermodynamic conditions for main oxid tank pressurization	No primary failure mode other than gross structural		Low
1 1 6 4 Interconnect Lines Hot Gas Inlet Hot Gas Outlet Oxid Inlet Oxid Tank Pressure Fuel Tank Pressure		Conduct fuel rich gas to and from 1 1.6.3. Conduct oxid to 1 1 6.3. Conduct oxid from 1 1.6 3 to interface. Conduct GH_2 from check valve to interface.	All: No primary failure mode other than gross structural		Low

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
1% flow now goes through engine Slight change in M R	Assuming one engine can supply sufficient gas for tank No effect	No effect	Valve position discrete.	Need check valves with built-in proximity sensors	Booster A(4) B(4) C(4) Orbiter: A(4) B(4) C(2B)
GH_2 in manifold volume would exhaust out of malfunctioning check valve No adverse effect	Tank exhaust through nozzle On reentry propellant tank would probably collapse Inability to fill at adequate rate	Possible reentry hazard, mission termination	Valve position discrete, leak check at sched maint cycle	Redundant shutoff required	Booster A(4) B(4) C(1S) Orbiter A(4) B(4) C(1S)
Same as above	Same as above	Same as above	Same as above		Booster A(4) B(4) C(4) Orbiter A(4) B(4) C(4)
Same as above except that manifold volume would be evacuated only when oxid valves are opened	Same as above	Same as above	Same as above	Same as above	Booster A(4) B(4) C(1S) Orbiter A(4) B(4) C(1S)
--	--	--	System leak checks at sched maint cycle	Design and test for adequate safety margin	Booster A(4) B(4) C(4) Orbiter A(4) B(4) C(4)
--	--	--	Same as above	--	Booster A(4) B(4) C(4) Orbiter A(4) B(4) C(4)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.1.7.1-1a Preburner Oxidizer Purge Solenoid Valve		Provides helium to preburners. Oxidizer circuit downstream of shutoff. For purging prior to FS_1 and after FS_2, purge is on prior to launch on both stages, and orbiter purge remains on during boost phase.	Fails to open at start, or premature closure at start.		Low
			Fails to close at start of engine.		Low
			Fails to open at shutdown, or premature closure.		Low
			Fails to close after shutdown.		Low
			Operates slowly.		Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 1.0 & 4.0
SUBSYSTEM 1.1 & 4.1

ASSEMBLY 1.1.7 & 4.1.7

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Possible failure to come to NPL due to icing in platelets Engine cutoff. Possible hard start.	Booster Loss of redundancy Orbiter Loss of one engine	Booster. No effect Orbiter: Possible mission loss	Valve position discrete.	Interlock with launch sequence Consider parallel redundant valves	Booster: A(4) B(2B) C(4) Orbiter A(4) B(4) C(2A)
No effect at start. Check valve prevents back-flow of lox No effect at shutdown. Shutoff redundancy lost. (See check valve analysis.)	No effect.	No effect.	Valve position discrete	--	Booster: A(4) B(4) C(4) Orbiter. A(4) B(4) C(4)
Preburner face burning. Possible turbine damage	No effect	No effect.	Valve position discrete.	Would require inspection at next maintenance cycle.	Booster: A(4) B(4) C(4) Orbiter A(4) B(4) C(4)
No effect	None. System valve must be shut off.	No effect.	Valve position discrete.	Stage shutoff redundancy.	Booster: A(4) B(4) C(4) Orbiter A(4) B(4) C(4)
Possibly same effect as failure to open at shutdown.	No effect	No effect.	Valve position analog.	Examination of valve trace would reveal time sensitive wear changes.	Booster. A(4) B(4) C(4) Orbiter. A(4) B(4) C(4)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.1.7.1-1b & 4.1.7.1-1b Main TCA Fuel Purge Solenoid Valve		Provides helium purge to entire engine system fuel circuits downstream of main fuel valve. Required prior to FS_1 for air/moisture evacuation; Post-FS_2 to control shut down mixture ratio. Operates on 28 vdc command, fails closed on loss of power.	Fails to open prior to start, or premature closure at start.		Low
			Fails to close at start.		Low
			Opens slowly at start.		Low
			Fails to open at shutdown, or premature closure at shutdown.		Low
			Fails to close after purge complete.		Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 1.0 & 4.0 | SUBSYSTEM 1.1 & 4.1 | ASSEMBLY 1.1.7 & 4.1.7 | SHEET 2 of 3

FAILURE EFFECT ON: SUBSYSTEM	FAILURE EFFECT ON: SYSTEM	FAILURE EFFECT ON: MISSION	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
Booster Probable liquid air in fuel system at start, probable detonation Orbiter No effect	Booster Possible failure to start due to ice in system Orbiter. No effect (altitude start)	Booster Probable loss of redundancy Orbiter No effect	Valve position discrete	Interlock with start sequence	Booster A(4) B(2B) C(4) Orbiter. A(4) B(4) C(4)
Check valve provides shutoff redundancy. Slight change in start characteristic due to excess helium.	No effect	No effect.	Valve position discrete	--	Booster A(4) B(4) C(4) Orbiter A(4) B(4) C(4)
No effect.	No effect.	No effect.	Valve position discrete, with functional check at maintenance cycle.	--	Booster A(4) B(4) C(4) Orbiter A(4) B(4) C(4)
Possible M R. problem resulting in main injector damage.	No effect.	No effect.	Valve position discrete	Main injector inspection at maintenance cycle.	Booster A(4) B(4) C(4) Orbiter. A(4) B(4) C(4)
No effect.	Excessive helium usage	No effect.	Valve position discrete.	--	Booster A(4) B(4) C(4) Orbiter. A(4) B(4) C(4)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.1.7 1-1c & 4.1.7.1-1c Main TCA Oxidizer Purge Solenoid Valve		Provide on-off control of helium purge to main combustion chamber oxidizer passages, to prevent ice formation and H_2 entry prior to start, and to control mixture ratio at shutdown.	Fails to open prior to start.		Low
			Fails to close prior to start.		Low
			Fails to open at shutdown or opens slowly at shutdown, or premature closure.		Low
			Fails to close after shutdown.		Low
			Opens slowly at start.		Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 1.0 & 4.0
SUBSYSTEM 1.1 & 4.1

ASSEMBLY 1.1.7 & 4.1.7

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Possible loss of chamber performance. Burnout with premature shutdown.	Booster Loss of redundancy Orbiter No effect (altitude start)	No effect	Valve position discrete.	Interlock with start sequence.	Booster: A(4) B(2B) C(4) Orbiter A(4) B(4) C(4)
Check valve provides shutoff redundancy, slight change in start characteristic.	No effect.	No effect.	Valve position discrete.	--	Booster A(4) B(4) C(4) Orbiter· A(4) B(4) C(4)
Probable injector damage.	No effect.	No effect.	Valve position discrete	Injector inspection at maintenance cycle, possible malfunctioning engine on next flight	Booster A(4) B(4) C(4) Orbiter: A(4) B(4) C(4)
No effect.	Excessive use of GHe	No effect.	Valve position discrete	--	Booster A(4) B(4) C(4) Orbiter: A(4) B(4) C(4)
No effect.	No effect.	No effect.	Valve position discrete	Probably will open slowly at shutdown. Functional at maintenance cycle	Booster. A(4) B(4) C(4) Orbiter. A(4) B(4) C(4)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1 1 7 1-1d High Pressure OTPA Cavity Seal Purge Valve, Solenoid.		Provide on-off control of helium purge to the cavity seal between the oxidizer and fuel effluent from the high pressure OTPA pump and turbine, for overboard dump. To be on prior to loading propellants and during engine burn, booster and orbiter. This valve is is designed to fail open. (Un-energized open.)	Failure to open prior to loading propellants and engine start.		Low
1 1 7 1-1e Engine System Purge Control Solenoid Valve.		Provide on-off control of purge gases to main fuel and oxidizer suction lines prior to propellant loading. Selects: 1) Fuel Line, 2) Oxid line, 3) Both on, 4) All off. 28 vdc valve, multiple inputs, fails to all-off position on power loss Valve must be in "both-on" position prior to propellant loading, and must be in off position at the start of loading.	Fails to actuate to oxid position. (Or "both")		Low
			Fails to actuate to fuel position (or "both")		Low
			Fails to return to off position at loading		Low
1 1.7.1-1f Two-Way GN_2/GHe Select Solenoid Valve.		Provide selection of GN_2 or GHe as purge gas, prior to propellant loading, and during flight Fails in GHe position with loss of power Must be in GHe position prior to fuel purging, and prior to prop. loading.	Fails to shuttle to GN_2 position, or to return to GHe position.		Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 1 0 & 4 0 | SUBSYSTEM 1 1 & 4 1 | ASSEMBLY 1.1 7 & 4.1 7 | SHEET 1 of 1

FAILURE EFFECT ON: SUBSYSTEM	SYSTEM	MISSION	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
Possible detonation at start (See recommendations)	--	Launch delay	Valve position discrete	Interlock with loading sequence ready system Loading should not proceed unless this valve indicates open	Booster A(4) B(4) C(4) Orbiter A(4) B(4) C(4)
Possible moisture in system Engine fails to come to full power, possible TPA damage due to plugged passages Premature shutdown	Booster Launch delay Orbiter Launch delay	Booster No effect Orbiter No effect	Valve position discretes	Interlock with loading ready signal; establish procedures	Booster A(4) B(3) C(4) Orbiter A(4) B(3) C(4)
Same as above	Same as above	Same as above	Same as above	Same as above	Booster A(4) B(3) C(4) Orbiter A(4) B(3) C(4)
Helium would enter fuel, oxid, or both suction lines during loading No effect	--	Possible launch delay	Valve position discrete	Interlock "off" position with loading ready signal	Booster A(4) B(3) C(4) Orbiter: A(4) B(3) C(4)
No effect Interlock system and procedure requires GHe position for preload purge Excessive use of GHe on ground if valve failed to shuttle to GN_2 position	--	--	Valve position discrete	--	Booster A(4) B(C) C(4) Orbiter: A(4) B(C) C(4)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.1.7.1-2a & 4.1.7.1-2a Oxidizer Preburner Oxidizer Inlet Purge Check Valve		Prevent backflow of oxid from reaching purge shutoff valve, and from reaching fuel preburner check valve Must flow through during purging.	Fails to open during pre-start purge.		Low
			Fails to close after pre-start purge.		Low
			Fails to open at postfire purge.		Low
			Fails to close after post-fire purge.		Low
1.1.7.1-2b & 4.1.7.1-2b Fuel Preburner Oxidizer Inlet Purge Check Valve		Prevent backflow of oxidizer from reaching purge solenoid valve. Must flow-through during purge	Failure to open at start of purge before FS-1		Low
			Failure to close at end of prestart purge.		Medium
			Failure to open at shut-down purge after FS-2.		Low
			Failure to close at shut-down purge.		Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 1 0 & 4 0
SUBSYSTEM 1 1 & 4 1

ASSEMBLY 1 1 7 & 4 1.7
SHEET 1 of 2

FAILURE EFFECT ON: SUBSYSTEM	FAILURE EFFECT ON: SYSTEM	FAILURE EFFECT ON: MISSION	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
Possible formation of ice in injector, low performance, engine may fail to start	Booster Possible loss of redundancy Orbiter No effect	No effect	Valve position discrete, functional checks at maint cycle with N_2	No known check valves made with position indicators	Booster A(4) B(3) C(4) Orbiter A(4) B(4) C(4)
Possible cross flow of oxidizer to fuel preburner circuit, with mixture ratio control problems Loss of shutoff redundancy	No effect	No effect	Leak check at maint cycle	Cross-flow depends upon opening ΔP in check valve design	Booster A(4) B(4) C(4) Orbiter: A(4) B(4) C(4)
Possible injector face burning and turbine damage	No effect	No effect	Valve position discrete preburner chamber pressure	Effect is on subsequent flight (potentially).	Booster A(4) B(4) C(4) Orbiter A(4) B(4) C(4)
No effect	No effect	No effect	--	--	Booster A(4) B(4) C(4) Orbiter A(4) B(4) C(4)
Possible failure to start due to ice formation, engine fails to come to NPL Engine cutoff possible hard start	Booster Loss of redundancy Orbiter Loss of one engine	Booster No effect Orbiter Possible mission loss	Valve position discrete	Interlock with start sequence	Booster A(4) B(2B) C(4) Orbiter A(4) B(4) C(4)
No effect Lox/gox trapped in line to solenoid valve until shutdown Loss of shutoff redundancy in backflow mode.	No effect	No effect	--	--	Booster A(4) B(4) C(4) Orbiter A(4) B(4) C(4)
Possible preburner or turbine damage	No effect	No effect	Valve position discrete functional system at maint cycle	Affects next flight, potentially.	Booster A(4) B(4) C(4) Orbiter A(4) B(4) C(4)
No effect	No effect	No effect	--	--	Booster A(4) B(4) C(4) Orbiter A(4) B(4) C(4)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.1 7.1 2c & 4.1.7.1-2c Main TCA Fuel Inlet Purge Check Valve		Prevent backflow of H_2 from reaching solenoid valve. Must flow-through during purge. Redundant backflow shutoff.	Fails to open at pre-FS_1 purge.		Low
			Fails to close at end of pre-FS_1 purge		Medium
			Fails to open at shutdown purge (FS_2)		Low
			Fails to close at end of post FS_2 purge		Low

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Booster	Booster Loss of redundancy	Booster No effect	Valve position discrete	Interlock with start sequence	Booster A(4) B(2B) C(4) Orbiter A(4) B(4) C(4)
LH_2 reaches shutoff solenoid valve Loss of shutoff redundancy	No effect	No effect	Valve position discrete, leak check at maint cycle	--	Booster A(4) B(4) C(4) Orbiter A(4) B(4) C(4)
Possible M R problem resulting in injector damage	No effect	No effect	Valve position discrete, functional check at maint cycle	--	Booster A(4) B(4) C(4) Orbiter A(4) B(4) C(4)
No effect	No effect	No effect	Leak check at maint cycle	Could affect next flight, if shutoff valve failed to close tight (Secondary failure)	Booster: A(4) B(4) C(4) Orbiter A(4) B(4) C(4)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.1.7 1.-2d & 4.1.7.1-2d Main TCA Oxidizer Purge Check Valve		Prevent liquid oxidizer from reaching solenoid valve. Must flow through during purge.	Fails to open at pre-FS_1 purge.		Low
			Fails to close at end of pre-FS_1 purge.		Medium
			Fails to open at shutdown purge (FS_2).		Low
			Fails to close after FS_2 purge.		Medium

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 1.0 & 4.0 | SUBSYSTEM 1.1 & 4.1 | ASSEMBLY 1.1.7 & 4.1.7

FAILURE EFFECT ON: SUBSYSTEM	FAILURE EFFECT ON: SYSTEM	FAILURE EFFECT ON: MISSION	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
Possible loss of chamber performance. Burnout with premature shutdown.	Booster Loss of redundancy Orbiter No effect (altitude start)	Booster* No effect Orbiter* No effect	Valve position discrete.	Interlock with start sequence	Booster: A(4) B(2B) C(4) Orbiter: A(4) B(4) C(4)
Loss of shutoff redundancy - lox reaches shutoff solenoid valve.	No effect.	No effect.	Valve position discrete; leak check at maintenance cycle.	--	Booster* A(4) B(4) C(4) Orbiter: A(4) B(4) C(4)
Probable injector damage.	No effect.	No effect.	Valve position discrete	Damage affects next flight - inspect injector.	Booster* A(4) B(4) C(4) Orbiter: A(4) B(4) C(4)
No effect.	No effect.	No effect.	Leak check at maintenance cycle	Could affect next flight if solenoid valve had excessive leakage in reverse direction.	Booster: A(4) B(4) C(4) Orbiter: A(4) B(4) C(4)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.1.7.1.-2e & 4.1 7.1-2e High Pressure O.T.P.A. Seal Cavity Purge Check Valve		Provide redundant backflow shutoff to prevent oxidizer or fuel from reaching purge distribution system. (See purge solenoid valve 1.1.7.1-1d.) Must flow through during purge (preloading through engine shutdown). Note: Not redundant in truest sense, since solenoid valve is fail-open.	Fails to open prior to loading of propellants.		Low
			Failure to close at shutdown of purge.		Medium

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 1.0 & 4.0 | SUBSYSTEM 1.1 & 4.1 | ASSEMBLY 1.1.7 & 4.1.7

FAILURE EFFECT ON: SUBSYSTEM	SYSTEM	MISSION	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
Possible detonation at start, see recommendations.	--	Possible launch delay.	Valve position discrete, seal cavity pressure.	Interlock measurement with loading ready sequence, purge system checks at maintenance cycle should catch malfunctioning check valve.	Booster: A(4) B(2B) C(4) Orbiter: A(4) B(2B) C(4)
Any residual propellants may reach shut-off valve. Would be very low in pressure, and probably would not reach the purge system in event of solenoid valve failure (open).	No effect.	No effect.	--	--	Booster: A(4) B(4) C(4) Orbiter: A(4) B(4) C(4)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1 1.7.1-2f & 4.1.7.1-2f Fuel Suction Line Purge Check Valve		Provide redundant shutoff to prevent back flow of fuel into purge system, and possibly into oxidizer system. (Depends upon design of 1.1.7.1-1e.) Must flow through during purge.	Fails to open during purge prior to propellant loading.		Low
			Fails to close at end of purge prior to propellant loading.		Low
1.1.7.1-2g & 4.1.7.1-2g Oxidizer Suction Line Purge Check Valve		Provide redundant shutoff to prevent back flow of oxidizer into purge system, and possibly into fuel system (depends upon design of 1.1.7.1-1e).	Fails to open during purge prior to propellant loading.		Low
			Fails to close at end of purge prior to propellant loading.		Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM

SUBSYSTEM 1.1 & 4.1

ASSEMBLY # 1.1.7 & 4.1.7

FAILURE EFFECT ON: SUBSYSTEM	SYSTEM	MISSION	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
Loss of purge - probable formation of ice in fuel system, engine fails to start (see recommendations).	--	Possible launch delay	Valve position discrete, purge check at maintenance cycle.	Interlock with propellant loading ready signal. Depending upon design of engine purge select valve, this check valve may not be necessary. For backflow to occur, purge pressure would have to drop below either line pressure.	Booster. A(4) B(2B) C(4) Orbiter A(4) B(2B) C(4)
Loss of backflow shutoff redundancy.	No effect.	No effect	Valve position discrete, leak checks at maintenance cycle.	--	Booster A(4) B(4) C(4) Orbiter: A(4) B(4) C(4)
Loss of purge - probable formation of ice in oxidizer system. Possible engine failure come to NPL. Possible turbopump damage due to plugged passage (see recommendations).	--	Possible launch delay	Valve position discrete, purge check at maintenance cycle.	Interlock with propellant loading ready signal Depending upon design of engine purge select valve, this check valve may not be necessary. For backflow to occur, purge pressure would have to drop below either line pressure.	Booster A(4) B(2B) C(4) Orbiter A(4) B(2B) C(4)
Loss of backflow shutoff redundancy	No effect.	No effect.	Valve position discrete, leak checks at maintenance cycle	--	Booster A(4) B(4) C(4) Orbiter A(4) B(4) C(4)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
4.1.8 1 Extendible Nozzle (orbiter only)		Remove heat from combustion gas and discharge by radiation. Contain internal thrust, side loads, transmit loads to orbiter nozzle. Provide seal and lock at orbiter nozzle interface.	Crack, or other structural failure, leading to loss of a section or all of nozzle.		Low
4.1.8.2 Extendible Nozzle Coolant Valve (orbiter only)		Provide on-off control of fuel flow from low pressure TPA discharge to orbiter nozzle manifold, to provide film cooling of extendible nozzle, sealing surface, and aft supports of nozzle deployment kit.	Failure to open.		Low
			Opens slowly.		Low
			Closes prematurely		Low
			Failure to close at shutdown.		Low
			Excessive seat leakage.		Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 4 0
SUBSYSTEM 4.1
ASSEMBLY 4 1 8
SHEET 1 of 2

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Loss of performance with premature shutdown	Loss of one engine, probable thrust-vector control problem	Possible mission loss	Guidance package detection of loss of ΔV and/or thrust vector problem.		Orbiter A(4) B(4) C(2A)
Engine shutdown.	Loss of one engine.	Mission loss	Valve position discrete Proximity type switch		Orbiter. A(4) B(4) C(2A)
No effect, or, if long enough, same as failure to open	Same as above	Same as above	Same as above		Orbiter A(4) B(4) C(2A)
Engine shutdown	Same as above	Same as above	Same as above		Orbiter A(4) B(4) C(2A)
Very small increase in shutdown impulse	No effect Prevalve shutoff provides redundancy Minor corrective maneuver may be required	No effect	Same as above		Orbiter A(4) B(4) C(4)
Possible fire hazard at launch	Possible fire hazard at launch	Possible launch abort	Vehicle compartment GH_2 sensors Leak check as part of scheduled maintenance cycle		Orbiter A(4) B(2B) C(2A)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
4.1.8 3 Extendible Nozzle Deployment Kit (Orbiter Only)*		Extends and retracts nozzle in response to power commands Extension required. Prior to shutdown in booster, and after orbiter.shutdown. Double redundancy drive mechanism, lock/seal drive mechanism	Primary system fails to extend or retract nozzle or stopping at intermediate position		Low
			Secondary system fails to extend nozzle or stopping at intermediate position, slow extension,		Low
			Distortion of guide structure on landing		Low
			Failure of primary lock drive mechanism at locking.		Medium
			Failure of secondary lock drive mechanism at locking.		Low
			Secondary nozzle extension drive mechanism or lock drive mech. fails at retraction		Low

* Critical components

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Loss or drive redundancy	No effect	No effect	Nozzle position discrete (fully extended, fully retracted) Motor current	--	Orbiter A(4) B(2B) C(4)
Low performance, hot gas leak, possible engine damage	Loss of one engine	Mission loss	Nozzle extension discrete (fully extended, fully retracted) Motor current	Test both primary and redundant drive mechanisms at maintenance cycle	Orbiter A(4) B(2B) C(2A)
No effect	No effect	No effect	Functional test at maint cycle	Effect could be inability to extend nozzle on next flight	Orbiter A(4) B(4) C(4)
Loss of redundancy	None	None	Lock position discrete motor current	--	Orbiter A(4) B(4) C(4)
Reduced film coolant flow inside nozzle, possible nozzle damage, possible engine loss	Possible loss of one engine	Possible mission loss	Lock position discrete motor current		Orbiter A(4) B(4) C(2A)
Loss of nozzle on reentry	Loss of nozzle	Reentry hazard	Lock position discrete nozzle position discrete Motor current	--	Orbiter A(4) B(4) C(1S)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.2 1 1 Oxidizer Feed Line - (Vacuum Jacketed) 4 2 1 1 Oxidizer Feed Lines (Vacuum Jacketed)	L-1A L-6A L-4B L-2A L-7A L-5B L-3A L-1B L-6B L-4A L-2B L-5A L-3B L-4A L-4B L-13A L-13B	Supplies LO_2 to AJ-400 main engines.	1) Minor leakage		Low
			2) Major leakage		Low
			3) Loss of vacuum in line		Medium
1 2 1 2 Oxidizer Prevalve 4.2 1 2 Oxidizer Isolation Valve	V-77A V-82A V-80B V-78A V-83A V-81B V-79A V-77B V-82B V-80A V-78B V-83B V-81A V-79B V-1A V-1B V-2A V-2B	Safety valve - isolates engine from oxidizer source	1) Fail open.		Low
			2) Fail closed		Low
			3) Fail to relieve at specified back pressure		Low
			4) Valve leaks past seat.		Medium

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 1 0 and 4 0

SUBSYSTEM 1 2 and 4 2

ASSEMBLY 1 2 1 and 4 2 1

SHEET 1 of 1

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
1) Negligible - create oxidizer rich atmosphere in vicinity of leak Subsystem volume capable of absorbing minor leakage	1) None	1) None	1) Hazardous gas detector	1) Engine compartment relief and purge	1) A(4) B(3) C(4)
2) Degraded performance associated main engine excessive oxidizer loss	2) Total performance grossly reduced	2) Probable mission termination	2) Engine inlet pressure measurement	2) Same as above	2) A(4) B(2B) C(1)
3) Loss of ability to maintain engine inlet conditions	3) Loss of engine	3) No effect on mission if only one booster engine is shutdown	3) Engine inlet temperature measurement	3) Burst disc should be installed to prevent implosion of the pressure carrier in the event of a high pressure condition in the annulus	3) A(4) B(2B) C(2A)
1) No direct effect due to required normally open condition for operational mode	1) No direct effect Secondary engine shut off capability impaired	1) No effect on mission performance	1) Valve position indicator	1) None	1) A(4) B(4) C(4)
2) Shutdown of affected engine	2) No performance degradation Remaining engines sequenced to emergency power level	2) No degradation to mission	2) Valve position indicator	2) None	2) A(4) B(2B) C(3)
3) No effect - valve opened by command or loss of power	3) No effect - redundant relief function	3) No effect	3) Pressure measurement downstream of valve	3) None	3) A(4) B(3) C(4)
4) No effect - engine valve used as shutoff mechanism	4) No effect - secondary shutoff system capability	4) No effect	4) Pressure measurement downstream of valve	4) None	4) A(4) B(4) C(4)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1 2 2.2 Oxidizer Isolation Valve	V-1A V-1B V-2A V-2B	Emergency LO_2 isolation at main tank (normally open).	1) Failed open. 2) Failed closed. 3) Fails to relieve at specified backpressure. 4) Leakage past valve seat 5) Major flange leakage	1) Failed open. 2) Failed closed. 3) Fails to relieve at specified back-pressure 4) Leakage past valve seat. 5) Major flange leakage	Low Low Low Medium Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 1 0
SUBSYSTEM 1 2

ASSEMBLY 1 2.2

SHEET 1 of 1

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
No effect - required to be open for operation	Postfiring tank isolation not possible	No effect	Valve position indicator	Delete component requirement for this valve	1) A(4) B(4) C(4)
Terminates approximately one half of the main LO_2 flow.	System partially operative main engines starved of oxidizer	Probable mission termination	Valve position indicator.	A higher design safety factor for the distribution line would eliminate the need for this component	2) A(4) B(3,2B) C(2A)
No effect - valve is opened electrically	No effect - redundant relief mode for system	None	Pressure measurement downstream of valve		3) A(4) B(4) C(4)
No effect	No functional effect emergency isolation of main tank propellant is compromised.	None	Pressure measurement downstream of valve	Same as above	4) A(4) B(4) C(4)
Loss of transferrable propellant	System partially operative main engines starved of oxidizer	Probable mission termination	Downstream pressure measurements		5) A(4) B(2B) C(2A)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1 2 4.2 Oxidizer Fill Valve 1 2 9.3 Fuel Fill Valve (Booster) 4.2.3.2 Oxidizer Fill Valve (Orbiter)	V-7A V-7B V-19A V-19B V-7	Provides positive shutoff for propellant full and drain Valve incorporates internal relief feature. Precluding overpressure condition between valve and fill coupling	1) Fails open, minor internal leakage, major internal leakage. 2) Fails closed 3) Major external leakage (upstream flange). 4) Major external leakage (downstream flange). 5) Fails to relieve at designed back pressure.		Low - medium Low Medium Low Low
1.2 4.3 Oxidizer Fill Coupling 1 2.8.2 Fuel Fill Coupling (Booster) 4 2.3.3 Oxidizer Fill Coupling (Orbiter)	C-1A C-1B C-5A C-5B C-1	Provides coupling for GSE fill line. Provides low level propellant loss capability during disconnection	1) Fails closed or minor internal leakage. 2) Major leakage, internal or external, fails open		Low - medium Low
1.2 3.2 Oxidizer Vent Valve 1 2 8.3 Fuel Vent Valve (Booster) 4 2.2.2 Oxidizer Vent Valve 4 2 7 3 Fuel Vent Valve (Orbiter)	V-3A V-16A V-5B V-4A V-17A V-6B V-5A V-18A V-15A V-6A V-3B V-16A V-15A V-4B V-17A V-18A V3, V4, V5, V6 V10, V11, V12, V13	Provide safety/prepressure control and automatic venting capability for the main propellant tank.	1) Fails open or internal leakage.		Low
				Fails open, internal leakage, or major leakage upstream of valve package	Very low
			2) Fails closed		Low
				Fails closed	Very low
1.2.8.2 Fuel Tank Vent Coupling (Booster) 4 2.7 2 Fuel Tank Vent Coupling (Orbiter	C-3A C-3B C-3	Provides rapid connection and disconnection between stage and ground vent system.	Structural failure only.		Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM: 1 0 & 4 0

SUBSYSTEM 1 2 & 4.2

ASSEMBLY 1.2.3, 1 2.4, 1 2.8, 1.2.9
4 2.3, 4.2.4, 4.2.8, 4.2.9

SHEET 1 of 1

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
1) No effect - checking mechanism of fill coupling maintains leak integrity 2) No effect - valve is normally closed during flight 3) No effect - upstream line inactive during flight 4) Subsystem operation impaired 5) No effect - coupling relief mechanism opens under overpressure	1) No effect due to shutoff redundancy of coupling check/shutoff mechanism 2) No effect 3) No effect 4) Degraded performance due to major loss of oxidizer 5) No effect	1) No effect 2) No effect 3) No effect 4) Mission flight termination 5) No effect	1) Valve position indicator 2) Valve position indicator 3) Valve position indicator 4) Pressure measurement downstream of valve 5) Pressure measurement downstream of valve	1) None 2) None. 3) None 4) None 5) Coupling design requires safety relief	1) A(4) B(4) C(4) 2) A(4) B(3) C(4) 3) A(4) B(3) C(4) 4) A(4) B(3) C(2A) 5) A(4) B(4) C(4)
1) No effect - no primary function in flight 2) No effect - fill valve provides positive propellant shutoff	1) No effect 2) No effect	1) No effect 2) No effect - relatively small quantity of propellants leak external to spacecraft	1) Position indicator 2) Position indicator for positive disconnect verification and coupling status	1) None 2) None	1) A(4) B(3) C(4) 2) A(4) B(3) C(4)
No effect due to series redundancy	No effect	No effect.	Position indicator	None	1) A(4) B(3) C(4)
Loss of tank pressure	System operation impaired System unable to maintain required propellant pressure Main engine becomes inoperative	Mission termination	Position indicator, propellant tank pressure measurement.	None	A(3) B(2B) C(1)
No effect due to parallel valve redundancy	No effect.	No effect	Position indicator	None	2) A(4) B(3) C(4)
Minimum operational effect	Possible hazard to propellant tanks	Possible mission termination	Tank pressure measurement	None.	A(4) B(2B) C(2A)
No effect	No effect	No effect	Position indicator for uncoupling verification	None	A(4) B(3) C(4)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.2 5 1 Main Booster Oxidizer Tank 1 2 10 1 Main Booster Fuel Tank 4.2.4.1 Main Orbiter Oxidizer Tank 4 2 9 1 Main Orbiter Fuel Tank	T-1A T-1B T-2A T-2B T1 and T2 T3	Contain and store propellant for main engine utilization. Also the booster oxidizer tank contains residual gas for the APS usage.	1) Minor external leakage. 2) Major external leakage		Low-medium Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM: 1.0 and 4.0

SUBSYSTEM 1.2 and 4.2

ASSEMBLY: 1.2.5 and 4.2.4; 1.2.7 and 4.2.6; 1.2.10 and 4.2.9

SHEET 1 of 1

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
None - subsystem volume capable of absorbing minor leakage Subsystem operation impaired	No effect, leakage too slight to cause fire hazard Fire hazard potential high Occurrence could drastically affect system operation Contingency supply of APS O_2 gas is depleted	No effect Immediate mission flight termination Hazard monitoring system required to operate	Hazardous gas analyzer in tank compartment Hazardous gas analyzer in tank compartment and tank pressure and quantity measurements	None Multi-gas analyzers	A(4) B(4) C(4) A(4) B(1) C(1)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.2 6.2 Helium Coupling	C2	Provide connection for ground supplied helium. The helium is circulated into the main oxidizer distribution line to initiate lox recirculation and geyser suppression.	1) Fails open.		Low
				Fails open.	Low
			2) Fails closed		Low
4 2.5.2 Helium coupling 4.2.5 3 Helium coupling	C-2 C-8	Provide coupling for ground supplied helium line The helium is ingested into the main oxidizer distribution line to initiate LO_2 recirculation and geysering suppression	1) Fails open or major internal leakage		Low
				Fails open or major internal leakage	Very low
			2) Fails closed		Low
			3) Internal leakage (major or minor)		Medium
				Internal leakage minor.	Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 1 0 and 4 0
SUBSYSTEM 1 2 and 4 2

ASSEMBLY: 1.2.6 and 4 2.5
SHEET 1 of 1

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
No effect - secondary check valve maintains subsystem integrity	No effect	No effect	Pressure measurement between CV for ground test	None	A(4) B(4) C(4)
Rapid loss of propellant through the coupling with possible stage fire	System inoperable due to loss of LO_2	Mission termination	Line pressure measurement and temperature measurement downstream of coupling	None	A(3) B(3) C(2A)
No effect - normally closed during flight	No effect	No effect	Same as above	None	A(4) B(4) C(4)
No effect - secondary check valve maintains subsystem integrity	No effect	No effect	Pressure transducer between check valves for ground test	None	A(4) B(4) C(4)
Rapid loss of propellant through coupling with possible stage fire	System degradation due to propellant loss	Mission termination	Position indicator for both valve poppets	None	A(3) B(3) C(2A)
No effect - normally closed during flight	No effect	No effect	Same as above	None	A(4) B(4) C(4)
No effect - series redundant checking feature	No effect	No effect	Pressure measurement between poppets for ground checkout	None	A(4) B(4) C(4)
No effect - subsystem volume capable of absorbing minor leakage but possible stage fire could exist if leakage was not stopped	No effect	No effect Minor leakage external to spacecraft	Same as above	None	A(4) B(3) C(4)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1.2.7.1 Fuel Feedline - (Booster)	L-13A L-18A L-16B L-14A L-19A L-17B L-15A L-13B L-18B L-16A L-14B L-19B L-17A L-15B	Supplies fuel to main engine.	1) Minor leakage.		Medium
4 2.6 1 Fuel Feedline (Orbiter)	L-8 and L-9		2) Major leakage.		Low
1 2 7.2 Fuel Isolation Valve (Booster)	V-8A V-13A V-11B V-9A V-14A V-12B V-10A V-8B V-13B V-11A V-9B V-14B V-12A V-10B	Fuel safety valve - isolates propellant from main engine.	1) Fails open		Low
4.2.6.2 Fuel Isolation Valve (Orbiter)	V-8 and V-9		2) Fails closed.		Low
			3) Fails to relieve at specified backpressure.		Low
			4) Valve internal leakage past seat.		Medium

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 1 0 and 4 0

SUBSYSTEM 1 2 and 4 2

ASSEMBLY 1 2.7 & 4 2 7

SHEET 1 of 1

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
1) No effect - subsystem capable of absorbing minor leakage	1) None - system protected by inert atmosphere in engine compartment	1) No effect	1) Hazardous gas detector	Provide engine compartment relief and purge	A(4) B(3) C(4)
2) Impaired subsystem performance Fuel starvation to adjacent main engine	2) Degraded system performance due to excessive loss of fuel	2) Probable mission termination	2) Pressure measurement and compartment hazardous gas detector	2) Same as above	A(4) B(2B) C(1)
1) No direct effect due to required open condition for operational mode	3) No direct effect Secondary engine shutoff capability impaired	3) No effect	3) Valve position indicator	3) None	A(4) B(3) C(4)
2) Engine controller senses LH_2 loss, initiating engine shutdown	4) No performance degradation Remaining engines sequenced to emergency power level	4) No mission impact	4) Valve position indicator	4) None	A(4) B(2B) C(4)
3) No effect during subsystem operation	5) No effect during system operation After thrust termination, the isolation valve is opened on command to relieve overpressure lockup	5) No effect	5) Pressure measurement downstream of valve	5) None	A(4) B(4) C(4)
4) No effect - engine valve acts as secondary shutoff	6) No effect Primary shutoff capability is afforded by main engine valve	6) No effect	6) Pressure measurement downstream of valve	6) None	A(4) B(4) C(4)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
1 3.1 3 Oxidizer Pressure Control Valve (Booster) 4 3.1.2 Oxidizer Pressure Control Valve (Orbiter) 1.3.1 7 Fuel Pressure Control Valve (Booster) 4.3.1.6 Fuel Pressure Control Valve (Orbiter)	V-20A V-20B V-21A V-21B V-19 V-20 V-22A V-22B V-23A V-23B V-21 V-22	Provides a step regulation of autogenous hydrogen and oxygen gas for tank pressurization	1) Fails open. 2) Fails closed 3) Leaks internally	1) Fails open 2) Leaks past seat	Low Low Low Low Low
1.3.1 4 Oxidizer Pressurant Filter (Booster) 4.3.1.4 Oxidizer Pressurant Filter (Orbiter) 1.3 1.8 Fuel Pressurant Filter (Booster) 4.3.1 8 Fuel Pressurant Filter (Orbiter)	F-1A F-1B F-2 F-2A F-2B F-3	Provides filtering of autogenous pressurant gas to preclude contamination of downstream control orifice	1) Filter clogs. 2) Filter ruptures. 3) External leakage. (minor)		Low Low Low
1 3.2.2 Helium Coupling - Oxidizer (Booster) 4 3.2.2 Helium Coupling - Oxidizer (Orbiter) 1 3 2.4 Helium Coupling - Fuel (Booster) 4.3 2 4 Helium Coupling - Fuel (Orbiter)	C-6A C-6B C-6 C-4A C-4B C-4	Connects GSE Helium supply for tankage pre-pressurization.	1) Fails closed 2) Fails open or major internal leakage		Low Low
				1) Fails open or major internal leakage (check valves).	Very low

FAILURE EFFECT ON SUBSYSTEM	FAILURE EFFECT ON SYSTEM	FAILURE EFFECT ON MISSION	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
No effect - series redundant valves Subsystem pressure operates at low end of pressure supply limits (This condition occurs at end of powered flight). Subsystem operates at upper end of pressurization band	No effect System operates at lower end of tank pressure band Propellant tank is at upper end of pressure operating limit Vent valve operation to relieve tank if required	No effect No effect. No effect No effect No effect	Valve position indicator Valve position indicator and tank ullage pressure	None None None None None	1) A(4) B(4) C(4) 2) A(4) B(4) C(4) 3) A(4) B(4) C(4)
Decrease in tank pressure Contamination of downstream components No effect	System forced to operate out-of-limits Tank pressure loss Potential fire hazard	Probable loss of mission Probable termination of mission If leakage is high enough - mission could be aborted	ΔP transducer across filter ΔP transducer across filter Gas detector in area or bay containing filter	Filter should be designed to blow out under high ΔP conditions None	1) A(4) B(4) C(2A) 2) A(4) B(4) C(2A) 3) A(4) B(4) C(1)
1) No flight effect but unable to load helium if ground failure occurs 2) No effect due to series redundant check valve	No effect No effect	No effect No effect	Position indicator Position indicator	Provide ground pressure measurement between check valve sections Provide ground pressure measurement between check valve sections	1) A(4) B(3) C(4) 2) A(4) B(3) C(4)
Excessive loss of pressurant gas	System failure due to tank pressure loss	Probable termination of mission	Pressure transducer in autogenous line, downstream	None	A(4) B(4) C(2A)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
4.4.1.1 Oxidizer Distribution Line	L-17 L-18	Ducting for transmittal of liquid oxygen.	Structural (fatigue causing leakage)		Low
4 4 1 2 Oxidizer Isolation Valve	V-23	Controls liquid oxygen fill and drain for the on-orbit LO_2 tank.	1) Fail open. 2) Fail closed. 3) Fail to relieve at specific back pressure 4) Internal leakage 5) External leakage		Low Low Medium Low Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 4 0
SUBSYSTEM 4 4
ASSEMBLY 4 4 1
SHEET 1 of 1

FAILURE EFFECT ON: SUBSYSTEM	FAILURE EFFECT ON: SYSTEM	FAILURE EFFECT ON: MISSION	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
L-17 no effect after loading L-18 loss of tank pressure	L-17 no effect L-18 decrease in pressure and flowrate supplied to propellant conditioning system	Decrease in performance of APS system	Monitor line pressure	None	A(1) B(2B) C(1)
1) No effect - propellant stopped at main engine valve 2) No effect 3) No effect - pressure can be relieved through main LO_2 tank isolation valve 4) No effect - propellant stopped at main engine valve 5a) Loss of tank pressure 5b) Possible fire hazard if fuel is present in compartment	1) No effect 2) Automatic shutdown of main engine if on-orbit tank is being used as supply 3) No effect 4) No effect 5) Decrease in pressure and flowrate supplied to propellant conditioning system No effect - Compartment purge capable of handling limited leakage	1) No effect 2) Mission would be terminated 3) No effect 4) No effect 5) Decrease in APS performance No effect	1) Monitor valve position 2) Monitor valve position 3) Pressure measurement downstream of valve 4) None 5a) Monitor on-orbit tank pressure 5b) Hazardous gas detector in closed compartment	1) None 2) None 3) None 4) None 5a) None 5b) None	1) A(4) B(3) C(4) 2) A(1) B(2B) C(1) 3) A(4) B(3) C(4) 4) A(4) B(3) C(4) 5a) A(1) B(2B) C(1) 5b) A(4) B(3) C(3)

☐ Effect on external subsystems.

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
4.4 2 2 Oxidizer Vent Heat Exchanger	H-1	Provide cooling of tank suction line during vent to compensate for heat leak into tank	1) Major external leakage. 2) Restricts flow of gas during vent.		Low Low
4.4 2.1 Oxidizer Tank Vent Valve*	V-24 V-25	Permit overboard vent of propellant tank ullage gas. Isolate airborne system from ground system.	1) Valve fails closed. 2) Valve fails open or leaks internally	2R) Valve fails open or leaks internally	1) Medium 2) Low

*Critical component.

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 4 0
SUBSYSTEM 4 4
ASSEMBLY 4.4 2
SHEET 1 of 1

FAILURE EFFECT ON SUBSYSTEM	FAILURE EFFECT ON SYSTEM	FAILURE EFFECT ON MISSION	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
1) Contamination of subsystem compartment with GO_2 2) Vent rate capability reduced	1) No effect 2) Propellant tank pressure relief rate reduced	1) No effect on crew safety or primary mission objective 2) No effect on crew safety or primary mission objective	1) Measure subsystem compartment pressure 2) Monitor tank vent rate or measure pressure loss across heat exchanger	1) None 2) None	1) A(3) B(4) C(3) 2) A(3) B(4) C(3)
1) Vent assembly rendered useless for propellant tank pressure relief 2) No effect 2R) Overboard loss of pressurization gas subsystem cannot be isolated.	1) Potential for over-pressurization of on-orbit propellant tank exists 2) No effect 2R) Impossible to pressurize on-orbit propellant tank	1) Major effect on crew safety and primary mission objective 2) No effect on crew safety or primary mission objective 2R) Major effect on primary mission objective - no effect on crew safety	1) Valve position switch 2) Valve position switch 2R) Valve position switch	1) Redesign valve system to parallel-series configuration 2), 2R) Provide pressure measurement between series redundant valves for single point failure detection	1) A(2A,1) B(3) C(2A,1) 2) A(3) B(4) C(3) 2R) A(2A) B(3) C(2A)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
4.4 3 1 Oxidizer Tank 4.4.6 1 Fuel Tank	T-4 T-5 T-6	1) Contain and store propellants for main engine contingency supply 2) Contain and store propellants for APS on-orbit usage and A/B-S reentry landing engines.	Minor external leakage.		Low-medium
			Major external leakage (oxidizer tank).		Very low.
			Major external leakage (fuel tank).		Very low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM. 4 0

SUBSYSTEM 4.4

ASSEMBLY: 4.4.3 and 4 4 6

SHEET 1 of 1

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
None - Subsystem volume capable of absorbing minor leakage	Fire hazard possible	No effect	Hazardous gas analyzer in tank compartment	Provide compartment purge for all closed compartments	A(4) B(4) C(4)
Subsystem operation impaired, fire hazard potential high	Occurrence could drastically affect system operation Resupply for ACPS on accumulators is terminated	Immediate mission termination	Hazardous gas analyzer in tank compartment requires propellant tank pressure and quantity measurements.	Same as above	A(2A) B(2B) C(1 ,2A)
Same as above	Same as above Resupply for ACPS H_2 accumulators terminated LH_2 supply for ABS engines is not available	Immediate mission termination.	Same as above	Same as above	A(2A) B(2B) C(1 ,2A)

Effect on external subsystem

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
4 4 4 2 Fuel Isolation Valve*	V-26 V-27	Isolate contingency fuel supply from main engines	1) Valve fails open during main engine operation 2) Fail to relieve at specific back pressure 3) Internal leakage. 4) External leakage. 5) Fails closed 6) Valve fails open after main engine burn.		1) Very low 2) Low 3) Medium 4) Low 5) Low 6) Low
* = Critical component.					

FAILURE MODE AND EFFECTS ANALYSIS

[ ] INTERFACE WITH SUBSYSTEM

SYSTEM 4 0

SUBSYSTEM 4 4

ASSEMBLY: 4.4.4

SHEET 1 of 1

FAILURE EFFECT ON: SUBSYSTEM	FAILURE EFFECT ON: SYSTEM	FAILURE EFFECT ON: MISSION	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
1) Propellant would be exhausted 2) No effect 3) Possible loss of contingency fuel supply 4) Loss of tank pressure Fire hazard in tank compartment 5) Loss of fuel supply capability 6) Some loss of fuel	1) A/B propellant would be depleted if main engine burn is continued. 2) No effect - pressure would be relieved into main fuel tank 3) Possible loss of some A/B fuel 4) Decrease in pressure and flowrate supplied to propellant conditioning system Fire hazard 5) Loss of contingency fuel supply 6) LH_2 would be introduced into the main propulsion system propellant lines	1) Mission is terminated 2) No effect 3) Possible loss of mission objectives 4) Decrease in APS performance None unless oxidizer leakage present Compartment is purged 5) Primary mission objectives jeopardized 6) Possible reduction of mission objectives	1) Valve position indicator 2) Line pressure measurement 3) On-orbit tank pressure measurement and line temperature downstream of valve 4) Monitor on-orbit tank pressure Hazardous gas detector 5) Position indicator 6) Temperature sensor in line downstream of valve	1) Redesign system such that on-orbit tanks are isolated from main tankage Alternative - Place on-orbit tanks in series with main fuel tank 2) None 3) None 4) Provide purge capability for all closed compartments 5) None 6) None	1) A(3) B(2B) C(2A) 2) A(4) B(4) C(4) 3) A(3) B(2B) C(3) 4) A(3) B(3) C(3) 5) A(4) B(3) C(3) 6) A(4) B(3) C(3)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
4.4.5.2 Fuel Tank Vent Valve*	V-28 V-29 V-30 V-31	Provides controlled venting and automatic overpressure relief for the on orbit main propellant fuel tank.	Fails open.		Low
				Fails open.	Very low.
			Fails closed.		Low
				Fails closed	Very low.
4.4.5.4 Fuel Vent Line Coupling	C-11	Provides ground coupling capability for fuel tank vent.	Leaks externally.		Low

*Critical component.

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 4 0
SUBSYSTEM 4.4

ASSEMBLY- 4.4.5

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
No effect due to series redundancy.	No effect	No effect	Position indicator	None	A(4) B(2B) C(4)
Loss of tank pressurization capability.	Degraded system operation Resupply for ACPS H_2 accumulators hampered. LH_2 supply to ABS engines is terminated.	Mission termination	Valve position indicators propellant tank pressure and quantity measurements	None	A(2A) B(2B) C(2A, 1S)
No effect due to parallel redundancy	No effect	No effect	Position indicator	None	A(4) B(3) C(4)
Normal tank venting capacity impaired	Automatic relief of propellant tank is lost Backup method of relieving tank pressure could be employed by opening propellant isolation valves and venting thru main tank	Immediate termination of flight	Position indicator and tank pressure measurement	None	A(2A) B(2B) C(2A)
No effect-coupling does not have a poppet Coupling is normally open in flight	No effect	No effect.	Position indicator for proper decoupling verification	None	A(4) B(3) C(4)

[ ] Effect On External Subsystem

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
4.5.1.2 Oxidizer Tank Pressurization Line Filter 4.5.1.6 Fuel Tank Pressurization Line Filter	F-4	Remove particles and/or contaminants before gas reaches the regulator package.	Filter becomes clogged, resulting in filter rupture.		Very low.
4.5.1.3 Oxidizer Tank Pressurization Regulator* 4.5.1.7 Fuel Tank Pressurization Regulator*	R-5 thru R-8 R-9 thru R-12	Reduces supply pressure to regulated tank pressure.	Fails open or fails to regulate.		Medium
				Fails open or fails to regulate.	Low
			Fails closed.		Low
				Fails closed.	Low
4.5.1.4 Oxidizer Tank Pressurization Valve 4.5.1.8 Fuel Tank Pressurization Valve	V-32 V-33 V-34 V-35	Provides positive isolation of high pressure gas from low-pressure subsystem.	Fails open or leaks internally. Fails closed.		Low to medium. Low
				Fails closed.	Very Low

*Critical component.

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Possible reduction in pressurant flowrate and contamination of downstream regulators.	Possible reduction of on-orbit tank pressure.	Could cause mission termination	Downstream pressure measurement	Design features should include filter blowout provisions into one bank of controlling regulators.	A(2A) B(4) C(2A)
No effect due to regulator series redundancy	No effect	No effect.	Operating pressure bank selected for detection	None	A(4) B(3) C(4)
Overpressure condition downstream of regulators.	Tanks pressure at upper limits - tank vent relieves.	Flight termination	Downstream pressure measurement	None	A(2A) B(2B) C(1 , 2A)
No effect due to parallel redundancy	No effect	No effect.	Operating pressure band selection	None	A(4) B(3) C(4)
Pressurization to on-orbit propellant tank, terminated	System ability to supply propellant to APS and A/B impaired.	Immediate flight termination	Tank pressure measurement.		A(1 ,2A) B(2B) C(1 ,2A)
Pressure regulators operate to maintain required pressure.	No effect.	No effect	Valve position indicators.	None	A(4) B(3) C(4)
No effect due to valve (parallel) redundancy	No effect.	No effect	Valve position indicator	None	A(4) B(2B) C(4)
Pressurization to on-orbit propellant tank - terminated.	System ability to supply propellants to APS and A/B impaired	Immediate flight termination	Propellant tank pressure measurement.	None	A(1 ,2A) B(2B) C(1 ,2A)

[box] Effect On External Subsystem

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
Propellant Inlet Manifold	None.	Distribute fuel and oxidizer to the coaxial injector.	Cracking due to thermal fatigue or vibration.		Low
Coaxial Injector	None.	Inject fuel and oxidizer into the thrust chamber in such a manner as to achieve complete mixing for combustion.	Cracking due to thermal fatigue or vibration.		Low
			Clogging of injectors due to propellant contaminants.		Low
Thrust Chamber	TC-1 TC-20 TC-2 TC-21 TC-3 TC-22 TC-4 TC-23 TC-5 TC-24 TC-6 TC-25 TC-7 TC-26 TC-8 TC-27 TC-9 TC-28 TC-10 TC-29 TC-11 TC-30 TC-12 TC-31 TC-13 TC-32 TC-14 TC-33 TC-15 TC-34 TC-16 TC-35 TC-17 TC-36 TC-18 TC-37 TC-19 TC-38	Contain combustion gas and accelerate the gas through a converging-diverging nozzle to produce thrust.	Cracking due to thermal fatigue or vibration.		Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 2.0, 5.0
SUBSYSTEM 2.1, 2.5, 5.1, 5.4

ASSEMBLY 2.1.1, 2.5.1, 5.1.1, 5.4.1
SHEET 1 of 1

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Possible pre-mixing of propellants with resulting fire or explosion hazard. Failed thruster must be isolated. Possible loss of one level of redundancy	No effect.	Possible effect on crew safety or primary mission objective.	Measure igniter chamber pressure, visual inspection.	Perform scheduled visual inspection during maintenance.	Booster A(4) B(4) C(3) Orbiter A(4) B(4) C(3)
Improper mixing of propellants with resulting combustion instability or thrust chamber burnthrough. Failed thruster must be isolated Possible loss of one level of redundancy.	No effect	No effect on crew safety or primary mission objective.	Measure igniter chamber pressure, visual inspection.	Perform scheduled visual inspection during maintenance.	Booster: A(4) B(4) C(4) Orbiter: A(4) B(4) C(4)
Improper mixing of propellants with resulting combustion instability or thrust chamber burnthrough. Failed thruster must be isolated Possible loss of one level of redundancy.	No effect	No effect on crew safety or primary mission objective	Measure igniter chamber pressure, visual inspection.	Perform scheduled visual inspection during maintenance.	Booster: A(4) B(4) C(4) Orbiter: A(4) B(4) C(4)
Possible hot gas external leak and/or burnthrough Possible loss of performance Failed thruster must be isolated. Possible loss of one level of redundancy	No effect	No effect on crew safety or primary mission objective	Measure igniter chamber pressure, visual inspection	Perform scheduled visual inspection during maintenance.	Booster: A(4) B(4) C(4) Orbiter: A(4) B(4) C(4)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
Igniter Fuel Valve	None	Provide fuel to igniter chamber in response to 28 vdc command. Fail closed on loss of power.	Valve fails to open or close prematurely.		Low
			Valve opens slowly.		Low
			Valve fails to close or closes slowly.		Low
Igniter Oxidizer Valve	None	Provide oxidizer to igniter chamber in response to 28 vdc command. Fail closed on loss of power.	Valve fails to open or closes prematurely		Low
			Valve opens slowly.		Low
			Valve fails to close or closes slowly.		Low
Spark Plug	None	Provide controlled spark gap for high voltage discharge to ignite propellants.	Short to ground or wear causing excessive gap.		Medium

3 ⊕

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 2.0, 5 0
SUBSYSTEM 2.1, 2.5, 5.1, 5.4

ASSEMBLY 2.1.2, 2.5.2, 5.1.2, 5.4.2
SHEET 1 of 2

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Failure to achieve thrust with selected thruster. Failed thruster must be isolated Possible loss of one level of redundancy.	No effect	No effect on crew safety or primary mission objective.	Measure igniter chamber pressure	None	Booster A(4) B(4) C(4) Orbiter: A(4) B(4) C(4)
Failure to achieve thrust with selected thruster. Possible ignition chamber burnout. Failed thruster must be isolated Possible loss of one level of redundancy.	No effect	No effect on crew safety or primary mission objective.	Measure igniter chamber pressure.	None	Booster A(4) B(4) C(4) Orbiter: A(4) B(4) C(4)
Overboard loss of propellant. Failed thruster must be isolated. Possible loss of one level of redundancy.	No effect.	No effect on crew safety or primary mission objective.	Measure igniter chamber pressure.	None	Booster. A(4) B(4) C(4) Orbiter A(4) B(4) C(4)
Failure to achieve thrust with selected thruster Failed thruster must be isolated. Possible loss of one level of redundancy.	No effect.	No effect on crew safety or primary mission objective	Measure igniter chamber pressure	None.	Booster: A(4) B(4) C(4) Orbiter A(4) B(4) C(4)
Failure to achieve thrust with selected thruster Failed thruster must be isolated. Possible loss of one level of redundancy	No effect.	No effect on crew safety or primary mission objective.	Measure igniter chamber pressure.	None	Booster A(4) B(4) C(4) Orbiter: A(4) B(4) C(4)
Possible ignition chamber burnout and/or overboard loss of propellant. Failed thruster must be isolated. Possible loss of one level of redundancy	No effect.	No effect on crew safety or primary objective.	Measure igniter chamber pressure	None.	Booster A(4) B(4) C(4) Orbiter. A(4) B(4) C(4)
Failure to achieve thrust with selected thruster. Possible overboard loss of propellants. Failed thruster must be isolated. Possible loss of one level of redundancy.	No effect.	No effect on crew safety or primary objective	Measure igniter chamber pressure	None	Booster: A(4) B(4) C(4) Orbiter A(4) B(4) C(4)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
Spark Cable	None	Conduct high voltage pulses from exciter to spark plug.	Short to open circuit.		Low
Exciter	None	Convert 28 vdc input to 30,000 volts at 250 pps output for spark ignition.	Fails to produce pulses or produces low level pulses only.		Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 2.0, 5.0

SUBSYSTEM 2.1, 2.5, 5.1, 5.4

ASSEMBLY: 2.1.2, 2.5.2, 5.1.2, 5.4.2

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Failure to achieve thrust with selected thruster Possible overboard loss of propellants Failed thruster must be isolated Possible loss ot one level of redundancy	N- effect.	No effect on crew safety or primary mission objective.	Measure igniter chamber pressure.	None	Booster: A(4) B(4) C(4) Orbiter: A(4) B(4) C(4)
Failure to achieve thrust with selected thruster. Possible overboard loss of-propellants Failed thruster must be isolated. Possible loss of one level of redundancy.	No effect	No effect on crew safety or primary mission objective.	Measure igniter chamber pressure.	None	Booster: A(4) B(4) C(4) Orbiter: A(4) B(4) C(4)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
Bi-Propellant Main Thrust Chamber Valve	FV-1 OV-1 FV-2 OV-2 FV-3 OV-3 FV-4 OV-4 FV-5 OV-5 FV-6 OV-6 FV-7 OV-7 FV-8 OV-8 FV-9 OV-9 FV-10 OV-10 FV-11 OV-11 FV-12 OV-12 FV-13 OV-13 FV-14 OV-14 FV-15 OV-15 FV-16 OV-16 FV-17 OV-17 FV-18 OV-18 FV-19 OV-19 FV-20 OV-20 FV-21 OV-21 FV-22 OV-22 FV-23 OV-23 FV-24 OV-24 FV-25 OV-25 FV-26 OV-26 FV-27 OV-27 FV-28 OV-28 FV-29 OV-29 FV-30 OV-30 FV-31 OV-31 FV-32 OV-32 FV-33 OV-33 FV-34 OV-34 FV-35 OV-35 FV-36 OV-36 FV-37 OV-37 FV-38 OV-38	Provide on-off control of oxid and fuel to thrust chamber in response to 28 vdc input command. Fail closed on loss of power.	Fails to open.		Low
			Opens too slowly.		Low
			Fails to close or closes too slowly.		Low
			Closes prematurely.		Low
			Oxid or fuel valve fails to open (linkage failure).		Low
			Oxid valve fails to close on shutdown.		Low
			Fuel valve fails to close on shutdown.		Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 2.0, 5.0
SUBSYSTEM 2.1, 2.5, 5.1, 5.4

ASSEMBLY: 2.1.3, 2.5.3, 5.1.3, 5.4.3

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Failure to achieve thrust with selected thruster. Failed thruster must be isolated Possible loss of one level of redundancy	No effect.	No effect on crew safety or primary mission objective.	Measure igniter chamber pressure.	None.	Booster: A(4) B(4) C(4) Orbiter: A(4) B(4) C(4)
Depending upon delay, subsystem may isolate selected thruster Possible loss of one level of redundancy	No effect.	No effect on crew safety or primary mission objective.	Measure igniter chamber pressure.	None.	Booster: A(4) B(4) C(4) Orbiter: A(4) B(4) C(4)
Extended burn possible. Loss of shutoff redundancy. Failed thruster must be isolated.	Possible corrective command from guidance and navigation.	No effect on crew safety or primary mission objective	Measure igniter chamber pressure	None.	Booster: A(4) B(4) C(4) Orbiter: A(4) B(4) C(4)
Premature loss of thrust. Failed thruster must be isolated	Possible corrective command from guidance and navigation.	No effect on crew safety or primary mission objective.	Measure igniter chamber pressure.	None.	Booster: A(4) B(4) C(4) Orbiter: A(4) B(4) C(4)
Fails to achieve thrust with selected thruster. Failed thruster must be isolated with possible loss of one level of redundancy.	No effect.	No effect on crew safety or primary mission objective.	Measure igniter chamber pressure.	None	Booster: A(4) B(4) C(4) Orbiter: A(4) B(4) C(4)
Slightly extended burn time. Possible injector burnout. Failed thruster must be isolated with possible loss of one level of redundancy	No effect.	No effect on crew safety or primary mission objective.	Measure igniter chamber pressure	None.	Booster: A (4) B (4) C (4) Orbiter: A (4) B (4) C (4)
Slightly extended burn time. Failed thruster must be isolated with possible loss of one level of redundancy.	No effect.	No effect on crew safety or primary mission objective.	Measure igniter chamber pressure.	None.	Booster: A(4) B(4) C(4) Orbiter: A(4) B(4) C(4)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
Bi-Propellant Isolation Valve	FV-1 OV-1 FV-2 OV-2 FV-3 OV-3 FV-4 OV-4 FV-5 OV-5 FV-6 OV-6 FV-7 OV-7 FV-8 OV-8 FV-9 OV-9 FV-10 OV-10 FV-11 OV-11 FV-12 OV-12 FV-13 OV-13 FV-14 OV-14 FV-15 OV-15 FV-16 OV-16 FV-17 OV-17 FV-18 OV-18 FV-19 OV-19 FV-20 OV-20 FV-21 OV-21 FV-22 OV-22 FV-23 OV-23 FV-24 OV-24 FV-25 OV-25 FV-26 OV-26 FV-27 OV-27 FV-28 OV-28 FV-29 OV-29 FV-30 OV-30 FV-31 OV-31 FV-32 OV-32 FV-33 OV-33 FV-34 OV-34 FV-35 OV-35 FV-36 OV-36 FV-37 OV-37 FV-38 OV-38	Provide positive shutoff of propellant to individual thrusters. Provide on-off control of propellants to igniter valves and bi-propellant control valve. Fail closed on loss of power.	Failure to open prior to thruster use.		Low
			Failure to close after thruster usage.		Low
			Valve opens slowly.		Low
			Valve closes slowly.		Low
			Valve closes prematurely.		Low
			One valve fails to open (either oxid or fuel). Structural failure.		Low
			One valve closes prematurely A. Before operation. B. During operation.		Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 2.0, 5.0

SUBSYSTEM 2.1, 2.5, 5.1, 5.4

ASSEMBLY 2.1.3, 2.5.3, 5.1.3, 5.4.3

FAILURE EFFECT ON: SUBSYSTEM	SYSTEM	MISSION	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
Selected thruster rendered inoperative. Failed thruster must be isolated with possible loss of one level of redundancy.	No effect.	No effect on crew safety or primary mission objective	Measure igniter chamber pressure or valve position.	None	Booster A(4) B(3) C(4) Orbiter A(4) B(3) C(4)
Thruster cannot be isolated.	No effect.	No effect on crew safety or primary mission objective.	Measure valve position.	Bleed off system at safing or prior to reentry.	Booster A(4) B(4) C(4) Orbiter A(4) B(4) C(4)
No effect.	No effect.	No effect on crew safety or primary mission objective	Measure valve position.	None.	Booster. A(4) B(4) C(4) Orbiter. A(4) B(4) C(4)
No effect.	No effect	No effect on crew safety or primary mission objective.	Measure valve position.	None.	Booster. A(4) B(4) C(4) Orbiter A(4) B(4) C(4)
Loss of thrust in selected thruster. Failed thruster must be isolated with possible loss of one level of redundancy	No effect.	No effect on crew safety or primary mission objective.	Measure valve position.	None.	Booster A(4) B(4) C(4) Orbiter A(4) B(4) C(4)
Selected thruster rendered inoperative. Thruster cannot be isolated.	No effect.	No effect on crew safety or primary mission objective.	Measure igniter chamber pressure.	None	Booster A(4) B(3) C(4) Orbiter A(4) B(3) C(4)
A. Failure to achieve thrust. B. If fuel valve, loss of thrust, probable high M.R. and thruster damage If oxid valve, loss of thrust, failed thruster must be isolated with possible loss of one level of redundancy.	No effect	No effect on crew safety or primary mission objective.	Measure igniter chamber pressure.	This mode of failure is rather remote.	Booster A(4) B(4) C(4) Orbiter A(4) B(4) C(4)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
2.2.1.1 & 5 2 1.1 Accumulator Tankage	T-4 T-5 T-6 T-7 T-8 T-9 T-10 T-11	Receive GO_2 and GH_2 propellants for storage at approximately 1500 psia and 500°R to minimize conditioning equipment restarts.	1) Major external leakage 2) Minor external leakage		1) Low 2) Low
2 2 1 2 & 5.2.1.2 Filter	F-4 F-5 F-6 F-7 F-8 F-9 F-10 F-11	Remove particulate contaminants from gaseous propellants upon expulsion from accumulators	1) Flow path through filter element obstructed 2) Major external leakage. 3) Minor external leakage		1) Low 2) Low 3) Medium
2.2 1.3 & 5 2 1.3 Pressure Regulator	R-5 R-18 R-31 R-6 R-19 R-32 R-7 R-20 R-33 R-8 R-21 R-34 R-9 R-22 R-35 R-10 R-23 R-36 R-11 R-24 R-12 R-25 R-13 R-26 R-14 R-27 R-15 R-28 R-16 R-29 R-17 R-30	Reduce accumulator supply pressure from 1500 psia to pressure levels commensurate with flow rate requirements for APS thrusters	1) Fails open or fails to to regulate. 2) Fails closed.		1) Medium 2) Low
				1) Fails open or fails to regulate 2) Fails closed.	1) Low 2) Low
2 2 1.4 & 5.2.1.4 Solenoid Valve	V-29 V-42 V-30 V-43 V-31 V-44 V-32 V-33 V-34 V-35 V-36 V-37 V-38 V-39 V-40 V-41	Admit regulated propellants to propellant feed assembly.	1) Valve fails to open. 2) Valve fails to close or leaks internally.		1) Medium 2) Low
				1) Valve fails to open. 2) Valve fails to close or leaks internally.	1) Medium 2) Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 2.0 & 5 0
SUBSYSTEM 2 2 & 5 2

ASSEMBLY 2 2 1 / 5 2 1
SHEET 1 of 1

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
1) *Contamination of subsystem* compartment Pressure loss of affected assembly and all interconnected assemblies with time 2) Same as above	1) Performance degradation or complete system operability loss 2) Same as above	1) Major effect on crew safety and primary mission objective 2) Same as above	Measure accumulator pressure and subsystem compartment pressure	Include accumulator isolation valves and bypass lines to permit isolation of failed accumulator and maintain complete system operation or establish safety factor greater than that required for normal operating equipment	1) A(2A) B(2B) C(2A) 2) A(2A) B(2B) C(2A)
1) Propellant delivery capability to affected engine subsystems reduced 2) Contamination of subsystem compartment Pressure loss of affected assembly and all interconnected assemblies with time 3) Same as above	1) Performance degradation of affected engine subsystems 2) Performance degradation or complete system operability loss 3) Same as 2) above	1) Major effect on crew safety and primary mission objective 2) Same as 1) above 3) Same as 1) above	1) Measure pressure drop across filter 2) Perform periodic leak checks 3) Same as 2) above	None	1) A(2A) B(3) C(2A) 2) A(2A) B(3) C(2A) 3) A(3) B(4) C(3)
1) No effect 2) No effect	1) No effect 2) No effect	1) No effect on crew safety or primary mission objective 2) No effect on crew safety or primary mission objective	1) Monitor pressure regulator band width 2) Measure downstream pressure	None	1) A(4) B(4) C(4) 2) A(4) B(4) C(4)
1) Possible overpressurization of affected ACS thrusters 2) Assembly rendered useless for delivery of propellants to affected thrusters	1) ACS thruster performance degraded Possible thruster loss due to explosion or fire 2) Complete loss of affected thruster modules	1) Major effect on crew safety and primary mission objective 2) Major effect on crew safety and primary mission objective	1) Monitor pressure regulator band width 2) Measure downstream pressure	None	1) A(2A) B(3) C(2A) 2) A(2A) B(4) C(2A)
1) No effect 2) Assembly cannot be isolated	1) No effect 2) No effect	1) No effect on crew safety or primary mission objective 2) Same as 1) above	Valve position switch, Measure pressure downstream of valve	Perform valve cycle and leak test.	1) A(3) B(4) C(3) 2) A(3) B(4) C(3)
1) Assembly rendered useless for delivery of propellants to affected thrusters 2) Assembly cannot be isolated	1) Complete loss of affected thruster modules 2) No effect	1) Major effect on crew safety or primary mission objective 2) No effect on crew safety or primary mission objective	Same as 1) above		1) A(2A) B(3) C(2A) 2) A(3) B(4) C(3)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
2 2.2.1 & 5.2.2 1 Quick Disconnect Coupling	C-8 C-9 C-10	Allow connection of ground lines for loading and unloading GO_2 and GH_2 propellants.	1) Coupling restricts propellant inflow and outflow. 2) Major external leakage. 3) Minor external leakage.		1) Low 2) Medium 3) Medium
2.2 2 2 & 5 2 2 2 Solenoid Valve	V-79 V-80 V-44 V-70	Admit GO_2 and GH_2 propellants to fill lines Isolate airborne system from ground loading system.	1) Valve fails to open 2) Valve fails to close or leaks internally		1) Low 2) Medium
2.2 2.3 & 5.2.2.3 Relief Valve	V-25 V-27 V-45 V-71	Preclude overpressurization of auxiliary propulsion system.	1) Relieves at too low pressure 2) Relieves at too high pressure 3) Major external leakage. 4) Minor external leakage		1) Low 2) Low 3) Low 4) Medium
2.2.2.4 & 5 2.2.4 Manual Valve	V-26 V-28 V-67 V-68	Permit manual relief capability to auxiliary propulsion system	1) Valve fails closed. 2) Valve fails open or leaks internally		1) Low 2) Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 20 & 50
SUBSYSTEM 2.2 & 5 2

ASSEMBLY 2.2.2 / 5 2.2

SHEET 1 of 1

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
1) Propellant loading and unloading rates reduced 2) No effect 3) No effect	1) No effect 2) No effect 3) No effect	1) No effect on crew safety or primary mission objective 2) Same as above. 3) Same as above	Measure pressure drop across coupling Perform leak checks	None	1) A(4) B(4) C(4) 2) A(4) B(4) C(4) 3) A(4) B(4) C(4)
1) Propellants cannot be loaded or unloaded 2) No effect	1) System rendered inoperable 2) No effect	1) Major effect on primary mission objective, no effect on crew safety 2) No effect on crew safety or primary mission objective	1) Valve position switch 2) Valve position switch provide pressure tap between series redundant valves for single point failure detection	1) None 2) Perform valve cycle and leak test	1) A(2B) B(4) C(2B) 2) A(3) B(4) C(3)
1) Accumulator pressures below operating requirements 2) Accumulator pressures above operating requirements 3) Accumulator pressure decay with time 4) Accumulator pressure decay with time	1) Performance degraded due to low accumulator pressures 2) Safety margin reduced Potential for rupture or leak of components increased 3) Overboard propellant loss resulting in eventual loss of system 4) Overboard propellant loss resulting in eventual loss of system	1) Possible effect on crew safety and primary mission objective 2) Major effect on crew safety and primary mission objective 3) Same as 2) above 4) Same as 2) above	1) None 2) None 3) Perform leak test 4) Perform leak test		1) A(3) B(4) C(3) 2) A(2A,1S) B(1S) C(2A,1S) 3) A(2A,1S) B(4) C(2A,1S) 4) A(3) B(4) C(3)
1) Accumulator pressure cannot be relieved manually 2) Accumulator pressure decay with time	1) No effect 2) Overboard propellant loss resulting in eventual loss of system operability	1) No effect on primary mission objective or crew safety 2) Major effect on crew safety and primary mission objective	1) Perform valve cycle test 2) Perform leak test and valve cycle test		1) A(3) B(4) C(3) 2) A(2A) B(3) C(2A)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
2.3.1.1 Turbine *	U-1 U-2 U-3	Convert gas generator thrust to rotating power and transmit to power train	1) Turbine fails to rotate at required RPM. 2) Turbine fails to rotate		1) Low 2) Low
2 3.1.2 Power Train *	PT-1 PT-2 PT-3	Transmit turbine power to pump.	Power linkage fails.		Low
2 3 1 3 Pump *	P-1 P-2 P-3	Receive liquid hydrogen at 20 psia, boost to accumulator pressure or A/B engine system pressure, and deliver to heat exchangers or A/B propellant distribution lines	1) Major external leakage due to seal failure. 2) Impeller fails to rotate at required RPM. 3) Impeller fails to rotate.		1) Medium 2) Low 3) Low
2 3.1.4 Solenoid Valve	V-90 V-91 V-92 V-93 V-94 V-63	Admit liquid hydrogen into suction side of pump	1) Valve fails to open. 2) Valve fails to close or leaks internally.		1) Medium 2) Low
				1) Valve fails to open. 2) Valve fails to close or leaks internally	1) Medium 2) Low
2.3.1 5 Check Valve	V-64 V-65 V-66 V-67 V-68 V-69	Insure unidirectional flow of liquid hydrogen from discharge side of pump. Preclude reverse flow of gaseous and/or liquid hydrogen in system during A/B engine start	1) Valve fails to open. 2) Valve fails to close or leaks internally		1) Low 2) Low
				1) Valve fails to open. 2) Valve fails to close or leaks internally.	1) Low 2) Medium

* Critical component

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 2 0
SUBSYSTEM 2 3

ASSEMBLY: 2 3.1
SHEET 1 of 2

FAILURE EFFECT ON SUBSYSTEM	FAILURE EFFECT ON SYSTEM	FAILURE EFFECT ON MISSION	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
1) Insufficient power delivered to pump resulting in performance degradation 2) No power delivered to pump	1) Accumulator repressurization rate capability and LH_2 flowrate to A/B engine system reduced 2) Same as 1) above	1) No effect on crew safety or primary mission objective 2) Same as 1) above	Measure turbine speed	None.	1) A(3) B(3) C(3) 2) A(3) B(3) C(3)
No power delivered to pump	Accumulator repressurization rate capability and LH_2 flowrate to A/B engine system reduced	No effect on crew safety or primary mission objective	Measure turbine speed and pump speed or gearbox temperature	Perform scheduled inspection and maintenance of lubrication system	1) A(3) B(3) C(3)
1) Contamination of subsystem compartment 2) Unable to deliver LH_2 to heat exchanger and A/B engine system at proper flowrate 3) Same as 2) above	1) Accumulator repressurization rate capability and LH_2 flowrate to A/B engine system reduced 2) Same as 1) above 3) Same as 1) above	1) No effect on crew safety or primary mission objective. 2) Same as 1) above 3) Same as 1) above	1) Measure pump discharge pressure or compartment temperature 2) Measure pump speed 3) Measure pump speed	None	1) A(3) B(4) C(3) 2) A(3) B(4) C(3) 3) A(3) B(4) C(3)
1) Turbopump rendered useless to subsystem 2) Assembly cannot be isolated	1) Accumulator repressurization rate capability and LH_2 flowrate to A/B engine system reduced 2) Possible effect on pumps in airbreathing engines due to the delivery of high pressure bi-phase hydrogen	1) No effect on crew safety or primary mission objective 2) No effect on crew safety or primary mission objective	Use valve position switch and measure pump suction pressure	Perform valve cycle and leak test	1) A(3) B(4) C(3) 2) A(4) B(4) C(4)
1) Turbopump rendered useless to subsystem 2) Assembly cannot be isolated	1) Same as 1) above 2) Same as 2) above	1) No effect on crew safety or primary mission objective. 2) Major effect on crew safety or primary mission objective			1) A(3) B(4) C(3) 2) A(3) B(4) C(2A)
1) Assembly rendered useless for delivery of LH_2 to A/B engine system A/B engine propellant delivery line cannot be purged. 2) No effect	1) LH_2 flowrate capability degraded 2) No effect	1) No effect on crew safety or primary mission objective 2) No effect	Measure pump discharge pressure or line pressure downstream of valve	1) Perform check valve functional test. 2) Perform check valve functional test.	1) A(3) B(4) C(3) 2) A(4) B(4) C(4)
1) Same as 1) above 2) Reverse flow of LH_2 possible	1) Same as 1) above 2) No effect	1) Same as 1) above. 2) No effect	Provide pressure tap between series redundant valves for single point failure detection	Redundancy may not be required	1) A(3) B(4) C(3) 2) A(4) B(4) C(4)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
2.3.1.6.1 Heat Exchanger	H-1 H-2 H-3	Convert liquid hydrogen to gaseous form using hot exhaust gases from gas generator and deliver to hydrogen gas accumulators at approximately 1500 psia.	1) Partial blockage of coil by contaminants in LH_2 2) Coil major leakage. 3) Coil minor leakage		1) Low 2) Low 3) Medium
2.3 1.6 2 Solenoid Valve	V-45 V-46 V-47 V-48 V-49 V-50	Direct flow of liquid hydrogen from discharge side of pump to A/B engine system or heat exchanger as required by system demand	1) Valve fails to open. 2) Valve fails to close or leaks internally.		1) Medium 2) Low
				1) Valve fails to open. 2) Valve fails to close or leaks internally.	1) Medium 2) Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 2 0
SUBSYSTEM 2 3

ASSEMBLY 2 3.1

SHEET 2 of 2

FAILURE EFFECT ON: SUBSYSTEM	FAILURE EFFECT ON: SYSTEM	FAILURE EFFECT ON: MISSION	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
1) Reduced capability to recharge accumulators 2) Turbine overspeed potential exists 3) Reduced capability to recharge accumulators	1) Accumulator repressurization rate capability reduced 2) Accumulator overpressurization possible 3) Accumulator repressurization rate capability reduced	1) No effect on crew safety or primary mission objective. 2) Same as 1) above 3) Same as 1) above.	Measure heat exchanger outlet pressure If pressure falls below lower limit, pump suction valves must be closed to isolate system	None	1) A(3) B(3) C(3) 2) A(3) B(3) C(3) 3) A(3) B(3) C(3)
1) Assembly rendered useless for accumulator repressurization Gas generator cannot be purged. 2) No effect	1) Accumulator repressurization rate capability reduced. 2) No effect	1) No effect on crew safety or primary mission objective 2) No effect	Use valve position switch, measure pump discharge pressure or gas generator inlet pressure	None	1) A(3) B(4) C(3) 2) A(3) B(4) C(3)
1) Same as 1) above 2) LH_2 flow to heat exchanger cannot be controlled	1) Same as 1) above 2) Possible over-pressurization of H_2 accumulators Capability to deliver LH_2 to air-breathing engines impaired	1) Same as 1) above 2) Possible effect on crew safety or primary mission objective	Use valve position switch, measure pump discharge pressure or gas generator inlet pressure	Perform valve cycle and leak check	1) A(3) B(4) C(3) 2) A(2A) B(3) C(2A)

COMPONENT IDENTIFICATION — NAME	COMPONENT IDENTIFICATION — DRAWING NUMBER	FUNCTION OF COMPONENT	FAILURE MODE — PRIMARY	FAILURE MODE — REDUNDANT	PROBABILITY OF MALFUNCTION OCCURRENCE
2 3 2 1 Gas Generator	G-1 G-2 G-3	Provide turbine drive gases for the turbopump assembly and a high temperature heat source for the heat exchangers.	1) Major hot gas external leakage. 2) Blockage of propellant injectors		1) Low 2) Low
2 3 2 2 Heat Exchanger	H-4 H-5 H-6	Assure delivery of gaseous hydrogen at the proper conditions to the hydrogen accumulators and gas generator bootstrap system	1) Partial blockage of coil by contaminants in LH_2. 2) Coil major leakage 3) Coil minor leakage.		1) Low 2) Low 3) Medium
2 3.2.3, 2.3 2 4 Solenoid Valve	GOV-1 GFV-1 GOV-2 GFV-2 GOV-3 GFV-3	Admit GO_2 and GH_2 propellants to the gas generator	1) Valve fails to open 2) Valve fails to close or leaks internally.		1) Medium 2) Low
				1) Valve fails to open 2) Valve fails to close or leaks internally	1) Medium 2) Low
2 3 2 5 Check Valves	V-51 V-95 V-52 V-96 V-53 V-97	Allow unidirectional flow of GH_2 to the accumulators Preclude backflow of high pressure gas through the heat exchanger	1) Valve fails to open 2) Valve fails to close or leaks internally		1) Low 2) Low
				1) Valve fails to open 2) Valve fails to close or leaks internally.	1) Medium 2) Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 2 0
SUBSYSTEM 2 3

ASSEMBLY 2 3 2
SHEET 1 of 1

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
1) Loss of subsystem 2) Possible performance degradation of turbine	1) Compartment fire could result 2) Decrease in turbine output would affect repressurization capability and also affect LH_2 flowrate to A/B engines	1) Catastrophic loss of stage. 2) Loss of hydrogen conditioning subsystem could affect mission termination	Measure gas generator chamber pressure	None	1) A(1) B(3) C(1) 2) A(2A) B(3) C(2A)
1) Reduced capability to recharge accumulators 2) Turbine overspeed potential exists 3) Reduced capability to recharge accumulators	1) Accumulator repressurization rate capability reduced 2) Accumulator overpressurization possible 3) Accumulator repressurization rate capability reduced	1) No effect on crew safety or primary mission objective 2) Same as 1) above 3) Same as 1) above	Measure heat exchanger outlet pressure If pressure falls below lower limit, pump suction valves must be closed to isolate system	None	1) A(3) B(3) C(3) 2) A(3) B(3) C(3) 3) A(3) B(3) C(3)
1) Turbopump rendered useless 2) No effect	1) Possible performance degradation due to loss of turbopump assembly 2) No effect	1) No effect on crew safety or primary mission objective 2) No effect on crew safety or primary mission objective	Use valve position switch, measure gas generator chamber pressure	None	1) A(3) B(4) C(3) 2) A(3) B(4) C(3)
1) Turbopump rendered useless 2) Overboard loss of propellants Assembly cannot be isolated	1) Possible performance degradation due to loss of turbopump assembly 2) Accumulator pressure loss with increasing time resulting in system loss	1) No effect on crew safety of primary mission objective. 2) Major effect on crew safety and primary mission objective	Use valve position switch, measure gas generator chamber pressure	Perform valve cycle and leak test	1) A(3) B(4) C(3) 2) A(2A) B(3) C(2A)
1) Eminent turbopump failure due to deadhead pumping Subassembly rendered useless for accumulator recharge 2) No effect	1) Accumulator repressurization rate capability reduced 2) No effect	1) No effect on crew safety or primary mission objective 2) Same as above	1) Measure heat exchanger outlet pressure 2) Provide pressure tap between series redundant valves for single point failure detection	1) None 2) Perform check valve functional test	1) A(3) B(4) C(3) 2) A(4) B(4) C(4)
1) Same as 1) above. 2) No effect	1) Same as 1) above 2) No effect	1) Same as 1) above 2) No effect	Provide pressure tap between series redundant valves for single point failure detection	Perform check valve functional test	1) A(3) B(4) C(3) 2) A(4) B(4) C(4)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
2 4.1.1 Turbine*	U-4 U-5 U-6	Convert gas generator thrust to rotating power and transmit to power train	1) Turbine fails to rotate at required RPM 2) Turbine fails to rotate.		1) Low 2) Low
2 4 1 2 Power Train*	PT-4 PT-5 PT-6	Transmit turbine power to compressor.	Power linkage fails		Low
2 4 1 3 Compressor*	CV-1 CV-2 CV-3	Remove ullage gas from main LO_2 tank at 35 to 40 psia and compress to 1500 psia for delivery to GO_2 accumulators	1) Major external leakage due to seal failure 2) Compressor blade fails. 3) Compressor bearing fails.		1) Medium 2) Low 3) Medium
2 4 1 4 Check Valve	V-54 V-85 V-55 V-86 V-56 V-87	Insure uni-directional flow of 1500 psia GO_2 into accumulators Preclude reverse flow of high pressure GO_2 into compressor.	1) Valve fails to open 2) Valve fails to close or leaks internally		1) Low 2) Medium
				1) Valve fails to open 2) Valve fails to close or leaks internally.	1) Low 2) Medium
2 4 1 5 Solenoid Valve	V-57 V-58 V-59 V-60 V-61 V-62	Admit low pressure (35 - 40 psia) GO_2 to compressor.	1) Valve fails to open. 2) Valve fails to close or leaks internally		1) Medium 2) Medium
				1) Valve fails to open 2) Valve fails to close or leaks internally	1) Medium 2) Medium
* = Critical component					

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 2 0
SUBSYSTEM 2 4

ASSEMBLY 2 4 1
SHEET 1 of 1

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
1) Insufficient power delivered to compressor resulting in reduced output of high pressure GO_2 2) No power delivered to compressor resulting in reduced output of high pressure GO_2	1) Accumulator repressurization rate capability reduced 2) Same as above	1) No effect on crew safety or primary mission objective 2) Same as above	Measure turbine speed	None	1) A(3) B(3) C(3) 2) A(3) B(3) C(3)
No power delivered to compressor	Accumulator repressurization rate capability reduced	No effect on crew safety or primary mission objective	Measure turbine speed and compressor speed or gearbox temperature	Perform scheduled inspection and maintenance of lubrication system	A(3) B(3) C(3)
1) Contamination of subsystem compartment by GO_2 2) Reduced output of high pressure GO_2 3) Same as 2) above	1) No effect 2) Accumulator repressurization rate capability reduced 3) Same as 2) above	1) No effect on crew safety or primary mission objective 2) Same as above 3) Same as above	1) Measure compressor discharge pressure or compartment pressure 2) Inspection 3) Measure compressor speed and/or bearing temperature	1) None 2) Perform scheduled inspection per postflight procedures 3) None	1) A(3) B(3) C(3) 2) A(3) B(3) C(3) 3) A(3) B(3) C(3)
1) Assembly rendered useless to subsystem for accumulator repressurization subsystem performance degraded 2) No effect	1) Accumulator repressurization rate capability reduced 2) No effect	1) No effect on crew safety or primary mission objective 2) Same as above	Measure compressor discharge pressure Provide pressure tap between series redundant valves for single point failure detection	Perform check valve functional test	1) A(3) B(4) C(3) 2) A(4) B(4) C(4)
1) Same as 1) above 2) Possible reverse flow of high pressure GO_2 into compressor	1) Same as 1) above 2) Potential exists for over-pressurization of main LO_2 tanks	1) Same as 1) above 2) Possible effect on crew safety and primary mission objective	Measure compressor discharge pressure Provide pressure tap between series redundant valves for single point failure detection	Perform check valve functional test	1) A(3) B(4) C(3) 2) A(2A) B(3) C(2A)
1) Assembly rendered useless to subsystem for accumulator repressurization 2) No effect	1) Accumulator repressurization rate capability reduced 2) No effect	1) No effect on crew safety or primary mission objective 2) Same as 1) above	Use valve position switch, measure compressor inlet pressure	Perform valve cycle and leak check	1) A(3) B(4) C(3) 2) A(4) B(4) C(4)
1) Same as 1) above 2) Assembly cannot be isolated	1) Same as 1) above 2) No effect	1) Same as 1) above 2) Same as 1) above	Use valve position switch, measure compressor inlet pressure	Perform valve cycle and leak check	1) A(3) B(4) C(3) 2) A(3) B(4) C(3)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
2 4.2 1 Gas Generator	G-4 G-5 G-6	Provide turbine drive gases for the turbocompressor assembly.	1) Major hot gas external leakage 2) Blockage of propellant injectors		1) Low 2) Low
2 4 2 2 Solenoid Valve	GOV-4 GOV-5 GOV-6	Admit GO_2 propellants to the gas generator.	1) Valve fails to open. 2) Valve fails to close or leaks internally		1) Medium 2) Medium
				1) Valve fails to open. 2) Valve fails to close or leaks internally.	1) Medium 2) Medium
2 4 2 3 Solenoid Valve	GFV-4 GFV-5 GFV-6	Admit GH_2 propellants to the gas generator.	1) Valve fails to open. 2) Valve fails to close or leaks internally.		1) Medium 2) Medium
				1) Valve fails to open. 2) Valve fails to close or leaks internally	1) Medium 2) Medium

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 2 0
SUBSYSTEM 2 4
ASSEMBLY 2 4 2
SHEET 1 of 1

FAILURE EFFECT ON SUBSYSTEM	FAILURE EFFECT ON SYSTEM	FAILURE EFFECT ON MISSION	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
1) Contamination of subsystem compartment 2) Possible performance degradation of turbine	1) Accumulator repressurization rate capability reduced 2) Same as above	1) No effect on crew safety or primary mission objective 2) Same as above	Measure gas generator chamber pressure	None	1) A(3) B(3) C(3) 2) A(3) B(3) C(3)
1) Turbocompressor assembly rendered useless to subsystem for accumulator recharge Assembly cannot be purged 2) No effect	1) Accumulator repressurization rate capability reduced 2) No effect	1) No effect on crew safety or primary mission objective 2) Same as above	Use valve position switch, measure gas generator inlet pressure	Perform valve cycle and leak test	1) A(3) B(4) C(3) 2) A(4) B(4) C(4)
1) Same as 1) above 2) Overboard loss of propellants-assembly cannot be isolated	1) Same as 1) above 2) Accumulator pressure loss with time resulting in eventual system loss	1) Same as 1) above 2) Major effect on crew safety and primary mission objective	Use valve position switch, measure gas generator inlet pressure	Perform valve cycle and leak test	1) A(3) B(4) C(3) 2) A(2A) B(3) C(2A)
1) Turbocompressor assembly rendered useless to subsystem for accumulator recharge - assembly cannot be purged 2) No effect	1) Accumulator repressurization rate capability reduced 2) No effect	1) No effect on crew safety or primary mission objective 2) Same as above	Use valve position switch, measure gas generator inlet pressure	Perform valve cycle and leak test	1) A(3) B(4) C(3) 2) A(4) B(4) C(4)
1) Same as 1) above 2) Overboard loss of propellants Assembly cannot be isolated	1) Same as 1) above 2) Accumulator pressure loss with time resulting in eventual system loss	1) Same as 1) above 2) Major effect on crew safety and primary mission objective	Use valve position switch, measure gas generator inlet pressure	Perform valve cycle and leak test	1) A(3) B(4) C(3) 2) A(2A) B(3) C(2A)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
2.6.1 1 Gas Generator	G-7 G-8 G-9	Provide turbine drive gases for the turbine	1) Hot gas external leakage (major) 2) Blockage of propellant injectors.		1) Low 2) Low
2 6.1.2 Turbine*	X-1 X-2 X-3	Convert gas generator thrust to rotating power and transmit to power train.	1) Turbine fails to rotate at required RPM. 2) Turbine fails to rotate.		1) Low 2) Low
2.6.1 3 Power Train*	PT-7 PT-8 PT-9	Transmit turbine power to booster power converter	Power linkage fails		Low
2 6 1 4 GH_2 Solenoid Valve	GFV-7 GFV-8 GFV-9	Admit GH_2 propellants to the gas generator.	1) Valve fails to open 2) Valve fails to close or leaks internally.		1) Medium 2) Medium
				1) Valve fails to open. 2) Valve fails to close or leaks internally.	1) Medium 2) Medium
2 6.1.5 GO_2 Solenoid Valve	GOV-7 GOV-8 GOV-9	Admit GO_2 propellants to the gas generator.	1) Valve fails to open 2) Valve fails to close or leaks internally.		1) Medium 2) Medium
				1) Valve fails to open 2) Valve fails to close or leaks internally	1) Medium 2) Medium
* = Critical component					

Effect on external subsystem

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 2 0
SUBSYSTEM 2 6

ASSEMBLY: 2.6.1

SHEET 1 of 1

FAILURE EFFECT ON: SUBSYSTEM	SYSTEM	MISSION	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
1) Contamination of subsystem compartment 2) Possible performance degradation of turbine	1) Maximum power output capability to booster power converters reduced 2) Same as above	1) No effect on crew safety or primary mission objective 2) Same as above	Measure gas generator chamber pressure	None	1) A(3) B(4) C(3) 2) A(3) B(4) C(3)
1) Insufficient power delivered to power converter 2) No power delivered to power converter	1) Maximum power output capability to booster power converters reduced 2) Same as above	1) No effect on crew safety or primary mission objective 2) Same as above	Measure turbine speed	None	1) A(3) B(4) C(3) 2) A(3) B(4) C(3)
No power delivered to power converter	Maximum power output capability to booster power converters reduced	No effect on crew safety or primary mission objective	Measure turbine speed and power converter output or gearbox temperature	Perform scheduled inspection and maintenance of lubrication system	A(3) B(4) C(3)
1) Turbine drive assembly rendered useless to subsystem for power supply to power converters Assembly cannot be purged 2) No effect	1) Maximum power output capability to booster power converters reduced 2) No effect	1) No effect on crew safety or primary mission objective 2) Same as above	Use valve position switch, measure gas generator inlet pressure	Perform valve cycle and leak test.	1) A(3) B(4) C(3) 2) A(4) B(4) C(4)
1) Same as 1) above 2) Overboard loss of propellants Assembly cannot be isolated	1) Same as 1) above 2) Accumulator pressure loss with time resulting in eventual loss of system	1) Same as 1) above 2) Major effect on crew safety and primary mission objective	Use valve position switch, measure gas generator inlet pressure	Perform valve cycle and leak test	1) A(3) B(4) C(3) 2) A(2A) B(3) C(2A)
1) Turbine drive assembly rendered useless to subsystem for power supply to power converters Assembly cannot be purged 2) No effect	1) Maximum power output capability to booster power converters reduced 2) No effect	1) No effect on crew safety or primary mission objective 2) Same as 1) above	Use valve position switch, measure gas generator inlet pressure	Perform valve cycle and leak test.	1) A(3) B(4) C(3) 2) A(4) B(4) C(4)
1) Same as 1) above 2) Overboard loss of propellants Assembly cannot be isolated	1) Same as 1) above 2) Accumulator pressure loss with time resulting in eventual loss of system	1) No effect on crew safety or primary mission objective 2) Major effect on crew safety and primary mission objective	Use valve position switch, measure gas generator inlet pressure	Perform valve cycle and leak test	1) A(3) B(4) C(3) 2) A(2A) B(3) C(2A)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
5 3 1.1 Gas Generator	G-1 G-2 G-3	Provide turbine drive gases for the turbopump assembly and a high temperature heat source for the heat exchanger.	1) Major hot gas external leakage. 2) Blockage of propellant injectors.		1) Low 2) Low
5 3 1 2 Heat Exchanger	H-4 H-5 H-6 H-7 H-8 H-9	Assure delivery of gaseous hydrogen and oxygen at the proper conditions to the hydrogen and oxygen accumulators, respectively, and to the gas generator bootstrap system.	1) Partial blockage of coil by contaminants in LO_2 or LH_2 2) Coil major leakage 3) Coil minor leakage.		1) Low 2) Low 3) Medium
5 3 1.3 and 5 3 1.4 GO_2 and GH_2 Solenoid Valve	GOV-1 GOV-2 GOV-3 GFV-1 GFV-2 GFV-3	Admit GO_2 and GH_2 propellants to the gas generator	1) Valve fails to open. 2) Valve fails to close or leaks internally		1) Medium 2) Low
				1) Valve fails to open. 2) Valve fails to close or leaks internally	1) Medium 2) Medium
5 3 1.5 and 5 3.1 6 GO_2 and GH_2 Check Valve	V-46 V-47 V-48 V-49 V-50 V-51 V-80 V-81 V-82 V-83 V-84 V-85	Allow unidirectional flow of GH_2 or GO_2 to the accumulators. Preclude backflow of high pressure gas through the heat exchanger	1) Valve fails to open 2) Valve fails to close or leaks internally		1) Low 2) Low
				1) Valve fails to open. 2) Valve fails to close or leaks internally	1) Low 2) Medium

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 5 0
SUBSYSTEM 5 3

ASSEMBLY: 5.3.1

FAILURE EFFECT ON: SUBSYSTEM	FAILURE EFFECT ON: SYSTEM	FAILURE EFFECT ON: MISSION	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
1) Contamination of subsystem compartment 2) Possible performance degradation of turbine	1) Accumulator repressurization rate capability and H_2 flow-rate to A/B engine system reduced 2) Same as above	1) No effect on crew safety or primary mission objective 2) Same as above.	Measure gas generator chamber pressure	None	1) A(3) B(3) C(3) 2) A(3) B(3) C(3)
1) Reduced capability to recharge accumulators 2) Turbine overspeed potential exists. 3) Reduced capability to recharge accumulators	1) Accumulator repressurization rate capability reduced 2) Accumulator overpressurization possible 3) Accumulator repressurization rate capability reduced	1) No effect on crew safety or primary mission objective 2) Same as above 3) Same as above	Measure heat exchanger outlet pressure If pressure falls below lower limit, pump suction valves must be closed to isolate system	None	1) A(3) B(3) C(3) 2) A(3) B(3) C(3) 3) A(3) B(3) C(3)
1) Turbopump rendered useless 2) No effect	1) Possible performance degradation due to loss of turbopump assembly 2) No effect	1) No effect on crew safety or primary mission objective 2) Same as 1) above	Use valve position switch, measure gas generator chamber pressure	None	1) A(3) B(4) C(3) 2) A(3) B(4) C(3)
1) Turbopump rendered useless 2) Overboard loss of propellants Assembly cannot be isolated	1) Same as 1) above 2) Accumulator pressure loss with time resulting in eventual system loss	1) Same as 1) above 2) Major effect on crew safety and primary mission objective	Use valve position switch, measure gas generator chamber pressure	1) None 2) Perform valve cycle test and leak check	1) A(3) B(4) C(3) 2) A(2A) B(3) C(2A)
1) Eminent turbopump failure due to deadhead pumping Sub-assembly rendered useless for accumulator recharge 2) No effect	1) Accumulator repressurization rate capability reduced 2) No effect	1) No effect on crew safety or mission objective 2) Same as 1) above	1) Measure heat exchanger outlet pressure 2) Provide pressure tap between series redundant valves for single point failure determination.	1) None 2) Perform check valve functional test.	1) A(3) B(4) C(3) 2) A(4) B(4) C(4)
1) Same as 1) above 2) No effect	1) Same as 1) above 2) No effect	1) Same as 1) above 2) Same as 1) above	1) Same as 1) above 2) Same as 2) above	1) None 2) Perform check valve functional test.	1) A(3) B(4) C(3) 2) A(4) B(4) C(4)
				☐ Effect on External Subsystem	

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
5 3 2 1 Turbine*	U-1 U-2 U-3	Convert gas generator thrust to rotating power and transmit to power train.	1) Turbine fails to rotate at required RPM. 2) Turbine fails to rotate.		1) Low 2) Low
5 3 2 2 Power Train*	PT-1 PT-2 PT-3	Transmit turbine power to pump and power converters	Power linkage fails.		Low
5.3.2.3 Pump*	P-1 P-2 P-3 P-4 P-5 P-6	Receive liquid hydrogen at 20 psia, boost to accumulator pressure or A/B engine system pressure, and deliver to heat exchangers or A/B propellant delivery system.	1) Major external leakage due to seal fracture 2) Impeller fails to rotate at required RPM. 3) Impeller fails to rotate.		1) Medium 2) Low 3) Low
5.3 2 4 and 5 3 2.5 LO_2 and LH_2 Solenoid Valve	V-52 V-53 V-54 V-55 V-56 V-57	Admit liquid hydrogen or LO_2 into suction side of pump	1) Valve fails to open. 2) Valve fails to close or leaks internally		1) Medium 2) Low
				1) Valve fails to open 2) Valve fails to close or leaks internally.	1) Medium 2) Low
*Critical component.					

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 5 0
SUBSYSTEM 5 3
ASSEMBLY 5 3 2
SHEET 1 of 1

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
1) Insufficient power delivered to pump and orbiter power converters resulting in performance degradation 2) No power delivered to pump and orbiter power converters	1) Accumulator repressurization rate capability and H_2 flowrate to A/B engine system reduced 2) Same as above	1) No effect on crew safety or primary mission objective. 2) Same as above	Measure turbine speed	None	1) A(3) B(3) C(3) 2) A(3) B(3) C(3)
No power delivered to pump and orbiter power converters	Accumulator repressurization rate capability and H_2 flowrate to A/B engine system reduced Power output to orbiter power converters reduced	No effect on crew safety or primary mission objective	Measure turbine speed and pump speed on gearbox temperature	Perform scheduled inspection and maintenance of lubrication system	A(3) B(3) C(3)
1) Contamination of subsystem compartment 2) Unable to deliver LH_2 and/or LO_2 to heat exchanger and H_2 to A/B engine system at proper flowrate 3) Same as 2) above	1) Accumulator repressurization rate capability and H_2 flowrate to A/B engine system reduced 2) Same as 1) above 3) Same as 1) above	1) No effect on crew safety or primary mission objective 2) No effect on crew safety or primary mission objective 3) No effect on crew safety or primary mission objective	1) Measure pump discharge pressure or compartment temperature 2) Measure pump speed 3) Measure pump speed	None	1) A(3) B(4) C(3) 2) A(3) B(4) C(3) 3) A(3) B(4) C(3)
1) Turbopump rendered useless to subsystem 2) No effect	1) Accumulator repressurization rate capability and H_2 flowrate to A/B engine subsystem reduced. 2) No effect	1) No effect on crew safety or primary mission objective 2) Same as above	Use valve position switch, measure pump suction pressure	Perform valve cycle and leak test	1) A(3) B(4) C(3) 2) A(4) B(4) C(4)
1) Same as 1) above 2) Same as 2) above	1) Same as 1) above 2) Uncontrolled flow of LH_2 or LO_2 through pump, heat exchanger, and into accumulators Assembly cannot be isolated	1) Same as 1) above 2) Major effect on crew safety or primary mission objective	Use valve position switch, measure pump suction pressure	Perform valve cycle and leak test.	1) A(3) B(4) C(3) 2) A(3) B(4) C(2A)

☐ Effects on External Subsystem

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
3 1 1 1 and 6 1.1.1 Fan*	Not available	1) Supplies inlet air to compressor. 2) Contributes to thrust through bypass.	Failure to deliver inlet air to low pressure compressor.	None	Low
3 1.1.2 and 6.1 1.2 Low-Pressure Compressor*	Not available	Compresses fan inlet air to higher pressure and temperature	Failure to raise pressure and temperature of air supplied to high pressure compressor.	None	Low
3 1 1.3 and 6 1 1.3 High-Pressure Compressor*	Not available	Accepts air from low pressure compressor and conditions air for inlet to burner.	Inadequate pressure and temperature of air supplied to burner inlet	None	Low
3 1 1 4 and 6 1 1.4 Burner	Not available	Mixes air and fuel, ignites mixture and expels the combustion products	1) Fuel Manifold wear 2) Fuel injection can wear or burn-out 3) Combustion chamber wear or burn-out	None	Low
3 1 1 5 and 6 1.1 5 High-Pressure Turbine*	Not available	Drives the high pressure compressor	Loss of speed and failure to rotate high pressure compressor	None	Low
3.1.1 6 and 6.1 1 6 Low-Pressure Turbine*	Not available	Drives the low pressure compressor	Loss of speed and failure to rotate low pressure compressor.	None	Low
*Critical component.					

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 3 0 and 6 0
SUBSYSTEM 3 1 and 6 1

ASSEMBLY 3.1.1 / 6 1 1

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FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Decrease in power assembly efficiency and loss of thrust	Loss of thrust from one engine requires additional thrust output from the remaining operating engines	Booster vehicle loss with more than two engines out Orbiter vehicle loss with more than one engine out except when nonpowered landing is possible	1) In-place ground visual inspection with baroscope or pyrometer 2) Monitor vibration level 3) Monitor sound level 4) Monitor total specific fuel consumption (TSFC)	None	A(2A) B(4) C(2A)
Decrease in power assembly efficiency and loss of thrust	Loss of thrust from one engine requires additional thrust output from the remaining operating engines	Booster vehicle loss with more than two engines out Orbiter vehicle loss with more than one engine out except when nonpowered landing is possible	1) In-place ground visual inspection with baroscope or pyrometer 2) Monitor vibration level 3) Monitor sound level 4) Monitor total specific fuel consumption 5) Monitor engine pressure ratio	None	A(2A) B(4) C(2A)
Decrease in power assembly efficiency and loss of thrust	Loss of thrust from one engine requires additional thrust output from the remaining operating engines	Booster vehicle loss with more than two engines out Orbiter vehicle loss with more than one engine out except when nonpowered landing is possible	1) In-place ground visual inspection with baroscope or pyrometer 2) Monitor vibration level 3) Monitor sound level 4) Monitor TSFC 5) Monitor speed	None	A(2A) B(4) C(2A)
Burn through of outer engine casing with loss of thrust	Loss of thrust from one engine requires additional thrust output from the remaining operating engines	Vehicle loss from fire or explosion	1) Flame-out detection signal 2) Engine compartment fire signal 3) In-place ground visual inspection of fuel injection can and combustion chamber	Provide a combustion chamber design which utilizes six different ground removeable chambers and injection cans	A(1) B(2B) C(1)
Decrease in power assembly efficiency and loss of thrust	Loss of thrust from one engine requires additional thrust output from the remaining operating engines	Booster vehicle loss with more than two engines out Orbiter vehicle loss with more than one engine out except when nonpowered landing is possible	1) In-place ground visual inspection with baroscope or pyrometer 2) Monitor vibration level 3) Monitor sound level 4) Monitor TSFC	None	A(2A) B(4) C(2A)
Decrease in power assembly efficiency and loss of thrust	Loss of thrust from one engine requires additional thrust output from the remaining operating engines	Booster vehicle loss with more than two engines out Orbiter vehicle loss with more than one engine out except when nonpowered landing is possible	1) In-place ground visual inspection with baroscope or pyrometer 2) Monitor vibration level 3) Monitor sound level 4) Monitor TSFC 5) Monitor speed	None	A(2A) B(4) C(2A)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
3 1 2 1 and 6 1 2 1 Inlet Shutoff Valve	Not available	Allows the supply of LH_2 to the variable displacement pump from the Propellant Management Subsystem	1) Wear on seals 2) Electrical fatigue 3) Wear and yield on closure mechanism.	None	Medium
3 1.2 2 and 6 1.2.2 Variable Displacement Valve Pump	Not available	1) Accepts LH_2 from the Propellant Management Subsystem. 2) Delivers LH_2 through the fuel control system to the fuel heater	1) Wear on seals. 2) Wear and fatigue on blades 3) Wear and fatigue on shafts	None	Low
3.1.2.3 and 6.1.2.3 Cooldown and Pressure Relief Valve	Not available	Conditions LH_2 for entrance to the fuel heater.	1) Electrical fatigue. 2) Wear and fatigue on closure mechanism. 3) Wear on seals.	None	Medium
3 1 2 4 and 6 1.2.4 Fuel Heater	Not available	Accepts LH_2 and emits hydrogen vapor	1) Electrical fatigue 2) Wear on seals.	None	Low
3.1.2.5 and 6.1.2 5 Flowmeter	Not available	Measures the H_2 vapor flowrate from the fuel heater to the combustion chamber.	1) Electrical fatigue 2) Wear on seals.	None	Medium
3 1 2.6 and 6.1.2.6 Shutoff and Dump Valve	Not available	1) Controls flow of H_2 vapor from fuel heater to engine burner 2) After stopping flow to the engine the valve dumps excess propellant overboard	1) Electrical fatigue 2) Wear on seals. 3) Wear and fatigue on closure mechanism 4) Wear and fatigue on dump mechanism	None	Medium
3.1 2.7 and 6.1.2.7 Electronic Controller	Not available	1) Accepts inputs from gas path analysis, power level angle and flowmeter 2) Controls speed of variable displacement vane pump	1) Electrical fatigue. 2) Wear, fatigue, and yield on mechanical control mechanism	None	Medium

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Failure to attain engine start	Engine would not function	Booster vehicle loss with more than two engines out Orbiter vehicle loss with more than one engine out	1) Monitor valve open/close/intermediate status when system is in operation 2) Perform ground function and electrical checks	Provide valves in series-parallel.	A(2A) B(4) C(2A)
Decrease in power assembly efficiency and loss of thrust	Loss of thrust from one engine requires additional thrust output from the remaining operating engines	Booster vehicle loss with the equivalent of more than two engines out Orbiter vehicle loss with the equivalent of more than one engine out	Leak checks during leak checks of other system components	None	A(2A) B(4) C(2A)
Decrease in power assembly efficiency and loss of thrust	Loss of thrust from one engine requires additional thrust output from the remaining operating engines	Booster vehicle loss with the equivalent of more than two engines out Orbiter vehicle loss with the equivalent of more than one engine out	Perform ground function and electrical checks	Provide valves in parallel	A(2A) B(4) C(2A)
Decrease in combustion efficiency resulting in loss of thrust	Loss of thrust from one engine requires additional thrust output from the remaining operating engines	Booster vehicle loss with the equivalent of more than two engines out Orbiter vehicle loss with the equivalent of more than one engine out	Perform ground electrical checks and pressure decay leak tests	None	A(2A) B(4) C(2A)
Decrease in combustion efficiency resulting in loss of thrust	Loss of thrust from one engine requires additional thrust output from the remaining operating engines	Booster vehicle loss with the equivalent of more than two engines out Orbiter vehicle loss with the equivalent of more than one engine out	Perform ground electrical checks and functional test	Provide flowmeters in parallel	A(2A) B(4) C(2A)
Failure to attain engine start or possible decrease in power assembly efficiency and loss of thrust	Engine would not function and loss of thrust from one engine requires additional thrust output from the remaining operating engines	Booster vehicle loss with the equivalent of more than two engines out Orbiter vehicle loss with the equivalent of more than one engine out	1) Monitor valve position when system is in operation 2) Perform ground electrical and functional tests	Provide valves in parallel	A(2A) B(4) C(2A)
Failure to attain engine start or possible decrease in power assembly efficiency and loss of thrust	Engine would not function and loss of thrust from one engine requires additional thrust output from the remaining operating engines	Booster vehicle loss with the equivalent of more than two engines out Orbiter vehicle loss with the equivalent of more than one engine out	1) Monitor functioning status of controller during system operation 2) Perform ground electrical and functional tests	None	A(2A) B(4) C(2A)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
3.1.3.1 and 6 1.3 1 Scavenge Pump*	Not available	Transfer oil from bearings to storage tank.	1) Wear and fatigue on seals. 2) Wear and yield on drive mechanism 3) Wear and yield on gears. 4) Leakage.	None	Low
3.1.3.2 and 6.1.3.2 Oil Boost Pump and Main Oil Pressure Pump*	Not available	Supplies oil pressure for direction of oil to various bearings, gearboxes etc.	1) Wear and fatigue on seals. 2) Wear and yield on drive mechanism. 3) Wear and yield on gears 4) Leakage.	None	Low
3 1.3 3 and 6 1.3.3 Oil Strainer	Not available	Removes particles that may be detrimental to bearing operation	1) Clogging of screen. 2) Leakage	None	Medium
3 1.3 4 and 6.1.3.4 Boost Pump Relief Valve	Not available	Controls oil boost pump discharge pressure by relieving excess pressure caused by vehicle altitude changes	1) Wear and fatigue on seals. 2) Wear on sensing element. 3) Wear and yield on closure mechanism 4) Leakage.	None	Low
3.1 3.5 and 6.1 3.5 Boost Pump Regulating Valve	Not available	Supplements oil boost pump discharge pressure.	1) Wear and fatigue on seals. 2) Wear on sensing element. 3) Wear and yield on closure mechanism. 4) Leakage.	None	Low
3.1.3.6 and 6 1.3.6 Main Pressure Regulating Valve	Not available	Supplements oil pressure pump discharge pressure.	1) Wear and fatigue on seals 2) Wear on sensing element. 3) Wear and yield on closure mechanism 4) Leakage.	None	Low
6.1.3.7 Zero-G Pressure Supply System *Critical components.	Not available	Prevents oil evaporation during zero-G environment.	1) Wear and fatigue on seals. 2) Wear on sensing element. 3) Leakage.	None	Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM: 3.0 and 6.0
SUBSYSTEM: 3.1 and 6.1

ASSEMBLY: 3.1.3 / 6.1.3

FAILURE EFFECT ON: SUBSYSTEM	FAILURE EFFECT ON: SYSTEM	FAILURE EFFECT ON: MISSION	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
"Oil hiding" with prolonged engine use would cause bearing heating and eventual loss of engine power assembly efficiency	Loss of thrust from one engine requires additional thrust output from the remaining operating engines	Booster vehicle loss with more than two engines out. Orbiter vehicle loss with more than one engine out except where unpowered landing is possible.	Monitor oil level in storage tank Monitor oil temperature at storage tank inlet monitor oil pressure	None	A(2A) B(4) C(2A)
Low oil pressure results in improper bearing lubrication, bearing heating and eventual loss of engine power assembly efficiency	See above	See above.	Monitor oil pressure pump discharge flowrate and pressure Monitor oil boost pump discharge flowrate and pressure	None	A(2A) B(4) C(2A)
See above	See above	See above	Monitor oil pressure pump discharge pressure Monitor oil level in storage tank	None	A(2A) B(4) C(2A)
See above	See above	See above	Monitor oil level in storage tank Monitor oil boost pump discharge flowrate and pressure.	None	A(2A) B(4) C(2A)
See above	See above	See above	Monitor oil level in storage tank. Monitor oil boost pump discharge flowrate and pressure	None	A(2A) B(4) C(2A)
See above	See above	See above.	Monitor oil level in storage tank. Monitor oil pressure pump discharge pressure.	None	A(2A) B(4) C(2A)
See above.	See above	See above	Monitor oil level in storage tank. Monitor system temperature and pressure.	None	A(2A) B(4) C(2A)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
3.1.4.1 and 6 1.4.1 Solid-Start Cartridge	Not available	1) Provide engine start in event of failure of primary start technique. 2) Supply energy for rotating high pressure turbine until engine start is attained.	1) Electrical signal failure. 2) Squib failure due to seal loss or shorted bridgewire.	None	Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 3 0 and 6 0
SUBSYSTEM 3 1 and 6 1

ASSEMBLY 3 1 4 / 6 1 4

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FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Failure to attain engine start	Engine would not function	Booster vehicle loss with more than two engines out Orbiter vehicle loss with more than one engine out except when nonpowered landing is possible	Failure to start engine as evaluated by high pressure turbine speed	None	A(2A) B(4) C(2A)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
3.1 5 1 and 6 1.5 1 Igniter Plug	Not available	Provide fuel ignition.	Electrical short circuit	None	Low
3 1.5.2 and 6.1.5 2 Ignition Compositor	Not available	Provide high voltage for igniter plug	Electrical short-open circuit.	None	Low
3.1 5 3 and 6 1.5.3 Ignition Exciter	Not available	Converts input voltage to ignition pulses.	1) Input filter short-open 2) Motor brushes 3) Transformer short-open. 4) Selenium rectifier short. 5) Wear and fatigue on cams 6) Wear and fatigue on switches. 7) Wear and fatigue on drive mechanism	None	Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 3 0 and 6 0

SUBSYSTEM 3 1 and 6 1

ASSEMBLY: 3 1 5 / 6 1.5

SHEET 1 of 1

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Failure to achieve fuel ignition	Engine would not function	Booster vehicle loss with more than two engines out Orbiter vehicle loss with more than one engine out except when nonpowered landing is possible	Monitor voltage output of ignition exciter	None	A(2A) B(4) C(2A)
Failure to achieve fuel ignition	Engine would not function	See above	Monitor voltage output of ignition exciter	None	A(2A) B(4) C(2A)
Failure to achieve fuel ignition	Engine would not function	See above	Monitor voltage output of ignition exciter Monitor input voltage and current of ignition exciter	None	A(2A) B(4) C(2A)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
3 2.1 1 Inlet Pressurization Diffuser	Not available	Provide uniform distribution of gas into ullage area	Structural (fatigue failure).	None	Low
3.2.1.2 Hemisphere Segments	Not available	Welded segments provide storage vessel for LH_2.	Structural (leakage due to fatigue failure).	None	Low
3.2.1 3 Outlet Line	Not available	Provides LH_2 transfer to turbofan engines	Structural (leakage due to fatigue failure).	None	Low
3 2.1.4 Vent Line	Not available	Provides gas transfer for relieving tank gas pressure	Structural (leakage due to fatigue failure)	None	Low
3.2 1 5 Mounting Brackets	Not available	Maintain position of tank assembly inside the main LH_2 propulsion system storage vessel.	Structural (fatigue failure).	None	Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 3 0

SUBSYSTEM 3 2

ASSEMBLY 3 2 1

SHEET 1 of 1

FAILURE EFFECT ON SUBSYSTEM	FAILURE EFFECT ON SYSTEM	FAILURE EFFECT ON MISSION	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
Improper tank pressure and loss of adequate tank outflow characteristics	Hydrogen conditioning system pump damage due to particle injection Loss of engine thrust	Vehicle loss with an equivalent of two engines out	Failure would be detected by subsystem performance	None	A(3) B(2B) C(2A)
Improper tank pressure and loss of adequate tank outflow characteristics	Loss of engine thrust	Vehicle loss with an equivalent of two engines out	1) Visual periodic inspection 2) Periodic tank pressure decay check	None	A(3) B(2B) C(2A)
Loss of adequate LH_2 tank outflow rate	Loss of engine thrust	Vehicle loss with an equivalent of two engines out	Visual periodic inspection	None	A(3) B(2B) C(2A)
Loss of tank pressure and adequate tank outflow characteristics	Loss of engine thrust	Vehicle loss with an equivalent of two engines out	Visual periodic inspection	None	A(3) B(2B) C(2A)
Loss of LH_2 supply	Loss of engine thrust and damage to main propulsion system tankage	Vehicle loss	Visual periodic inspection	None	A(1) B(2B) C(1)

☐ Effects on external subsystems

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
3 2 2.1 Storage Vessel Transfer Line (4-in -dia Line)	None	Transfers LH_2 from cruise tanks to hydrogen conditioning system	Structural (fatigue failure)	None	Low
3.2.2.2 Solenoid Valve Package (4-in valve)	V-54 V-55 V-56 V-84	Controls LH_2 outflow from cruise tank to hydrogen conditioning system.	1) Fail to open 2) Fail to close 3) Major leakage.	One valve in each parallel leg fails to open.	1) Low 2) Low 3) Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 3 0

SUBSYSTEM 3 2

ASSEMBLY 3 2.2

SHEET 1 of 1

FAILURE EFFECT ON: SUBSYSTEM	FAILURE EFFECT ON: SYSTEM	FAILURE EFFECT ON: MISSION	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
Loss of cruise tank pressure and adequate tank outflow characteristics	Loss of engine thrust	Vehicle loss with an equivalent of two engines out	Ground Visual Inspection	None	A(1) B(3) C(1)
1) One valve failure in each parallel leg would stop LH_2 flow to Hydrogen Conditioning system 2) None 3) Loss of system pressure	1) Turbofan engines would lose thrust 2) None 3) Turbofan engines would lose thrust	1) Vehicle loss with an equivalent of two engines out 2) None 3) Vehicle loss with an equivalent of two engines out	1) Monitor position of each valve 2) Monitor position of each valve 3) Monitor system pressure	1) None 2) None 3) None	1) A(1) B(3) C(1) 2) A(4) B(3) C(4) 3) A(1) B(3) C(1

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
3.2 3 1 and 6 2 1 2 Transfer Line B - 4-in -dia Line O - 2 5-in -dia Line	L-32 booster none orbiter	Ducting for Transfer of T/F fuel (LH_2) from APS Hydrogen Conditioning Subsystem (Booster) and Turbopump Assembly (Orbiter) to the Turbofan Engine Valve Package	Structural (fatigue failure).	None	Low
3 2 3 2 and 6 2 1 1 Solenoid-Valve Package (3 Packages on the Orbiter). (7 Packages on the Booster). (1/2-in Valves)	EFV-1 thru EFV-28 (Booster) EFV-1 thru EFV-12 (Orbiter)	To supply LH_2 from the Propellant Management Subsystem to the T/F engines.	1) Failure to open 2) Failure to close 3) Major leakage	One valve fails to open in each parallel leg	1) Low 2) None 3) Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 3 0 and 6 0

SUBSYSTEM 3 2 and 6 2

ASSEMBLY 3.2 3 / 6 2 1

SHEET 1 of 1

FAILURE EFFECT ON: SUBSYSTEM	FAILURE EFFECT ON: SYSTEM	FAILURE EFFECT ON: MISSION	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
Loss of adequate flow characteristics	Loss of engine thrust	Booster vehicle loss with an equivalent of two engines out Orbiter vehicle loss with an equivalent of one engine out except when nonpowered landing is possible	Ground visual inspection	None	A(1) B(3) C(1)
1) One valve failure in each parallel leg would stop LH_2 flow 2) None 3) Loss of system pressure	1) Turbofan engine would lose thrust 2) None 3) Turbofan engines would lose thrust	1) Booster vehicle loss with an equivalent of two engines out Orbiter vehicle loss with an equivalent of one engine out except when nonpowered landing is possible 2) None 3) Vehicle loss with an equivalent of two engines out	1) Monitor position of each valve 2) Monitor position of each valve 3) Monitor system pressure	1) None 2) None 3) None	1) A(1) B(3) C(1) 2) A(4) B(3) C(4) 3) A(1) B(3) C(1)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
3.2.4 1 Transfer Line (6-in. line)	L-31	Ducting for rapid transfer of fuel tank gas to atmosphere	Structural (fatigue failure causing leakage).	None	Low
3.2 4.2 Valve Package (6-in valves)	V-70 V-71 V-72 V-73	Controls rapid overboard dumping of fuel tank gas.	1) Failure to open. 2) Failure to close 3) Major leakage	One valve in each parallel leg fails to open	Low Low Low
3.2.4.3 Quick Disconnect Coupling (6-in. coupling)	C-10	Allows ground control for venting of fuel tank gas.	Structural (fatigue failure).	None	Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 3 0
SUBSYSTEM 3 2

ASSEMBLY 3 2.4

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Fuel tank gas would be vented to vehicle internal compartments	Thermodynamic conditions extĕrnal to components would change	None - line is isolated by vent valves	Ground visual inspection	None	A(4) B(2B) C(4)
1) One valve failure in each parallel leg would prevent tank venting 2) Fuel tank pressure could not be maintained 3) Fuel tank pressure could not be maintained	1) None - system could be vented through the functioning system in the other body of the body vehicle 2) Loss of engine thrust 3) Loss of engine thrust	1) None 2) Vehicle loss with an equivalent of two engines out. 3) Vehicle loss with an equivalent of two engines out	1) Monitor fuel tank pressure 2) Monitor valve position 3) Monitor fuel tank pressure	None None None	1) A(4) B(2B) C(4) 2) A(1) B(2B) C(1) 3) A(1) B(2B) C(1)
Fuel tank gas would be vented in vehicle main engine compartment	None	None - coupling isolated by vent valves	Ground visual inspection	None	A(4) B(3) C(4)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
3 2 5 1 Quick Disconnect Coupling	C-5	Provides coupling for GSE fill line Provides low level propellant loss capability during connection	1) Fails closed or minor internal leakage 2) Major leakage internal or external.	None	Low
3 2 5 2 Transfer Line	L-21	Ducting for transfer of propellant from quick disconnect coupling to fill valve.	Structural (fatigue failure causing leakage).	None	Low
3.2.5.3 Fill Valve (Solenoid Operated with Integral Relief Provisions)	V-74	Provides positive shutoff for propellant fill and drain	1) Fails open, minor internal leakage, major internal leakage. 2) Fails closed. 3) Major external leakage (upstream flange). 4) Major external leakage (downstream flange). 5) Fails to relieve at designed back pressure	None	1) Low 2) Low 3) Medium 4) Low 5) Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 3 0
SUBSYSTEM 3 2

ASSEMBLY 3.2 5

FAILURE EFFECT ON SUBSYSTEM	FAILURE EFFECT ON SYSTEM	FAILURE EFFECT ON MISSION	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
No effect - fill valve provides position propellant isolation	None	None	Ground visual inspection	None	A(4) B(3) C(4)
Fuel leakage into vehicle compartments during loading	None	None	Ground visual inspection	None	A(4) B(3) C(4)
1) No effect-checking mechanism at fill coupling maintain leak integrity 2) No effect-valve is normally closed during flight 3) No effect-upstream line inactive during flight 4) Loss of fuel tank pressure 5) No effect-coupling relief mechanism opens under overpressure	1) No effect due to shutoff redundancy of coupling check/ shutoff mechanism 2) None 3) None 4) Loss of turbofan engine thrust 5) None	1) None 2) None 3) None 4) Vehicle loss with an equivalent of two engines out except where unpowered landing is possible 5) None	1) Monitor valve position. 2) Monitor valve position. 3) Monitor tank pressure 4) Monitor tank pressure 5) Monitor tank pressure	1) None 2) None 3) None 4) None 5) Coupling design requires safety relief	1) A(4) B(4) C(4) 2) A(4) B(3) C(4) 3) A(4) B(3) C(4) 4) A(4) B(3) C(2A) 5) A(4) B(4) C(4)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
3.3.1.1 Transfer Line from Regulator Package to LH_2 tank (2-in line)	L-33A	Ducts GH_2 to pressurize the LH_2 A/B propellant supply tank for T/F engines.	Structural (fatigue failure causing leakage)	None	Low
3.3.1.2 Series - Parallel Regulator Package (2-in. regulator)	R-37A R-38A R-39A R-40A	Controls the pressure level and reduces the accumulator pressure from 1500 psia to LH_2 tank pressure of 20 psia.	1) Internal leakage. 2) External leakage (upstream side). 3) Wear, failed closed	None	1) Low 2) Low 3) Medium
3.3.1.3 Parallel Solenoid Valve Package (2-in. valve)	V-75A V-76A	Allows release of GH_2 from the accumulators to pressurize the LH_2 T/F supply tanks	1) Failure to open. 2) Failure to close. 3) Major leakage (extend).	1) Both valves fail to open. 2) Both valves fail to close.	1) Low 2) Low 3) Low
3.3.1.4 Filter (2-in. filter)	F-12	Removes particles or contaminants from GH_2 before gas reaches the pressure regulators	1) Clogging. 2) Leakage. 3) Rupture.	None	1) Low 2) Low 3) Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 3 0
SUBSYSTEM 3 3

ASSEMBLY 3.3.1
SHEET 1 of 1

FAILURE EFFECT ON: SUBSYSTEM	FAILURE EFFECT ON: SYSTEM	FAILURE EFFECT ON: MISSION	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
Fuel gas leakage in vehicle compartment	Major leakage would cause loss in tank gas pressure and decrease in turbofan engine thrust.	Vehicle loss with an equivalent of two engines out	Monitor tank gas pressure	None	A(1) B(3) C(1)
1) No effect due to relief valve built into regulator. 2) None 3) Loss of tank pressure	1) None 2) Increased requirements for H_2 gas supply 3) Decrease in turbofan engine thrust.	1) None 2) Decrease in mission capability 3) Vehicle loss with an equivalent of two engines out	1) Ground test 2) Monitor H_2 supply tank gas volume 3) Monitor regulator position	1) None 2) None 3) None	1) A(4) B(3) C(4) 2) A(3) B(3) C(3) 3) A(1) B(3) C(1)
1) Loss of tank pressure if both valves fail 2) No effect 3) None	1) Decrease in turbofan engine thrust 2) No effect 3) Increased requirements for H_2 gas supply.	1) Vehicle loss with an equivalent of two engines out 2) No effect 3) Decrease in mission capability	1) Monitor valve position 2) None because failure has no effect on system, subsystem or mission 3) Monitor H_2 supply tank gas volume	1) Valve should be made to fail normally open 2) None 3) None	1) A(1) B(3) C(1) 2) A(4) B(3) C(4) 3) A(3) B(3) C(3)
1) Decrease in tank pressure 2) None 3) Contamination	1) Decrease in turbofan thrust 2) Increased requirements for H_2 gas supply 3) Eventual damage of regulators	1) Vehicle loss with an equivalent of two engines out 2) Decrease in mission capability 3) Loss of regulators	1) Monitor tank gas pressure and periodic replacement 2) Monitor H_2 supply tank pressure and ground leak tests 3) Measure ΔP across filter	1) Provide series-parallel filters 2) None 3) Provide series-parallel filters	1) A(1) B(3) C(1) 2) A(3) B(3) C(3) 3) A(3) B(3) C(3)
				☐ Effects on external subsystems	

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
6 2.2 1 Pump*	P-7 P-8 P-9	Transmits LH_2 from storage vessel to turbofan subsystem.	1) Major external leakage. 2) Impeller fails to rotate at required RPM. 3) Impeller fails to rotate	None	Low
6 2 2.2 Solenoid-Operated Valve Package	V-58 V-59 V-60 V-61 V-62 V-63	Admits liquid H_2 into suction side of pump.	1) Fails to open 2) Fails to close 3) Major external leakage.	None	Low
6.2 2 3 Turbine*	V-4 V-5 V-6	Converts gas generator thrust to rotating power and transmits power to pump.	1) Turbine fails to rotate at required RPM. 2) Turbine fails to rotate 3) Power leakage fails.	None	Low
6.2 2.4 Check Valve	V-64 V-65 V-66	Insure one directional flow from discharge side of pump.	1) Fails to open 2) Fails to close 3) Internal leakage. 4) External leakage.	None	Medium

*Critical component

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 6 0
SUBSYSTEM 6.2

ASSEMBLY: 6.2.2
SHEET 1 of 1

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
Loss in upstream flowrate	Decrease in turbofan engine thrust	Vehicle loss with the equivalent of one engine out except when nonpowered landing is possible	Measure pump discharge pressure, suction pressure and vibration level	None	1) A(1) B(2B) C(1) 2) A(1S) B(2B) C(1) 3) A(1) B(2B) C(1)
1) Turbopump will fail to supply LH_2 2) Turbopump cannot be isolated 3) Decrease in pump suction pressure	Decrease in LH_2 flowrate to turbofan engines No effect Decrease in LH_2 flowrate to turbofan engines	Vehicle loss with the equivalent of one engine out except when nonpowered landing is possible No effect Vehicle loss with the equivalent of one engine out except when nonpowered landing is possible	Measure valve position and pump suction pressure Measure valve position Measure valve position and pump suction pressure	None	1) A(1) B(2B) C(1) 2) A(4) B(3) C(4) 3) A(1) B(2B) C(1)
Loss in upstream flowrate	Decrease in LH_2 flowrate to turbofan engines	Vehicle loss with the equivalent of one engine out except when nonpowered landing is possible.	Measure turbine speed and vibration level.	None	A(1) B(2B) C(1)
1) Loss in upstream flowrate 2) Causes possible back flow to turbopump 3) Allows pressurization of upstream liner 4) Loss in upstream pressure	1) Decrease in LH_2 flowrate to turbofan engines 2) Decrease in LH_2 flowrate to turbofan engines 3) No effect 4) Decrease in LH_2 flowrate to turbofan engines	Vehicle loss with the equivalent of one engine out except when nonpowered landing is possible	Measure pump discharge pressure and provide pressure tap between series redundant valves for single point detection. None	None	1), 2), & 4) A(1) B(2B) C(1) 3) A(4) B(4) C(4)

COMPONENT IDENTIFICATION		FUNCTION OF COMPONENT	FAILURE MODE		PROBABILITY OF MALFUNCTION OCCURRENCE
NAME	DRAWING NUMBER		PRIMARY	REDUNDANT	
6.2.3 1 Gas Generator	G-4 G-5 G-6	Provide turbine drive for the turbopump assembly.	1) Major hot gas external leakage 2) Blockage of propellant injectors	None	Low
6.2.3.2 H_2 Series Solenoid-Operated Valve Package	GFV-4 GFV-5 GFV-6	Admit GH_2 to the gas generator	1) Fails to open. 2) Fails to close. 3) Major external leakage	1) Both fail to open 2) Both fail to close	Low
6 2.3.3 O_2 Series Solenoid-Operated Valve Package	GOV-4 GOV-5 GOV-6	Admit GO_2 to the gas generator	1) Fails to open 2) Fails to close. 3) Major external leakage	1) Both fail to open 2) Both fail to close	Low

FAILURE MODE AND EFFECTS ANALYSIS

SYSTEM 6 0
SUBSYSTEM 6 2
ASSEMBLY 6 2 3
SHEET 1 of 1

FAILURE EFFECT ON			RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS	MISSION OPERATIONS / CRITICALITY CATEGORY
SUBSYSTEM	SYSTEM	MISSION			
1) Loss of subsystem 2) Decrease in combustion efficiency and hence decrease in turbine RPM	1) Compartment fire could result 2) Decrease in turbofan engine thrust	1) Catastrophic loss of stage 2) Vehicle loss with an equivalent of one engine out except where unpowered landing is possible	Measure chamber pressure	Compartment in vicinity of Gas Generators should have flame detectors	1) A(1) B(2B) C(1) 2) A(1) B(2B) C(1)
1) Combustion process will be incomplete 2) H_2 gas floods combustion chamber 3) Decrease in combustion efficiency	1) Decrease in turbofan engine thrust 2) Fuel saturated combustion causing decrease in turbopump efficiency and turbofan engine thrust 3) Decrease in turbofan engine thrust	Vehicle loss with an equivalent of one engine out except where unpowered landing is possible	Monitor valve position Monitor gas generator chamber pressure	None	A(1) B(2B) C(1)
1) Combustion process will be incomplete 2) O_2 gas floods combustion chamber 3) Decrease in combustion efficiency	1) Decrease in turbofan engine thrust 2) O_2 saturated combustion causing decrease in turbopump efficiency and turbofan engine thrust 3) Decrease in turbofan engine thrust	Vehicle loss with an equivalent of one engine out except where unpowered landing is possible	Monitor valve position Monitor gas generator chamber pressure	None	A(1) B(2B) C(1)

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FMEA ON CRITICAL COMPONENTS

SYSTEM 1.0 & 4.0
SUBSYSTEM 1.1 & 4.4

ASSEMBLY: 1.1.1 & 4.1.1
COMPONENT: 1.1.1.1 & 4.1.1.1

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Ball Bearings	Take out shaft axial/radial loads, transmit to housing, provide shaft/impeller/turbine position control within housing to prevent rub, and clearance variations.	Ball and race wear, spalling, brinnelling	Increased torque requirements, increased shaft vibration, displacement, labyrinth seal and impeller, turbine rub; leading to erratic start characteristics, low output.	Vibration, inlet pressure; discharge pressure, pump rpm; torque check at maint. cycle.	
		Cracked ball - disintegrating.	Abrupt reduction in flow/pressure output.	Pump rpm; discharge pressure vibration/displacement; torque check.	
		Cracked race.	Accelerated wear of balls. Same as first line entry.	Same as above.	
		Cracked retainer.	Same as above.	Same as above	
		Worn retainer	Same as above.	Same as above	
Impeller	Provide pressure rise.	Vane breakage structural fatigue	Reduced pressure/flow output Increased vibration. Possibility of jamming, with complete loss of output	Pump rpm, vibration, discharge pressure	
Shaft	Support turbine and impeller, transmit loads to bearings.	Breakage. Structural fatigue.	Abrupt loss of output. Turbine overspeed and severe damage to internal components	Pump discharge pressure; pump rpm. (Extremely rapid sequence of events - detection and reaction time usually insufficient to avoid damage.)	
Turbine Nozzles	Control flow of drive fluid to turbine blades (passive).	Spalling, cracking, pitting.	Reduction in turbine efficiency - reduced output.	Pump rpm; discharge pressure; inlet pressure.	
Turbine Blades	Convert drive fluid energy to shaft rotational energy.	Distortion	Reduction in turbine efficiency	Pump rpm; discharge pressure; inlet pressure.	
		Loss of blade(s) structural fatigue.	Reduced turbine efficiency. Progressive damage to turbine with very low output. Increased vibration.	Vibration; pump rpm; discharge & inlet pressure.	
Labyrinth Seals	Provide controlled leak seals at impeller inlet and outlet, and bearing coolant inlet passage	Secondary wear as a result of excessive shaft radial displacement (This is a function of design point clearances).	Reduced output.	Bearing detection system should provide primary data.	

FMEA ON CRITICAL COMPONENTS

SYSTEM 1.0 & 4.0
SUBSYSTEM 1.1 & 4.1

ASSEMBLY 1.1 1 & 4 1 1
COMPONENT 1 1 1 2 & 4 1.1.2
SHEET 1 of 2

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Ball Bearings (2 rows in pumping area, 2 rows in turbine).	Maintain impeller/turbine to housing clearances, take out axial and radial loads.	Ball and race wear, spalling, brinnelling	Increased torque required, increased shaft vibrations, displacements, reduced efficiency, possible impeller/turbine rub/shaft rub, low output.	Vibration, inlet pressure, pump rpm, discharge pressure.	
		Cracked ball disintegrating.	Abrupt reduction in flow/pressure output	Same as above	
		Cracked race.	Accelerated wear of balls, same as first line entry.	Same as above.	
		Cracked/worn retainer	Same as above.	Same as above.	
Drive Shaft	Transmit turbine drive energy to impellers, distribute loads to bearings, thrust balancer.	Breakage	Abrupt loss of pump output Probable turbine overspeed with severe internal damage.	Pump speed to provide as rapid a shutdown as possible	
Inducer/Impeller Blades	Provide pump pressure rise.	Crack with loss of blade piece.	Reduced output, increased vibration, possible jamming of piece with progressive damage to TPA. May pass through to preburners, nozzle, with subsequent damage.	Vibration, inlet pressure, outlet pressure, pump speed	
Piston Ring Seals	Provide interstage assembly pressure seals	Loss of spring tension, crack.	Reduced pumping efficiency	Inlet pressure, discharge pressure, pump speed, preburner power valve position	

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Liftoff Seal	Provide static seal between 3rd stage and turbine prior to operation, provide controlled flow seal dynamically.	Face wear, loss of retaining force	Increased static leakage to turbine and engine.	Leak check at maint. cycle.	
Thrust Balancer	Limit axial loads on bearings.	Face wear (bearing or other abnormal displacement is cause)	Reduced output, increased vibration.	Pump speed, vibration, inlet pressure, outlet pressure; preburner pressure/temp.	
Hot Gas Turbine	Convert hot gas stream energy to rotational energy.	Distortion of blade.	Reduced effeciency tip rub low output.	Pump speed, vibration preburner chamber pressure, temperature inlet pressure; discharge pressure	
		Loss of blades(s).	Increased vibration, reduced efficiency, possible progressive damage with loss of output.	Vibration, pump speed.	
		Disc distortion	Rub, with reduced efficiency; vibration increase.	Vibration; preburner chamber press./temp., pump speed, inlet pressure, outlet pressure.	
Turbine Nozzles	Control flow of hot gas to turbine blades	Pitting, distortion	Loss of efficiency, low output.	Same as above.	
Check Valve, Outlet of 3rd Stage, Inlet to First Stage.	Prevent excessive fuel leakage to chamber/outside of engine prior to start. Spring tension set to relieve somewhat above head/prepressure settings.	Fails to open at set pressure.	No effect on fuel TPA. Loss of coolant to OTPA turbine bearings	Valve position discrete; coolant outlet temperature.	
		Fails to close at shutdown, fails to seat adequately at shutdown	No effect on fuel TPA Small fuel leak through engine after shutdown, until prevalve is closed	Leak checks at maint. cycle valve position discrete.	

FMEA ON CRITICAL COMPONENTS

SYSTEM 1 0 & 4 0
SUBSYSTEM 1 1 & 4 1
ASSEMBLY 1 1 1 & 4 1 1
COMPONENT 1 1 1 3 & 4 1.1 3
SHEET 1 of 1

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Ball Bearings	Take out shaft axial/radial loads, transmit to housing, provide shaft/impeller/turbine position control within housing to prevent rub and clearance variations.	Ball and race wear, spalling, brinnelling	Increased torque requirements, increased shaft vibration, displacement, reduced efficiency.	Vibration, inlet pressure, discharge pressure, pump rpm, torque check at maint. cycle.	
			Labyrinth seal, impeller turbine rub due to excessive wear Possible detonation with pump rupture, fire.	Same as above.	
		Cracked ball, disintegrating.	Abrupt reduction in flow/pressure output.	Same as above.	
		Cracked race.	Accelerated wear of balls. Same as first line entry above	Same as above	
		Worn/cracked retainer	Same as above.	Same as above	
Impeller	Provide pressure rise	Vane breakage Structural fatigue.	Reduced pressure/flow output, increased vibration. Possibility of jamming, with complete loss of output Possibility of detonation with pump rupture, fire	Pump rpm vibration discharge pressure	
Shaft	Support turbine and impeller, transmit loads to bearings.	Breakage (structural fatigue)	Abrupt loss of output Rub, possible detonations with pump rupture, fire.	Pump discharge pressure, pump rpm (extremely rapid sequence of events).	
Turbine Nozzles	Control flow of drive fluid to turbine blades (passive)	Spalling, cracking, pitting.	Reduction in turbine efficiency, reduced output.	Pump rpm, inlet pressure, discharge pressure	
Turbine Blades	Convert drive fluid energy to shaft rotational energy.	Distortion.	Reduction in turbine efficiency.	Same as above.	
		Loss of blade(s), structural fatigue.	Reduced efficiency, progressive damage to turbine is probable, increased vibration; possible detonation with pump rupture, fire.	Vibration, pump rpm, inlet pressure, discharge pressure.	
Labyrinth Seals	Provide controlled leak seals at impeller inlet and outlet, and bearing coolant passage.	Secondary wear as a result of excessive shaft radial displacement (this is a function of design point clearances).	Reduced output.	Bearing detection system should provide primary data.	

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Labyrinth Seal, at Turbine Hydrostatic Seal	Provide gross back-flow protection for hydrostatic seal and running ring from turbine gases.	Secondary wear as a result of bearing wear.	No effect - bearing failure would precede any major effect.	--	
		Structural failure.	Distortion of hydrostatic and lift-off running ring Excessive fuel bypass from preburners - minor reduction in engine performance.	Leak checks at maint. cycle Engine performance parameters.	
Thrust balancer	Provide major portion of axial thrust takeout, to limit bearing loads	No primary mode of failure. Excess axial shaft motion due to worn bearings could cause face wear, and accelerate the bearing wear. (See bearings)	Reduced flow/pressure output.	Vibration, displacement; thrust balance cavity pressure.	
Lift-off Seal	Provide static seal between turbine roller bearing coolant and turbine area.	Wear, loss of seal tension (bellows or spring) cracked bellows.	Excess static overboard leakage of fuel (secondary failure). (Requires failure of H.P.F T P A. check valves)	Leak checks at maintenance cycle	
Hydrostatic Face and Journal Seals	Provide controlled flow seals between 2nd stage output and seal cavity, also between turbine roller bearing and seal cavity	No primary failure mode. Wear would result from excessive bearing wear (see bearings)	Reduced pump output	(See bearings)	
Filter	Provides filtered flow for bearings, hydrostatic seals, labyrinth, thrust balancer, preburner injectors. Self cleaning design.	Channel to plate separation opening the equiv orifice size.	Possible plugging of passages Accelerated bearing wear, possible seal wear with loss of pump performance.	(See bearings)	

FMEA ON CRITICAL COMPONENTS

SYSTEM 1 0 & 4 0
SUBSYSTEM 1.1 & 4.1

ASSEMBLY 1 1 1 & 4 1.1
COMPONENT 1.1.1 4 & 4 1 1 4
SHEET 1 of 4

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Roller Bearing (turbine area)	Transmit radial shaft loads to housing, maintain clearances.	Roller/race wear, spalling, brinelling End and rolling surface (minor wear).	Increased vibration, increased shaft displacement, slightly reduced performance	Vibration, shaft displacement	
		Same as above, except major wear	Turbine blade rub, labyrinth seal rub, increased vibration Reduced performance.	Vibration, shaft displacement pump rpm inlet pressure, discharge pressure, preburner chamber pressure, temp.	
		Cracked roller, disintegrating	Abrupt reduction in flow/pressure output, increased vibration, severe labyrinth seal rub, journal seal rub, possible detonation	Vibration, pump rpm inlet pressure discharge pressure	
		Cracked race	Accelerated wear of balls, same as first line entry above.	Vibration, shaft displacement.	
		Worn/cracked retainer.	Same as above.	Same as above	
Ball Bearings (2 rows) and Roller Bearing (between first and second stage pump impellers)	Transmit axial and radial shaft loads to housing Maintain clearances	Ball/race wear, roller/race wear (minor).	Same as Line 1 entry above.	Same as above	
		Same as above except major wear	Increased vibration, displacement, possible labyrinth/hydrostatic seal rub, possible impeller rub, with possible detonation, rupture of pump and fire	Pump rpm, vibration, displacement, inlet pressure discharge pressure	

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Ball/Roller Bearings (cont)	Continued	Cracked ball or roller, with disintegration	Abrupt reduction in pump output, increased vibration, impeller rub, seal rub, probable detonation with rupture of pump, fire	Vibration, shaft displacement, pump speed, discharge pressure inlet pressure	
		Cracked race	Accelerated wear of rollers/balls Same as Line 1 entry	Vibration, pump rpm displacement, inlet pressure, outlet pressure.	
		Worn/cracked retainer	Same as above	Same as above	
Inducer	Boost inlet pressure for first stage	Loss of vane or piece	Increased vibration, reduced output, possible jamming of piece in inducer, first stage or second stage, piece may go through to main TCA. Possible detonation, rupture of pump, fire	Vibration, pump rpm inlet pressure, first and second stage outlet pressure	
First/Second Stage Impellers	Provide required head rise	Loss of Vane or Piece	Same as above	Same as above	
Turbine	Convert hot gas flow energy to rotational energy	Blade distortion, disc distortion.	Turbine rub, reduced output, increased vibration	Vibration, pump rpm, preburner chamber pressure, temp., inlet pressure (lox), discharge pressure.	

FMEA ON CRITICAL COMPONENTS

SYSTEM 1 0 & 4 0
SUBSYSTEM 1 1 & 4.1
ASSEMBLY 1 1.1 & 4 1 1
COMPONENT 1.1.1 4 & 4 1 1 4

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Turbine (cont)	Continued	Loss of blade	Increased vibration, probable progressive turbine damage, loss of pump output.	Vibration, pump rpm discharge pressure inlet pressure.	
Turbine Nozzles	Control flow of hot gas to turbine (passive).	Distortion, spalling, crack.	Reduced turbine efficiency - low pump output	Pump rpm, preburner chamber pressure/temp. inlet pressure, discharge pressure	
Diameter Seal (upstream)	Provide an assembly seal between first stage and inducer.	Loss of spring tension/cracked ring (depends upon design)	Reduced output (minor) of pump.	Same as above	
Diameter Seals	Provide assembly seals in interpropellant seal cavity, between second stage and oxid vent cavity, also between turbine cavity and fuel vent cavity.	Loss of spring tension/cracked ring (depends upon design).	Reduced output (minor) of pump.	Seal cavity oxid. vent pressure, fuel vent pressure, plus parameters directly above.	
Labyrinth Seals - Inducer/ Impeller Area	Provides controlled flow seal at inducer outlet, first stage outlet, flow to bearings, second stage inlet.	Secondary wear as a result of bearing wear.	(See bearings) Reduced pumping efficiency. Possible detonation depending upon materials, degree of rubbing.	(See bearings)	
Labyrinth Seals, Seal Cavity	Provides controlled helium purge seal flow to oxid. and fuel vent cavities.	Same as above.	(See bearings) Excessive purge gas requirement	(See bearings) Seal cavity pressure.	

FMEA ON CRITICAL COMPONENTS

SYSTEM 1 0
SUBSYSTEM 1 1

ASSEMBLY· 1.1.1
COMPONENT 1 1.1.8
SHEET 1 of 1

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Motor Actuator and Gear Train	Provide driving force to open/ close valve via a gear train	Open winding, short to ground	Valve fails to open at start, or slow to close at shutdown	Valve position.	
		Shorted turns	Valve may open slowly	Valve position	
		Bearings wear, gall, or jam.	Slow open/close, failure to open, failure to close		
		Gear breakage (structural fatigue) possible jamming	Valve may fail to open, or it may fail to close	Valve position	
Linkage	Translate rotary gear output to linear valve motion	Cracked (structural fatigue)	Valve fails to open or closes slowly	Valve position	
Spring	Provide added closure force for sealing with no head pressure	Breakage (structural failure or loss of spring tension)	Fails to seal at bleed-in and shutdown.	Leak check at maint cycle	
Shaft Bearings	Transmit shaft radial loads to valve housing	Wear, galling of shaft.	Erratic valve opening/closing	Valve position trace	
Poppet Seal	Provide positive shutoff	Wear, particle in seal (secondary failure)	Excessive leak during chill-down, postfiring	Leak checks at maint cycle	
Filters, Flow-Through System	Prevent plugging of pressure balance orifices (0 05 to 0 1 in)	Plugging due to accrued contam (secondary effect) or, structural failure of either filter	Closes earlier in shutdown tail-off of pressure, valve fails to open at start possible premature closure	Valve position	
Static Seals	Prevent external leakage	Creep	None - external fire hazard	Leak checks at maint cycle	

FMEA ON CRITICAL COMPONENTS

SYSTEM 1 0 & 4 0 ASSEMBLY 1 1 1 & 4.1.1

SUBSYSTEM 1.1 & 4 1 COMPONENT 1 1.1 9 & 4 1 1 9

SHEET 1 of 1

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Motor Actuator and Gear Train	Provide driving force to open/close valve via a gear train.	Open winding, short to ground	Valve fails to open at start, slow to close at shutdown	Valve position.	
		Shorted turns.	Valve may open/close slowly	Valve position	
		Gear breakage (structural fatigue), possible jamming.	Failure to open/close	Valve position	
		Bearings wear, gall or jam	Slow to open/close, failure to open/close.	Valve position	
Linkage, Shaft	Translate rotary gear output to linear valve motion.	Cracked (structural fatigue)	Valve fails to open, closes slowly.	Valve position.	
Spring	Provide added closure force for sealing with no head pressure.	Breakage, loss of tension.	Fails to seal at chill-down or shut down, slow to close	Valve position. Plus leak checks at maint cycle	
Shaft Bearings	Transmit shaft radial loads to valve housing.	Wear, galling of shaft.	Erratic valve opening/closing	Valve position.	
Poppet Seal	Provide positive shutoff	Wear, particle imbedded in seal (secondary failure)	Excessive internal leak at chill down, post firing	Leak checks at maint cycle	
Pilot Valve (passive)	Provides pressure balance for opening	Fails to open (structural failure).	Fails to open	Valve position.	
		Fails to close (seal wear, contam.)	Small leak at shutdown	Leak checks at maint cycle.	
Static Seals	Prevent external leakage.	Creep.	None - external safety hazard	Leak checks at maint. cycle.	

FMEA ON CRITICAL COMPONENTS

SYSTEM 1.0 & 4.0
SUBSYSTEM 1.1 & 4.1

ASSEMBLY: 1.1.1 & 4.1.1
COMPONENT: 1.1.1.10 & 4.1.1.10
SHEET 1 of 1

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Motor/Gear Train Drive	Provide valve positioning force.	Open winding, short to ground	Failure to open, fails to close, fails static, not resp. to commands.	Valve position.	
		Shorted turns.	Slow response.	Valve position.	
		Gear failure (structural fatigue).	Failure to open, remains open at shutdown. Fails static with no response to commands.	Valve position.	
		Motor bearings gall, possibly jam.	Failure to open, slow to open/close, failure to close.	Valve position.	
Shaft	Transmits power from gear train to valve piston.	Breakage (structural failure).	Failure to open, failure to close at shutdown, fails static - no response to commands	Valve position.	
Shaft Bushings	Take out shaft radial loads & provide guide.	Wear, galling.	Failure to open, failure to close, erratic operation of valve.	Valve position.	
Shaft Seal (Primary)	Provide pressure seal between valve cavity and secondary seal.	Wear.	Possible slight effect on valve response.	Leak check at maint. cycle.	
Shaft Seal (Secondary)	Provide seal between primary seal and motor cavity.	Wear.	No effect. Secondary failure causing external leak.	Leak checks.	
Piston Ring (Upper)	Part of valve C_V determination.	Wear, loss of spring force	Slight change in valve C_V. Change in position for given power demand.	Valve position Preburner chamber pressure.	
Piston Ring (Lower)	Provide a pressure balance seal.	Wear, loss of spring force.	Increased opening time, decreased closing time,	Valve position. Preburner chamber pressure	
Static Seals	Prevent external leakage.	Creep.	None - external safety hazard	Leak checks at maint. cycle.	

FMEA ON CRITICAL COMPONENTS

SYSTEM 1 0 & 4 0
SUBSYSTEM 1 1 & 4.1
ASSEMBLY 1 1.1 & 4 1 1
COMPONENT 1.1.1.11 & 4 1.1 11
SHEET 1 of 1

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Motor/Gear Train Drive	Provides valve opening/positioning force.	Open winding, short to ground.	Failure to open, or premature closure	Valve position	
		Shorted turns.	Slow response.	Valve position	
		Gear failure (structural fatigue) possible jamming	Failure to open, premature closure, failure to close.	Valve position	
		Motor bearings gall and jam.	Failure to open, slow opening/closing, failure to close.	Valve position	
Shaft	Transmits power from gear train to valve piston.	Breakage (structural failure)	Failure to open, premature closure.	Valve position	
Shaft Bushings	Take out shaft radial loads, and provide guide	Wear, galling.	Failure to open, failure to close, erratic operation of valve	Valve position	
Shaft Seal (primary)	Provide pressure seal between valve cavity and secondary seal.	Wear	Slight effect on valve response time.	Leak check, valve position	
Shaft Seal (secondary)	Provide seal between primary seal and engine exterior.	Wear	Secondary failure resulting in external leak	Leak check	
Piston Ring (upper)	Provide restricted flow path during start to MPL.	Wear, loss of spring force.	Valve not controlling start and shutdown transient properly - slight change in position for given power demand	Valve position, preburner chamber pressure, temperature.	
Piston Ring (lower)	Provide a pressure bal. seal.	Wear, loss of spring force.	Increased opening time, decreased closing time (very small effect)	Same as above.	
Shutoff Seal	Provide positive shutoff.	Wear, contaminate particle in seal (secondary).	Excessive internal leakage of oxid.	Leak checks at maint. cycle.	
Static Seals	Prevent external leaks	Creep	None - external safety hazard	Leak checks at maintenance cycle	

FMEA ON CRITICAL COMPONENTS

SYSTEM 1 0 & 4 0
SUBSYSTEM 1 1 & 4 1
ASSEMBLY 1 1 3 & 4 1 3
COMPONENT 1 1 3 1 & 4 1 3 1
SHEET 1 of 1

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Oxidizer Valve, Solenoid 28 vdc	Provide on-off control of oxidizer flow to igniter in response to command 28 vdc valve is a fail-close on loss of power	Fails to open	Fails to ignite.	Valve position discrete	
		Opens slowly	Fails to ignite	Valve position discrete, preburner chamber pressure	
		Premature closure	Fails to ignite.	Same as above	
		Fails to close due to sticking at closure signal	Burnout of igniter chamber, with possible burn-through to hot gas manifold high temp discharge gas	Valve position discrete, main C C pressure	
		Seat leakage beyond spec limits	Hard start, possible igniter tube damage	Leak check at maintenance cycle Main C C pressure Physical check of igniter plug.	
Exciter (Redundant)	Convert 28 vdc to 30,000 volt 50 pps energy to plug	No output or low output	Fails to ignite	Igniter current	
Cable from Exciter to Plug (Each Exciter to Plug)	Conduct high-voltage pulses from exciter to spark plug	Open circuit	Fails to ignite	Igniter current	
		Short circuit, or spark gap to ground not allowing spark to discharge at plug	Fails to ignite	Ignition detector	
Spark Plug (Redundant)	Provide controlled spark gap	Short to ground	Fails to ignite	Ignition detector	

FMEA ON CRITICAL COMPONENTS

SYSTEM 1.0 & 4.0
SUBSYSTEM 1.1 & 4.1
ASSEMBLY. 1.1.1 & 4.1.1
COMPONENT 1.1.1.12 & 4.1.1.12
SHEET 1 of 1

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Motor/Gear Train Drive	Provide valve opening/positioning force.	Open winding, short to ground	Failure to open, premature closing.	Valve position.	
		Shorted turns.	Slow response.	Valve position	
		Motor bearings gall and jam.	Failure to open, slow to open/close, failure to close	Valve position.	
		Gear failure (structural fatigue), possible jamming.	Failure to open, premature closure; failure to close.	Valve position.	
Shaft	Transmits power from gear train to valve position.	Breakage (structural failure).	Failure to open, premature closure.	Valve position.	
Shaft Bushings	Take out shaft radial loads and provide guide.	Wear, galling.	Failure to open, failure to close, erratic operation of valve.	Valve position.	
Shaft Seal (Primary)	Provide pressure seal between valve cavity and secondary seal	Wear.	Slight effect on valve response, depending upon severity.	Leak checks, possibly valve position.	
Shaft Seal (Secondary)	Provide seal between primary seal and engine exterior.	Wear.	No effect Requires double failure - then external leak would be evidenced.	Leak checks.	
Piston Ring (Upper)	Provide restricted flow path during start to MPL.	Wear.	Slight increase of oxid flow to preburner during start and shutdown. Valve not controlling flow properly.	Preburner chamber pressure, temperature.	
Piston Ring (Lower)	Provide a pressure balance seal	Wear.	Slightly increased opening time, decreased closing time,	Valve position, preburner chamber pressure	
Shutoff Seal	Provide positive shutoff.	Wear/particle imbedding	Excessive internal leakage of oxid.	Leak checks at reg. maint. cycle.	
Static Seals	Prevent external leakage	Creep.	None - external safety hazard	Leak checks at reg maint. cycle.	

FMEA ON CRITICAL COMPONENTS

SYSTEM 1.0 & 4.0 ASSEMBLY 1 1.3 & 4.1.3

SUBSYSTEM 1.1 & 4 1 COMPONENT 1 1.3.1 & 4 1 3 1

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Oxidizer Valve, Solenoid, 28 vdc	Provide on-off control of oxidizer flow to igniter in response to command 28 vdc. Valve is a fail-close on loss of power.	Fails to open.	Fails to ignite.	Valve position discrete.	
		Opens slowly.	Fails to ignite.	Valve position discrete, preburner chamber pressure.	
		Premature closure.	Fails to ignite, premature loss of ignition	Same as above.	
		Fails to close due to sticking, at signal to close	Reduction in life expectancy of igniter assy, burnout of igniter chamber, metal contamination of preburner injector.	Valve position discrete. Check at maintenance cycle (functional and leak).	
		Seat leakage beyond spec limits.	Pressure spike in igniter chamber Possible igniter damage.	Leak check at maintenance cycle Conduct physical check of igniter plug	
Exciter (redundant)	Convert 28 vdc input signal to 30,000 volt 50 pps energy to plug	No output or low output	Fails to ignite.	Igniter current.	
Cable from Exciter to Plug (each exciter to plug)	Conduct high-voltage pulses from exciter to spark plug.	Open circuit.	Fails to ignite.	Igniter current.	
		Short circuit or spark gap to ground, not allowing spark to discharge at plug	Fails to ignite.	Ignition detector	
Spark Plug (redundant)	Provide controlled spark gap.	Short to ground.	Fails to ignite.	Ignition detector	

FMEA ON CRITICAL COMPONENTS

SYSTEM 1 0 & 4.0 ASSEMBLY 1.1 3 & 4 1 3
SUBSYSTEM 1 1 & 4 1 COMPONENT 1.1 3 2 & 4 1 3 2
SHEET 1 of 1

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Oxidizer Valve, Solenoid, 28 vdc	Provide on-off control of oxidizer flow to igniter in response to command 28 vdc. Valve is a fail-close on loss of power.	Fails to open.	Fails to ignite	Valve position discrete	
		Opens slowly.	Fails to ignite.	Valve position discrete, pre-burner chamber pressure.	
		Premature closure	Fails to ignite.	Same as above	
		Fails to close due to sticking, at closure signal	Reduction in life expectancy of igniter assy, burnout of igniter chamber, metal contamination of preburner injector	Valve position discrete, check at maintenance cycle, functional and leak check.	
		Seat leakage beyond spec limits.	Excessive pressure spike, possible igniter damage.	Leak check at maintenance cycle, check igniter plug condition	
Exciter (redundant)	Convert 28 vdc input signal to 30,000 volt 50 pps energy to plug.	No output or low output.	Fails to ignite.	Igniter current.	
Cable from Exciter to Plug (each exciter to plug)	Conduct high-voltage pulses from exciter to spark plug	Open circuit	Fails to ignite.	Igniter current.	
		Short circuit, or spark gap to ground not allowing spark to discharge at plug.	Fails to ignite.	Ignition detector	
Spark Plug (redundant)	Provide controlled spark gap.	Short to ground.	Fails to ignite.	Ignition detector	

FMEA ON CRITICAL COMPONENTS

SYSTEM 1 0 & 4 0
SUBSYSTEM 1 1 & 4 1

ASSEMBLY 1 1.4 & 4 1 4
COMPONENT- Gimbal Actuator & Power Pack
SHEET 1 of 2

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Hydraulic Power Pack	Provide hydraulic fluid at 3000 psig nominal to the TVC gimbal actuators	Minor fluid leakage (not at sufficient rate to deplete reserve fluid during mission.	Fault isolation and repair or replacement required prior to next flight	Reservoir fluid level measurement (piston position transducer)	
		Major fluid leakage (at rate sufficient to deplete reserve fluid and eventually starve pump inlet).	Impending loss of pressure to gimbal actuators, resulting in actuator slow response while accumulator discharges and then in hardover actuators	Same as above	Lock actuators in null position when this failure mode is detected
		Turbine-driven pump failure to deliver flow	Rapid loss of pressure to gimbal actuators as accumulator discharges (2 to 12 seconds, depending on actuator activity), resulting in actuator slow response for brief period and then in hardover actuators	Supply pressure measurement	Operate motor-driven pump and lock actuators in null position when this failure mode is detected
		Motor-driven pump failure to deliver flow	Inability to checkout or service gimbal actuator and power pack Loss of backup to turbine driven pump for actuator null lock operation	Supply pressure measurement.	
		Loss of accumulator gas charge	Neglible effect if turbine-driven pump is ok. However, if this condition exists, a sudden failure of the turbine-driven pump to deliver flow is likely to disable capability to lock actuators in null position (because of too rapid loss of pressure to actuators before motor-driven pump can come up to speed).	Accumulator gas pressure measurement	Possibly operate motor-driven pump whenever turbine-driven pump is operating (set pressure compensator on motor-driven pump to lower pressure so that it normally operates at no load)
		Excessive particulate contamination in hydraulic fluid (due to pump wear, erosion of fluid passages, etc)	Clogging of filters at actuator inlets, reducing filter effectiveness and allowing contamination to reach actuator servovalves May result in servovalve failure to function	Periodic sampling of hydraulic fluid for analysis (ground maintenance operation)	Flush and refill component with clean fluid when indicated by results of fluid sample analysis Replace actuator filters whenever extreme fluid contamination has occurred
Gimbal Actuator	Position the rocket engine for TVC	Minor internal leakage (servovalve able to deliver flow at load required to hold actuator at commanded position).	Slow response of gimbal actuator	Actuator position measurement command.	

FMEA ON CRITICAL COMPONENTS

SYSTEM 1 0 & 4 0
SUBSYSTEM 1 1 & 4.1

ASSEMBLY 1 1 4 & 4 1 4
COMPONENT Gimbal Actuator & Power Pack

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Gimbal Actuator (continued)		Major internal leakage (in excess of servovalve ability to deliver flow at pressure required to hold actuator at commanded position)	Actuator goes toward hardover position. Detection of error causes actuator to return to null and lock (as if both primary and secondary servovalves had failed as below)	Actuator position measurement compared to command.	
		Primary servovalve fails to respond to electrical input signal	No response of actuator to command. Detection by external system, which compares the input signal to the actuator output position, results in disabling of the primary servovalve and enabling of the secondary servovalve The actuator will then function normally	Same as above	
		Secondary servovalve fails to respond to electrical input signal (after disabling of primary servovalve).	No response of actuator to command Detection (as for primary servovalve failure) disables the secondary servovalve, arms the null lock, and allows the centering valve to drive the actuator to null position	Same as above	
		Actuator does not lock in null when required by other failure modes being detected or engine shutdown (Failure of solenoid valve, centering valve, selector valve, null lock, or feedback mechanism)	Actuator goes hardover and remains there	Actuator null position switch.	
		Null lock inadvertently arms (solenoid valve or disarm piston seal fails)	Actuator locks in null position	Actuator position measurement compared to command.	
		Feedback mechanism backlash (due to wear or partial failure).	Excessive null shift, loss of position accuracy, and possible unstable actuator position (oscillation)	Same as above	
		Feedback mechanism failure	Unmodulated actuator position (full extend or full retract positions only)	Same as above	Arm actuator null lock to lock in position if actuator passes through null.
		Extremely high fluid temperature due to excessive internal leakage from orifice wear	Excessive null shift	Same as above	
		Dynamic load damper failure (sticking piston, clogged orifice, or broken spring)	Unstable actuator position (oscillation)	Actuator position measurement analyzed for oscillation	Lock actuator in null position when this condition is detected

FMEA ON CRITICAL COMPONENTS

SYSTEM 1.0 & 4.0
SUBSYSTEM 1.1 & 4.1

ASSEMBLY. 1.1.5 & 4.1.5
COMPONENT: 1.1.5.4 & 4.1.5.4

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Power Modules for Valves, Ignition, Solenoid Locks, Motor Drives	Provide outputs to on-off, modulating valves, gimbal actuator servos, igniters, extendible nozzle drivers and locking mechanisms, gimbal actuator null locks.	Driver fails to deliver power on command	Loss of redundancy	Current sensors in driver circuits	
Power Modules for Instrumentation	Provide regulated power as required for transducers	Failure to regulate	Loss of redundancy	Primary/secondary comparison	
		Loss of power	Loss of redundancy	Primary/secondary comparison	
"BITE" Modules	Perform tests on processor, power modules.	Logic failure, loss of check capability	Loss of redundancy	Failure mode gives "switch" signal to CCU, or CPU to switch bite	
Channel Control Unit	Select functional modules based on bite signals for operable flow path This unit is fail neutral - a failure in the CCU results in continuation of the last structure An additional failure in the controller results in a safe engine shutdown via the shutdown module	Failure of select switches, logic.	Loss of select capability	None - fails neutral Shutdown module still available	
Emergency Shutdown Module	Shuts down engine on fixed sequence, selected in event of failure of the shutdown capability associated with other two channels.	Failure of logic switch	Loss of third level redundant shutdown capability	None	

FMEA ON CRITICAL COMPONENTS

SYSTEM 1 0 & 4 0
SUBSYSTEM 1 1 & 4.1
ASSEMBLY 1 1.5 & 4 1.5
COMPONENT 1.1.5.4 & 4 1.5.4
SHEET 1 of 2

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATIONS
DC Amplifier Analog Multiplexer	Amplify low level signals from transducers, to a level suitable for multiplexing, multiplex 16 channels into one output.	Amplifier zero drift	Loss of redundant data channel.	Computation comparison	
		Noisy channel.			
		Loss of signal.			
		Clamped full scale signal.			
		Gain change			
		Constant output from one channel (MUX switch fails to reopen)	Loss of 16 channel redundancy	Computation comparison.	
Node Analog Switches	Provide selection of any of the 16 channel amplif/MUX modules into one of two or both analog-to-digital converters	Loss of signal	Loss of all redundancy in one input subsystem (analog inputs).	Computation comparison.	
		Constant output - from one module (MUX switch fails to reopen).			
Analog-to-Digital Converter.	Convert high level analog signals from node switches to binary digits.	Ref. supply drift.	Same as above.	Computation comparison. BITE	
		"Hanging" digits or dropping digits.			
		Ref. resistor open, with digitizing error			
Digital Processor/Memory	Perform calculations, tests, sequencing, self checks.	Failure in core, logic failure, clock failure, power supply failure.	Loss of one complete channel.	Computation comparison.	
Counter Input Module	Convert periodic input signals (rpm flow) to binary digits.	Improper counting, logic failure.	Same as above	Computation comparison.	
Digital Interface	Provide logic interface between vehicle data/command bus and controller.	Logic element failure.	Same as above.	Diagnostic routine from vehicle comp/interface.	

FMEA ON CRITICAL COMPONENTS

SYSTEM 1 0 & 4 0
SUBSYSTEM 1 1 & 4 1

ASSEMBLY 1 1.5 & 4.1.5
COMPONENT Ignition Control Harness
SHEET 1 of 1

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Cable, from Controller to Exciter (Two Exciters, Two Cables) Fuel Preburner, Oxid Preburner, Main Combustion Chamber	Conduct 28 vdc on command from controller power bus to spark exciter unit	Open circuit at connectors	Loss of continuity	Igniter current	
		Short circuit to ground in cable or connector	Loss of power transmission to exciter	Ignitor current (breaker should blow, showing loss of current)	
		Open circuit in cable	Loss of continuity	Igniter current	
		High resistance connection	High resistance to current flow	Igniter current	
Cables from Controller to Individual Valves, Including Connectors	Conduct dc or ac from controller power bus to valves.	All modes result in loss or extreme degradation of conduction	The valves will fail to open, or will fail to prescribed condition, as specified The individual valve failure modes and effects include this mode	N/A	

FMEA ON CRITICAL COMPONENTS

SYSTEM 4.0
SUBSYSTEM 4 1

ASSEMBLY 4 1 8
COMPONENT 4.1.8.3
SHEET 1 of 1

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Motor Drive Unit for Extending Retracting Nozzle	Provides power to drive the extension assembly. (Redundant motor mechanisms). Operates from system electrical power.	Open circuit Short circuit	Failure to extend or retract, stopping at intermediate position	Nozzle position Motor current	
		Shorted turns	Slow operating, with potential for incomplete extension prior to separation/ignition	Nozzle position Motor current	
		Gear breakage, bearing galling, jamming (or circuit mech. slippage).	Slow operation, failure to extend/retract, stopping at intermediate position	Same as above	
Cable Drive	Transmit output force of motor drive unit to nozzle (redundant cable drives).	Breakage	Failure to extend/retract, stopping at intermediate position	Same as above	
Lock Drive Mechanism	Provide driving force for nozzle locking/sealing at extended position. (Redundant motor mechanisms.) Operates from system electrical power	Open circuit. Short circuit	Failure to lock, failure to unlock, partial unlock/lock	Lock position Motor current	
		Shorted turns	Slow operation - ultimate motor burnout	Motor current	
		Gear breakage, gears wear, jamming	Failure to lock/unlock, partial unlocking/locking	Motor current Lock position	

FMEA ON CRITICAL COMPONENTS

SYSTEM 1 0 & 4.0
SUBSYSTEM 1 1 & 4.1

ASSEMBLY. 1.1 5 & 4.1 5
COMPONENT: 1.1.5.4
SHEET 1 of 1

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Fuel Temperature, Fuel Preburner Inlet	Provide temperature data for mixture ratio control loop.	Shift of resistance vs temperature sensitivity	Change sensitivity	Compare redundant data	
Fuel Temp, Oxid Preburner Inlet		Open circuit	Loss of signal	Compare redundant data	
Oxid Temp, Oxidizer Flowmeter, Preburn		Low impedance short across signal leads	Change (reduction) of sensitivity	Compare redundant data	
Oxid Temp, Main Combustion Chamber Flowmeter					
Oxid Flow, Preburners	Provide oxid flow rate (volumetric) Data for mixture ratio control loop.	Open circuit in pickoff coil	Loss of signal, one coil	Compare redundant data - (second coil)	
Oxid Flow, Main Combustion Chamber		Low impedance short circuit across signal leads	Reduced output voltage, one coil	Compare redundant data - (second coil) (effect may be a signal below system threshold).	
		Bearing wear or contamination	Erratic output, change in calibration factor, loss of signal in both pickoff coils, due to rotor locking	Compare redundant data.	
Pressure, Main Combustion Chamber	Provide pressure feedback data for control loops (Thrust and mixture ratio)	Open circuit in power or signal leads	Loss of signal	Shunt calibrate or compare redundant data	
Fuel Pressure, Fuel Preburner Inlet		Low impedance short across power or signal leads	Reduction of sensitivity	Same as above	
			Zero off-set	Same as above.	
Fuel Pressure, Oxid Preburner Inlet		Open circuit in shunt calibration leg(s)	Failure to provide step output on one or both steps	Same as above	
Oxid Pressure, Oxid Flowmeter					
Oxid Pressure, Main Combustion Chamber Flowmeter		Shift of shunt calibration resistance valve	Nonlinear output of shunt calibration	Same as above	
Pressure, Fuel Preburner, Combustion Chamber		Low impedance from shunt calibration leg to any other	Zero off-set	Same as above	
			Nonlinear shunt calibration steps	Same as above	
Pressure, Oxid Preburner Combustion Chamber		Shift of shunt-to-force sensitivity bonding slip or change in mechanical properties	Change of output sensitivity with pressure	Compare Redundant Data	
ΔP, Inlet to Chamber, Fuel Preburner		Open circuit in one leg	Zero off-set (large)	Shunt calibration or compare redundant data	
ΔP, Inlet to Chamber, Oxid Preburner		Open circuit in two legs	Zero off-set or loss of signal	Same as above	
Oxid pressure, 1st Stage Disch, HPOTPA		Open circuit in three legs.	Loss of signal	Same as above	
Oxid Pressure, 2nd Stage Disch, HPOTPA					

FMEA ON CRITICAL COMPONENTS

SYSTEM 4.0
SUBSYSTEM 4.4

ASSEMBLY 4.4.2 Oxidizer Tank
COMPONENT 4 4.2 1 Vent Valve
SHEET 1 of 1

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Primary Pilot Valve	Provides force to open main valve	1) Fails open 2) Fails closed.	No effect No effect	Valve position indicator Valve position indicator	Method should be devised to checkout pilot valve
Secondary Pilot Valve	Backup to primary pilot valve	1) Fails open 2) Fails closed	Valve could not operate as a normally closed valve. Valve could not operate in the open mode	Valve position indicator Valve position indicator	Same as above

SYSTEM 4 0 | ASSEMBLY 4.4.4

FMEA ON CRITICAL COMPONENTS

SUBSYSTEM 4 4 | COMPONENT: 4.4.4.2 Fuel Isolation Valve

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Relief Valve	Prevents the overpressurization of feed lines downstream of the shutoff valve in the event all valves are closed and lines are filled with fuel	Fails closed. Fails open	Feed lines downstream would burst External leakage	Valve position indicator Valve position indicator	Devise method for valve checkout.
Actuator	Provides actuation for valve.	Fails to operate	Valve fails open or closed	Valve position indicator.	

SYSTEM 4 0

SUBSYSTEM 4 4

ASSEMBLY 4 4 5

COMPONENT 4 4 5 2 Fuel Tank Vent Valve

FMEA ON CRITICAL COMPONENTS

SHEET 1 of 1

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Primary Pilot Valve	Provides force to open main valve	Fails open. Fails closed.	No effect - secondary pilot would operate valve No effect - secondary pilot would operate valve	Valve position indicating switch. Valve position indicating switch.	Method should be devised to c/o pilot valve
Secondary Pilot Valve	Backup to primary pilot valve	Fails open. Fails closed	Valve could not operate as a normally closed valve Valve could not operate in the open mode	Valve position indicating switch. Valve position indicating switch.	Method should be devised to c/o pilot valve

FMEA ON CRITICAL COMPONENTS

SYSTEM 4 0

SUBSYSTEM 4 5

ASSEMBLY 4 5 1 & 4.5 2

COMPONENT 4.5.1.3 & 4.5.1.7
Regulator

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Relief Valve	Prevents the over-pressurization of the downstream on-orbit tankage	Fails closed. Fails open	Component would not operate as a relief valve Major leak path through regulator.	Tank pressure measurement. Tank pressure measurement	

FMEA ON CRITICAL COMPONENTS

SYSTEM 2 0
SUBSYSTEM 2 3, 2 4, 2 6
ASSEMBLY 2 3 1 1,2.4 1 1,2 6 1 2
COMPONENT Turbine
SHEET 1 of 1

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Turbine Case	Locate and support vanes and blade tip seals Support turbine exhaust ducting	Cracking due to high loads and thermal stress	Possible loss of vane or seal support	Visual inspection, measure turbine speed	None
Rotor Shaft	Support turbine disks Transmit torque from disks to power train and provide spacing for rotor parts	1) Shaft deplection due to high load or excessive temperatures 2) Fatigue cracking due to vibration 3) Shaft separation (secondary failure)	1) Possible rubbing of turbine blades against case Reduced bearing life 2) Reduced part life, possible shaft separation 3) Complete loss of turbine	1) Measure turbine vibration, visual inspection 2) Visual inspection 3) Measure turbine rotor speed, visual inspection	None
Turbine Disks	Support blade seals and spacers Provide axial spacing for rotor parts Transmit driving torque from blades to rotor	1) Radial growth due to overspeed or overheating 2) Galling or wear of blade attachment slots due to vibration or gas load	1) Limited growth will result in blade tip or seal rubbing and snap growth, which could result in rotor shaft unbalance 2) Reduced part life	1) Measure turbine vibration, visual inspection 2) Visual inspection	None
Turbine Blades	Transmit energy from gas stream to disks	1) Airfoil cracking due to vibration and centrifugal loads 2) Blade tip rub due to material creep or extreme gas generator condition	1) Reduced part life Possible loss of blade resulting in rotor unbalance and possible damage to downstream parts 2) Blade tip and case wear Possible vibration	1) Measure turbine vibration, visual inspection 2) Visual inspection	None
Seals	Form flow path at blade tips,	1) Wear due to rubbing 2) Distortion due to gas loads and thermal growth	1) Loss of efficiency due to leakage 2) Increased seal clearance resulting in gas leakage and performance loss	1) Visual inspection 2) Visual inspection	None
Vanes	Direct gas generator combustion products to turbine blades	1) Bending of vanes due to gas loads or overtemperature 2) Cracking due to blade wake-excited vibration 3) Erosion due to hot gas impingement	1) Loss of efficiency due to flow distortion 2) Reduced part life Possible total or partial vane loss resulting in downstream damage and/or loss of efficiency 3) Reduced part life	1) Visual inspection, measure gas temperature 2) Visual inspection 3) Visual inspection	None

FMEA ON CRITICAL COMPONENTS

SYSTEM 2 0
SUBSYSTEM 2 3

ASSEMBLY 2 3.1 3
COMPONENT Pump
SHEET 1 of 1

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Main Housing	Contain LH_2 propellant Locate and support bearings and seals Provide compartments for location and mounting of impeller and bearings Provide mounting pads for gearbox housing and structural members	1) Cracking of housing at mounting pads due to high loads and stress concentrations 2) Cracking of impeller support lugs due to high loads 3) Loosening of studs or bolts due to thermal expansion or high loads	1) External leakage of LH_2 and possible bearing misalignment with reduced part life 2) Reduced mount strength, possible impeller misalignment with reduced part life 3) External leakage of LH_2 and possible bearing misalignment with reduced part life	1) Visual inspection 2) Visual inspection 3) Visual inspection	None
Seals	Prevent leakage between impeller shaft and housing	1) Wear caused by time in operation or impeller unbalance 2) Distortion caused by excess pump pressure	1) External leakage of LH_2 with reduced part life 2) External leakage of LH_2 with reduced part life	1) Visual inspection, measure pump discharge pressure 2) Visual inspection, measure pump discharge pressure	None
Impeller	Transmit LH_2 propellant at a specified inlet pressure to a higher pressure at the pump outlet	1) Blade damage caused by pitting due to particle ingestion and/or local cavitation 2) Impeller misalignment due to bearing wear or improper assembly	1) Change in pump efficiency and increase in vibration 2) Impeller rub against main housing Reduced part life with loss in pump efficiency	1) Measure pump vibration, visual inspection 2) Measure pump speed, visual inspection	None
Bearings	Locate and support impeller within the main housing	Wear of bearings due to high loads or overheating	Reduced part life with possible bearing failure resulting in loss of impeller support Possible impeller rub against housing	Bearing temperature measurement, visual inspection	None

FMEA ON CRITICAL COMPONENTS

SYSTEM 2 0
SUBSYSTEM 2 4

ASSEMBLY 2 4 1
COMPONENT Compressor
SHEET 1 of 1

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Compressor Housing	Locate and support bearings and seals Provide compartment for location and mounting of shafts and bearings Contain high-pressure gaseous oxygen Provide mounting pads for gearbox housing and structural members	1) Cracking of housing at mounting pads due to high loads and stress concentrations 2) Cracking of shaft support lugs due to high loads 3) Loosening of studs or bolts due to thermal expansion or high loads	1) External leakage of high-pressure gaseous oxygen and possible bearing misalignment with reduced part life 2) Reduced mount strength, possible shaft misalignment with reduced part life 3) External leakage of high-pressure gaseous oxygen and possible bearing misalignment with reduced part life	1) Visual inspection 2) Visual inspection 3) Visual inspection	None
Rotor Shaft	Support compressor disks. Transmit driving torque to disks and provide spacing for rotor parts	1) Shaft deflection due to high load or excessive temperatures. 2) Fatigue cracking due to vibration 3) Shaft separation (secondary failure)	1) Possible rubbing of compressor blades against housing Reduced bearing life 2) Reduced part life, possible shaft separation 3) Complete loss of compressor	1) Measure compressor vibration, visual inspection 2) Visual inspection 3) Measure compressor rotor speed, compressor outlet pressure, visual inspection	None.
Compressor Blades	Increase pressure of gaseous oxygen to 1500 psia for oxygen accumulator resupply	1) Airfoil cracking due to vibration and centrifugal loads 2) Blade tip rub due to material creep or extreme gas generator condition	1) Reduced part life Loss of blade resulting in rotor unbalance and possible damage to downstream parts 2) Blade tip and housing wear Possible vibration	1) Measure compressor vibration, visual inspection 2) Visual inspection	None
Compressor Disks	Support blade seals and spacers Provide axial spacing for rotor parts Transmit driving torque to blades	1) Radial growth due to overspeed or overheating 2) Galling or wear of blade attachment slots due to vibration or gas load	1) Limited growth will result in blade tip or seal rubbing and snap growth, which could result in rotor shaft unbalance 2) Reduced part life	1) Measure compressor vibration, visual inspection 2) Visual inspection	None
High-Pressure Compressor Seals	Limit interstage gas recirculation	Seal distortion due to gas loads and thermal growth	Increased seal clearance resulting in greater interstage gas leakage and performance loss.	Visual inspection	None
Compressor Vanes and Stators	Direct gas from one rotor stage to the next	1) Bending of vanes due to gas loads or overtemperature 2) Airfoil cracking due to blade wake-excited vibration.	1) Loss of efficiency due to flow distortion 2) Reduced part life Possible total or partial vane loss resulting in downstream damage and/or loss of efficiency	1) Visual inspection Measure stage gas temperature 2) Visual inspection	None
Rotor Shaft Bearings	Locate and support rotor shaft within the compressor housing	Wear of bearings due to high loads or overheating	Reduced part life with possible bearing failure resulting in loss of shaft support Possible blade tip rub against housing	Bearing temperature measurement, visual inspection	None

FMEA ON CRITICAL COMPONENTS

SYSTEM 2 0
SUBSYSTEM 2 3, 2 4, 2.6

ASSEMBLY: 2 3.1, 2.4.1, 2.6.1
COMPONENT Power Train
SHEET 1 of 1

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Gearbox Housing	Locate and support bearings and seals Provide compartment for location and mounting of gears, shafts, bearings Provide mounting pads for turbine, pump, oil pumps, and structural members	1) Cracking of housing at mounting pads due to high loads and stress concentrations 2) Cracking of gearbox support lugs due to high loads 3) Loosening of studs or bolts due to thermal expansion or high loads	1) Oil leakage and possible bearing misalignment with reduced part life 2) Reduced mount strength, possible driveshaft misalignment with reduced part life 3) Oil leakage and possible gear misalignment, reduced part life	1) Visual inspection 2) Visual inspection, oil pressure measurement 3) Visual inspection	None
Gear Shafts	Support and position gears within the gearbox Transmit torque from gear to gear	1) Wear of splines due to part movement 2) Shear of spline due to overload	1) Reduced part life 2) Loss of torque transmission and support to gears Possible loss of oil pump or power transmission capability	1) Visual inspection 2) Visual inspection, oil pressure measurement	None
Bearings	Locate and support gear shafts within the gearbox	Wear of bearings due to high loads or overheating	Reduced part life with possible bearing failure resulting in loss of shaft support and loss of force transmission to components	Oil pressure measurement, oil temperature measurement	None
Gears	Transfer torque between shafts within gearbox	1) Gear wear due to high loading or oil contamination 2) Web cracking due to vibratory loading.	1) Reduced part life 2) Reduced part life with possible shear failure resulting in loss of power transmission to components	1) Visual inspection 2) Visual inspection	None
Seals	Contain oil and air pressure at component mounting pads	Wear or cracking due to misalignment or high load	Reduced part life, possible oil leakage	Measure oil level, visual inspection	None

FMEA ON CRITICAL COMPONENTS

SYSTEM 5 0
SUBSYSTEM 5 3

ASSEMBLY 5 3.2
COMPONENT Power Train
SHEET 1 of 2

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Gearbox Housing	Locate and support bearings and seals Provide compartment for location and mounting of gears, shafts, bearings. Provide mounting pads for clutch, pumps, oil pumps, heat exchangers and structural members	1) Cracking of housing at mounting pads due to high loads and stress concentrations 2) Cracking of gearbox support lugs due to high loads 3) Loosening of studs or bolts due to thermal expansion or high loads.	1) Oil leakage and possible bearing misalignment with reduced part life 2) Reduced mount strength, possible driveshaft misalignment with reduced part life 3) Oil leakage and possible gear misalignment, reduced part life	1) Visual inspection 2) Visual inspection, oil pressure measurement 3) Visual inspection	None
Gear Shafts	Support and position gears within the gearbox Transmit torque from gear to gear	1) Wear of splines due to part movement 2) Shear of spline due to overload	1) Reduced part life 2) Loss of torque transmission and support to gears Possible loss of oil pump or power transmission capability	1) Visual inspection 2) Visual inspection, oil pressure measurement.	None
Gear Shaft Bearings	Locate and support gear shafts within the gearbox	Wear of bearings due to high loads or overheating	Reduced part life with possible bearing failure resulting in loss of shaft support and loss of force transmission to components	Oil pressure measurement, oil temperature measurement	None
Gears	Transfer torque between shafts within gearbox	1) Gear wear due to high loading or oil contamination 2) Web cracking due to vibratory loading	1) Reduced part life 2) Reduced part life with possible shear failure resulting in loss of power transmission to components	1) Visual inspection 2) Visual inspection	None
Seals	Contain oil and air pressure at component mounting pads	Wear or cracking due to misalignment or high load	Reduced part life, possible oil leakage	Measure oil level, visual inspection	None
Clutch Housing	Locate and support bearings and seals Provide compartment for location and mounting of clutch, power shaft, bearings Provide mounting pads for turbine, gearbox, and structural members	1) Cracking of housing at mounting pads due to high loads and stress concentrations 2) Cracking of clutch support lugs due to high loads 3) Loosening of studs or bolts due to thermal expansion or high loads	1) Possible bearing misalignment with reduced part life 2) Reduced mount strength, possible power shaft misalignment with reduced part life 3) Possible bearing misalignment, reduced part life	1) Visual inspection 2) Visual inspection 3) Visual inspection	None
Power Shaft	Transmit power from turbine to gearbox through clutch plates Support clutch plates	1) Shaft deflection due to high load or excessive temperatures 2) Fatigue cracking due to vibration. 3) Shaft separation (secondary failure).	1) Clutch misalignment resulting in possible seal or clutch plate rubbing, reduced bearing life 2) Reduced part life, possible shaft separation 3) Axial shift of power shaft resulting in clutch plate rubbing, loss of power transmission capability	1) Measure clutch vibration, visual inspection 2) Visual inspection 3) Measure turbine speed, gearbox output, visual inspection	None

FMEA ON CRITICAL COMPONENTS

SYSTEM 5 0
SUBSYSTEM 5 3

ASSEMBLY 5 3.2
COMPONENT: Power Train
SHEET 2 of 2

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Power Shaft Bearings	Locate and support the power shaft within the clutch housing	Wear of bearings due to high loads or overheating	Reduced part life with possible bearing failure resulting in loss of shaft support and loss of force transmission to components	Bearing temperature measurement, visual inspection	None
Seals	Preclude contamination of clutch housing by external contaminants	Wear or cracking due to misalignment or high load	Reduced part life, possible clutch housing contamination	Visual inspection.	None
Clutch Plates	Control power transmission from turbine to gearbox	1) Cracking of plates due to high loads and stress concentrations 2) Separation of clutch plate (secondary failure).	1) Reduced part life, possible plate separation 2) Loss of power transmission control to gearbox, possible loss of clutch housing	1) Visual inspection 2) Measure clutch vibration, visual inspection.	None
Clutch Plate Control Solenoid	Control engagement of clutch plates	1) Failure to engage plates 2) Failure to disengage plates	1) Loss of power transmission capability to gearbox. 2) Possible overload of turbine	1) Measure turbine and gearbox outputs (speed) 2) Measure turbine speed	None

FMEA ON CRITICAL COMPONENTS

SYSTEM 3 0 & 6 0 ASSEMBLY 3 1 1 & 6 1 1
SUBSYSTEM 3.1 & 6 1 COMPONENT 3 1.1 1 & 6.1.1 1
SHEET 1 of 1

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Blades	Increase pressure of engine air to low-pressure compressor	1) Foreign object damage 2) Blade tip rub due to material creep or extreme engine conditions 3) Cracking of airfoil or dovetail due to blade flutter	1) Decrease in performance proportional to the extent of damage 2) Blade and seal damage 3) Possible loss of part of blade with downstream damage and high vibration	1) Ground inspection, increased vibration 2) Ground inspection 3) Inspection at overhaul, increased vibration	None
Fan Disks/Hubs	Support blades, blade locks, seals, and rim spaces Transmit driving torque to blades Provide axial spacing for rotor parts	1) Radial growth due to overspeed or overheating 2) Cracks in rim lugs or web due to cycle loading, 3) Galling or wear of blade attachment slots due to gas loads and vibration	1) Blade tip or seal rubbing resulting in rotor shift and unbalance, 2) Tensile yield or burst which results in severe engine damage 3) Reduced part life	1) Overhaul inspection and engine vibration 2) Overhaul inspection, engine vibration, loud noise 3) Overhaul inspection	None
Stator Vanes	Direct air from one rotor stage to the next.	1) Foreign object damage 2) Surface damage due to blade contact 3) Cracking due to vibration 4) Wear of surface due to damage 5) Loose fasteners	1) Decrease in performance 2) Decrease in performance 3) Possible part failure with downstream damage 4) Reduced part life 5) Downstream blade and vane damage	1) Overhaul inspection, increased Total Specific Fuel Consumption (TSFC) 2) Overhaul inspection, increased TSFC 3) Overhaul inspection, reduced engine pressure ratio 4) Overhaul inspection 5) Overhaul inspection	None
Bearings	Provide radial support to front fan rotor	1) Skid or wear due to low load 2) Wear or seizure due to overheating	1) Reduced part life possible premature failure 2) Same as above.	1) Overhaul inspection or engine vibration 2) Same as above	None

FMEA ON CRITICAL COMPONENTS

SYSTEM 3.0 & 6 0
SUBSYSTEM 3 1 & 6 1

ASSEMBLY 3 1.1 & 6.1.1
COMPONENT 3.1.1 2 & 6.1.1.2
SHEET 1 of 1

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Blades	Increase pressure of engine air to high-pressure compressor	1) Wear of shroud contact faces due to vibration 2) Foreign object damage 3) Blade tip rub due to material creep or extreme engine condition 4) Cracking of airfoil or dovetail due to blade flutter	1) Loose blades reduced vibration damping 2) Decrease in performance proportional to extent of damage 3) Blade and seal damage 4) Possible loss of part of blade with downstream damage and high vibration	1) Inspection at overhaul, noisy rundown, increased vibration 2) Ground inspection, increased vibration 3) Ground inspection 4) Inspection at overhaul, increased vibration	None
Disks/Hubs	Support blades, blade locks, seals and rim spacers Transmit driving torque to blades Provide axial spacing for rotor parts	1) Radial growth due to overspeed or overheating 2) Cracks in rim lugs or web due to cyclic loading 3) Galling or wear of blade attachment slots due to gas loads and vibration	1) Blade tip or seal rubbing resulting in rotor shift and unbalance 2) Tensile yield or burst which results in severe engine damage. 3) Reduced part life	1) Overhaul inspection and engine vibration 2) Overhaul inspection, engine vibration, loud noise. 3) Overhaul inspection.	None
Air Seals	Limit interstage air recirculation	Wear or cracking due to rubbing	Increased seal clearance resulting in higher interstage air leakage and performance loss	Overhaul inspection and increase in TSFC	None
Stator Vanes	Direct air from one rotor stage to the next	1) Foreign object damage 2) Surface damage due to blade contact. 3) Cracking due to vibration. 4) Wear of surfaces due to damage 5) Loose fasteners	1) Decrease in performance 2) Decrease in performance 3) Possible part failure with downstream damage. 4) Reduced part life 5) Downstream blade and vane damage	1) Overhaul inspection, increased TSFC. 2) Same as above 3) Overhaul inspection, reduced engine pressure ratio 4) Overhaul inspection 5) Overhaul inspection	None
Bearings	Provide radial support to front fan rotor	1) Skid or wear due to low load 2) Wear or seizure due to overheating	1) Reduced part life, possible premature failure 2) Same as above	1) Overhaul inspection or engine vibration 2) Same as above	None

FMEA ON CRITICAL COMPONENTS

SYSTEM 3 0 & 6.0
SUBSYSTEM 3.1 & 6.1
ASSEMBLY 3 1 1 & 6 1.1
COMPONENT 3.1.1 3 & 6 1 1 3
SHEET 1 of 3

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Blades	Increase pressure of engine air	1) Airfoil cracking due to vibrating and centrifugal loads 2) Wear of attachment lugs 3) Blade tip rub due to material creep or extreme engine condition	1) Reduce part life because of possible loss of blade airfoil resulting in rotor unbalance and damage to downstream parts 2) Reduce part life replacement at overhaul 3) Blade tip and seal wear, possible vibration reduced surge margin Possible IFS and PER for parts replacement	1) Engine vibration, increased TSFC overhaul inspection 2) Overhaul inspection 3) Overhaul inspection, increased TSFC	None
High-Compressor Disks/Hubs	Support blade seals and rim seals Provide spacing for rotor parts (integral spacers) Transmit driving torques to blades	1) Radial growth (yield or creep) due to overspeed or overheating. 2) Fatigue cracks in rim, lugs, bolt holes, or web due to cyclic loading 3) Galling or wear of blade attachment slots due to vibration and gas load	1) Limited growth will result in blade tip or seal rubbing and snap growth which could result in rotor shift and unbalanced engine shutdown & PER. 2) Cracks weaken disks and lead to tensile yield or burst which results in severe engine damage and engine shutdown 3) Reduced part life Removal at overhaul.	1) Overhaul inspection and engine vibration 2) Overhaul inspection, engine vibration and loud noise 3) Overhaul inspection	None
Seals	Limit interstage air recirculation.	Knife edge wear or cracking due to rubbing, seal land distortion due to gas loads and thermal growth and surface wear due to blade rub	Increased seal clearance resulting in greater interstage air leakage and performance loss Alteration of internal thrust balance could cause reduced life of thrust bearing	Overhaul inspection and increased TSFC	None

FMEA ON CRITICAL COMPONENTS

SYSTEM 3 0 & 6 0
SUBSYSTEM 3 1 & 6 1

ASSEMBLY 3.1.1 & 6.1.1
COMPONENT: 3.1.1 3 & 6.1.1.3

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
High-Pressure Compressor Variable Vanes	Direct engine air from one rotor stage to the next	1) Cracking of vane due to combined bending and vibrating loads. 2) Bending of blades due to gas loads or over-temperature 3) Wear of vane pivot due to vane movement. 4) Cracking of carbon support bearings due to shock loadings 5) Linkage disconnect or fracture due to vibration or high load	1) Loss of vanes resulting in loss of efficiency, damage to downstream parts and probable engine shutdown 2) Loss of efficiency and possible restriction of vane movement 3) Redúced part life Loosened fit of pivots with possible vane tilt and inner shroud axial shift 4) Same as above 5) Free stage would open to ma + position causing engine surge resulting in inflight shutdown	1) Increased Total Specific Fuel Consumption (TSFC), engine vibration, overhaul inspection 2) Increased TSFC, overhaul inspection 3) Overhaul inspection 4) Overhaul inspection 5) Overhaul inspection	None
Bearings	Provide radial support to rear of high pressure rotor.	1) Skidding of rollers due to low radial load. 2) Fretting or spinning of inner race on hub due to loss of restraint 3) Bearing wear or seizure due to overheating 4) Roller or race wear due to high load or rotor vibration	1) Reduced part life resulting in replacement at overhaul Possible premature failure resulting in engine shutdown 2) Same as above 3) Same as above. 4) Same as above.	1) Overhaul inspection, vibration 2) Same as above 3) Same as above 4) Same as above	None

FMEA ON CRITICAL COMPONENTS

SYSTEM 3 0 & 6.0
SUBSYSTEM 3 1 & 6 1
ASSEMBLY 3 1 1 & 6 1 1
COMPONENT 3 1 1.3 & 6 1 1.3

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Bearings (cont)	Same as above.	5) Cage wear or separation.	5) a) Contamination of oil resulting from wear b) Bearing failure results from separation leading to radial shift of rotor with probable blade and vane contact and engine shut-down	5) a) Overhaul inspection b) Engine vibration, RPM decrease	

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Turbine Blades	Transfer energy from gas stream to high-pressure disks.	1) Cracking of airfoil or attachment due to cyclic loading and vibration 2) Corrosion or erosion of blades	Possible blade loss resulting in reduced efficiency, high rotor unbalance, and impact damage to adjacent and downstream parts Reduced efficiency of turbine Blade pitting could lead to cracking	Inspect at overhaul Measure vibration Inspect at overhaul	Part replacement at overhaul. None
Turbine Disks	Supports blades, seals and spacers. Transmits torque to shaft	1) Disk burst due to overspeed 2) Radial growth due to overspeed 3) Crack in rim, bolt holes, or web due to cyclic loading	Severe engine damage. Probable case penetration with possible stage damage Limited growth will result in blade tip or seal rubbing Cracks weaken disk and lead to tensile yield and burst	Severe vibration, loud noise. Overhaul inspection, engine vibration Overhaul inspection	None

FMEA ON CRITICAL COMPONENTS

SYSTEM 3 0 & 6 0
SUBSYSTEM 3 1 & 6 1

ASSEMBLY 3 1 1 & 6 1 1
COMPONENT 3 1 1 5 & 6 1 1 5
SHEET 2 of 3

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Turbine Rim Spacer	Supports labyrinth seals Limits disk run axial deflections. Dampen disk rim vibration	1) Radial growth due to over-speed or overtemp 2) Cracking due to cyclic loading	Seal rub and wear, loss of efficiency due to interstage air recirculation Part replacement at overhaul.	Increased Total Specific Fuel Consumption (TSFC) Overhaul inspection Overhaul inspection	None
Turbine Blade Tip Seals	Forms flow path at blade tips	1) Wear due to blade rubbing 2) Distortion due to overheating	Air leakage past blade tips resulting in reduced turbine efficiency Seal damage and blade damage resulting in loss of turbine efficiency.	Increased TSFC Overhaul inspection Same as above Same as above	None
Turbine Case	Supports vanes and blade tip seals	Cracking due to high load and temperature	Possible loss of vane or seal support with vane deflection and possible rotor rub.	Overhaul inspection	Part removal at overhaul

FMEA ON CRITICAL COMPONENTS

SYSTEM 3 0 & 6 0
SUBSYSTEM 3.1 & 6 1

ASSEMBLY 3 1 1 & 6 1.1
COMPONENT 3 1 1 5 & 6 1.1.5

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Turbine Vanes	Directs the combustion gases to turbine blades	1) Bowing of vanes due to high temperature 2) Cracking of airfoils due to severe thermal gradients 3) Cracking of vane feet due to cyclic loading	Turbine gas flow distortion resulting in reduced efficiency Reduced part life Possible blade-vane rubbing	Increased Total Specific Fuel Consumption (TSFC) Overhaul inspection Overhaul inspection Increased TSFC Overhaul inspection	None Replace at overhaul None
Turbine Interstage Labyrinth Seals		Knife edge wear or cracking due to rubbing	Increased seal clearance resulting in greater interstage air leakage and performance loss.	Increased TSFC Overhaul inspection	None

FMEA ON CRITICAL COMPONENTS
LOW PRESSURE TURBINE

SYSTEM 3 0 & 6 0
SUBSYSTEM 3 1 & 6 1

ASSEMBLY 3.1 1 & 6.1.1
COMPONENT 3 1 1 6 and 6 1 1 6

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Turbine Blades	Transfer energy from gas stream to low pressure turbine disks	1) Cracking of airfoil or attachment due to cyclic loading and vibration 2) Corrosion or erosion of blades	Possible blade loss resulting in reduced efficiency, low rotor unbalance and impact damage to adjacent and downstream parts Reduced efficiency of turbine Blade pitting could lead to cracking	Inspect at overhaul Inspect at overhaul.	Part replacement at overhaul None
Turbine Disks	Supports blades, seals, and spacers Transmits torque to shaft	1) Disk burst due to overspeed 2) Radial growth due to overspeed 3) Crack in rim, bolt holes, or web due to cyclic loading	Severe engine damage Probable case penetration with possible stage damage. Limited growth will result in blade tip or seal rubbing Cracks weaken disk and lead to tensile yield and burst	Severe vibration Loud noise Overhaul inspection Engine vibration. Overhaul inspection	None None None

FMEA ON CRITICAL COMPONENTS
LPT

SYSTEM 3.0 & 6.0
SUBSYSTEM 3.1 & 6.1

ASSEMBLY 3.1.1 & 6.1.1
COMPONENT 3.1.1.6 & 6.1.1.6

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Turbine Rim Spacer	Supports labyrinth seals Limits disk run axial deflections Dampen disk rim vibrations.	1) Radial growth due to overspeed or overtemperature 2) Cracking due to cyclic loading	Same as HPT Same as HPT.	Increased Total Specific Fuel Consumption (TSFC) Overhaul inspection Overhaul inspection.	None None
Turbine Blade Tip Seals	Forms flow path at blade tips	1) Wear due to blade rubbing. 2) Distortion due to overheating	Air leakage past blade tip resulting in reduced turbine efficiency Seal and blade damage resulting in air leakage past blades and cooling air leakage.	Increased TSFC Overhaul inspection Increased TSFC. Overhaul inspection.	None None
Turbine Vanes	Directs the combustion gases to the turbine blades	1) Centering pin wear due to thermal growth and vibration 2) Deflection of vane platforms due to thermal gradients 3) Deflection of airfoil due to high temperature 4) Airfoil cracking at leading or trailing edge	Part replacement at overhaul Air leakage between platforms with reduced cooling and possible blade bowing Loss of efficiency Possible airfoil deflection	Overhaul inspection Increased TSFC Overhaul inspection Increased TSFC Overhaul inspection	None

SYSTEM 3.0 & 6.0
SUBSYSTEM 3.1 & 6.1

ASSEMBLY 3.1.1 & 6.1.1
COMPONENT 3.1.1.6 & 6.1.1.6

FMEA ON CRITICAL COMPONENTS
LPT

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Turbine Interstage Labyrinth Seal		Knife edge wear or cracking due to rubbing	Increased seal clearance resulting in greater interstage air leakage and performance loss	Increased Total Specific Fuel Consumption (TSFC) Overhaul inspection	None
Turbine Bearings	Provide radial support to rear end of low-pressure turbine rotor.	1) Roller skid or wear due to low load 2) Roller or race wear due to high load 3) Bearing wear or seizure due to overheating 4) Cage wear or separation 5) Fretting or spinning of outer race on hub due to loss of restraint	Possible premature failure resulting in engine shutdown. Same as above Same as above Contamination of oil results in bearing failure and engine shutdown Same as above	Engine vibration Engine vibration. Engine vibration RPM increase Engine vibration	

ASSEMBLY 3 1.3, 6 1 3

FMEA ON CRITICAL COMPONENTS

SYSTEM 3 0, 6 0

SUBSYSTEM 3 1, 6.1

COMPONENT 3 1 3 1 Scavenge
6 1 3 1 Pump

SHEET 1 of 1

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Scavenge Pump	Remove oil from gearbox compartments for return to oil tank.	1) Compartment flooding due to engine attitude, or pump cavitation. 2) Gear wear due to high loading or misalignment 3) Pump jamming due to contaminents. 4) Gear journal wear due to high loading.	1) Increased oil temperature. Possible oil leakage reduced part life Possible engine shutdown. 2) Reduced part life Possible gear failure with pump failure and compartment flooding (see above). 3) Compartment flooding (see above). 4) Reduced pump life and efficiency replacement at overhaul.	1) High oil temperature, low oil pressure and level, engine smoking, ground inspection. 2) Low oil level, engine smoking, overhaul inspection. 3) See 2) above 4) Overhaul inspection	None

ASSEMBLY 3 1 3, 6 1 3

COMPONENT 3.1 3 2 Oil Pressure
6.1 3 2 Pump

FMEA ON CRITICAL COMPONENTS

SYSTEM 3 0, 6 0
SUBSYSTEM 3.1, 6.1

SHEET 1 of 1

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Main Oil Pressure Pump	Supply pressurized oil to engine for lubrication and cooling.	1) Input shaft or pump housing damage due to high backpressure. 2) Pump jamming due to contaminents. 3) Gear journal wear due to high loading. 4) Gear Wear due to high loading or misalignment.	1) Reduced lubricant flow or possible loss of flow resulting in reduced bearing and seal life or engine shutdown. 2) Loss of oil pressure and flow resulting in engine shutdown. 3) Reduced oil pressure, part replacement 4) Reduced part life, possible gear fatigue with pump failure and engine shutdown.	1) Low oil pressure. 2) Low oil pressure 3) Low oil pressure. 4) Loss of oil pressure.	None

FMEA ON CRITICAL COMPONENTS

SYSTEM 6.0
SUBSYSTEM 6 2
ASSEMBLY 6 2 2
COMPONENT 6.2 2 1 Pump
SHEET 1 of 1

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Main Housing	Contains LH_2 propellant and, through proper sizing, controls suction and discharge propellant velocity.	1) Inlet pitting caused by cavitation and/or particle injestion 2) Outlet pitting caused by cavitation and/or particle injestion 3) Overpressure caused by excess suction pressure	1) Change in pump efficiency 2) Change in pump efficiency. 3) Change in impeller tip clearance and loss of pump efficiency	1) Evaluation of head rise across pump 2) Evaluation of head rise across pump 3) Evaluation of head rise across pump	Evaluation can be accomplished with computation of head rise and suction specific speed based on the following measurements: a) Pump speed, b) Suction pressure, c) Discharge pressure
Seals	Prevent leakage between impeller shaft and housing	1) Wear caused by time in operation 2) Overpressure caused by excess suction pressure 3) Fatigue caused by impeller unbalance.	1) External leakage causing change in loss of discharge pressure 2) External leakage causing loss in discharge pressure. 3) External leakage causing loss in discharge pressure	1) Limit usage based on time sensitivity 2) Measure discharge pressure 3) Measure discharge pressure and vibration level	None
Impeller	Transmits LH_2 propellant at a specified inlet pressure to a higher pressure at the pump outlet.	Blade damage caused by pitting from particle ingestion and/or local cavitation.	Change in pump efficiency and increase in vibration level.	Evaluation of head rise across the pump, and measure vibration level	None

FMEA ON CRITICAL COMPONENTS

SYSTEM 6.0
SUBSYSTEM 6 2
ASSEMBLY 6 2 2
COMPONENT 6 2 2 3 Turbine
SHEET 1 of 1

PART NAME	FUNCTION	FAILURE MECHANISM	FAILURE EFFECT ON COMPONENT	RECOMMENDATIONS FOR DETECTION METHOD	OTHER RECOMMENDATION
Rotor Blades	Transmits energy from gas stream to disks	1) Cracking due to cyclic loading and vibration. 2) Corrosion or erosion of blades.	1) Blade loss resulting in reduced efficiency. 2) Pitting which could lead to cracking.	Periodic visual inspection and vibration monitoring.	None
Disks	Support blades seals and spacers and transmits torque to shafts	1) Disk burst due to overspeed 2) Creep due to overspeed. 3) Cracks due to cyclic loading	1) Probable case penetration. 2) Seal rubbing and shaft unbalance. 3) Tensile yield and disk rupture	1) Measure turbine speed 2) Measure vibration level 3) Measure turbine speed.	None
Shaft	Transmits torque pump impeller rotation.	1) Deflection due to load 2) Cracking due to vibration.	1) Seal rubbing and rotor unbalance 2) Reduced life	1) Measure vibration. 2) Measure turbine speed	None
Seals	Form flow path at blade tips	1) Wear due to rubbing 2) Distortion due to thermal gradients	1) Loss of efficiency due to leakage. 2) Reduced efficiency.	1) Measure turbine speed 2) Measure turbine speed	None
Turbine Case	Support vanes and blade tip seals. Support turbine exhaust case	Cracking due to load and temperature.	Possible loss of vane or seal support.	Measure turbine speed	None
Vanes	Direct Combustion products to rotor blades.	1) Bowing due to temperature 2) Cracking due to thermal gradients 3) Erosion due to hot gas impingement 4) Cracking due to cyclic loading	1) Flow distortion and reduced efficiency. 2) Reduced part life 3) Reduced part life. 4) Possible blade vane rubbing	Measure turbine speed	None

APPENDIX C - LRU MAINTENANCE PROCEDURES

MAINTENANCE PROCEDURES
FOR THE LINE REPLACEABLE UNITS

This appendix is comprised of the summary maintenance procedures that were developed for the propulsion systems' Line Replaceable Units (LRUs). These procedures were prepared in the course of deriving the checkout functions to be performed as a part of LRU removal, replacement and retest.

The maintenance procedures for the booster and orbiter main propulsion systems are presented first. The auxiliary propulsion LRU maintenance procedures start on page C-57, and the airbreathing LRUs start on Page C-99.

MAINTENANCE PROCEDURE

LRU (1) LO_2 Tank Vent Package

LRU (12) LH_2 Tank Vent Package

SYSTEM - Booster and Orbiter Main Propulsion

SUBSYSTEM - Propellant Management

ASSEMBLY - Tank Vent

COMPONENT - N/A

TASK TIME - 1 hour

SPECIAL CONSIDERATIONS - Vent Subsystem to Ambient Pressure

PROCEDURE

1. REMOVAL

   a. Remove access panels to forward region.
   b. Install contamination protection equipment around valve.
   c. Install valve removal equipment.
   d. Disconnect electrical cables; sensors, valve flange retaining bolts to vent line; valve flange bolts to LOX and LH_2 tank.
   e. Remove valve, and all seals.
   f. Take swab samples per contamination procedure.
   g. Cap all line openings and valve openings.

2. REPLACEMENT

   a. Remove all protective caps.
   b. Take swab samples.
   c. Install valve seals; valves and bolt-up both ducts.
   d. Connect electrical cables and sensors.
   e. Remove all GSE.
   f. Install safety wire and perform visual inspection of area.

3. RETEST

   a. Perform electrical checks.
   b. Perform valve leak check.
   c. Perform valve functional check through main system computer.
   d. Checkout of sensors.

MAINTENANCE PROCEDURE

LRU (2) LO_2 Tank Isolation Valve

LRU (3) LH_2 Tank Isolation Valve

SYSTEM - Booster and Orbiter Main Propulsion

SUBSYSTEM - Main Propellant Management

ASSEMBLY - Distribution and Feed

COMPONENT - 1.2.2.2 and 1.2.7.2

TASK TIME - 3 hours

SPECIAL CONSIDERATIONS - Insure system is purged and vent to ambient.

PROCEDURE

1. REMOVAL

   a. Remove [illegible]s doors.
   b. Install contamination protection equipment around valve.
   c. Install valve removal GSE and duct supporting fixture.
   d. Disconnect electrical cables, sensors, valve flange retaining bolts to LOX engine distribution duct; valve flange bolts to tank sump.
   e. Remove valve and all seals.
   f. Take swap samples.
   g. Cap duct opening and sump opening.

2. REPLACEMENT

   a. Remove all protective caps.
   b. Take swap samples.
   c. Install valve seals; valve and secure both flange ends.
   d. Connect electrical cables and sensors.
   e. Remove all GSE.
   f. Install safety wire and perform visual inspection.

3. RETEST

   a. Perform electrical checkout.
   b. Perform valve leak check.
   c. Perform valve functional checkout through main system computer.
   d. Checkout of all sensors.
   e. Checkout of built-in relief valve.

MAINTENANCE PROCEDURE

LRU (4) LO_2 Prevalve

SYSTEM - Booster Main Propulsion

SUBSYSTEM - Main Propellant Management

ASSEMBLY - Oxidizer Feed

COMPONENT - 1.2.1.2

TASK TIME - 2 hours

SPECIAL CONSIDERATIONS - Insure system is purged and vented.

PROCEDURE

1. REMOVAL

   a. Remove access panels to rear base region.
   b. Install contamination protection equipment around valve.
   c. Install valve removal equipment.
   d. Disconnect electrical cables; sensors; valve flange retaining bolts to engine suction duct; valve flange bolts to oxidizer feed ducting.
   e. Remove valve, and all seals.
   f. Take swab samples per contamination procedure.
   g. Cap all duct openings.

2. REPLACEMENT

   a. Remove all protective caps.
   b. Take swab samples.
   c. Install valve seals; valves and bolt-up both ducts.
   d. Connect electrical cables and sensors.
   e. Removal all GSE.
   f. Install safety wire and perform visual inspection of area.

3. RETEST

   a. Perform electrical checks.
   b. Perform valve leak check.
   c. Perform valve functional check through main system computer.
   d. Checkout of sensors.

MAINTENANCE PROCEDURE

LRU (5) , (20) Booster/Orbiter LH_2 Fill Valve

LRU (18) , (15) Booster/Orbiter LO_2 Fill Valve

SYSTEM - Booster and Orbiter Propulsion

SUBSYSTEM - Main Propellant Management

ASSEMBLY - Fill and Drain

COMPONENT - N/A

TASK TIME - 1 hour

SPECIAL CONSIDERATIONS - Insure valve is purged.

PROCEDURE

1. REMOVAL

   a. Remove access panels to lower aft region.
   b. Install contamination protection equipment around valve.
   c. Install valve removal equipment.
   d. Disconnect electrical cables; sensors; valve flange retaining bolts to fill and drain lines.
   e. Remove valve, and all seals.
   f. Take swab samples per contamination procedure.
   g. Cap all line openings and valve openings.

2. REPLACEMENT

   a. Remove all protective caps.
   b. Take swab samples.
   c. Install valve seals; valves and bolt-up both ducts.
   d. Connect electrical cables and sensors.
   e. Remove all GSE.
   f. Install safety wire and perform visual inspection of area.

3. RETEST

   a. Perform electrical checks.
   b. Perform valve leak check.
   c. Perform valve function check through main system computer.
   d. Checkout of sensors.

MAINTENANCE PROCEDURE

LRU (6) , (25) Booster/Orbiter Fuel Autogenous Line Filter

LRU (7) , (22) Booster/Orbiter Oxidizier'Autogenous Line Filter

SYSTEM - Booster and Orbiter Main Propulsion

SUBSYSTEM - Main Pressurization

ASSEMBLY - Autogenous Pressurization

COMPONENT - 1.3.1.4 and 1.3.1.8

TASK TIME - .5 hour

SPECIAL CONSIDERATIONS - Insure system is vented to ambient.

PROCEDURE

1. REMOVAL

    a. Remove flange bolts, seals.
    b. Remove filter.

2. REPLACEMENT

    a. Clean flange ends.
    b. Insert new filter, seals.
    c. Bolt up flange fittings and install safety wire.

3. RETEST

    a. Leak check.

MAINTENANCE PROCEDURE

LRU (8) , (26) Booster/Orbiter Fuel Pressurant Control Valve Package

LRU (9) , (23) Booster/Orbiter Oxidizer Pressurant Control Valve Package

SYSTEM - Booster and Orbiter Main Propulsion

SUBSYSTEM - Main Pressurization

ASSEMBLY - Autogenous Pressurization

COMPONENT - 1.3.1.3 and 1.3.1.7

TASK TIME - 2 hours

SPECIAL CONSIDERATIONS - Insure system has been vented to ambient.

PROCEDURE

1. REMOVAL

a. Remove access doors.
b. Install contamination equipment.
c. Remove electrical wiring and sensors.
d. Cut brazed sleeves at notched sections.
e. Remove welded assembly and clean.

2. REPLACEMENT

a. Install welded assembly and perform brazing operation.
b. Connect electrical wiring and sensors.
c. Remove contamination protection GSE.

3. RETEST

a. Perform leak test.
b. Perform electrical test.
c. Operate valve with system pressurized with helium.

MAINTENANCE PROCEDURE

LRU (10) , (24) Booster/Orbiter Oxidizer Pressurant Control Orifice

LRU (11) , (27) Booster/Orbiter Fuel Pressurant Control Orifice

SYSTEM - Booster/Orbiter Main Propulsion

SUBSYSTEM - Main Pressurization

ASSEMBLY - Autogenous Pressurization

COMPONENT - 1.3.1.2 and 1.3.1.6

TASK TIME - .5 hour

SPECIAL CONSIDERATIONS - Insure system is vented to ambient.

PROCEDURE

1. REMOVAL

   a. Remove access panels.
   b. Remove lock-wire, flange bolts, and seals.
   c. Remove orifice.

2. REPLACEMENT

   a. Clean flange ends.
   b. Insert new orifice, record serial number.
   c. Insert new seals.
   d. Bolt up flange ends and install lock wire.

3. RETEST

   a. Leak check around flange.

MAINTENANCE PROCEDURE

LRU (13) Booster Fuel Fill Line Coupling

LRU (19) Orbiter Fuel Fill Coupling

LRU (16) Orbiter Oxidizer Fill Coupling

SYSTEM - Booster and Orbiter Main Propulsion

SUBSYSTEM - Propellant Management

ASSEMBLY - Fuel Fill and Drain

COMPONENT - 1.2.9.2

TASK TIME - 1 hour

PROCEDURE

1. REMOVAL

PRECAUTION - Vent subsystem to ambient pressure.

a. Remove bolts from flanges.
b. Remove sealing devices.
c. Remove structural mounts.
d. Remove coupling half.

2. REPLACEMENT

a. Install sealing devices after cleaning sealing surfaces.
b. Make structural attachments.
c. Install bolts and torque per specified value and sequence.
d. Perform retest procedure specified below.
e. Return system to secured state.

3. RETEST

a. Leak test bolted flange connection by:

1) Attaching GSE to newly installed coupling,
2) Close tank vent valves,
3) Pressurize through GSE with 20 psia helium,
4) Bubble test flanges for leaks.

MAINTENANCE PROCEDURE

LRU (14) Fuel Tank Vent Coupling

SYSTEM - Booster and Orbiter Main Propulsion

SUBSYSTEM - Propellant Management

ASSEMBLY - Fuel Vent Assembly

COMPONENT - N/A

TASK TIME - 1 hour

PROCEDURE

1. REMOVAL

   PRECAUTION - Vent subsystem to ambient pressure.

   a. Remove bolts from flanges.
   b. Remove sealing devices.
   c. Remove structural mounts.
   d. Remove coupling half.

2. REPLACEMENT

   a. Install sealing devices after cleaning sealing surfaces.
   b. Make structural attachments.
   c. Install bolts and torque per specified value and sequence.
   d. Perform retest procedure specified below.
   e. Return system to secured state.

3., RETEST

   a. Leak test bolted flange connection by:

      1) Attaching GSE to newly installed coupling,
      2) Close tank vent valves,
      3) Pressurize through GSE with 20 psia He,
      4) Bubble test flanges for leaks.

MAINTENANCE PROCEDURE

LRU (15) , (21) Booster/Orbiter Fuel Tank Prepressurization Coupling

LRU (17) , (13) Booster/Orbiter LO_2 Tank Prepressurization Coupling

SYSTEM - Booster and Orbiter Main Propulsion

SUBSYSTEM - Pressurization

ASSEMBLY - Helium Pressurization

COMPONENT - N/A

TASK TIME - 1 hour

PROCEDURE

1. REMOVAL

   PRECAUTION - Vent subsystem to ambient pressure

   a. Remove bolts from flanges.
   b. Remove sealing devices.
   c. Remove structural mounts.
   d. Remove coupling half.

2. REPLACEMENT

   a. Install sealing devices after cleaning sealing surfaces.
   b. Make structural attachments.
   c. Install bolts and torque per specified value and sequence.
   d. Perform retest procedure specified below.
   e. Return system to secured state.

3. RETEST

   a. Leak test bolted flange connection by:

      1) Attaching GSE to newly installed coupling,
      2) Close tank fill valves,
      3) Pressurize through GSE with 20 psia He,
      4) Bubble test flanges for leaks.

MAINTENANCE PROCEDURE

LRU (16) , (17) Booster/Orbiter LO_2 Recirculation Coupling

LRU (18) Orbiter LH_2 Recirculation Coupling

SYSTEM - Booster and Orbiter Main Propulsion

SUBSYSTEM - Propellant Management

ASSEMBLY - Geyser Suppression

COMPONENT - N/A

TASK TIME - 1 hour

PROCEDURE

1. REMOVAL

   PRECAUTION - Vent subsystem to ambient pressure

   a. Remove bolts from flanges.
   b. Remove sealing devices.
   c. Remove structural mounts.
   d. Remove coupling half.

2. REPLACEMENT

   a. Install sealing devices after cleaning sealing surfaces.
   b. Make structural attachments.
   c. Install bolts and torque per specified value and sequence.
   d. Perform retest procedure specified below.
   e. Return system to secured state.

3. RETEST

   a. Leak test bolted flange connection by:

      1) Attaching GSE to newly installed coupling,
      2) Close tank valves,
      3) Pressurize through GSE with 20 psia He,
      4) Bubble test flanges for leaks.

MAINTENANCE PROCEDURE

LRU (19) LO_2 Fill Coupling

SYSTEM - Booster Main Propulsion

SUBSYSTEM - Propellant Management

ASSEMBLY - Oxidizer Fill and Drain

COMPONENT - N/A

TASK TIME - 1 hour

PROCEDURE

1. REMOVAL

   PRECAUTION - Vent subsystem to ambient pressure.

   a. Remove bolts from flanges.
   b. Remove sealing devices.
   c. Remove structural mounts.
   d. Remove coupling half.

2. REPLACEMENT

   a. Install sealing devices after cleaning sealing surfaces.
   b. Make structural attachments.
   c. Install bolts and torque per specified value and sequence.
   d. Perform retest procedure specified below.
   e. Return system to secured state.

3. RETEST

   a. Leak test bolted flange connection by

      1) Attaching GSE to newly installed coupling,
      2) Close tank valves,
      3) Pressurize through GSE with 20 psia He,
      4) Bubble test flanges for leaks.

MAINTENANCE PROCEDURE

LRU (20) Main Booster Engine

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engines

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 8 hours

SPECIAL CONSIDERATIONS: Engine GSE is required for this procedure.

PROCEDURE

1. REMOVAL

   a. Install contamination protection equipment.
   b. Disconnect four (4) data cables, 3 power cables; GH_3 purge line.
   c. Attach engine handling fixture, gimbal support fixture.
   d. Disconnect propellant lines (48 ea-3/8" bolts); 2 gimbal pads; GH_2, GOX tank pressurization lines; recirculation lines.
   e. Remove engine, using handling fixture; flange seals.
   f. Take swab samples of LOX/GOX lines.
   g. Install closures on lines and electrical connectors.

2. REPLACEMENT

   a. Move engine into position.
   b. Remove suction line covers. Move engine into position, install seals, then mate engine to vehicle suction lines, install all bolts, torque, safety wire.
   c. Remove covers from tank pressurization lines - install seals, mate, bolt, safety wire.
   d. Remove covers from all other lines, repeat c.
   e. Connect gimbal pads; remove support fixture.
   f. Remove engine handling gear, contamination protection. Connect all electrical cables.

3. RETEST

   a. Leak check, 50 psi GH_3, interface joints only.
   b. Perform electrical power, and system electrical verification checks.
      1) Gimbal power,
      2) Controller functions,
      3) Valve functional via controller.
   c. Perform gimbal actuator alignment with optical test equipment.

MAINTENANCE PROCEDURE

LRU (4) On-Orbit LO_2 Vent Package

LRU (5) On-Orbit LH_2 Vent Package

SYSTEM - Orbiter Main Propulsion

SUBSYSTEM - On-Orbit Propellant

ASSEMBLY - Oxidizer Tank Vent, Fuel Tank Vent

COMPONENT - N/A

TASK TIME - 1 hour

SPECIAL CONSIDERATIONS - Vent subsystem to ambient pressure

PROCEDURE

1. REMOVAL

   a. Remove electrical connections and secure wiring.
   b. Cut brazed sleeves at notched section with cutting tool.
   c. Remove welded assembly and clean remainder of sleeve from mating line.

2. REPLACEMENT

   a. Install welded assembly and perform brazing operation on sleeves.
   b. Connect electrical wiring.
   c. Perform retest described below.
   d. Return system to secured state.

3. RETEST

   a. Leak Test - Pressurize tank with 20 psia He. Monitor tank pressure for decay. (This leak tests the upstream sleeve on the replaced LRU package). Install GSE to vent and close vent valve. Open all valves on the replaced package and monitor tank pressure for decay. (This leak tests the downstream sleeve on the replaced LRU package.
   b. Electrical - During leak test verify valve positions and continuity.

MAINTENANCE PROCEDURE

LRU (6) On-Orbit Fuel Tank Pressurant Filters

LRU (9) On-Orbit LO_2 Tank Pressurant Filters

SYSTEM - Orbiter Main Propulsion

SUBSYSTEM - On-Orbit Pressurization

ASSEMBLY - Fuel Tank Pressurization, Oxidizer Tank Pressurization

COMPONENT - N/A

TASK TIME - 1/2 hour

SPECIAL CONSIDERATIONS - Vent subsystem to ambient pressure.

PROCEDURE

1. REMOVAL

   a. Remove flange bolts, seal.
   b. Remove filter.

2. REPLACEMENT

   a. Clean flange ends.
   b. Install new filters and seals.
   c. Make bolted flange connections.

3. RETEST

   a. Leak Test

      1) Attach GSE to vent coupling,
      2) Open vent valves,
      3) Pressurize tanks with 20 psia He.
      4) Leak check filter connections.
      5) Vent and secure subsystem.

MAINTENANCE PROCEDURE

LRU (7) On-Orbit Fuel Tank Pressurant Control Regulator Package

LRU (10) On-Orbit LO_2 Tank Pressurant Control Regulator Package

SYSTEM - Orbiter Main Propulsion

SUBSYSTEM - On-Orbit Pressurization

ASSEMBLY - Fuel Tank Pressurization, Oxidizer Tank Pressurization

COMPONENT - N/A

TASK TIME - 1 hour

SPECIAL CONSIDERATIONS - Vent associated subsystems to ambient pressure.

PROCEDURE

1. REMOVAL

   a. Remove electrical connections and secure wiring.
   b. Cut brazed sleeves at notched section with cutting tool.
   c. Remove welded assembly and clean remainder of sleeve from mating lines.

2. REPLACEMENT

   a. Install welded assembly and perform brazing operation on sleeves.
   b. Connect electrical wiring.
   c. Perform Retest described below.
   d. Return system to secured state.

3. RETEST

   a. Leak Test - Load 1500 psia GH_2 into APS bottles. Open tank vent valves. Open solenoid valve for the regulator package which was just installed. Perform bubble leak test on regulator connections.
   b. Electrical - Perform continuity check.
   c. Functional - Close solenoid valve for the regulator package which was not replaced. Open solenoid valve for newly installed regulator package. Close tank vents. With 1500 psia in APS bottles verify tank pressure level within specified limits.

MAINTENANCE PROCEDURE

LRU (8) Fuel Tank Pressurant Shutoff Valve

LRU (11) Oxidizer Tank Pressurant Shutoff Valve

SYSTEM - Orbiter Main Propulsion

SUBSYSTEM - On-Orbit Pressurization

ASSEMBLY - Fuel Tank Pressurization, Oxidizer Tank Pressurization

COMPONENT - N/A

TASK TIME - 1 hour

SPECIAL CONSIDERATIONS - Vent associated subsystems to ambient pressure.

PROCEDURE

1. REMOVAL

   a. Remove electrical connections and secure wiring.
   b. Cut brazed sleeves at notched section with cutting tool.
   c. Remove welded assembly and clean remainder of sleeve from mating lines.

2. REPLACEMENT

   a. Install welded assembly and perform brazing operation on sleeves.
   b. Connection electrical wiring.
   c. Perform Retest described below.
   d. Return system to secured state.

3. RETEST

   a. Leak Test - Load 1500 psia GH_2 into APS bottles. Open tank vent valves. Open newly installed solenoid valves. Monitor tank for pressure decay.
   b. Electrical - During leak test verify valve positions and continuity.

MAINTENANCE PROCEDURE

LRU (28) Main Orbiter Engine

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 9 hours

SPECIAL CONSIDERATIONS - Engine GSE is required for this procedure. The removal, replacement, and checkout of some components on the orbiter engine will require extension of the nozzle to full aft position, and the use of a nozzle protective and support fixture. This will, in general, add approximately one half hour to the corresponding booster time.

PROCEDURE

This procedure will be exactly like that of the booster engine except for special precautions that must be taken with the extendible nozzle.

LRUs MAIN ENGINE SUBSYSTEM

This section of Appendix C presents the maintenance procedures for the Main Engine Subsystem. Many of these LRUs are shown in the exploded view of the main engine in Figure C-1.

MAINTENANCE PROCEDURE

LRU (1) Low Pressure Turbopump

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine

ASSEMBLY - Engine Power

COMPONENT - Low Pressure Fuel Turbopump

TASK TIME - 8 hours

PROCEDURE

1. REMOVAL

   a. Install contamination protection equipment.
   b. Disconnect hydraulic lines, cap.
   c. Remove sensors, cap lines and connectors.
   d. Connect handling equipment to L.P.T.P.A.
   e. Remove turbine drivelines; L.P. discharge line; seals, cap lines, and exposed joints.
   f. Disconnect suction line to L.P.T.P.A. (24 ea. - 3/8" bolts).
   g. Remove TPS support brackets.
   h. Move L.P.T.P.A. aft to clear suction spool.
   j. Disconnect upper suction spool (24 ea. - 3/8" bolts). Remove spool.
   k. Remove L.P.T.P.A. forward and out; seals. cap lines.

2. REPLACEMENT

   a. Move L.P.T.P.A. into position - aft of normal.
   b. Remove cap and install seal L.P. suction line.
   c. Install L.P. suction spool; seal to L.P.T.P.A.
   e. Connect L.P.T.P.A. support bracket.
   f. Install L.P.T.P.A. turbine driveline; L.P.T.P.A. discharge line including seals. Remove handling equipment.
   g. Connect hydraulic lines.
   h. Install sensors. Mate connectors.

3. RETEST

   a. Leak check, 50 psig GHe.
   b. Sensors elect, ok via controller.

EXPLODED VIEW - MAIN ENGINE SUBSYSTEM

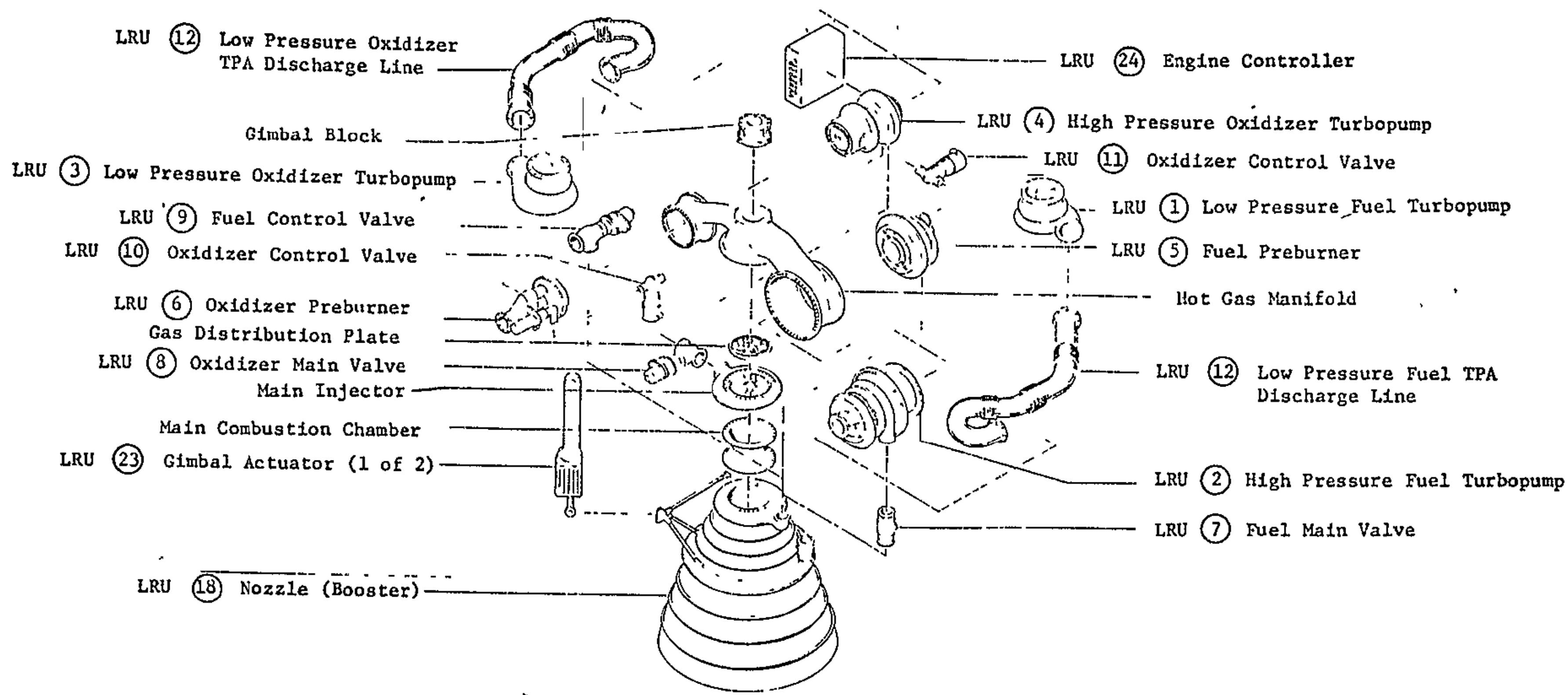

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Figure C-1

MAINTENANCE PROCEDURE

LRU (2) High Pressure Turbopump

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine

ASSEMBLY - Engine Power

COMPONENT - High Pressure Fuel Turbopump

TASK TIME - 8 hours

PROCEDURE

1. REMOVAL
   a. Install contamination protection equipment.
   b. Remove sensors; L.P.T.P.A. discharge lines; seals, cap lines and connectors.
   c. Disconnect L.P.T.P.A. turbine driveline; LH_2 recirc. line; main fuel valve; H_2 cooling lines; purge lines.
   d. Install tooling on H.P.T.P.A. discharge line to clear joing to fuel valve.
   e. Remove H.P.T.P.A.; seals, cap openings.

2. REPLACEMENT
   a. Remove protective caps.
   b. Install seals; H.P.T.P.A. release discharge line and connect to H.P.T.P.A. (or valve).
   c. Install seals; L.P.T.P.A. discharge line.
   d. Connect L.P.T.P.A. turbine driveline; LH_2 recirculation line (after installing new seals); H_2 cooling; purge lines.
   e. Remove handling equipment.
   f. Install sensors; connect cables.

3. RETEST
   a. Leak check GH_e, interface seals (includes sensors).
   b. Sensors check: VIA controller, at combined systems test.

MAINTENANCE PROCEDURE

LRU (3) Low Pressure Turbopump

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine

ASSEMBLY - Engine Power

COMPONENT - Low Pressure Oxidizer Turbopump

TASK TIME - 8 hours

PROCEDURE

1. REMOVAL

   a. Install contamination protection equipment.
   b. Remove sensors, cap lines, connectors.
   c. Connect handling equipment to TPA.
   d. Remove turbine driveline; L.P. discharge line; seals, cap lines, and exposed joints.
   e. Disconnect suction line to L.P.T.P.A. (24 - 3/8" bolts).
   f. Remove TPA support brackets; L.P. OPTA; seals.
   g. Take swab sample.
   h. Install closure on suction spool.

2. REPLACEMENT

   a. Move L.P.O.T.A. into position with handling equipment
   b. Remove suction line closure.
   c. Install seal on suction line; L.P.O.T.P.A.; seals; turbine drive line; L.P.O.T.P.A. discharge line; O.T.P.A. support brackets.
   d. Remove handling equipment.
   e. Install sensors; connect cables, safety wire.

3. RETEST

   a. Leak check GH_e, 50 psig.
   b. Sensors: VIA controller at combined systems test.

MAINTENANCE PROCEDURE

LRU (4) High Pressure Turbopump

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine

ASSEMBLY - Engine Power

COMPONENT - High Pressure Oxidizer Turbopump

TASK TIME - 8 hours

PROCEDURE

1. REMOVAL
   a. Install contamination protection equipment.
   b. Remove sensors; disconnect cables; cap lines and connectors.
   c. Remove L.P.O.T.P.A. discharge line; line to preburner shutoff valve; discharge line to main TCA valve; seals; H_2 coolant lines. Install closures.
   d. Attach handling equipment.
   e. Remove H.P.O.T.P.A. (36 - 1/2" bolts); seals. Install closure.

2. REPLACEMENT
   a. Remove closure.
   b. Install seal; H.P.O.T.P.A., fasten to hot gas manifold (36 - 1/2" bolts).
   c. Remove handling equipment.
   d. Install seals; discharge line; line to preburner; L.P.O.T.P.A. discharge line; H_2 coolant lines.
   e. Install sensors. Connect cables, safety wire.

3. RETEST
   a. Leak check: GH_e, 50 psig.
   b. Sensors: VIA controller at combined systems test.

MAINTENANCE PROCEDURE

LRU (5) Fuel Preburner

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine

ASSEMBLY - Engine Power

COMPONENT - Fuel Preburner

TASK TIME - 2.5 hours

PROCEDURE

1. REMOVAL
   a. Install contamination protection equipment.
   b. Remove sensors. Cap lines and connectors.
   c. Disconnect LOX inlet line; fuel inlet line, igniter lines; spark cable; igniter valve electrical line; oxygen valve control cable.
   d. Attach handling equipment.
   e. Remove preburner (36 bolts); seals. Cap all lines.

2. REPLACEMENT
   a. Move preburner into place, using handling equipment.
   b. Remove caps, closures.
   c. Install seals; preburner to hot gas manifold (36 bolts).
   d. Remove handling equipment.
   e. Connect LOX inlet line; fuel inlet line; igniter lines; electrical cables.
   f. Install sensors. Connect cables. Safety wire.

3. RETEST
   a. Leak check: 50 psig GH_e
   b. Electrical: Perform igniter, valve, and sensor electrical checks VIA controller at combined systems test.

MAINTENANCE PROCEDURE

LRU (6) Oxidizer Preburner

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine

ASSEMBLY - Engine Power

COMPONENT - Oxidizer Preburner

TASK TIME - 3 hours

PROCEDURE

1. REMOVAL

   a. Install contamination protection equipment.
   b. Remove sensors. Cap lines and connectors.
   c. Disconnect preburner oxidizer shutoff valve; fuel inlet line; igniter lines; oxidizer line to fuel preburner; igniter valve electrical line; control cables to LOX and LH_2 control valves.
   d. Attach handling equipment.
   e. Remove preburner (36 bolts); seals. Cap all lines.

2. REPLACEMENT

   a. Move preburner into place, using handling equipment.
   b. Remove caps, closures.
   c. Install seals; preburner to hot gas manifold (36 bolts).
   d. Remove handling equipment.
   e. Connect preburner oxidizer shutoff valve; fuel inlet line; igniter lines; oxidizer line to fuel preburner; igniter valve electrical line; control cables to LOX and LH_2 control valves.
   f. Install sensors. Connect cables. Install safety wires.

3. RETEST

   a. Leak check: 50 psig GH_e
   b. Electrical: Spark, control valves igniter valves, sensors at combined systems test.

MAINTENANCE PROCEDURE

LRU (7) Main Valve

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine

ASSEMBLY - Engine Power

COMPONENT - Fuel Main Valve

TASK TIME - 4 hours

PROCEDURE

1. REMOVAL
   a. Disconnect electrical cables; sensors; valve body retaining bolts from pump discharge and orifice housings; regenerate nozzle cooling line; chamber coolant line; nozzle coolant outlet line; fuel line to fuel preburner.
   b. Remove fuel line assembly (all lines itemized above); valve; seals.
   c. Cap all lines, openings.

2. REPLACEMENT
   a. Remove caps.
   b. Install seals; valve; fuel line assembly.
   c. Connect electrical cables; sensors. Install safety wire.

3. RETEST
   a. Leak check: Upstream of valve - 50 psig GH_e. Downstream of valve - TBD.
   b. Valve functional: VIA controller at combined systems test.
   c. Sensors: VIA controller at combined systems test.

MAINTENANCE PROCEDURE

LRU (8) Main Valve

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine

ASSEMBLY - Engine Power

COMPONENT - Oxidizer Main Valve

TASK TIME - 3 hours

PROCEDURE

1. REMOVAL

   a. Install contamination protection equipment.
   b. Disconnect electrical cables; sensors; valve body retaining bolts to pump discharge line; oxidizer turbine driveline from discharge line.
   c. Remove pump discharge line to valve; valve; seals. Take swab samples.
   d. Cap all lines and openings; electrical connectors.

2. REPLACEMENT

   a. Remove protective caps.
   b. Install seals; valve; pump discharge line.
   c. Connect oxidizer turbine driveline; electrical cables; sensors. Install safety wire.

3. RETEST

   a. Leak check upstream of valve - 50 psig GH_e. Downstream-TBD.
   b. Valve functional VIA controller at combined systems test.
   c. Sensors VIA controller at combined systems test.

MAINTENANCE PROCEDURE

LRU (9) Fuel Control Valve

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine

ASSEMBLY - Engine Power

COMPONENT - Fuel control valve, oxidizer preburner

TASK TIME - 1 hour

PROCEDURE

1. REMOVAL
   a. Disconnect electrical cables; fuel line to valve.
   b. Remove valve; seals.
2. REPLACEMENT
   a. Install seals, valve.
   b. Connect fuel line; electrical cables.
3. RETEST
   a. Leak check upstream of valve - 50 psig GH_e.
      Downstream of valve - TBD.
   b. Valve functional VIA controller at combined systems test.

MAINTENANCE PROCEDURE

LRU (10) Oxidizer Control Valve

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine

ASSEMBLY - Engine Power

COMPONENT - Oxidizer Control Valve, Oxidizer Preburner

TASK TIME - 1 hour

PROCEDURE

1. REMOVAL
   a. Disconnect electrical cables; valve body from oxidizer distribution line downstream of shutoff valve; valve body from preburner.
   b. Remove valve; seals.
   c. Take swab sample.
   d. Cap lines; openings.

2. REPLACEMENT
   a. Remove caps.
   b. Install seals; valve.
   c. Connect electrical cables.
   d. Install safety wires.

3. RETEST
   a. Leak check upstream of valve - 50 psig GH_e. Downstream of valve - TBD.
   b. Valve functional VIA controller at combined systems test.

MAINTENANCE PROCEDURE

LRU (11) Oxidizer Control Valve

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine

ASSEMBLY - Engine power

COMPONENT - Oxidizer Control Valve, Fuel Preburner

TASK TIME - 1 hour

PROCEDURE

1. REMOVAL
   a. Disconnect electrical cables; oxidizer line to valve body.
   b. Remove valve; seals.
   c. Take swab sample.
   d. Install caps.

2. REPLACEMENT
   a. Remove caps.
   b. Install seals; valve.
   c. Connect oxidizer line.
   d. Connect electrical cables.

3. RETEST
   a. Leak check upstream of valve - 50 psig GH_e. Downstream of valve - TBD.
   b. Valve functional VIA controller at combined systems test.

MAINTENANCE PROCEDURE

LRU (12) Propellant Lines

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine

ASSEMBLY - Engine Power

COMPONENT - Interconnect Articulating Lines, Consisting of:

(1)	L.P.F.T.P.A. Discharge Line	97 lb
(2)	L.P.O.T.P.A. Discharge Line	66 lb
(3)	L.P.F.T.P.A. Turbine Drive Line	10 lb
(4)	L.P.O.T.P.A. Turbine Drive Line	10 lb

TASK TIME - N/A

GENERAL - All four lines require disconnects at both ends and new seals. The discharge lines require handling equipment due to the weight. Each line requires a vacuum check with portable test equipment. Approximate time per line: 1 hour.

1. REMOVAL
   a. Disconnect sensors; bolts at line ends.
   b. Remove line; seals.
   c. Install caps on openings.

2. REPLACEMENT
   a. Remove caps.
   b. Install seals; lines; sensors. Safety wire.
   c. Connect cables to sensors.

3. RETEST
   a. Leak check 50 psig GH_e.
   b. Vacuum check - use shop equipment.
   c. Sensors VIA controller at combined systems test.

MAINTENANCE PROCEDURE

LRU (13) Interconnect Lines

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine

ASSEMBLY - Engine Power

COMPONENT - Interconnect Lines, Consisting of:
(1) Fuel Suction
(2) Fuel Main Valve Outlet
(3) Fuel Inlet, Fuel Preburner
(4) Fuel Inlet, Oxidizer Preburner
(5) Oxidizer Suction
(6) Oxidizer Valve Outlet
(7) Oxidizer Inlet, Fuel Preburner
(8) Oxidizer Inlet, Oxidizer Preburner
(9) Fuel Coolant, Gas Manifold

GENERAL - The removal, replacement, and checkout procedures are essentially unique. Some grouping is possible. Details are given within each group. None of the line sections is expected to exceed 30 lbs weight.

A. SUCTION LINES (Engine to vehicle interface).
Elapsed Time - 2 hours per line

1. REMOVAL

a. Install contamination protection equipment, bellows compressor.
b. Remove 38 - 3/8" bolts (24 ea. end).
c. Compress bellows.
d. Remove suction line; seals.
e. Install closures on line/opening.

2. INSTALLATION

a. Install bellows compressor.
b. Remove caps, closures.
c. Install seals; suction line; release compresser; bolts; safety wire.

3. RETEST

a. Leak check 50 psig GH_e.

B. FUEL MAIN VALVE OUTLET
Elapsed Time - 3 hours

1. REMOVAL

a. Remove flange bolts at fuel main valve outlet; chamber coolant valve inlet; nozzle coolant manifold outlet; main fuel line at fuel preburner inlet; sensors.
b. Separate lines and remove outlet line, seals.
c. Cap lines and connectors.

2. REPLACEMENT

a. Install seals; line; bolts; sensors; safety wire.

3. RETEST

a. Leak check 50 psig GH_e.
b. Electrical VIA controller at combined systems test.

C. FUEL INLET, FUEL PREBURNER
Elapsed Time - 3 hours

1. REMOVAL

a. Remove bolts at orifice flange; bolts at nozzle coolant manifold outlet; bolts at fuel preburner inlet; sensors.
b. Disconnect fuel line to oxidizer preburner, at fuel preburner.
c. Remove fuel inlet line, seals.
d. Cap all openings, lines.

2. REPLACEMENT

a. Install seals; fuel inlet line.
b. Connect fuel line to oxidizer preburner; nozzle coolant manifold outlet.
c. Install sensors; safety wire.

3. RETEST

a. Leak check 50 psig GH_e
b. Electrical: sensors VIA controller at combined systems test.

D. FUEL INLET, OXIDIZER PREBURNER
Elapsed Time - 2 hours

1. Removal

a. Remove sensors. Cap lines, connectors.
b. Disconnect flanges at both ends of fuel line.
c. Remove fuel line; seals.

2. REPLACEMENT

a. Install seals; fuel line; sensors; safety wire.

3. RETEST

a. Leak check 50 psig GH_e.
b. Electrical: Sensors VIA controller at combined systems test.

E. OXIDIZER INLET, FUEL PREBURNER
Elapsed Time - 2 hours

1. REMOVAL

   a. Disconnect flanges at both ends of line.
   b. Remove line, seals.
   c. Cap openings.

2. REPLACEMENT

   a. Install seals; line; safety wire.

3. RETEST

   a. Leak check 50 psig GH_e.

F. OXIDIZER VALVE OUTLET; OXIDIZER INLET, OXIDIZER PREBURNER; FUEL COOLANT, GAS MANIFOLD.
Elapsed Time - Each - 3 hours

GENERALIZED PROCEDURE

These lines are short sections, requiring disconnect at both ends, and seal removal. The configurations of the lines are TBD. Replacement and checkout involves seals, reconnection of flanges, and pressure check.

MAINTENANCE PROCEDURE

LRU (14) Select Valve

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine

ASSEMBLY - Engine Power

COMPONENT - Oxidizer Recirculation Select Valve

TASK TIME - 3 hours

PROCEDURE

1. REMOVAL

   a. Install contamination protection equipment.
   b. Disconnect electrical cables. Cap connectors.
   c. Disconnect oxidizer recirculation line from valve to interface, at valve; oxidizer recirculation line from HPOTPA to valve at valve; valve from LPOTPA turbine. Remove valve, seals.
   d. Inspect for particles, contamination.
   e. Cap all lines, openings.

2. REPLACEMENT

   a. Remove caps.
   b. Install seals, valve.
   c. Connect electrical cables.
   d. Install safety wire.

3. RETEST

   a. Leak check: GN_2, 50 spi, with valve in "tank" and "turbine" positions.
   b. Electrical check: Functional valve with leak check, via controller.

MAINTENANCE PROCEDURE

LRU (15) Select Valve

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine

ASSEMBLY - Engine Power

COMPONENT - Fuel Recirculation Select Valve

TASK TIME - 3 hours

PROCEDURE

1. REMOVAL

   a. Install contamination protection equipment.
   b. Disconnect electrical cables; cap connectors.
   c. Disconnect fuel recirculation line from valve to interface, at valve; fuel recirculation line from HPFTPA to valve at valve; valve from LPFTPA turbine. Remove valve, seals.
   d. Inspect for particles, contamination.
   e. Cap all lines, openings.

2. REPLACEMENT

   a. Remove caps.
   b. Install seals, valve.
   c. Connect electrical cables.
   d. Install safety wire.

e. RETEST

   a. Leak check: GH_e, 50 psi, with valve in "tank" and "turbine" positions.
   b. Electrical: Functional valve with leak check, via controller.

MAINTENANCE PROCEDURE

LRU (16) Control Valve

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine

ASSEMBLY - Engine Power

COMPONENT - Fuel Recirculation Control Valve

TASK TIME - 3 hours

PROCEDURE

1. REMOVAL

   a. Install contamination protection equipment.
   b. Disconnect electrical cables. Cap connectors.
   c. Disconnect fuel recirculation line from valve to regulator at valve; valve from HPFTPA. Remove valve, seals.
   d. Inspect for particles, contamination.
   e. Cap line, openings.

2. REPLACEMENT

   a. Remove caps.
   b. Install seals, valve.
   c. Connect electrical cables.
   d. Install safety wire.

3. RETEST

   a. Leak check: 50 psi GH_e, with select valve to turbine.
   b. Electrical: Open and close valve via controller.

MAINTENANCE PROCEDURE

LRU (17) Recirculation Regulator

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine

ASSEMBLY - Engine Power

COMPONENT - Fuel Recirculation Regulator

TASK TIME - 2 hours

PROCEDURE

1. REMOVAL

   a. Install contamination protection equipment.
   b. Disconnect line from regulator to select valve, at regulator; line from regulator to control valve at regulator. Remove regulator, seals.
   c. Inspect for particles, contamination.
   d. Cap lines.

2. REPLACEMENT

   a. Remove caps.
   b. Install seals, valve, safety wire.

3. RETEST

   a. Leak Check: 50 psi GH_e, with recirculation select valve to turbine.

MAINTENANCE PROCEDURE

LRU (18) Booster Nozzle

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine

ASSEMBLY - Thrust Chamber

COMPONENT - Booster Nozzle

TASK TIME - 8 hours

PROCEDURE

1. REMOVAL
   a. Install contamination protection equipment; nozzle support equipment; gimbal actuator support equipment.
   b. Disconnect gimbal rod ends; coolant inlet line; coolant outlet line.
   c. Disconnect nozzle (48 ea - 1/2" bolts).
   d. Remove nozzle; seals.
   e. Install protective covers.

2. REPLACEMENT
   a. Remove protective covers.
   b. Move nozzle into position, using handling equipment.
   c. Install seals.
   d. Connect nozzle (48 ea - 1/2" bolts); coolant lines; gimbal actuator rod ends.
   e. Install safety wire.
   f. Remove nozzle and gimbal support equipment.

3. RETEST
   a. Leak check: 50 psig GH_e.

MAINTENANCE PROCEDURE

LRU (19) Coolant Control Valve

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine

ASSEMBLY - Thrust Chamber

COMPONENT - Chamber Coolant Control Valve

TASK TIME - 1 hour

PROCEDURE

1. REMOVAL

   a. Disconnect valve electrical connectors; chamber coolant valve (16 ea - 1/4" bolts).
   b. Disconnect coolant valve from fuel discharge line "Spider" (8 ea - 1/4" bolts).
   c. Remove coolant valve; seals.
   d. Install caps on line, opening.

2. REPLACEMENT

   a. Remove caps.
   b. Install seals; valve; chamber coolant line.
   c. Connect electrical connectors.
   d. Install safety wire.

3. RETEST

   a. Leak check: Upstream of valve - 50 psig GH_e. Downstream of valve - 50 psig GH_e.
   b. Electrical: Valve functional at combined systems test.

MAINTENANCE PROCEDURE

LRU (20) Interconnect Lines

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine

ASSEMBLY - Thrust Chamber

COMPONENT - Interconnect Lines, Consisting of:
(1) Main Chamber Coolant Inlet (TBD)
(2) Nozzle Coolant Inlet (TBD)
(3) Main Injector Inlet.

TASK TIME - N/A

PROCEDURE

GENERAL - The main injector inlet line is definable at this time. The line runs from the oxidizer pump 2nd stage outlet to the main oxidizer valve inlet. The other lines are TBD, but in general are short small diameter lines. This procedure covers only the main injector inlet (oxidizer) line.

1. REMOVAL
   Elapsed Time - 2 hours

   a. Install contamination protection equipment.
   b. Remove sensors. Cap lines, connectors.
   c. Disconnect oxidizer line to LPFTPA; ignitor oxidizer line; main injector line at both ends.
   d. Remove main injector line; seals.
   e. Cap lines, openings.

2. REPLACEMENT

   a. Remove caps, closures.
   b. Install seals; main injector line.
   c. Connect oxidizer line to LPFTPA; ignitor oxidizer line.
   d. Install sensors; safety wire.

3. RETEST

   a. Leak check - 50 psig GH_e.
   b. Electrical - Sensors VIA controller at combined systems test.

MAINTENANCE PROCEDURE

LRU (21) TCA Igniters

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine

ASSEMBLY - Ignition

COMPONENT - Preburner and Main TCA Igniters

TASK TIME - 1 hour

PROCEDURE

1. REMOVAL

   a. Disconnect high voltage spark cables; igniter valve cables; propellant lines; sensors. Cap all lines, connectors.
   b. Remove igniter bolts; igniter assembly.
   c. Install protective cover.

2. REPLACEMENT

   a. Remove protective covers.
   b. Install igniter assembly.
   c. Connect propellant lines; spark cable; valve cables; sensors. Install safety wire.

3. RETEST

   a. Leak check - downstream of igniter valves, 50 psig GH_e. Upstream of igniter valves, 50 psig GH_e.
   b. Valve functional - VIA controller at combined systems test.
   c. Sensors - VIA controller at combined systems test.

MAINTENANCE PROCEDURE

LRU (22) Interconnect Lines

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine

ASSEMBLY - Ignition

COMPONENT - Interconnect lines, consisting of preburner and main TCA igniter propellant inlet lines.

TASK TIME - Each 2 hours

PROCEDURE - (ALL)

1. REMOVAL
   a. Disconnect flanges at both ends of line.
   b. Remove support clamps; line; seals.
2. REPLACEMENT
   a. Install seals; line; support clamps.
3. RETEST
   a. Leak check - 50 psig GH_e.
   b. Electrical - None.

MAINTENANCE PROCEDURE

LRU (23) Gimbal Actuators

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine

ASSEMBLY - Thrust Vector Control

COMPONENT - Gimbal Actuators and Power Pack

TASK TIME - N/A

PROCEDURE

GENERAL - The actuators (2) weigh approximately 100 lb, each, attached by clevis/spherical rod ends. The main pump weighs approximately 15 lb and the electrical auxiliary pump weighs approximately 20 lb. The major replacement effort centers around the actuator, and is the main subject of this procedure.
Task Time - 8 hours.

A. ACTUATORS

1. REMOVAL

   a. Install contamination protection equipment.
   b. Disconnect electrical cables; hydraulic lines. Cap all lines, connectors.
   c. Attach nozzle positioning equipment; actuator handling equipment.
   d. Remove clevis pins; actuator.

2. REPLACEMENT

   a. Position actuator, using handling equipment.
   b. Attach rod ends to upper and lower clevis.
   c. Connect hydraulic lines; electrical cables.
   d. Install safety wire.

3. RETEST

   a. Adjust nozzle zero position.
   b. Bleed-in hydraulic lines.
   c. Leak check - high pressure system operating auxiliary pump from shop power.
   d. Electrical - test actuator and servo system at combined systems test VIA controller.

B. MAIN PUMP Estimated time - 3 hours

1. <u>REMOVAL</u>

   a. Install contamination protection equipment.
   b. Disconnect hydraulic lines. Cap all openings, lines.
   c. Remove main pump (TBD bolts); seal.

2. <u>REPLACEMENT</u>

   a. Install seal; main pump; safety wire.
   b. Connect hydraulic lines.

3. <u>RETEST</u>

   a. Bleed-in system.
   b. Leak check - operate auxiliary pump to obtain full system pressure at flanges.

MAINTENANCE PROCEDURE

LRU (24) Engine Controller

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine

ASSEMBLY - Engine Control

COMPONENT - Engine Controller

TASK TIME - 60 minutes

PROCEDURE

1. REMOVAL

   a. Attach handling fixture.
   b. Disconnect interconnects cables
   c. Remove attachment bolts.
   d. Remove controller.

2. REPLACEMENT

   a. Position controller.
   b. Install attachments bolts.
   c. Connect interconnect cables.
   d. Safety wire.
   e. Remove handling fixture.

3. RETEST

   a. Connect test GSE (may be via vehicle).
   b. Load diagnostic program.
   c. Operate controller, perform internal tests.
   d. Reload operational program.
   e. Perform internal tests.
   f. Perform engine functional check including all programs.

MAINTENANCE PROCEDURE

LRU (25) Wire Harness

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine

ASSEMBLY - Engine Control

COMPONENT - Ignition and Valve Control Harness

TASK TIME - 1 hour per subassembly

PROCEDURE

GENERAL - The harness configuration will probably consist of two to four subassembly harnesses, with multi-pin connectors at the controller, and fanning out to individual valves by area grouping. The ignition harness (low voltage) may be integral with the control cables. The high voltage conductors are considered part of the ignitor component.

1. REMOVAL

   a. Remove safety wires; support clamps.
   b. Disconnect connectors, both ends. Cap.
   c. Remove harness.

2. REPLACEMENT

   a. Position harness.
   b. Connect cable connectors.
   c. Install cable clamps; safety wires.

3. RETEST

   a. Electrical - Via controller at combined systems test.
   b. Valve functional - Via controller at combined systems test.

MAINTENANCE PROCEDURE

LRU (26) Instrumentation Harness

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine

ASSEMBLY - Engine Control

COMPONENT - Instrumentation Harness

TASK TIME - 2 hours per subassembly

GENERAL - The probable configuration is a set of six to ten subassemblies, serving perhaps ten transducers, with one multi-pin connector at the controller end. This discussion deals with each subassembly.

PROCEDURE

1. REMOVAL

   a. Disconnect connectors at transducer and controller ends. Cap connectors.
   b. Remove cable clamps; harness.

2. REPLACEMENT

   a. Place harness in position.
   b. Connect connectors, both ends.
   c. Install cable clamps, safety wires.

3. RETEST

   a. Electrical - Via controller at combined systems test.

MAINTENANCE PROCEDURE

LRU (27) Check Valve

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine

ASSEMBLY - Tank Pressurant

COMPONENT - Fuel Tank Pressurization Check Valve

TASK TIME - 1 hour

PROCEDURE

1. REMOVAL

   a. Disconnect valve flanges.
   b. Remove valve, seals.
   c. Cap lines.

2. REPLACEMENT

   a. Remove caps.
   b. Install seals; valve.

3. RETEST

   a. Leak check - Upstream and downstream requires simultaneous application of 25 psig GH_e.

MAINTENANCE PROCEDURE

LRU (28) Check Valve

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine

ASSEMBLY - Tank Pressurant

COMPONENT - Oxidizer Tank Pressurization Check Valve

TASK TIME - 1 hour

PROCEDURE

1. REMOVAL
   a. Disconnect valve flanges.
   b. Remove valve; seals.
   c. Take swab sample.
   d. Cap lines.

2. REPLACEMENT
   a. Remove caps.
   b. Install seals; valve.

3. RETEST
   a. Leak check - upstream and downstream requires simultaneous application of 25 psig GH_e.

MAINTENANCE PROCEDURE

LRU (29) Heat Exchanger

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine

ASSEMBLY - Tank Pressurant

COMPONENT - Oxidizer Heat Exchanger

TASK TIME - 1 hour

PROCEDURE

1. REMOVAL
   a. Install contamination protection equipment.
   b. Disconnect hot gas inlet line; hot gas outlet line; oxidizer inlet line; oxidizer outlet line.
   c. Remove heat exchanger mounting bracket; heat exchanger; seals.
   d. Install caps on lines.

2. REPLACEMENT
   a. Remove caps.
   b. Install seals; heat exchanger; bracket.

3. RETEST
   a. Leak test - oxidizer lines, TBD. Hot gas lines - 50 psig, GH_e.

MAINTENANCE PROCEDURE

LRU (30) Purge Valves

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine

ASSEMBLY - Engine Purge

COMPONENT - Purge Valves

TASK TIME - Each component, 30 minutes.

PROCEDURE

1. REMOVAL
   a. Disconnect electrical connector.
   b. Remove flange bolts; valve; seals.
   c. Cap lines; openings.

2. REPLACEMENT
   a. Remove caps, closures.
   b. Install seals; valve.
   c. Connect electrical connector.
   d. Install safety wire.

3. RETEST
   a. Leak check - TBD
   b. Electrical check - operate valve.

MAINTENANCE PROCEDURE

LRU (31) Extendable Nozzle

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine, Orbiter Only

ASSEMBLY - Extendable Nozzle

COMPONENT - Extendable Nozzle

TASK TIME - 16 hours

PROCEDURE

1. REMOVAL

   a. Attach nozzle handling equipment, with nozzle in 90% aft position.
   b. Remove seal ring.
   c. Disconnect drive cable clamps; position sensor cables.
   d. Remove nozzle.

2. REPLACEMENT

   a. Move nozzle into position, using handling equipment nozzle to be at 90% aft position - match position index marks.
   b. Attach drive cable clamps.
   c. Install seal ring.
   d. Connect position sensor cables.
   e. Install safety wires.
   f. Remove handling equipment.

3. RETEST

   a. Mechanical - Using shop power, operate nozzle to fully stowed, full aft, and fully stowed.

MAINTENANCE PROCEDURE

LRU (32) Nozzle Deployment Kit

SYSTEM - Main Propulsion

SUBSYSTEM - Main Engine, Orbiter Only.

ASSEMBLY - Extendable Nozzle

COMPONENT - Extendable Nozzle Deployment Kit

TASK TIME - 8 hours (one guide rail, cable, drive assembly kit).

PROCEDURE

1. REMOVAL

   a. Install nozzle support equipment nozzle extended.
   b. Disconnect electrical cables. Cap connectors.
   c. Remove cable; drive unit.
   d. Disconnect guide column supports.
   e. Remove guide column.

2. REPLACEMENT

   a. Install guide column; cable and drive unit.
   b. Connect electrical cables; safety wire.
   c. Remove nozzle support equipment.

3. RETEST

   a. Operational - Using shop power, return nozzle to stowed position, and cycle to full extension/fully stowed.

LRUs Auxiliary Propulsion System

This section of Appendix C contains the maintenance procedures for the Booster and Orbiter Auxiliary Propulsion Systems.

MAINTENANCE PROCEDURE

LRU (1) Engine Package, Booster - RCS/Separation

LRU (1) Engine Package, Orbiter - RCS/OMS

SYSTEM - Auxiliary Propulsion

SUBSYSTEM - RCS, OMS, Separation Engine

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 3 hours

PROCEDURE (Refer to Figure C-2)

1. REMOVAL

   a. Assemble engine package removal fixture.
   b. Disconnect mounting bolts; lockwire.
   c. Remove mounting bolts.
   d. Remove engine package

2. REPLACEMENT

   a. Attach mounting fixture to engine package.
   b. Orient package to mounting index-guide pins.
   c. Install seals; engine package-to-vehicle-mounting-pad seals on thruster assembly.
   d. Orient engine package to mounting pad indexing pins and slide toward the mounting pad until contact is made.
   e. Install engine package mounting bolts through mounting pads to threaded holes in vehicle mounting pad.
   f. Install lockwire.

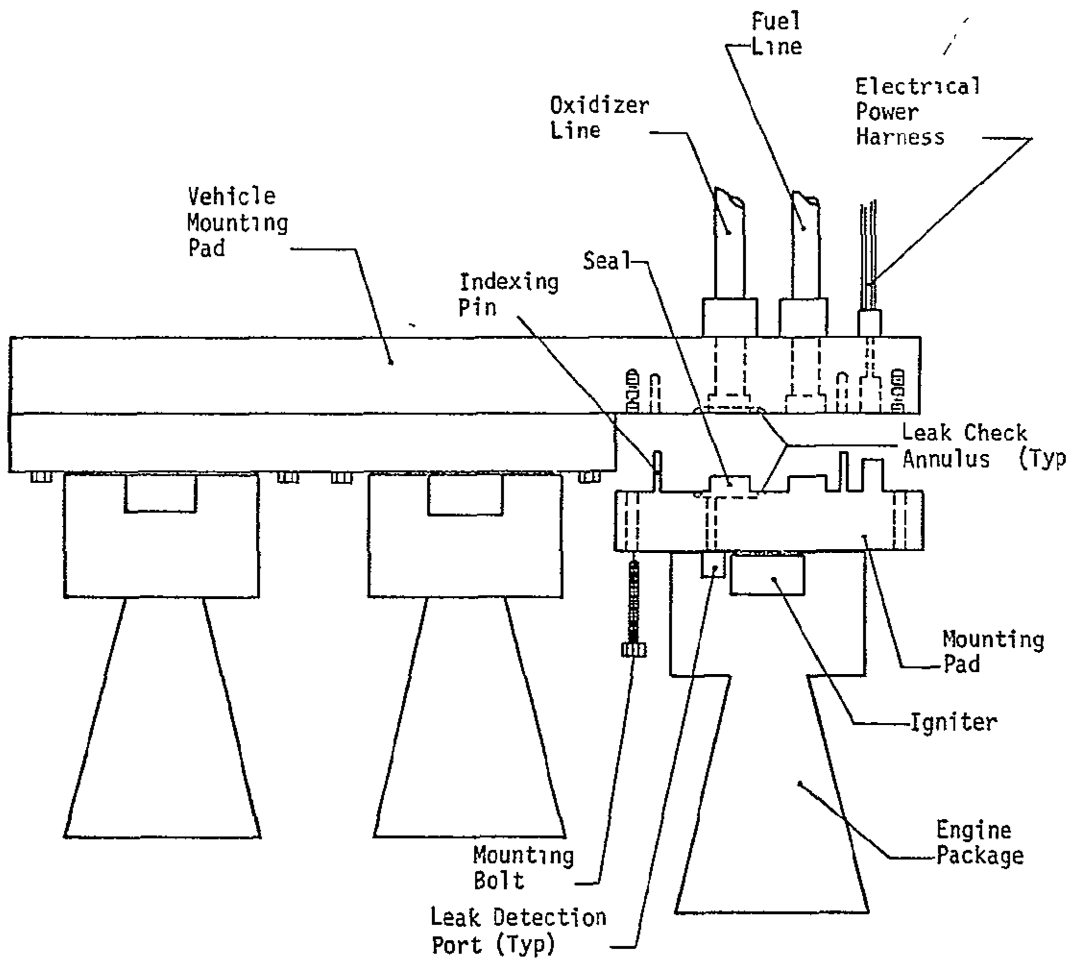
3. RETEST

   a. Leak check -

      1) Apply nitrogen or helium pressure to the oxidizer and fuel lines with the bipropellant isolation valves in a closed position.
      2) Monitor leak detection ports for interface seal integrity.

   b. Electrical -

      1) Actuate the igniter valve similar to that for thruster operation.
      2) Energize the igniter spark plug and visually monitor spark through the thrust chamber exit with appropriate tooling.



- Electrical harness includes igniter power, instrumentation, and valve actuation circuit.
- Each propellant delivery interface has leak check annulus and port.
- Vehicle Mounting Pad is hard-mounted to vehicle.
- All engine control valves included in engine package.

Fig C-2 RCS/OMS/Separation Engine Package Removal and Replacement

MAINTENANCE PROCEDURE

LRU (2) , (3) Booster GO_2, GH_2 Filter

LRU (2) , (3) Orbiter GO_2, GH_2 Filter

SYSTEM - Auxiliary Propulsion

SUBSYSTEM - APS Propellant Management

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 3/4 hour

PROCEDURE

1. REMOVAL

   a. Cut brazed sleeves with cutting tool.
   b. Remove filter and clean propellant distribution lines.

2. REPLACEMENT

   a. Install replacement filter and braze sleeves to propellant distribution lines.
   b. Remove brazing equipment and perform visual inspection.

3. RETEST

   a. Verify accumulator isolation valves closed in affected subsystem (O_2 or H_2).
   b. Connect helium pressurization line to appropriate quick-disconnect coupling.
   c. Pressurize accumulators to 1500 psia.
   d. Monitor accumulator pressure for decay.
   e. If pressure decay noted, perform bubble leak test on replaced filter to verify.
   f. Reduce accumulator pressure to 19 psia.
   g. Disconnect pressurization system.

MAINTENANCE PROCEDURE

LRU (4) , (5) Booster GH_2, GO_2 Solenoid Valve

LRU (4) , (5) Booster GH_2, GO_2 Solenoid Valve

SYSTEM - Auxiliary Propulsion

SUBSYSTEM - APS Propellant Management

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 3/4 hour

PROCEDURE

1. REMOVAL

   a. Disconnect electrical control and instrumentation.
   b. Cut brazed sleeves with cutting tool.
   c. Remove solenoid valve and clean propellant feed lines.

2. REPLACEMENT

   a. Install replacement solenoid valve and braze sleeves to propellant feed lines.
   b. Remove brazing equipment and perform visual inspection.
   c. Connect electrical control and instrumentation.

3. RETEST

   a. Apply 28 vdc electrical actuation signal to solenoid valve and verify response with position indicator instrumentation.
   b. Connect helium pressurization line to appropriate quick-disconnect coupling.
   c. Close solenoid valve.
   d. Pressurize accumulators to 1500 psia.
   e. Monitor accumulator pressure for decay (internal leakage).
   f. Perform bubble leak test (external leakage).
   g. Open solenoid valve and monitor feed line pressure.
   h. Reduce accumulator pressure to 19 psia.
   i. Disconnect pressurization system.

MAINTENANCE PROCEDURE

LRU (6) Booster/Orbiter GH_2 Check Valve Package

SYSTEM - Auxiliary Propulsion

SUBSYSTEM - Booster Hydrogen Conditioning
Orbiter Propellant Conditioning

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 3/4 hour

PROCEDURE

1. REMOVAL

   a. Cut brazed sleeves with cutting tool.
   b. Remove check valve package and clean propellant lines.

2. REPLACEMENT

   a. Install replacement check valve package, verify installation in proper direction, braze sleeves to propellant lines.
   b. Remove brazing equipment and perform visual inspection.

3. RETEST

   a. Verify accumulator isolation valves closed in affected subsystem.
   b. Connect helium pressurization line to GH_2 quick-disconnect coupling.
   c. Pressurize accumulators to 1500 psia.
   d. Monitor accumulator pressure for decay. (Downstream leak check, internal leak check).
   e. Pressurize upstream side to 1500 psia. (Upstream leak check, internal leak check).
   f. Reduce pressure in accumulators and verify check valve operation.
   g. Perform external bubble leak check if required.
   h. Reduce system pressure to 19 psia.
   i. Disconnect pressurization system.

MAINTENANCE PROCEDURE

LRU (7) Booster/Orbiter Gas Generator GH_2 Propellant Valve Package

SYSTEM - Auxiliary Propulsion

SUBSYSTEM - Booster Hydrogen Conditioning, Booster Oxygen Conditioning, Booster APU, Orbiter Propellant Conditioning

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 1 hour

PROCEDURE

1. REMOVAL

   a. Disconnect electrical control and instrumentation.
   b. Cut brazed sleeves with cutting tool.
   c. Remove gas generator GH_2 propellant valve package and clean propellant lines.

2. REPLACEMENT

   a. Install replacement valve package and braze sleeves to propellant lines.
   b. Remove brazing equipment and perform visual inspection.
   c. Connect electrical control and instrumentation.

3. RETEST

   a. Apply 28 vdc electrical actuation signal to each solenoid valve and verify response with position indicator instrumentation.
   b. Connect helium pressurization line to GH_2 quick-disconnect coupling.
   c. Close both solenoid valves.
   d. Pressurize accumulators to 1500 psia.
   e. Monitor accumulator pressure for decay with:

      1) Main GH_2 valve closed, isolation valve open,
      2) Main GH_2 valve open, isolation valve closed, (internal leakage)

   f. Perform bubble leak test on upstream brazed joint with both valves closed (external leakage).
   g. Close turbine overboard dump valve.*

*This valve is required to allow pressurization of gas generator and turbine for leak checks and has not been identified in the DRM.

h. Open main GH_2 and isolation valves and pressurize gas generator and turbine.
i. Perform bubble leak test on downstream brazed joint (external leakage).
j. Reduce accumulator pressure to 19 psia.
k. Close main GH_2 and isolation valves and open overboard dump valve.
l. Disconnect pressurization system.

MAINTENANCE PROCEDURE

LRU (8) Booster/Orbiter Gas Generator GO_2 Propellant Valve Package

SYSTEM - Auxiliary Propulsion

SUBSYSTEM - Booster Hydrogen Condition, Booster Oxygen Conditioning, Booster APU, Orbiter Propellant Conditioning

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 1 hour

PROCEDURE

1. REMOVAL

   a. Disconnect electrical control and instrumentation.
   b. Cut brazed sleeves with cutting tool.
   c. Remove gas generator GO_2 propellant valve package and clean propellant lines.

2. REPLACEMENT

   a. Install replacement valve package and braze sleeves to propellant lines.
   b. Remove brazing equipment and perform visual inspection.
   c. Connect electrical control and instrumentation.

3. RETEST

   a. Apply 28 vdc electrical actuation signal to each solenoid valve and verify response with position indicator instrumentation.
   b. Connect helium pressurization line to GO_2 quick-disconnect coupling
   c. Close both solenoid valves.
   d. Pressurize accumulators to 1500 psia.
   e. Monitor accumulator pressure for decay with:
      1) Main GO_2 valve closed, isolation valve open.
      2) Main GO_2 valve open, isolation valve closed. (internal leakage).
   f. Perform bubble leak test on upstream brazed joint with both valves closed (external leakage).

g. Close turbine overboard dump valve.*
h. Open main GO_2 and isolation valves and pressurize gas generator and turbine.
i. Perform bubble leak test on downstream brazed joint (external leakage).
j. Reduce accumulator pressure to 19 psia.
k. Close main GO_2 and isolation valves and open overboard dump valve.
l. Disconnect pressurization system.

*This valve is required to allow pressurization of gas generator and turbine for leak checks and has not been identified in the DRM.

MAINTENANCE PROCEDURE

LRU (9) Booster LH_2 Check Valve Package

SYSTEM - Booster Auxiliary Propulsion

SUBSYSTEM - Booster Hydrogen Conditioning

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 3/4 hour

PROCEDURE

1. REMOVAL

    a. Cut brazed sleeves with cutting tool.
    b. Remove check valve package and clean propellant lines.

2. REPLACEMENT

    a. Install replacement check valve package, verify installation in proper direction, braze sleeves to propellant lines.
    b. Remove brazing equipment and perform visual inspection.

3. RETEST

    a. Pressurize airborne cruise tank and propellant distribution line to 25 psia.
    b. Open LH_2 pump isolation and suction valves.
    c. Monitor system pressure for decay and, if required perform bubble leak check for external leakage.
    d. Reduce cruise tank and propellant distribution line pressure to ambient.
    e. Close cruise tank propellant distribution valves and monitor propellant distribution line pressure (internal leakage).
    f. Reduce system pressure to 19 psia.
    g. Disconnect pressurization system.

MAINTENANCE PROCEDURE

LRU (10) Booster Turbopumps

SYSTEM - Booster Auxiliary Propulsion

SUBSYSTEM - Hydrogen Conditioning

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 6 hours

PROCEDURES (Refer to Figures C-5 and C-6)

1. REMOVAL

   a. Drain gearbox lubrication system.
   b. Disconnect electrical instrumentation.
   c. Cut brazed sleeves on pump suction and discharge lines with cutting tool.
   d. Attach turbopump removal fixture.
   e. Remove mounting bolts from gas generator and mounting flanges on pump and turbine.
   f. Remove turbopump.
   g. Remove gas generator/turbine seals and clean.

2. REPLACEMENT

   a. Install gas generator/turbine seals.
   b. Attach mounting fixture to turbopump.
   c. Install replacement turbopump.
   d. Install mounting bolts in gas generator and mounting flanges.
   e. Remove mounting fixture.
   f. Braze pump suction and discharge lines.
   g. Remove brazing equipment and perform visual inspection.
   h. Connect electrical instrumentation.
   j. Replace gearbox lubrication oil.

3. RETEST

   a. Verify gearbox lubrication oil level.
   b. Pressurize APS hydrogen accumulators to 1500 psia.
   c. Open pump isolation and suction valves.
   d. Perform bubble leak check on pump suction and discharge line brazed connections.
   e. Close turbine overboard dump valve.*

*This valve is required to allow pressurization of gas generator and turbine for leak checks and has not been identified in the DRM.

f. Open gas generator main GH_2 and isolation valves and pressurize gas generator and turbine.
g. Perform bubble leak test on gas generator/turbine seals (external leakage).
h. Reduce accumulator pressure to 15 psia.
i. Connect cold-gas turbine drive ground support equipment.
j. Open turbine overboard dump valve.
k. Activate cold gas turbine drive gas.
l. Verify turbine speed instrumentation, and lubrication system operation.
m. Perform visual inspection for gearbox/pump seal leakage.
n. Deactivate cold-gas turbine drive gas.
o. Disconnect cold-gas turbine drive ground support equipment.
p. Pressurize accumulator to 19 psia.
q. Close pump isolation and suction valves and gas generator main GH_2 and isolation valves.
r. Disconnect pressurization system.

MAINTENANCE PROCEDURE

LRU (11) Booster Turbopump Suction Valve Package

LRU (16) Orbiter LH_2 Pump Suction Valve Package

SYSTEM - Auxiliary Propulsion

SUBSYSTEM - Booster Hydrogen Condition, Orbiter Propellant Conditioning,

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 1 hour

PROCEDURES

1. REMOVAL

   a. Disconnect electrical control and instrumentation.
   b. Cut brazed sleeves with cutting tool.
   c. Remove valve package and clean suction lines.

2. REPLACEMENT

   a. Install replacement valve package and braze sleeves to suction lines.
   b. Remove brazing equipment and perform visual inspection.
   c. Connect electrical control and instrumentation.

3. RETEST

   a. Apply 28 vdc electrical actuation signal to each solenoid valve and verify response with position indicator instrumentation.
   b. Close both solenoid valves.
   c. Connect helium pressurization line and pressurize appropriate tank (cruise tank or on-orbit LH_2 tank) to 30 psia.
   d. Monitor tank pressure for decay with:
      1) Suction valve closed, isolation valve open.
      2) Suction valve open, isolation valve closed. (internal leakage).
   e. Perform bubble leak test on brazed joints with both valves open (external leakage).
   f. Reduce system pressure to 19 psia.
   g. Close pump suction and isolation valves.
   h. Disconnect pressurization system.

MAINTENANCE PROCEDURE

LRU (12) Booster Gas Generator/Heat Exchanger Package

SYSTEM - Booster Auxiliary Propulsion

SUBSYSTEM - Hydrogen Conditioning Subsystem

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 4 hours

PROCEDURES (Refer to Figure C-3)

1. REMOVAL

   a. Disconnect electrical instrumentation and control.
   b. Cut brazed sleeves with cutting tool.
   c. Remove mounting bolts from turbine inlet duct and structural mounting pads.
   d. Remove gas generator/heat exchanger package and clean lines.
   e. Remove turbine inlet duct seal.

2. REPLACEMENT

   a. Install replacement turbine inlet duct seal.
   b. Install replacement gas generator/heat exchanger.
   c. Install mounting bolts in turbine inlet duct and structural mounting pads.
   d. Braze heat exchanger inlet and outlet lines and gas generator propellant lines.
   e. Remove brazing equipment and perform visual inspection.
   f. Connect electrical instrumentation and control.

3. RETEST

   a. Pressurize APS hydrogen accumulators and LH_2 cruise tanks to 30 psia.
   b. Open LH_2 pump isolation and suction valves and accumulator resupply and isolation valves.
   c. Perform bubble leak check on heat exchanger inlet and outlet brazed connections (external leakage).
   d. Close accumulator resupply and isolation valves.
   e. Close turbine overboard dump valve.*

*This valve is required to allow pressurization of gas generator and turbine for leak checks and has not been identified in the DRM.

f. Increase APS hydrogen accumulator pressure to 1500 psia.
g. Open gas generator main GH_2 and isolation valves and pressurize gas generator, turbine, and heat exchanger to 1500 psia.
h. Monitor heat exchanger outlet pressure (internal leakage) and perform bubble leak check on turbine inlet duct seal (external leakage).
i. Reduce accumulator pressure and cruise tank pressure to 19 psia.
j. Close gas generator main GH_2 and isolation valves and open overboard dump valve.
k. Disconnect pressurization system.

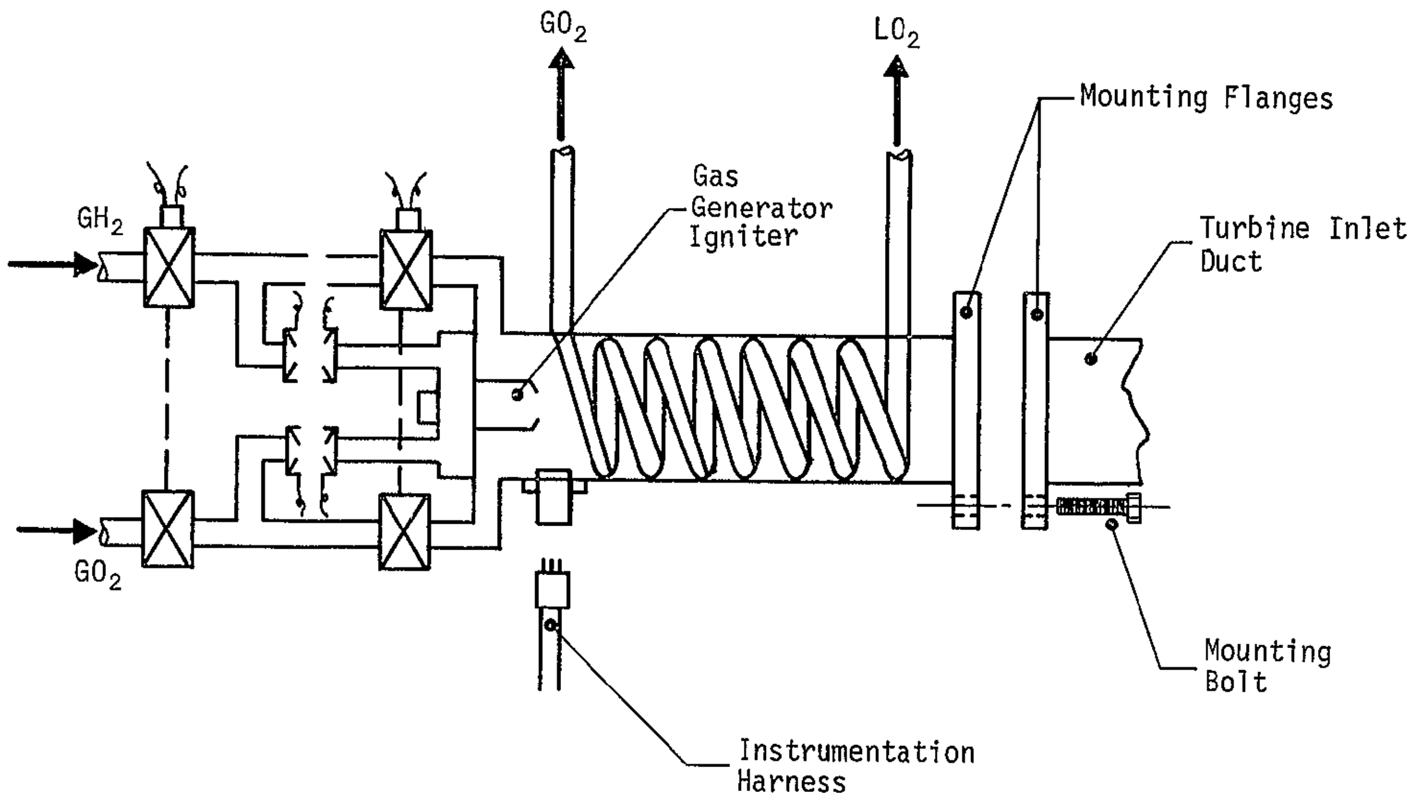


Fig. C-3 Booster Gas Generator/Heat Exchanger Package Removal and Replacement

MAINTENANCE PROCEDURE

LRU (13) Booster LH_2 Solenoid Valve Package

SYSTEM - Booster Auxiliary Propulsion

SUBSYSTEM - Hydrogen Conditioning

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 1 hour

PROCEDURES

1. REMOVAL

   a. Disconnect electrical control and instrumentation.
   b. Cut brazed sleeves with cutting tool.
   c. Remove LH_2 solenoid valve package and clean lines.

2. REPLACEMENT

   a. Install replacement valve package and braze sleeves to lines.
   b. Remove brazing equipment and perform visual inspection.
   c. Connection electrical control and instrumentation.

3. RETEST

   a. Apply 28 vdc electrical actuation signal to each solenoid valve and verify response with position indicator instrumentation.
   b. Close both solenoid valves.
   c. Open LH_2 pump suction and isolation valves.
   d. Pressurize APS hydrogen accumulators to 30 psia and on-orbit LH_2 tanks to 15 psia.
   e. Monitor accumulator pressure for decay with:
      1) Resupply valve closed, isolation valve open.
      2) Resupply valve open, isolation valve closed (internal leakage).
   f. Open both solenoid valves and pressurize LH_2 tank to 30 psia.
   g. Perform bubble leak test on brazed joints with solenoid valves open (external leakage).
   h. Reduce system pressure to 19 psia.
   i. Close accumulator resupply and isolation valves.
   j. Close LH_2 pump suction and isolation valves.
   k. Disconnect pressurization system.

MAINTENANCE PROCEDURE

LRU (14) Booster/Orbiter Gas Generator

SYSTEM - Auxiliary Propulsion

SUBSYSTEM - Booster Hydrogen Conditioning, Booster Oxygen Conditioning, Booster APU, Orbiter Propellant Conditioning

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 3 hours

PROCEDURE (Refer to Figure C-4)

1. REMOVAL

   a. Disconnect electrical instrumentation and control.
   b. Cut brazed sleeves with cutting tool.
   c. Remove mounting bolts from turbine inlet duct and structural mounting pads.
   d. Remove gas generator and clean propellant lines.
   e. Remove turbine inlet duct seal.

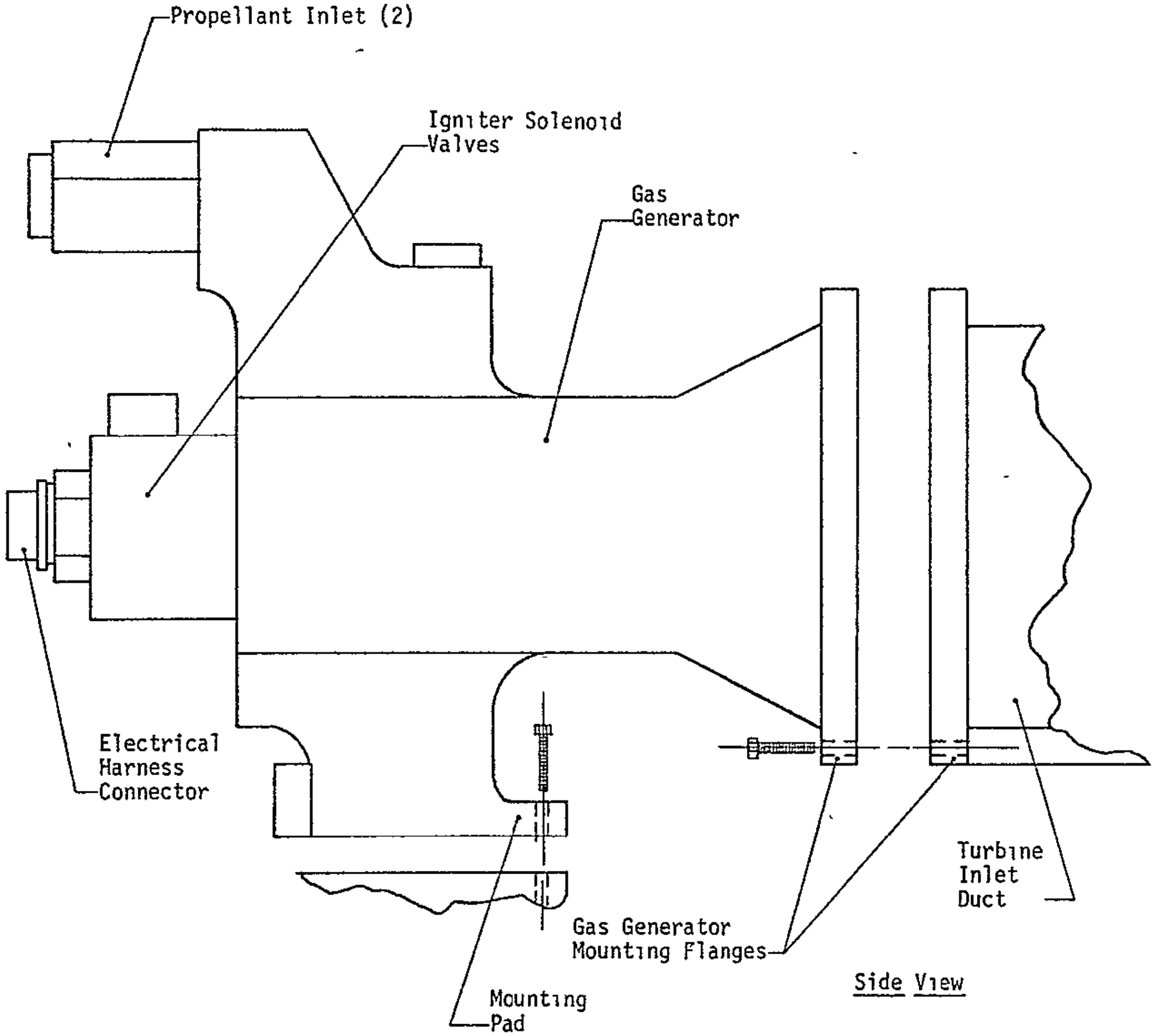
2. REPLACEMENT

   a. Install replacement turbine inlet duct seal.
   b. Install replacement gas generator.
   c. Install mounting bolts in turbine inlet duct and structural mounting pads.
   d. Braze propellant inlet lines.
   e. Remove brazing equipment and perform visual inspection.
   f. Connect electrical instrumentation and control.

3. RETEST

   a. Close turbine overboard dump valve*.
   b. Open gas generator main propellant and isolation valves.
   c. Pressurize appropriate accumulators to 1500 psia.
   d. Perform bubble leak check on turbine inlet duct seal (external leakage).
   e. Reduce accumulator pressure to 19 psia.
   f. Close gas generator main propellant and isolation valves and open overboard dump valve.
   g. Disconnect pressurization system.
   h. If required, a hot firing test may be performed by loading APS propellants and cycling gas generator through a start and shut-down sequence. This test must be followed by a system purge and safing procedure.

*This valve is required to allow pressurization of gas generator and turbine for leak checks and has not been identified in the DRM.



- Electrical harness includes igniter power, igniter valve control, and instrumentation.
- Mounting flanges have removable seals.

Fig. C-4 Gas Generator Removal and Replacement

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MAINTENANCE PROCEDURE

LRU (15) Booster Compressor GO_2 Inlet Valve Package

SYSTEM - Booster Auxiliary Propulsion

SUBSYSTEM - Oxygen Conditioning

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 1 hour

PROCEDURE

1. REMOVAL

   a. Disc onnect electrical control and instrumentation
   b. Cut brazed sleeves with cutting tool.
   c. Remove compressor GO_2 inlet valve package and clean propellant lines.

2. REPLACEMENT

   a. Install replacement valve package and braze sleeves to propellant lines.
   b. Remove brazing equipment and perform visual inspection.
   c. Connect electrical control and instrumentation.

3. RETEST

   a. Apply 28 vdc electrical actuation signal to each solenoid valve and verify response with position indicator instrumentation.
   b. Connect helium pressurization line to main LO_2 quick-disconnect coupling.
   c. Close both solenoid valves.
   d. Pressurize system to 30 psia.
   e. Monitor main LO_2 tank pressure for decay with:
      1. GO_2 propellant valve closed, isolation valve open.
      2. GO_2 propellant valve open, isolation valve closed (internal leakage).
   f. Perform bubble leak test on brazed joints with both valves open (external leakage).
   g. Reduce main LO_2 tank pressure to 19 psia.
   h. Close GO_2 propellant and isolation valves.
   i. Disconnect pressurization system.

MAINTENANCE PROCEDURE

LRU (16) Booster Turbocompressor

SYSTEM - Booster Auxiliary Propulsion

SUBSYSTEM - Oxygen Conditioning

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 5 hours

PROCEDURE

1. REMOVAL

   a. Disconnect electrical instrumentation.
   b. Remove mounting bolts from GO_2 outlet and overboard ducting flanges.
   c. Remove mounting bolts from compressor inlet and turbine inlet flanges.
   d. Attach turbocompressor removal fixture.
   e. Remove mounting bolts from mounting pads.
   f. Remove turbocompressor.
   g. Remove flange seals and clean flanges.

2. REPLACEMENT

   a. Attach mounting fixture to replacement turbocompressor.
   b. Install replacement flange seals.
   c. Install replacement turbocompressor and install mounting bolts in mounting pads.
   d. Install mounting bolts in compressor inlet and turbine inlet flanges.
   e. Install mounting bolts in GO_2 outlet and overboard ducting flanges.
   f. Remove turbocompressor mounting fixture.
   g. Connect electrical instrumentation and perform visual inspection.

3. RETEST

   a. Close turbine overboard dump valve.*
   b. Open gas generator main propellant and isolation valves.
   c. Pressurize appropriate accumulators to 1500 psia.
   d. Perform bubble leak check on turbine inlet and outlet duct seals (external leakage).

*This valve is required to allow pressurization of gas generator and turbine for leak checks and has not been identified in the DRM.

e. Reduce accumulator pressure to 19 psia.
f. Close gas generator main propellant and isolation valves and open overboard dump valve.
g. Connect helium pressurization line to main LO_2 quick-disconnect coupling.
h. Open GO_2 propellant and isolation valves.
i. Pressurize system to 30 psia.
j. Perform bubble leak test on GO_2 outlet and overboard ducting flanges of compressor (external leakage).
k. Reduce main LO_2 tank pressure to 19 psia.
l. Close GO_2 propellant and isolation valves.
m. Disconnect pressurization systems.
n. Connect cold-gas turbine drive ground support equipment.
o. Activate cold gas turbine drive gas.
p. Verify turbocompressor speed instrumentation.
q. Deactive cold-gas turbine drive ground support equipment.
r. Disconnect cold-gas turbine drive ground support equipment.

MAINTENANCE PROCEDURE

LRU (17) Booster GO_2 Check Valve Package

LRU (18) Orbiter GO_2 Check Valve Package

SYSTEM - Auxiliary Propulsion

SUBSYSTEM - Booster Oxygen Conditioning, Orbiter Propellant Conditioning

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 3/4 hour

PROCEDURE

1. REMOVAL

   a. Cut brazed sleeves with cutting tool.
   b. Remove check valve package and clean propellant lines.

2. REPLACEMENT

   a. Install replacement check valve package, verify installation in proper direction, braze sleeves to propellant lines.
   b. Remove brazing equipment and perform visual inspection.

3. RETEST

   a. Verify accumulator isolation valves closed in affected subsystem.
   b. Connect helium pressurization line to GO_2 quick-disconnect coupling.
   c. Verify compressor GO_2 propellant and isolation valves (booster) or LO_2 pump suction and isolation valves (orbiter) closed.
   d. Pressurize accumulators to 1500 psia.
   e. Monitor accumulator pressure for decay. (Downstream leak check, internal leak check).
   f. Pressurize upstream side to 1500 psia. (Upstream leak check, internal leak check).
   g. Reduce pressure in accumulators and verify check valve operation.
   h. Perform external bubble leak check if required.
   i. Reduce system pressure to 19 psia.
   j. Disconnect pressurization system.

MAINTENANCE PROCEDURE

LRU (18) Booster Turbine

LRU (15) Orbiter Turbine

SYSTEM - Auxiliary Propulsion

SUBSYSTEM - Booster Hydrogen Conditioning, Booster Oxygen Conditioning, Booster APU, Orbiter Propellant Conditioning

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 4 hours

PROCEDURE (Refer to Figure C-5)

1. REMOVAL

   a. Disconnect electrical instrumentation.
   b. Remove mounting bolts from gas generator and overboard ducting flanges.
   c. Disconnect rotor shaft coupling.
   d. Remove mounting bolts from mounting pads and remove turbine.
   e. Remove inlet and outlet duct seals and clean.

2. REPLACEMENT

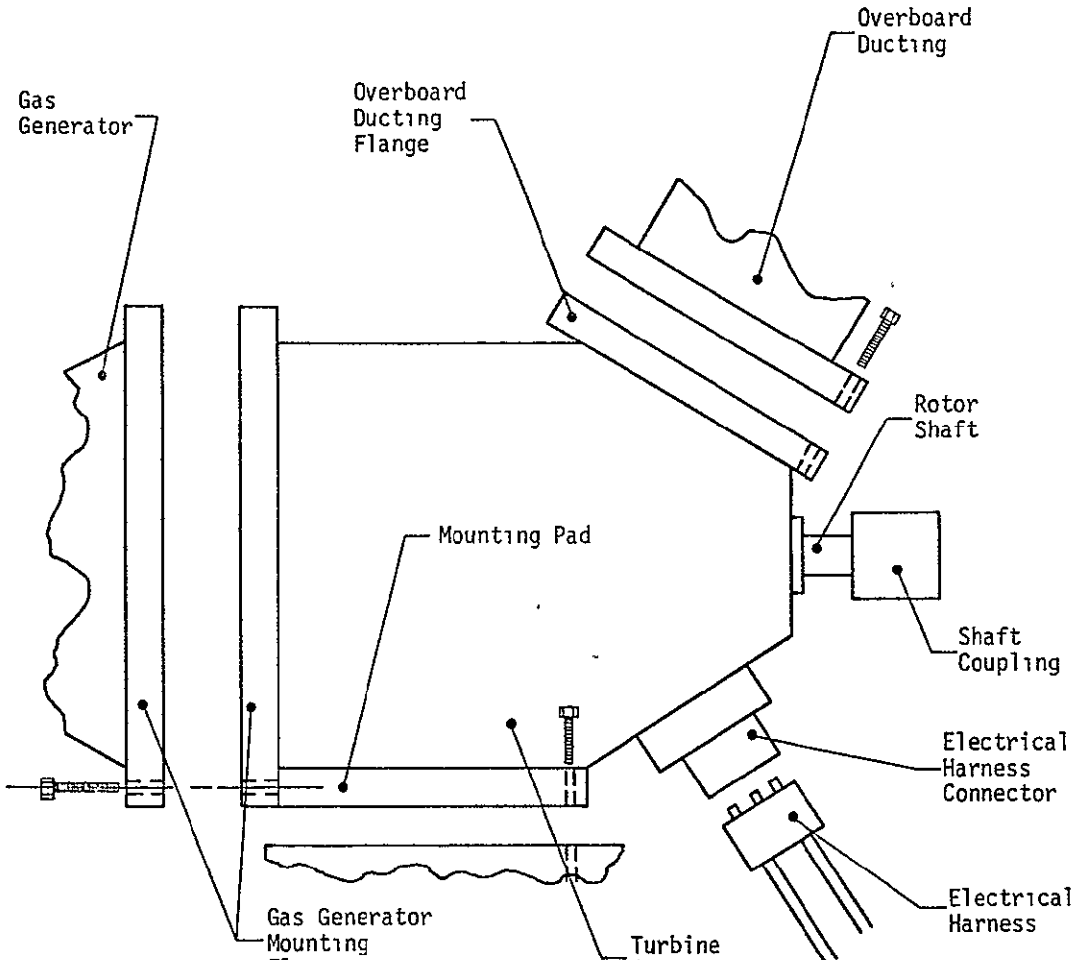
   a. Install replacement inlet and outlet duct seals.
   b. Install replacement turbine.
   c. Install mounting bolts in mounting pads and inlet and outlet flanges.
   d. Connect rotor shaft coupling.
   e. Connect electrical instrumentation.

3. RETEST

   a. Close turbine overboard dump valve.*
   b. Open gas generator main propellant and isolation valves.
   c. Pressurize appropriate accumulators to 1500 psia.
   d. Perform bubble leak check on turbine inlet and outlet duct seals (external leakage).
   e. Reduce accumulator pressure to 19 psia.
   f. Close gas generator main propellant and isolation valves and open overboard dump valve.
   g. Disconnect pressurization system.

*This valve is required to allow pressurization of gas generator and turbine for leak checks and has not been identified in the DRM.

h. Connect cold-gas turbine drive ground support equipment.
i. Activate cold-gas turbine drive gas.
j. Verify turbine speed instrumentation and proper operation of turbine-driven equipment.
k. Deactivate cold-gas turbine drive gas.
l. Disconnect cold-gas turbine drive ground support equipment.



Side View

- Electrical harness includes turbine instrumentation circuits.
- Mounting flanges have removable seals.

Fig. C-5 Turbine Removal and Replacement

MAINTENANCE PROCEDURE

LRU (18) , (22) Orbiter/Booster GH_2 Manual Valve

LRU (21) , (19) Orbiter/Booster GO_2 Manual Valve

SYSTEM - Auxiliary Propulsion

SUBSYSTEM - Booster/Orbiter Propellant Management

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 3/4 hour

PROCEDURE

1. REMOVAL

   a. Cut brazed sleeves with cutting tool.
   b. Remove valve and clean propellant fill lines.

2. REPLACEMENT

   a. Install replacement valve and braze sleeves to propellant fill lines.
   b. Remove brazing equipment and perform visual inspection.

3. RETEST

   a. Verify accumulator isolation valves closed in affected subsystem (O_2 or H_2).
   b. Connect helium pressurization line to appropriate quick-disconnect coupling.
   c. Verify manual valve closed.
   d. Pressurize accumulators to 1500 psia.
   e. Monitor accumulator pressure for decay.
   f. If pressure decay noted, perform bubble leak test on replaced valve to verify.
   g. Cycle valve open and closed to verify operation.
   h. Reduce accumulator pressure to 19 psia.
   i. Disconnect pressurization system.

MAINTENANCE PROCEDURE

LRU (19) , (23) Orbiter/Booster GH_2 Relief Valve

LRU (22) , (20) Orbiter/Booster GO_2 Relief Valve

SYSTEM - Auxiliary Propulsion

SUBSYSTEM - Booster/Orbiter Propellant Management

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 3/4 hour

PROCEDURE

1. REMOVAL

   a. Cut brazed sleeves with cutting tool.
   b. Remove valve and clean propellant fill lines.

2. REPLACEMENT

   a. Install replacement valve and braze sleeves to propellant fill lines.
   b. Remove brazing equipment and perform visual inspection.

3. RETEST

   a. Verify accumulator isolation valves closed in affected subsystem (O_2 or H_2).
   b. Connect helium pressurization line to appropriate quick-disconnect coupling.
   c. Pressurize accumulators to 1500 psia.
   d. Monitor accumulator pressure for delay.
   e. If pressure decay noted, perform bubble leak test on replaced valve to verify.
   f. Reduce accumulator pressure to 19 psia.
   g. Disconnect pressurization system.

MAINTENANCE PROCEDURE

LRU (20) , (24) Orbiter/Booster GH_2 Quick-Disconnect/Solenoid Valve Package

LRU (23) , (21) Orbiter/Booster GO_2 Quick-Disconnect/Solenoid Valve Package

SYSTEM - Auxiliary Propulsion

SUBSYSTEM - Booster/Orbiter Propellant Management

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 1 hour

PROCEDURE

1. REMOVAL

   a. Disconnect electrical control and instrumentation.
   b. Cut brazed sleeves with cutting tool.
   c. Remove mounting bolts from vehicle structure mounting flange on coupling.
   d. Remove valve package and clean propellant fill lines.

2. REPLACEMENT

   a. Install replacement valve package.
   b. Install mounting bolts in vehicle structure mounting flange on coupling.
   c. Braze sleeves to propellant fill lines.
   d. Remove brazing equipment and perform visual inspection.
   e. Connect electrical control and instrumentation.

3. RETEST

   a. Apply 28 vdc electrical actuation signal to solenoid valve and verify response with position indicator instrumentation.
   b. Verify accumulator isolation valves closed in affected subsystem (O_2 or H_2).
   c. Connect helium pressurization line to appropriate quick-disconnect coupling.
   d. Open solenoid valve and pressurize accumulators to 1500 psia.
   e. Close solenoid valve and remove pressurization line.
   f. Monitor accumulator pressure for decay (internal leakage).
   g. Perform bubble leak test on brazed sleeve (external leakage).
   h. Open solenoid valve and perform bubble leak test on quick-disconnect coupling.
   i. Close solenoid valve and connect pressurization line.
   j. Open solenoid valve and reduce accumulator pressure to 19 psia.
   k. Disconnect pressurization system.

MAINTENANCE PROCEDURE

LRU (25) Booster/Orbiter GO_2 Regulator Package

LRU (26) Booster/Orbiter GH_2 Regulator Package

SYSTEM - Auxiliary Propulsion

SUBSYSTEM - Booster/Orbiter Propellant Management

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 1 hour

PROCEDURE

1. REMOVAL

   a. Disconnect electrical control and instrumentation.
   b. Cut brazed sleeves with cutting tool.
   c. Remove mounting bolts from vehicle structure mounting pads.
   d. Remove regulator package and clean propellant distribution lines.

2. REPLACEMENT

   a. Install replacement regulator package.
   b. Install mounting bolts in vehicle structure mounting pads.
   c. Braze_sleeves to propellant distribution lines.
   d. Remove brazing equipment and perform visual inspection.
   e. Connect electrical control and instrumentation.

3. RETEST

   a. Apply 28 vdc electrical actuation signal to each regulator and verify response.
   b. Verify accumulator isolation valves closed in affected subsystem (O_2 or H_2).
   c. Connect helium pressurization line to appropriate quick-disconnect coupling.
   d. Close accumulator isolation valve in parallel regulator package.
   e. Pressurize accumulators to 1500 psia.
   f. Perform bubble leak check on brazed sleeves (external leakage).
   g. Verify proper pressure in propellant feed lines.
   h. Reduce system pressure (accumulators and feed lines to 19 psia.)
   i. Disconnect pressurization system.

MAINTENANCE PROCEDURE

LRU (9) Orbiter LH_2 Pump

SYSTEM - Orbiter Auxiliary Propulsion

SUBSYSTEM - APS Propellant Conditioning

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 4 hours

PROCEDURE (Refer to Figure C-6)

1. REMOVAL

   a. Drain gearbox lubration system.
   b. Disconnect electrical instrumentation.
   c. Cut brazed sleeves on pump suction and discharge lines with cutting tool.
   d. Remove mounting bolts from gearbox and mounting flanges.
   e. Remove LH_2 pump and clean lines.
   f. Remove gearbox/pump seals.

2. REPLACEMENT

   a. Install replacement gearbox/pump seals.
   b. Install replacement pump.
   c. Install mounting bolts in gearbox and mounting flanges.
   d. Braze pump suction and discharge lines.
   e. Remove brazing equipment and perform visual inspection.
   f. Connect electrical instrumentation.
   g. Replace gearbox lubrication oil.

3. RETEST

   a. Verify gearbox lubrication oil level.
   b. Pressurize APS hydrogen accumulators and on-orbit LH_2 tanks to 30 psia.
   c. Open pump isolation and suction valves.
   d. Perform bubble leak check on pump suction and discharge line brazed connections.
   e. Reduce system pressure to 19 psia.
   f. Close pump suction and isolation valve.
   g. Disconnect pressurization system.
   h. Connect cold-gas turbine drive ground support equipment.
   i. Activate cold-gas turbine drive gas.
   j. Verify pump speed instrumentation and lubrication system operation.
   k. Perform visual inspection for gearbox/pump seal leakage.
   l. Deactivate cold-gas turbine drive gas.
   m. Disconnect cold-gas turbine drive ground support equipment.

MAINTENANCE PROCEDURE

LRU (10) Orbiter LO_2 Pump

SYSTEM - Orbiter Auxiliary Propulsion

SUBSYSTEM - APS Propellant Conditioning

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 4 hours

PROCEDURE (Refer to Figure C-6)

1. REMOVAL

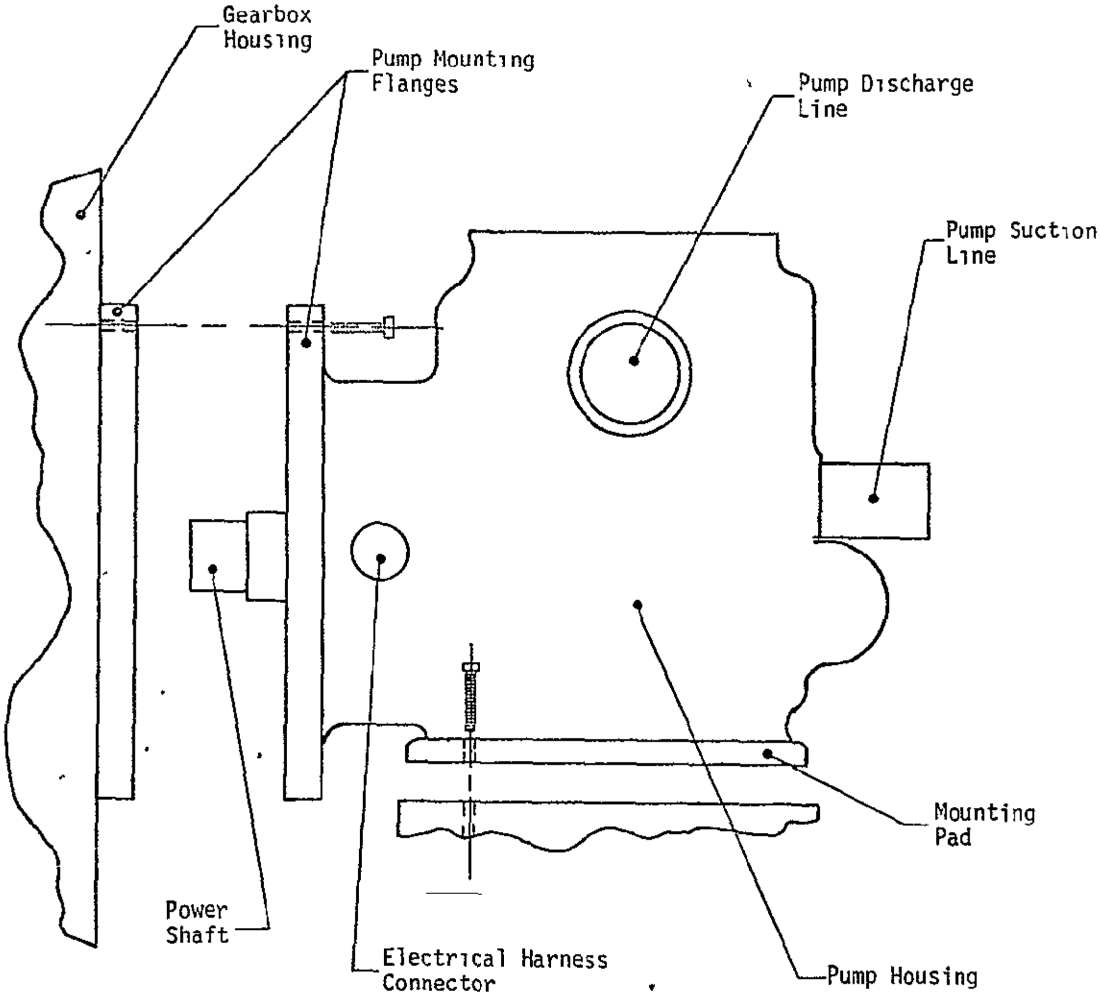
   a. Drain gearbox lubrication system.
   b. Disconnect electrical instrumentation.
   c. Cut brazed sleeves on pump suction and discharge lines with cutting tool.
   d. Remove mounting bolts from gearbox and mounting flanges.
   e. Remove LO_2 pump and clean lines.
   f. Remove gearbox/pump seals.

2. REPLACEMENT

   a. Install replacement gearbox/pump seals.
   b. Install replacement pump.
   c. Install mounting bolts in gearbox and mounting flanges.
   d. Braze pump suction and discharge lines.
   e. Remove brazing equipment and perform visual inspection.
   f. Connect electrical instrumentation.
   g. Replace gearbox lubrication oil.

3. RETEST

   a. Verify gearbox lubrication oil level.
   b. Pressure APS oxygen accumulators and on-orbit LO_2 tanks to 30 psia.
   c. Open pump isolation and suction valves.
   d. Perform bubble leak check on pump suction and discharge line brazed connections.
   e. Reduce system pressure to 19 psia.
   f. Close pump suction and isolation valves.
   g. Disconnect pressurization system.
   h. Connect cold-gas turbine drive ground support equipment.
   i. Actuate cold-gas turbine drive gas.
   j. Verify pump speed instrumentation and lubrication system operation.
   k. Perform visual inspection for gearbox pump seal leakage.
   l. Deactivate cold-gas turbine drive gas.
   m. Disconnect cold-gas turbine drive ground support equipment.



- Electrical harness includes pump speed instrumentation.
- Pump mounting flanges have removable seals.

Fig. C-6 Typical LH_2/LO_2 Pump Removal and Replacement

MAINTENANCE PROCEDURE

LRU (11) Orbiter LO_2 Heat Exchanger

SYSTEM - Orbiter Auxiliary Propulsion

SUBSYSTEM - APS Propellant Conditioning

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 2 hours

PROCEDURE (Refer to Figure C-7)

1. REMOVAL

   a. Disconnect electrical instrumentation.
   b. Cut brazed sleeves with cutting tool.
   c. Remove mounting bolts from turbine exhaust and overboard ducting flanges.
   d. Remove heat exchanger and clean lines.
   e. Remove seals from ducting flanges.

2. REPLACEMENT

   a. Install replacement ducting seals.
   b. Install replacement heat exchanger.
   c. Install mounting bolts in turbine exhaust and overboard ducting flanges.
   d. Braze heat exchanger inlet and outlet lines.
   e. Remove brazing equipment and perform visual inspection.
   f. Connect electrical instrumentation.

3. RETEST

   a. Pressurize APS oxygen accumulators and on-orbit LO_2 tanks to 30 psia
   b. Open LO_2 pump isolation and suction valves.
   c. Perform bubble leak check on heat exchanger inlet and outlet brazed connections (external leakage).
   d. Close LO_2 pump suction and isolation valves.
   e. Close turbine overboard dump valve*.
   f. Increase APS oxygen accumulator pressure to 1500 psia.

---

* This valve is required to allow pressurization of gas generator and turbine for leak checks and has not been identified in the DRM.

g. Open gas generator main GO_2 and isolation valves and pressurize gas generator, turbine, and heat exchanger to 1500 psia.

h. Monitor LO_2 pump discharge pressure (internal leakage) and perform bubble leak check on turbine exhaust and overboard ducting seals (external leakage).

i. Reduce accumulator pressure to 19 psia.

j. Close gas generator main GO_2 and isolation valves and open overboard dump valve.

k. Disconnect pressurization system.

MAINTENANCE PROCEDURE

LRU (12) Orbiter LH_2 Heat Exchanger

SYSTEM - Orbiter Auxiliary Propulsion

SUBSYSTEM - APS Propellant Conditioning

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 2 hours

PROCEDURE (Refer to Figure C-7)

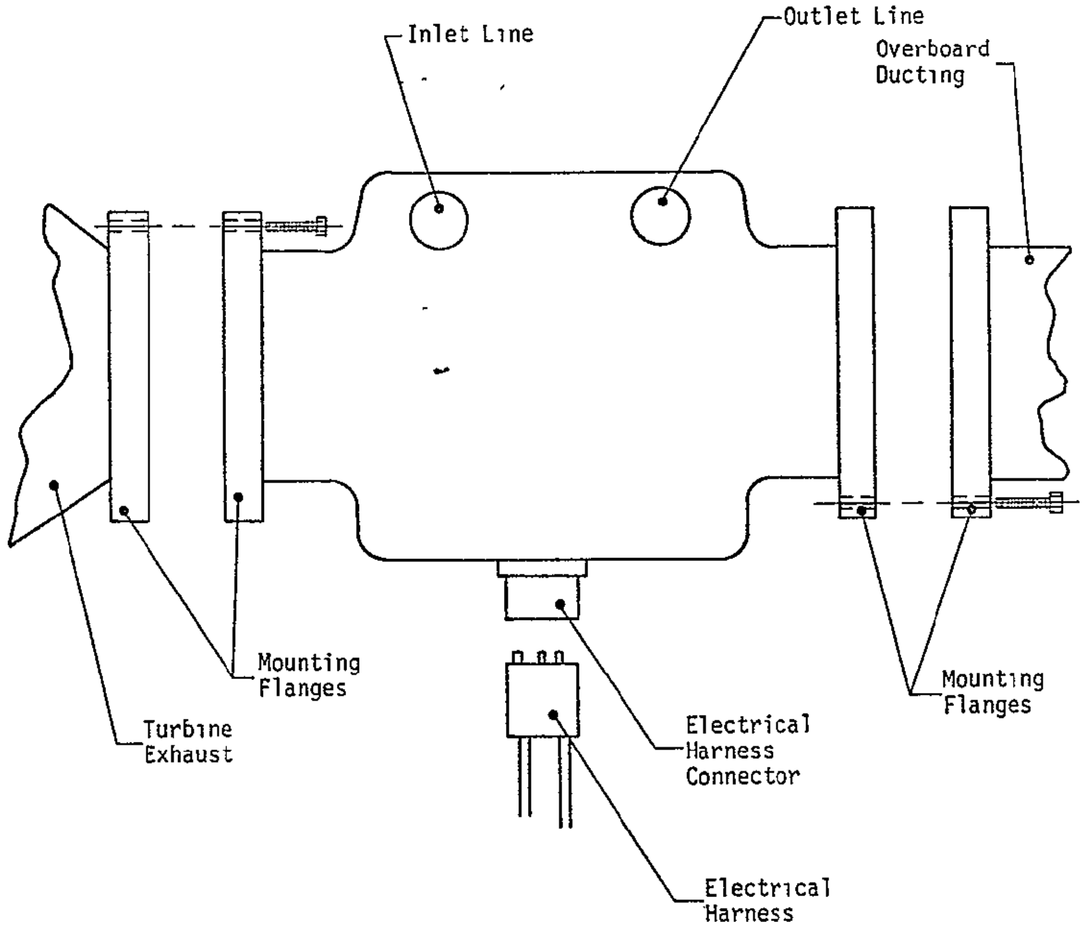
1. REMOVAL
   a. Disconnect electrical instrumentation.
   b. Cut brazed sleeves with cutting tool.
   c. Remove mounting bolts from turbine exhaust and overboard ducting flanges.
   d. Remove heat exchanger and clean lines.
   e. Remove seals from ducting flanges.

2. REPLACEMENT
   a. Install replacement ducting seals.
   b. Install replacement heat exchanger.
   c. Install mounting bolts in turbine exhaust and overboard ducting flanges.
   d. Braze heat exchanger inlet and outlet lines.
   e. Remove brazing equipment and perform visual inspection.
   f. Connect electrical instrumentation.

3. RETEST
   a. Pressurize APS hydrogen accumulators and on-orbit LH_2 tanks to 30 psia.
   b. Open LH_2 pump isolation and suction valves.
   c. Perform bubble leak check on heat exchanger inlet and outlet brazed connections (external leakage).
   d. Close LH_2 pump suction and isolation valves.
   e. Close turbine overboard dump valve*.
   f. Increase APS hydrogen accumulator pressure to 1500 psia
   g. Open gas generator main GH_2 and isolation valves and pressurize gas generator, turbine, and heat exchanger to 1500 psia.
   h. Monitor LH_2 pump discharge pressure (internal leakage) and perform bubble leak check on turbine exhaust and overboard ducting seals (external leakage).

* This valve is required to allow pressurization of gas generator and turbine for leak checks and has not been identified in the DRM.

i. Reduce accumulator pressure to 19 psia.
j. Close gas generator main GH_2 and isolation valves and open overboard dump valve.
k. Disconnect pressurization system.



- Electrical harness includes pressure and temperature instrumentation circuits.
- Flanges have removable seals.

Fig. C-7 Typical Orbiter LH_2, LO_2 Heat Exchanger Removal and Replacement

MAINTENANCE PROCEDURE

LRU (13) Orbiter Power Train Unit

SYSTEM - Orbiter Auxiliary Propulsion

SUBSYSTEM - APS Propellant Conditioning

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 6 hours

PROCEDURE (Refer to Figure C-7)

1. REMOVAL
   a. Drain gearbox lubrication system.
   b. Disconnect electrical harness.
   c. Remove mounting bolts from LH_2 and LO_2 pump mounting flanges, remove pumps and pump seal.
   d. Disconnect turbine and APU power shafts.
   e. Remove mounting bolts from mounting pads.
   f. Remove power train unit.

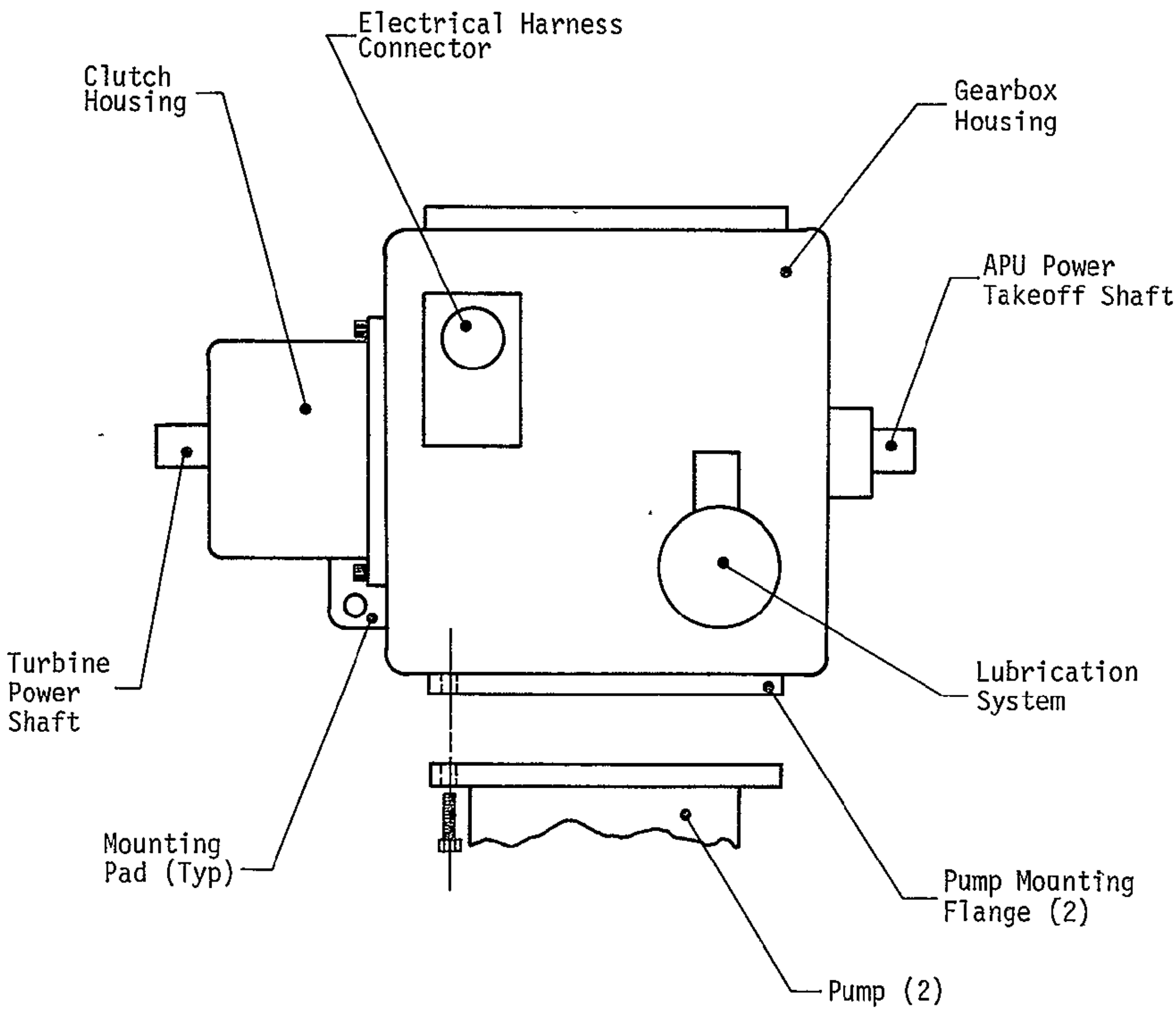
2. REPLACEMENT
   a. Install replacement power train unit.
   b. Install mounting bolts in mounting pads.
   c. Connect turbine and APU power shafts.
   d. Replace pump seals.
   e. Install LO_2 and LH_2 pumps and mounting bolts.
   f. Connect electrical harness.
   g. Replace gearbox lubrication system oil and perform visual inspection.

3. RETEST
   a. Verify gearbox lubrication system oil level.
   b. Connect cold-gas turbine drive ground support equipment
   c. Verify turbine overboard dump valve open*.
   d. Activate cold-gas turbine drive gas.
   e. Activate gearbox control and verify APU, LH_2 pump, and LO_2 pump operation.
   f. Verify lubrication system instrumentation and operation.
   g. Perform visual inspection for pump seal leakage.
   h. Deactivate cold-gas turbine drive gas.
   i. Disconnect cold-gas turbine drive ground support equipment.

---

* This valve is required to allow pressurization of gas generator and turbine for leak checks and has not been identified in the DRM.

Top View



- Electrical harness includes clutch and gearbox control and instrumentation circuits.
- Pump mounting flanges have removable seals.

Fig. C-8 Orbiter Power Train Unit Removal and Replacement

MAINTENANCE PROCEDURE

LRU (17) Orbiter LO_2 Pump Suction Valve Package

SYSTEM - Orbiter Auxiliary Propulsion

SUBSYSTEM - APS Propellant Conditioning

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 1 hour

PROCEDURE

1. REMOVAL
   a. Disconnect electrical control and instrumentation.
   b. Cut brazed sleeves with cutting tool.
   c. Remove valve package and clean suction lines.

2. REPLACEMENT
   a. Install replacement valve package and braze sleeves to suction lines.
   b. Remove brazing equipment and perform visual inspection.
   c. Connect electrical control and instrumentation.

3. RETEST
   a. Apply 28 VDC electrical activation signal to each solenoid valve and verify response with position indicator instrumentation.
   b. Close both solenoid valves.
   c. Connect helium pressurization line and pressurize on-orbit LO_2 tank to 30 psia.
   d. Monitor tank pressure for decay with:
      1) Suction valve closed, isolation valve open.
      2) Suction valve open, isolation valve closed.
   e. Perform bubble leak test on brazed joints with both valves open (external leakage).
   f. Reduce system pressure to 19 psia.
   g. Close pump suction and isolation valves.
   h. Disconnect pressurization system.

LRUs Airbreathing Propulsion System

This section of Appendix C contains the maintenance procedures for the Booster and Orbiter Airbreathing Propulsion Systems. The maintenance procedures for the LRUs within the turbofan engine are also included in this section.

MAINTENANCE PROCEDURE

LRU (1) Turbofan Engine

SYSTEM - Booster Airbreathing Propulsion

SUBSYSTEM - Turbofan Engine

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 6 hours

SPECIAL CONSIDERATIONS

A. New engine has experienced "hot firing" acceptance test.
B. Electrical, pneumatic and hydraulic connections are minimized.
C. A ferry mission will occur prior to launch so that engine can be fired after installation.

PROCEDURE (Refer to Figure C-9)

1. REMOVAL

PRECAUTION - Vent associated subsystems to ambient pressure.

a. Remove upper wing box panel (see following Figure).
b. Disconnect electrical, pneumatic and hydraulic connections.
c. Install engine removal ground support equipment.
d. Remove engine mounting brackets.
e. Raise engine from wing compartment with ground support equipment.
f. Secure electrical, pneumatic and hydraulic connections.

2. REPLACEMENT

a. Lower engine into wing compartment with ground support equipment.
b. Install engine mounting brackets.
c. Remove ground support equipment.
d. Make electrical, pneumatic and hydraulic connections.
e. Perform retest procedure below.
f. Install upper wing box panel.
g. Return system to secured state.

3. RETEST

a. Helium leak test fuel system connections. (Pressure Decay Test through Propellant Management System).
b. Electrical Continuity.
c. Perform engine start dry simulation test.

MAINTENANCE PROCEDURE

LRU (5) Cruise Tank Vent Disconnect Coupling

SYSTEM - Booster Airbreathing Propulsion

SUBSYSTEM - Propellant Management

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 3/4 hour

PROCEDURE

1. REMOVAL

   PRECAUTION - Vent subsystem to ambient pressure.

   a. Remove bolts from flanges.
   b. Remove sealing devices.
   c. Remove structural mounts.
   d. Remove coupling half.

2. REPLACEMENT

   a. Install sealing devices after cleaning seal surfaces.
   b. Make structural attachments.
   c. Install bolts and torque per specified value and sequence.
   d. Perform Retest Procedure specified below.
   e. Return system to secured state.

3. RETEST

   a. Leak test bolted flange connections by:

      1) Attaching GSE to newly installed coupling.
      2) Close tank vent valves
      3) Pressurize through GSE with 20 psia helium.
      4) Bubble test flanges for leaks.

MAINTENANCE PROCEDURE

LRU (6) Cruise Tank Fill Valve

SYSTEM - Booster Airbreathing Propulsion

SUBSYSTEM - Propellant Management

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 3/4 hour

PROCEDURE

1. REMOVAL

   PRECAUTION - Vent subsystem to ambient pressure.

   a. Remove electrical connections and secure wiring.
   b. Disconnect flange bolts and remove sealing devices.
   c. Remove valve.

2. REPLACEMENT

   a. Clean sealing surfaces as required.
   b. Install new valve and new sealing devices.
   c. Install flange bolts and torque to specified value and sequence.
   d. Perform retest described below.
   e. Return system to secured state.

3. RETEST

   a. Leak Test - Pressurize Cruise Tank with 20 psia He. Monitor Cruise Tank pressure for decay. (This leak tests the valve flange closest to the cruise tank). Open the Fill Valve and monitor Cruise Tank pressure for decay. (This leak tests the valve flange furthest from the tank).
   b. Electrical - During leak test verify valve positions and continuity.

MAINTENANCE PROCEDURE

LRU (7) Cruise Tank Fill Coupling

SYSTEM - Booster Airbreathing Propulsion

SUBSYSTEM - Propellant Management

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 3/4 hour

PROCEDURE

1. REMOVAL

PRECAUTION - Vent subsystem to ambient pressure.

a. Remove bolts from flanges.
b. Remove sealing devices.
c. Remove structural mounts.
d. Remove coupling half.

2. REPLACEMENT

a. Install sealing devices after cleaning sealing surfaces.
b. Make structural attachments.
c. Install bolts and torque per specified value and sequence.
d. Perform Retest Procedure specified below.
e. Return system to secured state.

3. RETEST

a. Leak test bolted flange connections by:

1) Attach helium supply to fill coupling.
2) Close fill valve.
3) Pressurize with 20 psia He.
4) Bubble test flanges for leaks.

MAINTENANCE PROCEDURE

LRU (8) Cruise Tank Pressurization Regulator Package

SYSTEM - Booster Airbreathing Propulsion

SUBSYSTEM - Pressurization

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 1 hour

PROCEDURE

1. REMOVAL

PRECAUTION - Vent associated subsystems to ambient pressure.

a. Remove electrical connections and secure wiring.
b. Cut brazed sleeves at notched section with cutting tool.
c. Remove welded assembly and clean remainder of sleeve from mating lines.

2. REPLACEMENT

a. Install welded assembly and perform brazing operation on sleeves.
b. Connect electrical wiring.
c. Perform Retest described below.
d. Return system to secured state.

3. RETEST

a. Leak Test - Load 1500 psia GH_2 into APS bottles. Open Cruise Tank vent valves. Open solenoid valve for the regulator package which was just installed. Perform bubble leak test on regulator.connections.

b. Electrical - Perform continuity check.
c. Functional - Close solenoid valve for the regulator package which was not replaced. Open solenoid valve for new installed regulator package. Close cruise tank vents. Close Fuel Distributing Valves. With 1500 psia GH_2 in APS bottles, verify Cruise Tank pressure at 20 ± 2 psia.

MAINTENANCE PROCEDURE

LRU (9) Cruise Tank Pressurization Valve Package

SYSTEM - Booster Airbreathing Propulsion

SUBSYSTEM - Pressurization

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 1 hour

PROCEDURE

1. REMOVAL

   PRECAUTION - Vent associated subsystems to ambient pressure.

   a. Remove electrical connections and secure wiring.
   b. Cut brazed sleeves at notched section with cutting tool.
   c. Remove welded assembly and clean remainder of sleeve from mating lines.

2. REPLACEMENT

   a. Install welded assembly and perform brazing operation on sleeves.
   b. Connect electrical wiring.
   c. Perform Retest described below.
   d. Return system to secured state.

3. RETEST

   a. Leak Test - Load 1500 psia GH_2 into APS bottles. Open Cruise Tank Vent valves. Open newly installed solenoid valves. Monitor Cruise Tank for pressure decay.
   b. Electrical - During leak test verify valve positions and continuity.

MAINTENANCE PROCEDURE

LRU (10) Pressurization Filter

SYSTEM - Booster Airbreathing Propulsion

SUBSYSTEM - Pressurization

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 3/4 hour

PROCEDURE

1. REMOVAL

   PRECAUTION - Vent associated subsystems to ambient pressure.

   a. Cut brazed sleeves at notched section with cutting tool.
   b. Remove welded assembly and clean remainder of sleeve from mating lines.

2. REPLACEMENT

   a. Install welded assembly and perform brazing operation on sleeve.
   b. Perform Retest described below.
   c. Return system to secured state.

3. RETEST

   a. Leak Test - Load 1500 psia GH_2 into APS bottles. Monitor APS bottles for decay. (This test will verify leakage integrity of brazed connections).

MAINTENANCE PROCEDURE

LRU (3) GH_2 Valve Package

LRU (5) GO_2 Valve Package

SYSTEM - Orbiter Airbreathing Propulsion

SUBSYSTEM - Propellant Management

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 1 hour

PROCEDURE

1. REMOVAL

   PRECAUTION - Vent associated subsystem to ambient pressure.

   a. Remove electrical connections and secure wiring.
   b. Cut brazed sleeves at notched section with cutting tool.
   c. Remove welded assembly and clean remainder of sleeve from mating lines.

2. REPLACEMENT

   a. Install new valve package and perform brazing operation on sleeves.
   b. Connect electrical wiring.
   c. Perform Retest described below.
   d. Return system to secured state.

3. RETEST

   a. Leak Test - Pressurize APS bottles with 1500 psia He. Monitor bottles for pressure decay. (This leak tests the upstream brazed sleeve connection). Open valves and monitor bottles for pressure decay. (This leak tests the downstream brazed sleeve connection).
   b. Electrical - During leak test verify valve positions.

MAINTENANCE PROCEDURE

LRU (4) Gas Generator Assembly

SYSTEM - Orbiter Airbreathing Propulsion

SUBSYSTEM - Propellant Management

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 2 hours

PROCEDURE

1. REMOVAL

   PRECAUTION - Vent associated subsystems to ambient pressure.

   a. Remove electrical connections and secure wiring.
   b. Disconnect bolts at turbopump inlet duct.
   c. Cut brazed sleeves at inlet/outlet ports with cutting tool.
   d. Remove gas generator assembly and clean remainder of brazed sleeve from mating lines.

2. REPLACEMENT

   a. Install new gas generator assembly and perform brazing operation on sleeves.
   b. Install new seal at turbopumps inlet duct and bolt flanges together using specified torque value and tightening sequence.
   c. Connect electrical wiring.
   d. Perform Retest described below.
   e. Return system to secured state.

3. RETEST

   a. Leak Test - Pressurize GO_2 APS bottles with 1500 psia He. Open GO_2 valves at inlet to gas generator assembly. Monitor for pressure decay at GO_2 bottles. (This leak tests the brazed sleeve connection at GO_2 valve and the turbopump inlet duct bolted flange). Vent GO_2 bottles and close GO_2 valve. Perform same procedure using GH_2 bottles and GH_2 inlet valves.
   b. Electrical - Apply electrical power and monitor current and voltage at igniter plug. During leak test verify GO_2 and GH_2 valve positions.

MAINTENANCE PROCEDURE

LRU (6) LH_2 Valve Package

SYSTEM - Orbiter Airbreathing Propulsion

SUBSYSTEM - Propellant Management

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 1 hour

PROCEDURE

1. REMOVAL

PRECAUTION - Vent associated subsystem to ambient pressure.

a. Remove electrical connections and secure wiring.
b. Cut brazed sleeves at notched section with cutting tool.
c. Remove welded assembly and clean remainder of sleeve from mating lines.

2. REPLACEMENT

a. Install new valve package and perform brazing operation on sleeves.
b. Connect electrical wiring.
c. Perform Retest described below.
d. Return system to secured state.

3. RETEST

a. Leak Test - Pressurize on-orbit LH_2 tanks with 20 psia He. Monitor tank pressure for decay. (This leak tests the upstream sleeve on the replaced LRU package). Open the solenoid valves on the replaced package and again monitor on-orbit LH_2 tanks for pressure decay. (This leak tests the downstream sleeve on the replaced LRU package).
b. Electrical - During leak test verify valve positions and continuity.

MAINTENANCE PROCEDURE

LRU (7) Turbopump Assembly

SYSTEM - Orbiter Airbreathing Propulsion

SUBSYSTEM - Propellant Management

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 2 hours

PROCEDURE

1. REMOVAL

PRECAUTION - Vent associated subsystems to ambient pressure.

a. Remove electrical connections and secure wiring.
b. Disconnect bolts at Gas Generator Assembly outlet duct.
c. Cut brazed sleeves at suction and discharge sides of the pump with cutting tool.
d. Remove turbopump assembly and clean remainder of brazed sleeves from mating lines.

2. REPLACEMENT

a. Install new turbopump assembly and perform brazing operation on sleeves.
b. Install new seal at turbopump inlet duct and bolt flanges together using specified torque value and tightening sequence.
c. Connect electrical wiring.
d. Perform retest described below.
e. Return system to secured state.

3. RETEST

a. Leak Test - Pressurize GO_2 APS bottles with 1500 psia He. Open GO_2 valves at inlet to Gas Generator Assembly. Monitor for pressure decay at GO_2 bottles. (This leak tests the seal at the turbopump inlet duct). Vent GO_2 APS bottles and close GO_2 valves. Pressurize on-orbit LH_2 tanks with 20 psia He. Open LH_2 valves at inlet to pump. Monitor LH_2 tank pressure for decay. (This leak tests the brazed connections at suction and discharge sides of the pump).
b. Electrical - Verify valve positions during leak test.

MAINTENANCE PROCEDURE

LRU (8) Check Valve Package

SYSTEM - Orbiter Airbreathing Propulsion

SUBSYSTEM - Propellant Management

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 3/4 hour

PROCEDURE

1. REMOVAL

   PRECAUTION - Vent associated subsystems to ambient pressure.

   a. Cut brazed sleeves at notched section with cutting tool.
   b. Remove valve package and clean remainder of sleeve from mating lines.

2. REPLACEMENT

   a. Install new valve package and perform brazing operation on sleeves.
   b. Perform Retest described below.
   c. Return system to secured state.

3. RETEST

   a. Leak Test - Pressurize on-orbit LH_2 tanks with 20 psia He. Open LH_2 valves at inlet to turbopump. Monitor LH_2 tank pressure for decay. (This technique will simultaneously leak check both the upstream and downstream brazed connections.

MAINTENANCE PROCEDURE

LRU (2) Fuel Control Assembly

SYSTEM - Booster/Orbiter Airbreathing Propulsion

SUBSYSTEM - Turbofan Engine

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 3 hours

PROCEDURE

1. REMOVAL

   PRECAUTION - Vent associated subsystems to ambient pressure.

   a. Remove electrical connections to component modular package.
   b. Remove electrical connections to electronic controller.
   c. Disconnect plumbing connections to component modular package and remove the package.
   d. Remove electronic controller.

2. REPLACEMENT

   a. Install new, preprogrammed, Electronic Controller.
   b. Install component modular package and connect plumbing lines.
   c. Make electrical connections.
   d. Perform Retest described below.
   e. Return system to secured state.

3. RETEST

   a. Leak Test - Pressurize Propellant Management Subsystem with helium. Open valves in Fuel Control Assembly and bubble check plumbing connections.
   b. Electrical - Perform Dry Engine start simulation. Verify valve functions and Electronic Controller performance.

MAINTENANCE PROCEDURE

LRU (3) Electronic Controller

SYSTEM - Booster/Orbiter Airbreathing Propulsion

SUBSYSTEM - Turbofan Engine

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 2 hours

PROCEDURE

1. REMOVAL

   PRECAUTION - Vent associated subsystems to ambient pressure.

   a. Remove electrical connections.
   b. Remove mounting hardware.
   c. Remove electronic controller.

2. REPLACEMENT

   a. Install new, preprogrammed, Electronic Controller.
   b. Make electrical connections.
   c. Perform Retest described below.
   d. Return system to secured state.

3. RETEST

   a. Electrical - Perform Dry Engine start simulation. Verify Electronic Controller performance.

MAINTENANCE PROCEDURE

LRU (4) Scavenge Pump

SYSTEM - Booster/Orbiter Airbreathing Propulsion

SUBSYSTEM - Turbofan Engine

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 3 hours

PROCEDURES

1. REMOVAL

PRECAUTION - Vent pressure from Lubrication Assembly.

a. Remove electrical connections and secure wiring.
b. Drain lube oil from engine.
c. Cut brazed sleeves at notched section with cutting tool.
d. Remove modular package and clean remainder of sleeve from mating lines.

2. REPLACEMENT

a. Install new modular package and perform brazing operation on sleeves.
b. Connect electrical wiring.
c. Flush oil system.
d. Refill oil system.
e. Perform retest described below.
f. Return system to secured state.

3. RETEST

a. Leak Test - Function Lubrication Assembly and monitor lube oil pressure for decay. Perform visual inspection of connection for leaks during functional test.
b. Electrical - Verify electrical connections and functions during leak test.

MAINTENANCE PROCEDURE

LRU (5) Oil Boost Pump or

LRU (6) Oil Pressure Pump

SYSTEM - Booster/Orbiter Airbreathing Propulsion

SUBSYSTEM - Turbofan Engine

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 2 hours

PROCEDURES

1. REMOVAL

   PRECAUTION - Vent pressure from Lubrication Assembly.

   a. Remove electrical connections and secure wiring.
   b. Drain lube oil from engine.
   c. Cut brazed sleeves at notched section with cutting tool.
   d. Remove pump and clean remainder of sleeve from mating lines.

2. REPLACEMENT

   a. Install new pump and perform brazing operation on sleeves.
   b. Connect electrical wiring.
   c. Flush oil system.
   d. Refill oil system.
   e. Perform retest described below.
   f. Return system to secured state.

3. RETEST

   a. Leak Test - Function Lubrication Assembly and monitor lube oil pressure for decay. Perform visual inspection of connections for leaks during functional test.
   b. Electrical - Verify electrical connections and functions during leak test.

MAINTENANCE PROCEDURE

LRU (7) Oil Strainer

SYSTEM - Booster/Orbiter Airbreathing Propulsion

SUBSYSTEM - Turbofan Engine

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 1 1/2 hours

PROCEDURE

1. REMOVAL

PRECAUTION - Vent pressure from Lubrication Assembly.

a. Drain lube oil from engine.
b. Disconnect threaded fittings and remove oil strainer.
c. Visually inspect sealing surfaces for damage (if damaged refinish surface as specified by procedures).

2. REPLACEMENT

a. Install new oil strainer and torque threaded fittings as specified.
b. Flush oil system.
c. Refill oil system.
d. Perform retest described below.
e. Return system to secured state.

3. RETEST

a. Leak Test - Function Lubrication Assembly and monitor lube oil pressure for decay. Perform visual inspection of connections for leaks during functional tests.
b. Electrical - Verify electrical connections and functions during leak test.

MAINTENANCE PROCEDURE

LRU (8) Boost Pump Relief Valve or

LRU (9) Boost Pump Regulating Valve or

LRU (10) Main Pressure Regulating Valve

SYSTEM - Booster/Orbiter Airbreathing Propulsion

SUBSYSTEM - Turbofan Engine

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 2 hours

PROCEDURE

1. REMOVAL

   PRECAUTION - Vent pressure from Lubrication Assembly.

   a. Remove electrical connections and secure wiring.
   b. Drain lube oil from engine.
   c. Cut brazed sleeves at notched section with cutting tool.
   d. Remove valve and clean remainder of sleeve from mating lines.

2. REPLACEMENT

   a. Install new valve and perform brazing operation on sleeves.
   b. Connect electrical wiring.
   c. Flush oil system.
   d. Refill oil system.
   e. Perform retest described below.
   f. Return system to secured state.

3. RETEST

   a. Leak Test - Function Lubrication Assembly and monitor lube oil pressure for decay. Perform visual inspection of connections for leaks during functional test.
   b. Electrical - Verify electrical connections and functions during leak test.

MAINTENANCE PROCEDURE

LRU (11) Zero-G Lube Pressure System

SYSTEM - Orbiter Airbreathing Propulsion

SUBSYSTEM - Turbofan Engine

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 3 hours

PROCEDURE

1. REMOVAL

PRECAUTION - Vent pressure in Lubrication Assembly to ambient.

a. Remove electrical connections and secure wiring.
b. Drain lube oil from engine.
c. Cut brazed sleeves at notched section with cutting tool.
d. Remove modular package and clean remainder of sleeve from mating lines.

2. REPLACEMENT

a. Install new modular package and perform brazing operation on sleeves.
b. Connect electrical wiring.
c. Flush oil system.
d. Refill oil system.
e. Perform retest described below.
f. Return system to secured state.

3. RETEST

a. Leak Test - Pressurize gas container in zero-g lube pressure system with gaseous nitrogen. Function the zero-g pressure system and monitor lube oil pressure for decay.
b. Electrical - Verify zero-g lube system is functioning.

MAINTENANCE PROCEDURE

LRU (12) Ignition Exciter

SYSTEM - Booster/Orbiter Airbreathing Propulsion

SUBSYSTEM - Turbofan Engine

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 1 hour

PROCEDURE

1. REMOVAL

   a. Remove electrical connections from ignition compositor and ignition exciter.
   b. Remove ignition compositor from ignition exciter.
   c. Remove ignition exciter.

2. REPLACEMENT

   a. Install new ignition exciter.
   b. Re-install ignition compositor on ignition exciter.
   c. Install electrical connections.
   d. Perform retest described below.

3. RETEST

   a. Electrical - Apply electrical power to ignition exciter. Monitor input voltage and current to exciter; output voltage and current from ignition compositor. Visually evaluate spark at ignition plug.

MAINTENANCE PROCEDURE

LRU (13) Ignition Compositor

SYSTEM - Booster/Orbiter Airbreathing Propulsion

SUBSYSTEM - Turbofan Engine

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 1 hour

PROCEDURE

1. REMOVAL

   a. Remove electrical connections from ignition compositor and ignition exciter.
   b. Remove ignition compositor from ignition exciter.

2. REPLACEMENT

   a. Install new ignition compositor.
   b. Install electrical connections.
   c. Perform retest described below.

3. RETEST

   a. Electrical - Apply electrical power to ignition exciter. Monitor input voltage and current to exciter; output voltage and current from ignition compositor. Visually evaluate spark at ignition plug.

MAINTENANCE PROCEDURE

LRU (14) Ignition Plug

SYSTEM - Booster/Orbiter Airbreathing Propulsion

SUBSYSTEM - Turbofan Engine

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 1 hour

PROCEDURE

1. REMOVAL

   a. Remove electrical connections.
   b. Remove ignition plug from engine power assembly burner.

2. REPLACEMENT

   a. Install new ignition plug.
   b. Install electrical connections.
   c. Perform retest described below.

3. RETEST

   a. Electrical - Apply electrical power to ignition exciter. Monitor input voltage and current to exciter; output voltage and current from ignition compositor. Visually evaluate spark at ignition plug.

MAINTENANCE PROCEDURE

LRU (15) Solid Start Cartridge

SYSTEM - Booster/Orbiter Airbreathing Propulsion

SUBSYSTEM - Turbofan Engine

ASSEMBLY - N/A

COMPONENT - N/A

TASK TIME - 1 hour

PROCEDURE

1. REMOVAL

   PRECAUTION - Remove Vehicle Electrical Power prior to Start Cartridge Removal.

   a. Remove electrical connections.
   b. Remove cartridge.

2. REPLACEMENT

   a. Install new start cartridge.
   b. Install electrical connections.
   c. Reconnect vehicle electrical power.
   d. Perform retest described below.

3. RETEST

   a. Electrical - Apply electrical power to ignition exciter. Monitor input voltage and current to exciter; output voltage and current from ignition compositor. Visually evaluate spark at ignition plug.

APPENDIX D - CHECKOUT AND MONITORING REQUIREMENTS ANALYSIS

APPENDIX D

CHECKOUT AND MONITORING
REQUIREMENTS ANALYSIS

This appendix replaces the Checkout and Monitoring Requirements Analysis, Appendix D of MCR-70-274 (Issue 1), and MCR-70-306 (Issue 3). A conversion has been made from a subsystem-by-subsystem analysis of the orbiter stage to a detailed phase-by-phase analysis to improve the continuity of the previous analysis and to include GSE requirements and the detailed measurement requirements. The result is a step-by-step sequence for a nominal mission, including the values expected for a given measurement at a given time, and justification for the required measurements.

This task was accomplished by taking the previous analysis and molding the activities of each subsystem during a given phase into a cohesive phase analysis. This phase analysis was then evaluated against the subsystems requirements documentation. This procedure was followed through each mission phase. Finally, the detailed operations of the tasks that were indicated in the phase-by-phase analysis were added.

Glossary of Symbols:

ELEMENTS

V = valve
L = line
E.C. = engine controller
T.F. = turbofan
T.R. = thruster
T.C. = thrust chamber
FCA = fuel control assembly
LA = lube assembly
G = gas generator
PT = power train
TP = turbopump
FM = flowmeter
FH = fuel heater
H = heat exchanger
C = coupling
T = tank
GOV = LO_2 valve
GFV = LH_2 valve
EFV = engine fuel valve
IGN = ignition
U = turbine
SC = start cartridge
CL = clutch
P = pump
FD = flame detector
COMP = compartment

USES

R = readiness
S = status
M = monitor
C = control
C/O = checkout

This page not used.

ORBITER

I. FERRY PREFLIGHT

1. Connect the Ground Power GSE.
2. Power up OCMS.
3. Perform an OCMS self-check, including engine controllers.
4. Power up all propulsion systems.
   a) Make the following MPS readiness checks.

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	4	V-1	LOIV-1	1	R	Closed
		V-2	LOIV-2			
		V-3	LOVV-1			
		V-4	LOVV-2			
		V-5	LOVV-3			
		V-6	LOVV-4			
		V-7	LOFV-1			
		V-8	LFIV-1			
		V-9	LFIV-2			
		V-10	LFTVV-1			
		V-11	LFTVV-2			
		V-12	LFTVV-3			
		V-13	LFTVV-4			
		V-14	LFFV-1			
		V-19	LOPCV-1			
		V-20	LOPCV-2			
		V-21	LFPCV-1			
		V-22	LFPCV-2			
		V-23	LOIV-3			
		V-24	LOTVV-1			
		V-25	LOTVV-2			
		V-26	LFIV-3			
		V-27	LFIV-4			
		V-28	LFTVV-5			
		V-29	LFTVV-6			
		V-30	LFTVV-7			
		V-31	LFTVV-8			
		V-32	LOPV-1			
		V-33	LOPV-2			
		V-34	LFPV-1			
		V-35	LFPV-2			
		C-1	LOFC-1			
		C-2	LHC-1,2			
		C-3	LFTVC-1			
		C-4	LHC-3,4			
		C-5	LFFC-1			
F.P.	4	C-6	LHC-5,6	1	R	Closed

FERRY PREFLIGHT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	4	C-8	LHC-7,8	1	R	Closed
		C-11	LFVC-1			Closed
		T-3	PFT-1			19 PSIA
		T-5	PfT-2			
		T-6	PfT-3			
		T-1	PoT-1			
		T-2	PoT-2			
		T-4	PoT-3			
		L-17	PoL-2			
		L-20	PfL-1			
		L-21	PfL-4			
		C-5/V-14	PfF-1			
		C-1/V-7	PoF-1			
		L-8	PfS-1			
		L-9	PfS-2			
		L-3	PoS-1			
		L-4	PoS-2			19 PSIA
		T-4	QoT-7			UNC
		T-4	QoT-8			
		T-4	QoT-9			
		T-5	QfT-4			
		T-5	QfT-5			
		T-5	QfT-6			
		T-6	QfT-7			
		T-6	QfT-8			
		T-6	QfT-9			UNC
		T-5	TfT-2			AMBIENT
		T-6	TfT-3			
		T-4	ToT-3			
		L-20	TfL-1			
		L-21	TfL-4			
			TfL-5			
		L-17	ToL-2			
F.P.	4		ToL-4	1	R	AMBIENT

b) Perform main engine readiness checks. (Include Gimbal Locks & Ign.)

c) Verify all main engine covers installed.

Make the following APS readiness checks.

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	5		PoL-8	1	R	19 PSIA
			PoL-9			
			PfL-9			
			PfL-10			19 PSIA
		T.C.-(1-37)	LBIV-(1-37)	1/valve=37		Closed
		T.C.-(1-37)	LMBV-(1-37)			
		T.C.-(1-37)	LIOV-(1-37)	1/valve=37		Closed
F.P.	5	T.C.-(1-37)	VII-(1-37)	1/T.C.=37	R	OV
F.P.	5	T.C.-(1-37)	LIFV-(1-37)	1/valve=37		Closed

FERRY PREFLIGHT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	5	V-36	LOPV-3	1	R	Closed
		V-37	LOPV-4			
		V-38	LOPV-5			
		V-39	LOPV-6			
		V-40	LFPV-3			
		V-41	LFPV-4			
		V-42	LFPV-5			
		V-43	LFPV-6			
		C-9	LOFC-2			
		C-10	LFFC-2			
		V-44	LOFV-2			
		V-70	LFFV-2			Closed
		T-8	PoT-4			19 PSIA
		T-9	PoT-5			
		T-10	PfT-4			
		T-11	PfT-5			19 PSIA
		T-8	ToT-4			AMBIENT
		T-9	ToT-5			
		T-10	TfT-4			
		T-11	TfT-5			AMBIENT
		GOV-1	LGOV-1			Closed
		GOV-1	LGOV-1I			
		GOV-2	LGOV-2			
		GOV-2	LGOV-2I			
		GOV-3	LGOV-3			
		GOV-3	LGOV-3I			
		GFV-1	LGFV-1			
		GFV-1	LGFV-1I			
		GFV-2	LGFV-2			
		GFV-2	LGFV-2I			
		GFV-3	LGFV-3			
		GFV-3	LGFV-3I			
		V-52	LLIV-1			
		V-52	LPSV-1			
		V-53	LLIV-2			
		V-53	LPSV-2			
		V-54	LLIV-3			
		V-54	LPSV-3			
		V-55	LFIV-1			
		V-55	LPSV-4			
		V-56	LFIV-2			
		V-56	LPSV-5			
		V-57	LFIV-3			
		V-57	LPSV-6			Closed
		G-1	VII-38			OV
		G-2	VII-39			OV
F.P.	5	G-3	VII-40	1	R	OV

FERRY PREFLIGHT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	5	G-1	LIOV-38	1	R	Closed
		G-1	LIFV-38			
		G-2	LIOV-39			
		G-2	LIFV-39			
		G-3	LIOV-40			
F.P.	5	G-3	LIFV-40	1	R	Closed

Visually verify that all RCS and OMS protective covers are installed.

Request vehicle to close all RCS thermal protective doors and confirm.

Perform the following A/B readiness checks.

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	6	GFV-4	LGFV-4I	1	R	Closed
		GFV-4	LGFV-4			
		GFV-5	LGFV-5I			
		GFV-5	LGFV-5			
		GFV-6	LGFV-6I			
		GFV-6	LGFV-6			
		GOV-4	LGOV-4I			
		GOV-4	LGOV-4			
		GOV-5	LGOV-5I			
		GOV-5	LGOV-5			
		GOV-6	LGOV-6I			
		GOV-6	LGOV-6			
		V-58	LFIV-4			
		V-59	LPSV-7			
		V-60	LFIV-5			
		V-61	LPSV-8			
		V-62	LFIV-6			
		V-63	LPSV-9			
		EFV-1	LEFV-1			
		EFV-2	LEFV-2			
		EFV-3	LEFV-3			
		EFV-4	LEFV-4			
		EFV-5	LEFV-5			
		EFV-6	LEFV-6			
		EFV-7	LEFV-7			
		EFV-8	LEFV-8			
		EFV-9	LEFV-9			
		EFV-10	LEFV-10			
		EFV-11	LEFV-11			
		EFV-12	LEFV-12			Closed
			PfL-11			19 PSIA
			PfL-12			
F.P.	6		PfL-13	1	R	19 PSIA

A/B E.C. - 1,2,3 perform the following readiness checks.

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	7	FCA-1	LFIVA/B-1	1	R	Closed
F.P.	7	FCA-1	LCPRV-1	1	R	Closed

FERRY PREFLIGHT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	7	FCA-1	LSPV-1	1	R	Closed
		IGN-1	VIIA/B-1			OVDC
		FCA-2	LFIVA/B-2			Closed
		FCA-2	LCPRV-2			
		FCA-2	LSPV-2			Closed
		IGN-2	VIIA/B-2			OVDC
		FCA-3	LFIVA/B-3			Closed
		FCA-3	LCPRV-3			
		FCA-3	LSPV-3			Closed
F.P.	7	IGN-3	VIIA/B-3	1	R	OVDC

Verify that the turbofan engine cradles are lowered and locked.

Verify that all turbofan engine covers have been removed.

LOAD

Connect the Propellant Servicing and Pressurization GSE to the appropriate couplings and perform the following status checks:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	7	C-1	LOFC-1	1	S	Open
		C-2	LHC-1			
		C-2	LHC-2			
		C-5	LFFC-1			
		C-8	LHC-7			
		C-8	LHC-8			
		C-9	LOFC-2			
		C-10	LFFC-2			
F.P.	7	C-11	LFVC-1	1	S	Open

Open the following valves and verify position.

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	8	V-7	LOFV-1	1	S	Open
		V-23	LOIV-3			
		V-24	LOTVV-1			
F.P.	8	V-25	LOTVV-2	1	S	Open

Command LOX to slow transfer mode.

Verify operation by checking;

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	9	L-17	ToL-2	1	S	$<200^{o}$R

When

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	10	T-4	QoT-7	10/Sec	C	Covered

Command LOX helium recirculation on and LOX transfer to fast fill.

When

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	11	T-4	QoT-8	10/Sec	C	Covered

FERRY PREFLIGHT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE

Command LOX transfer to slow fill, and terminate helium recirculation.

When

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	12	T-4	QoT-9	10/Sec	C	Covered

Command LOX transfer to mode hold.

Verify the following:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	13	T-4	ToT-3	1	S	164±3°R
↓	↓	L-17	ToL-2	↓	↓	164±3°R
		L-17	PoL-2			
		L-3	ToS-1			164±3°R
		L-4	ToS-2			164±3°R
		L-3	PoS-1			
		L-4	PoS-2			
F.P.	13	L-7	PgRL-1	1	S	

Check for leakage with scan cameras.

Open V-44; check

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	14	V-44	LOFV-2	1	S	Open

Off-Load the stored helium in T-8 and T-9

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	15	T-8	PoT-4	1/Sec	S	14.7 PSIA
F.P.	15	T-9	PoT-5	1/Sec	S	14.7 PSIA

Open V-70; check

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	16	V-70	LFFV-2	1	S	Open

Off-Load the stored helium in T-10 and T-11

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	17	T-10	PfT-4	1/Sec	S	14.7 PSIA
F.P.	17	T-11	PfT-5	1/Sec	S	14.7 PSIA

Load T-8 and T-9 with GO2.

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	18	T-8	PoT-6	1/Sec	C	1500 PSIA
↓	↓	T-8	ToT-4	↓	↓	
		T-9	PoT-7			1500 PSIA
F.P.	18	T-9	ToT-5	1/Sec	C	

Compute accumulator quantity and send stop signal to the GSE at full load.

Close V-44; check

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	19	V-44	LOEV-2	1	S	Closed

FERRY PREFLIGHT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
Monitor						
F.P.	20	T-8	PoT-6	1/Sec	M	1500 PSIA
↓	↓	T-8	ToT-4	↓	↓	
		T-9	PoT-7			1500 PSIA
F.P.	20	T-9	ToT-5	1/Sec	M	
for decay.						
Load T-10 and T-11 with GH2.						
F.P.	21	T-10	PfT-6	1/Sec	C	1500 PSIA
↓	↓	T-10	TfT-4	↓	↓	
		T-11	PfT-7			1500 PSIA
F.P.	21	T-11	TfT-5	1/Sec	C	
Compute accumulator quantity and send stop signal to GSE at full load.						
Close V-70; check						
F.P.	22	V-70	LFFV-2	1	S	Closed
Monitor.						
F.P.	23	T-10	PfT-6	1/Sec	M	1500 PSIA
↓	↓	T-10	TfT-4	↓	↓	
		T-11	PfT-7			1500 PSIA
F.P.	23	T-11	TfT-5	1/Sec	M	
for decay.						
Reverify						
F.P.	24		PoL-8	1	S	19 PSIA
↓	↓		PoL-9	↓	↓	↓
			PfL-9			
F.P.	24		PfL-10	1	S	19 PSIA
Command open; verify						
F.P.	25	V-28	LFTVV-5	1	S	Open
↓	↓	V-29	LFTVV-6	↓	↓	↓
		V-30	LFTVV-7			
F.P.	25	V-31	LFTVV-8	1	S	Open
Command open; verify						
F.P.	26	V-27	LFIV-4	1	S	Open
↓	↓	V-14	LFFV-1	↓	↓	↓
F.P.	26	V-26	LFIV-3	1	S	Open

FERRY PREFLIGHT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE

Commence slow fuel transfer to T-5 and T-6.

Verify operation by checking;

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	27	L-20	TfL-1	1	S	<50°R
↓	↓	L-21	TfL-4	↓	↓	<50°R
F.P.	27		TfL-5	1	S	<50°R

When both

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	28	T-5	QfT-4	10/Sec	C	Covered
F.P.	28	T-6	QfT-7	10/Sec	C	Covered

Command fuel transfer to fast fill

When

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	29	T-5	QfT-5	10/Sec	C	Covered

or,

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	30	T-6	QfT-8	10/Sec	C	Covered

Command fuel transfer to slow fill.

When

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	31	T-5	QfT-6	10/Sec	C	Covered

Or,

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	32	T-6	QfT-9	10/Sec	C	Covered

Command fuel transfer to mode hold when the other one covers,

or TBD seconds after the first one covers.

Verify no leakage with compartment detectors.

Verify safe condition with compartment fire detectors.

Verify;

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	33	T-5	TfT-2	1	S	36-40°R
↓	↓	T-6	TfT-3	↓	↓	↓
		L-20	TfL-1			
		L-21	TfL-4			
		L-8	TfS-1			
		L-9	TfS-2			36-40°R
		L-8	PfS-1			
F.P.	33	L-9	PfS-2	1	S	

FERRY PREFLIGHT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
Command and verify:						
F.P.	34	V-14	LFFV-1	1	S	Closed
If						
F.P.	35	T-4	QoT-9	1	S	Uncovered
Command LOX transfer to slow fill.						
When						
F.P.	36	T-4	QoT-9	10/sec	C	Covered
Command LOX transfer to stop.						
Command and verify;						
F.P.	37	V-7	LOFV-1	1	S	Closed
If						
F.P.	38	T-5	QfT-6	1	S	Uncovered
and/or						
F.P.	39	T-6	QfT-9	1	S	Uncovered
Command and verify						
F.P.	40	V-14	LFFV-1	1	R	Open
Command fuel transfer to slow fill.						
When						
F.P.	41	T-5	QfT-6	10/sec	C	Covered
or						
F.P.	42	T-6	QfT-9	10/sec	C	covered
Command fuel transfer to stop when the other covers, or TBD seconds after the first one covers.						
Command and verify:						
F.P.	43	V-14	LFFV-1	1	S	Closed

FERRY PREFLIGHT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
Command and verify;						
F.P.	44	V-24	LOTVV-1	1	S	Closed
		V-25	LOTVV-2			
		V-28	LFTVV-5			
		V-29	LFTVV-6			
		V-30	LFTVV-7			
F.P.	44	V-31	LFTVV-8	1	S	Closed
Pressurization						
Verify						
F.P.	45	T-8	PoT-6	1	R	1500 PSIA
		T-9	PoT-7			1500 PSIA
F.P.	45	T-4	PoT-3	1	R	<30 PSIA
Command and verify;						
F.P.	46	V-33	LOPV-2	1	S	Open
Verify						
F.P.	47	T-4	PoT-3	1	S	35-40 PSIA
Command and verify;						
F.P.	48	V-33	LOPV-2	1	S	Closed
Command and verify;						
F.P.	49	V-24	LOTVV-1	1	S	Open
F.P.	49	V-25	LOTVV-2	1	S	Open
Verify;						
F.P.	50	T-4	PoT-3	1	S	Ambient
Command and verify;						
F.P.	51	V-24	LOTVV-1	1	S	Closed
F.P.	51	V-25	LOTVV-2	1	S	Closed
Command and verify;						
F.P.	52	V-32	LOPV-1	1	S	Open
verify;						
F.P.	53	T-4	PoT-3	1	S	35-40 PSIA

FERRY PREFLIGHT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
Command and verify;						
F.P.	54	V-32	LOPV-1	1	S	Closed
Verify;						
F.P.	55	T-10	PfT-6	1	S	1500 PSIA
↓	↓	T-11	PfT-7	↓	↓	1500 PSIA
↓	↓	T-5	PfT-2	↓	↓	<30 PSIA
F.P.	55	T-6	PfT-3	1	S	<30 PSIA
Command and verify;						
F.P.	56	V-35	LFPV-2	1	S	Open
Verify:						
F.P.	57	T-5	PfT-2	1	S	35-40 PSIA
F.P.	57	T-6	PfT-3	1	S	35-40 PSIA
Command and verify;						
F.P.	58	V-35	LFPV-2	1	S	Closed
Command and verify;						
F.P.	59	V-28	LFTVV-5	1	S	Open
↓	↓	V-29	LFTVV-6	↓	↓	↓
↓	↓	V-30	LFTVV-7	↓	↓	↓
F.P.	59	V-31	LFTVV-8	1	S	Open
Verify:						
F.P.	60	T-5	PfT-2	1	S	Ambient
F.P.	60	T-6	PfT-3	1	S	Ambient
Command and verify;						
F.P.	61	V-28	LFTVV-5	1	S	Closed
↓	↓	V-29	LFTVV-6	↓	↓	↓
↓	↓	V-30	LFTVV-7	↓	↓	↓
F.P.	61	V-31	LFTVV-8	1	S	Closed
Command & verify;						
F.P.	62	V-34	LFPV-1	1	S	Open
Verify;						
F.P.	63	T-5	PfT-2	1	S	35-40 PSIA
F.P.	63	T-6	PfT-3	1	S	35-40 PSIA

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FERRY PREFLIGHT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
Command and verify;						
F.P.	64	V-34	LFPV-1	1	S	Closed
Monitor:						
F.P.	65	T-4	PoT-3	1/Sec	S	35-40 PSIA
↓	↓	T-5	PfT-2	↓	↓	↓
F.P.	65	T-6	PfT-3	1/Sec	S	35-40 PSIA
For ____ minutes for decay						
Command and Verify;						
F.P.	66	V-32	LOPV-1	1	S	Open
↓	↓	V-33	LOPV-2	↓	↓	↓
↓	↓	V-34	LFPV-1	↓	↓	↓
F.P.	66	V-35	LFPV-2	1	S	Open
Retract and verify;						
F.P.	67	C-1	LOFC-1	1	S	Closed
↓	↓	C-2	LHC-1	↓	↓	↓
↓	↓	C-2	LHC-2	↓	↓	↓
↓	↓	C-5	LFFC-1	↓	↓	↓
↓	↓	C-8	LHC-7	↓	↓	↓
↓	↓	C-8	LHC-8	↓	↓	↓
↓	↓	C-9	LOFC-2	↓	↓	↓
↓	↓	C-10	LFFC-2	↓	↓	↓
F.P.	67	C-11	LFVC-1	1	S	Closed
Commence;						
F.P.	68	T-8	PoT-6	1/Sec	M,C	1500 PSIA
↓	↓	T-8	ToT-4	↓	↓	
↓	↓	T-9	PoT-7	↓	↓	1500 PSIA
↓	↓	T-9	ToT-5	↓	↓	
↓	↓	T-10	PfT-6	↓	↓	1500 PSIA
↓	↓	T-10	TfT-4	↓	↓	
↓	↓	T-11	PfT-7	↓	↓	1500 PSIA
F.P.	68	T-11	TfT-5	1/Sec	M,C	
Compute and display quantity on request.						
Command and verify;						
F.P.	69	GOV-1	LGOV-1I	1	S	Open
↓	↓	GOV-2	LGOV-2I	↓	↓	↓
↓	↓	GOV-3	LGOV-3I	↓	↓	↓
↓	↓	GFV-1	LGFV-1I	↓	↓	↓
↓	↓	GFV-2	LGFV-2I	↓	↓	↓
↓	↓	GFV-3	LGFV-3I	↓	↓	↓
F.P.	69	V-52	LLIV-1	1	S	Open

FERRY PREFLIGHT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	69	V-53	LLIV-2	1	S	Open
↓	↓	V-54	LLIV-3	↓	↓	↓
		V-55	LFIV-1			
		V-56	LFIV-2			
F.P.	69	V-57	LFIV-3	1	S	Open

Command the APU shaft clutches to engage on all three sections.

Command and verify;

F.P.	70	G-1	VII-38	1	S	28 VDC
↓	↓	G-2	VII-39	↓	↓	↓
F.P.	70	G-3	VII-40	1	S	28 VDC

Command & verify;

F.P.	70	G-1	LIOV-38	1	S	Open

Initiate igniter spark, verify;

F.P.	71	G-1	IIE-38	1	S	Pulses
F.P.	71	G-1	PC-38	1	S	

Command and verify;

F.P.	71	G-1	LIFV-38	1	S	Open
F.P.	71	G-1	PC-38	1	S	

Command and verify;

F.P.	72	GOV-1	LGOV-1	1	S	Open
F.P.	72	G-1	PC-38	1	S	

Command and verify:

F.P.	73	GFV-1	LGFV-1	1	S	Open
F.P.	73	G-1	PC-38	1	S	

Check;

F.P.	74	G-1	TC-1	1	S	
↓	↓	U-1	NT-1	2/Sec	C	
		PT-1	NS-1	1	S	
		PT-1	QPTL-1	↓	S	
		PT-1	PPTL-1		S	
F.P.	74	PT-1	TPTL-1	1	S	

When NT-1 reaches steady-state, command igniter spark off and verify;

F.P.	75	G-1	IIE-38	1	S	0

FERRY PREFLIGHT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
Command and verify;						
F.P.	76	G-2	LIOV-39	1	S	Open
Initiate igniter spark, verify						
F.P.	77	G-2	IIE-39	1	S	Pulses
F.P.	77	G-2	PC-39	1	S	
Command and verify;						
F.P.	78	G-2	LIFV-39	1	S	Open
F.P.	78	G-2	PC-39	1	S	
Command and verify;						
F.P.	79	GOV-2	LGOV-2	1	S	Open
F.P.	79	G-2	PC-39	1	S	
Command and verify;						
F.P.	80	GFV-2	LGFV-2	1	S	Open
F.P.	80	G-2	PC-39	1	S	
Check;						
F.P.	81	G-2	TC-2	1	S	
↓	↓	U-2	NT-2	2/sec	C	
		PT-2	NS-2	1	S	
		PT-2	QPTL-2	↓	↓	
		PT-2	PPTL-2			
F.P.	81	PT-2	TPTL-2	1	S	
When NT-2 reaches steady-state, command igniter spark off, verify;						
F.P.	82	G-2	IIE-39	1	S	0
Command and verify;						
F.P.	83	G-3	LIOV-40	1	S	Open
Initiate Igniter Spark, verify;						
F.P.	84	G-3	IIE-40	1	S	Pulses
F.P.	84	G-3	PC-40	1	S	
Command and verify;						
F.P.	85	G-3	LIFV-40	1	S	Open
F.P.	85	G-3	PC-40	1	S	

FERRY PREFLIGHT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE

Command and verify;

F.P.	86	GOV-3	LGOV-3	1	S	Open
F.P.	86	G-3	PC-40	1	S	

Command and verify;

F.P.	87	GFV-3	LGFV-3	1	S	Open
F.P.	87	G-3	PC-40	1	S	

Check;

F.P.	88	G-3	TC-3	1	S	
↓	↓	U-3	NT-3	2/Sec	C	
↓	↓	PT-3	NS-3	1	S	
↓	↓	PT-3	QPTL-3	↓	↓	
↓	↓	PT-3	PPTL-3	↓	↓	
F.P.	88	PT-3	TPTL-3	1	S	

When NT-3 reaches steady-state, command igniter spark off, verify;

F.P.	89	G-3	IIE-40	1	S	0

Commence monitoring:

F.P.	90	G-1	PC-38	1/Sec	M	
↓	↓	G-1	TC-1	1/Sec	↓	
↓	↓	U-1	NT-1	2/Sec	↓	
↓	↓	PT-1	QPTL-1	1/2 sec	↓	
↓	↓	PT-1	PPTL-1	1/2 sec	↓	
↓	↓	PT-1	TPTL-1	1/2 sec	↓	
↓	↓	PT-1	NS-1	1/2 sec	↓	
↓	↓	G-2	PC-39	1/Sec	↓	
↓	↓	G-2	TC-2	1/Sec	↓	
↓	↓	U-2	NT-2	2/Sec	↓	
↓	↓	PT-2	QPTL-2	1/2 sec	↓	
↓	↓	PT-2	PPTL-2	1/2 sec	↓	
↓	↓	PT-2	TPTL-2	1/2 sec	↓	
↓	↓	PT-2	NS-2	1/2 sec	↓	
↓	↓	G-3	PC-40	1/Sec	↓	
↓	↓	G-3	TC-3	1/Sec	↓	
↓	↓	U-3	NT-3	2/Sec	↓	
↓	↓	PT-3	QPTL-3	1/2 sec	↓	
↓	↓	PT-3	PPTL-3	1/2 sec	↓	
↓	↓	PT-3	TPTL-3	1/2 sec	↓	
F.P.	90	PT-3	NS-3	1/2 sec	M	

91 Connect A/B Ground Start GSE

FERRY PREFLIGHT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
Command and verify;						
F.P.	92	V-58	LFIV-4	1	S	Open
↓	↓	V-60	LFIV-5	↓	↓	↓
		V-62	LFIV-6			
		V-59	LPSV-7			
		V-61	LPSV-8			
F.P.	92	V-63	LPSV-9	1	S	Open
Command and verify;						
F.P.	93	G-4	IIE-41	1	S	Pulses
Command and verify;						
F.P.	94	GFV-4	LGFV-4I	1	S	Open
F.P.	94	GFV-4	LGFV-4	1	S	Open
Command and verify;						
F.P.	95	GOV-4	LGOV-4I	1	S	Open
F.P.	95	GOV-4	LGOV-4	1	S	Open
After TBD seconds, check;						
F.P.	96	U-4	NT-4	1	C,S	S.S.
↓	↓	PT-4	PTPL-1	↓	S	
		PT-4	QTPL-1		↓	
		PT-4	TTPL-1			
F.P.	96	P-7	PPD-7	1	S	
Terminate spark, verify;						
F.P.	97	G-4	IIE-41	1	S	0
Check;						
F.P.	98	P-8	PPD-8	1	S	$<$TBD PSIA
F.P.	98	P-9	PPD-9	1	S	$<$TBD PSIA
Command and verify;						
F.P.	99	G-5	IIE-42	1	S	Pulses
Command and verify;						
F.P.	100	GFV-5	LGFV-5I	1	S	Open
F.P.	100	GFV-5	LGFV-5	1	S	Open
Command and verify;						
F.P.	101	GOV-5	LGOV-5I	1	S	Open
F.P.	101	GOV-5	LGOV-5	1	S	Open

FERRY PREFLIGHT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
After TBD seconds, check:						
F.P.	102	U-5	NT-5	1	C,S	S.S.
↓	↓	PT-5	PTPL-2	↓	S	
		PT-5	QTPL-2		↓	
		PT-5	TTPL-2			
F.P.	102	P-8	PPD-8	1	S	
Terminate spark, verify;						
F.P.	103	G-5	IIE-42	1	S	0
Command and verify;						
F.P.	104	G-6	IIE-43	1	S	Pulses
Command and verify;						
F.P.	105	GFV-6	LGFV-6I	1	S	Open
F.P.	105	GFV-6	LGFV-6	1	S	Open
Command and verify;						
F.P.	106	GOV-6	LGOV-6I	1	S	Open
F.P.	106	GOV-6	LGOV-6	1	S	Open
After TBD seconds, check:						
F.P.	107	U-6	NT-6	1	C,S	S.S.
↓	↓	PT-6	PTPL-3	↓	S	
		PT-6	QTPL-3		↓	
		PT-6	TTPL-3			
F.P.	107	P-9	PPD-9	1	S	
Terminate spark, verify;						
F.P.	108	G-6	IIE-43	1	S	0
Command and verify;						
F.P.	109	EFV-1	LEFV-1	1	S	Open
↓	↓	EFV-2	LEFV-2	↓	↓	↓
		EFV-3	LEFV-3			
F.P.	109	EFV-4	LEFV-4	1	S	Open
Check:						
F.P.	110		PfL-11	1	S,C	
F.P.	110		TfL-6	1	S,C	

FERRY PREFLIGHT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
Command and verify;						
F.P.	111	EFV-5	LEFV-5	1	S	Open
↓	↓	EFV-6	LEFV-6	↓	↓	↓
		EFV-7	LEFV-7			
F.P.	111	EFV-8	LEFV-8	1	S	Open
Check:						
F.P.	112		PfL-12	1	S,C	
F.P.	112		TfL-7	1	S,C	
Command and verify;						
F.P.	113	EFV-9	LEFV-9	1	S	Open
↓	↓	EFV-10	LEFV-10	↓	↓	↓
		EFV-11	LEFV-11			
F.P.	113	EFV-12	LEFV-12	1	S	Open
Check:						
F.P.	114		PfL-13	1	S,C	
F.P.	114		TfL-8	1	S,C	
Commence monitoring:						
F.P.	115	G-4	PC-41	10/Sec	M	
↓	↓	G-4	TC-4	1/Sec	↓	
		U-4	NT-4	5/Sec		
		P-7	PPD-7	5/Sec		
		G-5	PC-42	10/Sec		
		G-5	TC-5	1/Sec		
		U-5	NT-5	5/Sec		
		P-8	PPD-8	5/Sec		
		G-6	PC-43	10/Sec		
		G-6	TC-6	1/Sec		
		U-6	NT-6	5/Sec		
		P-9	PPD-9	5/Sec		
			PfL-11	5/Sec		
			PfL-12	5/Sec		
			PfL-13	5/Sec		
		PT-4	QTPL-1	1/2 Sec		
		PT-4	PTPL-1	1/2 Sec		
		PT-4	TTPL-1	1/2 Sec		
		PT-5	QTPL-2	1/2 Sec		
		PT-5	PTPL-2	1/2 Sec		
		PT-5	TTPL-2	1/2 Sec		
		PT-6	QTPL-3	1/2 Sec		
		PT-6	PTPL-3	1/2 Sec		
F.P.	115	PT-6	TTPL-3	1/2 Sec	M	

FERRY PREFLIGHT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE

Command turbofan #1 to start.

Activate turbofan Ground Start GSE.

The engine controller commands and verifies:

F.P.	116	FCA-1	LFIVA/B-1	1	S	Open
↓	↓	FCA-1	NVDVP-1	↓	↓	
		FCA-1	PDVDVP-1			
		FCA-1	LCPRV-1			Open
		FH-1	VFH-1			28 VDC
		FH-1	IFH-1			
		IGN-1	VIIA/B-1			28 VDC
		IGN-1	III-1			Pulses
		LA-1	PLPD-1			
		LA-1	PSPD-1			
		LA-1	TSPD-1			
		LA-1	QLO-1			
F.P.	116	FM-1	FfF-1	1	S	

When:

F.P.	117	TF-1	NHPT-1	100/Sec	C	Nx

The engine controller commands and verifies:

F.P.	118	FCA-1	LSPV-1	1	S	Open

A/B E.C.-1 verifies combustion by checking:

F.P.	119	FD-1	FLB-1	A.R.	S	On

E.C.-1 commences to monitor the following for gas path analysis:

F.P.	120	TF-1	PFI-1	100/Sec	C	
↓	↓	↓	TIA-1	↓	↓	
			NF-1			
			NHPT-1			
			FfF-1			
			PHPT-1			
			THPT-1			
			PED-1			
			TED-1			
			TLPTD-1			
			TCI-1			
F.P.	120	TF-1	PDVDVP-1	100/Sec	C	

At steady-state thrust, the engine controller commands and verifies:

F.P.	121	IGN #1	III-1	1	S	0

FERRY PREFLIGHT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE

E.C.-1 commenses to monitor:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	122	LA-1	QLO-1	5/Sec	M	
↓	↓	LA-1	PLPD-1	5/Sec	↓	
		LA-1	PSPD-1	5/Sec		
		LA-1	TSPD-1	5/Sec		
		LA-1	PG-1	5/Sec		
		FCA-1	IFH-1	1/Sec		
		COMP-1	FIC-1	1/Sec		

Command turbofan 2 to start. Activate the turbofan Ground Start GSE

E.C. -2 commands and verifies:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	123	FCA-2	LFIVA/B-2	1	S	Open
↓	↓	FCA-2	NVDVP-2	↓	↓	
		FCA-2	PDVDVP-2			
		FCA-2	LCPRV-2			Open
		FH-2	VFH-2			28 VDC
		FH-2	IFH-2			
		IGN #2	VIIA/B-2			28 VDC
		IGN #2	III-2			Pulses
		LA-2	PLPD-2			
		LA-2	PSPD-2			
		LA-2	TSPD-2			
		LA-2	QLO-2			
F.P.	123	FM-2	FfF-2	1	S	

When:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	124	TF-2	NHPT-2	100/Sec	C	Nx

The engine controller commands and verifies:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	125	FCA-2	LSPV-2	1	S	Open

E.C.-2 verifies combustion by checking:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	126	FD-2	FLB-2	A.R.	S	On

E.C.-2 commences to monitor the following for gas path analysis:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	127	TF-2	PFI-2	100/Sec	C	
↓	↓	↓	TIA-2	↓	↓	
			NF-2			
			NHPT-2			
			FfF-2			
			PHPT-2			
			THPT-2			
			PED-2			
			TED-2			
			TLPTD-2			
			TCI-2			
F.P.	127	TF-2	PDVDVP-2	100/Sec	C	

<u>FERRY PREFLIGHT</u> (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE

At steady-state thrust, E.C.-2 commands and verifies:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	128	IGN. #2	III-2	1	S	0

E.C.-2 Commences to monitor:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	129	LA-2	QLO-2	5/Sec	M	
↓	↓	LA-2	PLPD-2	↓	↓	
		LA-2	PSPD-2			
		LA-2	TSPD-2			
		LA-2	PG-2	5/Sec		
		ECA-2	IFH-2	1/Sec		
F.P.	129	COMP-2	FIC-2	1/Sec	M	Off

Command Turbofan 3 to start, activate Ground Start GSE.

E.C.-3 commands and verifies:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	130	FCA-3	LFIVA/B-3	1	S	Open
↓	↓	FCA-3	NVDVP-3	↓	↓	
		FCA-3	PDVDVP-3			
		FCA-3	LCPRV-3			Open
		FH-3	VFH-3			28 VDC
		FH-3	IFH-3			
		IGN. #3	VIIA/B-3			28 VDC
		IGN. #3	III-3			Pulses
		LA-3	PLPD-3			
		LA-3	PSPD-3			
		LA-3	TSPD-3			
		LA-3	QLO-3			
F.P.	130	FM-3	FfF-3	1	S	

When:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	131	TF-3	NHPT-3	100/Sec	C	Nx

E.C.-3 commands and verifies

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	132	FCA-2	LSPV-3	1	S	Open

E.C.-3 verifies combustion by checking:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	133	FD-1	FLB-3	A.R.	S	On

E.C.-3 commences to monitor the following for gas path analysis:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	134	TF-3	PFI-3	100/Sec	C	
↓	↓	↓	TIA-3	↓	↓	
			NF-3			
			NHPT-3			
			FfF-3			
			PHPT-3			
			THPT-3			
			PED-3			
F.P.	134	TF-3	TED-3	100/Sec	C	

FERRY PREFLIGHT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	134	TF-3	TLPTD-3	100/Sec	C	
↓	↓		TCI-3	↓	↓	
F.P.	134	TF-3	PDVDVP-3	100/Sec	C	

At steady-state thrust, E.C.#3 commands and verifies:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	135	IGN. #3	III-3	1	S	0

E.C. #3 commences to monitor:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.P.	136	LA-3	QLO-3	5/Sec	M	
		LA-3	PLPD-3			
		LA-3	PSPD-3			
		LA-3	TSPD-3			
		LA-3	PG-3	↓		
↓	↓	FCA-3	IFH-3	1/Sec	↓	
F.P.	136	COMP-3	FIC-3	1/Sec	M	Off

137 Stop and retract Ground Start GSE

138 Verify vehicle power buses.

Execute power transfer.

139 Disconnect Ground Power GSE.

FERRY FLIGHT

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
Make the following checks while at cruise altitude:						
F.F.	1	V-1	LOIV-1	1	S	Closed
		V-2	LOIV-2			
		V-3	LOVV-1			
		V-4	LOVV-2			
		V-5	LOVV-3			
		V-6	LOVV-4			
		V-7	LOFV-1			
		V-8	LFIV-1			
		V-9	LFIV-2			
		V-10	LFTVV-1			
		V-11	LFTVV-2			
		V-12	LFTVV-3			
		V-13	LFTVV-4			
		V-14	LFFV-1			
		V-19	LOPCV-1			
		V-20	LOPCV-2			
		V-21	LFPCV-1			
		V-22	LFPCV-2			
		V-23	LOIV-3			
		V-24	LOTVV-1			
		V-25	LOTVV-2			
		V-26	LFIV-3			
		V-27	LFIV-4			
		V-28	LFTVV-5			
		V-29	LFTVV-6			
		V-30	LFTVV-7			Closed
		V-31	LFTVV-8			Closed
		V-32	LOPV-1			Open
		V-33	LOPV-2			
		V-34	LFPV-1			
		V-35	LFPV-2			Open
		C-1	LOFC-1			Closed
		C-2	LHC-1,2			
		C-3	LFTVC-1			
		C-4	LHC-3,4			
		C-5	LFFC-1			
		C-6	LHC-5,6			
		C-8	LHC-7,8			
F.F.	1	C-11	LFVC-1	1	S	Closed
Monitor:						
F.F.	2	T-1	PoT-1	1/min	M	19 PSIA
		T-2	PoT-2	1/min		19 PSIA
		T-3	PfT-1	1/min		19 PSIA
		L-17	PoL-2	1/min		
		L-20	PfL-1	1/min		
		L-21	PfL-4	1/min		
		L-17	ToL-2	1/min		
F.F.	2	L-20	TfL-1	1/min	M	

FERRY FLIGHT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.F.	2	L-21	TfL-4	1/min.	M	
		T-4	ToT-3	1/10 sec.		
		T-5	TfT-2	1/10 sec.		
		T-6	TfT-3	1/10 sec.		
		T-4	QoT-7	1/sec.		Until Uncovered
		T-4	QoT-8			
		T-4	QoT-9			
		T-5	QfT-4			
		T-5	QfT-5			
		T-5	QfT-6			
		T-6	QfT-7			
		T-6	QfT-8			
F.F.	2	T-6	QfT-9	1/sec.	M	Until Uncovered

Monitor:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.F.	3	T-8	PoT-6	1/sec	M,C	1500 PSIA
		T-8	ToT-4		M	
		T-9	PoT-7		M,C	1500 PSIA
		T-9	ToT-5		M	
		T-10	PfT-6		M,C	1500 PSIA
		T-10	TfT-4		M	
		T-11	PfT-7		M,C	1500 PSIA
F.F.	3	T-11	TfT-5	1/sec	M	

Compute and display accumulator quantity on request.

Continue to monitor:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.F.	4	G-1	PC-38	1/sec	M	
		G-1	TC-1	1/sec		
		U-1	NT-1	2/sec		
		PT-1	QPTL-1	1/2 sec		
		PT-1	PPTL-1	1/2 sec		
		PT-1	TPTL-1	1/2 sec		
		PT-1	NS-1	1/2 sec		
		G-2	PC-39	1/sec		
		G-2	TC-2	1/sec		
		U-2	NT-2	2/sec		
		PT-2	QPTL-2	1/2 sec		
		PT-2	PPTL-2	1/2 sec		
		PT-2	TPTL-2	1/2 sec		
		PT-2	NS-2	1/2 sec		
		G-3	PC-40	1/sec		
		G-3	TC-3	1/sec		
		U-3	NT-3	2/sec		
		PT-3	QPTL-3	1/2 sec		
		PT-3	PPTL-3	1/2 sec		
		PT-3	TPTL-3	1/2 sec		
F.F.	4	PT-3	NS-3	1/2 sec	M	

FERRY FLIGHT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
When:						
F.F.	5	T-8	PoT-6	1/sec	C	1500-X PSIA
Or:						
F.F.	6	T-9	PoT-7	1/sec	C	1500-X PSIA
Verify:						
F.F.	7	V-52	LLIV-1	1	S	Open
↓	↓	V-53	LLIV-2	↓	↓	↓
F.F.	7	V-54	LLIV-3	1	S	Open
Command and verify:						
F.F.	8	V-52	LPSV-1	1	S	Open
↓	↓	V-53	LPSV-2	↓	↓	↓
F.F.	8	V-54	LPSV-3	1	S	Open

Engage the clutches to P-1, P-2, P-3.

During G02 resupply monitor the following additional parameters:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.F.	9	P-1	PPD-1	2/sec	M	1500 PSIA
↓	↓	H-4	THE-1	1/2 sec	↓	
		H-4	PHEO-1	1/2 sec		1500 PSIA
		P-2	PPD-2	2/sec		1500 PSIA
		H-5	THE-2	1/2 sec		
		H-5	PHEO-2	1/2 sec		1500 PSIA
		P-3	PPD-3	2/sec		1500 PSIA
		H-6	THE-3	1/2 sec		
F.F.	9	H-6	PHEO-3	1/2 sec	M	1500 PSIA

When:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.F.	10	T-8	PoT-6	1/sec	C	1500 PSIA
F.F.	10	T-9	PoT-7	1/sec	C	1500 PSIA

Disengage clutches to P-1, P-2, and P-3.

Discontinue Resupply monitors.

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
F.F.	11	V-52	LPSV-1	1	S	Closed
↓	↓	V-53	LPSV-2	↓	↓	↓
F.F.	11	V-54	LPSV-3	1	S	Closed

FERRY FLIGHT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
When:						
F.F.	12	T-10	PfT-6	1/sec	C	1500-Z-PSIA
Or:						
F.F.	13	T-11	PfT-7	1/sec	C	1500-Z-PSIA
Verify:						
F.F.	14	V-55	LFIV-1	1	S	Open
↓	↓	V-56	LFIV-2	↓	↓	↓
F.F.	14	V-57	LFIV-3	1	S	Open
Command and verify:						
F.F	15	V-55	LPSV-4	1	S	Open
↓	↓	V-56	LPSV-5	↓	↓	↓
F.F.	15	V-57	LPSV-6	1	S	Open
Engage clutches to P-4, P-5, and P-6.						
During GH2 resupply monitor the following additional parameters:						
F.F.	16	P-4	PPD-4	2/sec	M	1500 PSIA
↓	↓	H-7	THE-4	1/2 sec	↓	
		H-7	PHEO-4	1/2 sec		1500 PSIA
		P-5	PPD-5	2/sec		1500 PSIA
		H-8	THE-5	1/2 sec		
		H-8	PHEO-5	1/2 sec		1500 PSIA
		P-6	PPD-6	2/sec		1500 PSIA
		H-9	THE-6	1/2 sec		
F.F.	16	H-9	PHEO-6	1/2 sec	M	1500 PSIA
When:						
F.F.	17	T-10	PfT-6	1/sec	C	1500 PSIA
F.F.	17	T-11	PfT-7	1/sec	C	1500 PSIA
Disengage clutches to P-4, P-5, and P-6.						
Discontinue resupply monitors.						
Command and verify:						
F.F.	18	V-55	LPSV-4	1	S	Closed
↓	↓	V-56	LPSV-5	↓	↓	↓
F.F.	18	V-57	LPSV-6	1	S	Closed

FERRY FLIGHT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
Continue to monitor:						
F.F.	19	G-4	PC-41	10/sec	M	
		G-4	TC-4	1/sec		
		U-4	NT-4	5/sec		
		P-7	PPD-7	5/sec		
		G-5	PC-42	10/sec		
		G-5	TC-5	1/sec		
		U-5	NT-5	5/sec		
		P-8	PPD-8	5/sec		
		G-6	PC-43	10/sec		
		G-6	TC-6	1/sec		
		U-6	NT-6	5/sec		
		P-9	PPD-9	5/sec		
			PfL-11	5/sec		
			PfL-12	5/sec		
			PfL-13	5/sec		
		PT-4	QTPL-1	1/2 sec		
		PT-4	PTPL-1			
		PT-4	TTPL-1			
		PT-5	QTPL-2			
		PT-5	PTPL-2			
		PT-5	TTPL-2			
		PT-6	QTPL-3			
		PT-6	PTPL-3			
F.F.	19	PT-6	TTPL-3	1/2 sec	M	

E.C. #1 continues to perform gas path analysis:

F.F.	20	TF-1	PFI-1	100/sec	C	
			TIA-1			
			NF-1			
			NHPT-1			
			FfF-1			
			PHPT-1			
			THPT-1			
			PED-1			
			TED-1			
			TLPTD-1			
			TCI-1			
F.F.	20	TF-1	PDVDVP-1	100/sec	C	

E.C. #1 continues to monitor:

F.F.	21	LA-1	QLO-1	5/sec	M	
			PLPD-1			
			PSPD-1			
			TSPD-1			
		LA-1	PG-1	5/sec		
		FCA-1	IFH-1	1/sec		
F.F.	21	COMP-1	FIC-1	1/sec	M	OFF

FERRY FLIGHT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTE VALUE
			E.C. #2 continues to perform gas path analysis:			
F.F.	22	TF-2	PFI-2	100/sec	C	
↓	↓	↓	TIA-2	↓	↓	
↓	↓	↓	NF-2	↓	↓	
↓	↓	↓	NHPT-2	↓	↓	
↓	↓	↓	FfF-2	↓	↓	
↓	↓	↓	PHPT-2	↓	↓	
↓	↓	↓	THPT-2	↓	↓	
↓	↓	↓	PED-2	↓	↓	
↓	↓	↓	TED-2	↓	↓	
↓	↓	↓	TLPTD-2	↓	↓	
↓	↓	↓	TCI-2	↓	↓	
F.F.	22	TF-2	PDVDVP-2	100/sec	C	
			E.C. #2 continues to monitor:			
F.F.	23	LA-2	QLO-2	5/sec	M	
↓	↓	↓	PLPD-2	↓	↓	
↓	↓	↓	PSPD-2	↓	↓	
↓	↓	↓	TSPD-2	↓	↓	
↓	↓	LA-2	PG-2	5/sec	↓	
↓	↓	FCA-2	IFH-2	1/sec	↓	
F.F.	23	COMP-2	FIC-2	1/sec	M	off
			E.C. #3 continues to perform gas path analysis:			
F.F.	24	TF-3	PFI-3	100/sec	C	
↓	↓	↓	TIA-3	↓	↓	
↓	↓	↓	NF-3	↓	↓	
↓	↓	↓	NHPT-3	↓	↓	
↓	↓	↓	FfF-3	↓	↓	
↓	↓	↓	PHPT-3	↓	↓	
↓	↓	↓	THPT-3	↓	↓	
↓	↓	↓	PED-3	↓	↓	
↓	↓	↓	TED-3	↓	↓	
↓	↓	↓	TLPTD-3	↓	↓	
↓	↓	↓	TCI-3	↓	↓	
F.F.	24	TF-3	PDVDVP-3	100/sec	C	
			E.C. #3 continues to monitor:			
F.F.	25	LA-3	QLO-3	5/sec	M	
↓	↓	↓	PLPD-3	↓	↓	
↓	↓	↓	PSPD-3	↓	↓	
↓	↓	↓	TSPD-3	↓	↓	
↓	↓	LA-3	PG-3	5/sec	↓	
↓	↓	FCA-3	IFH-3	1/sec	↓	
F.F.	25	COMP-2	FIC-3	1/sec	M	OFF

FERRY APPROACH & LANDING

1. Continue to monitor as in steps 2, 3, 4, 19, 20, 21, 22, 23, 24, and 25 of Ferry Flight.

2. After landing, taxi to revetment area.

Command & verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
FAL	3	V-59	LPSV-7	1	S	Closed
↓	↓	V-58	LFIV-4	↓	↓	↓
		V-61	LPSV-8			
		V-60	LFIV-5			
		V-63	LPSV-9			
FAL	3	V-62	LFIV-6	1	S	Closed

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
FAL	4	G-4	VII-41	1	S	OVDC
↓	↓	G-5	VII-42	↓	↓	↓
FAL	4	G-6	VII-43	1	S	OVDC

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
FAL	5	GOV-4	LGOV-4	1	S	Closed
↓	↓	GOV-4	LGOV-4I	↓	↓	↓
		GFV-4	LGFV-4			
		GFV-4	LGFV-4I			
		GOV-5	LGOV-5			
		GOV-5	LGOV-5I			
		GFV-5	LGFV-5			
		GFV-5	LGFV-5I			
		GOV-6	LGOV-6			
		GOV-6	LGOV-6I			
		GFV-6	LGFV-6			
FAL	5	GFV-6	LGFV-6I	1	S	Closed

Discontinue monitoring steps 2, 3, and 19 of Ferry Flight.
E.C.-1 commences monitoring.

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
FAL	6	FD-1	FLB-1	10/sec	M,C	On

E.C.-1 Checks

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
FAL	7	TF-1	TTB-1	25/sec	M	

For TBD Seconds

When

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
FAL	8		PfL-11	5/sec	C	<TBD

FERRY APPROACH & LANDING (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
E.C.-1 commands and verifies T.F.-1 shutdown						
FAL	9	FCA-1	LFIV A/B-1	1	S	Closed
↓	↓	FCA-1	LCPRV-1	↓	↓	Closed
		FH-1	VFH-1			OVDC
FAL	9	FCA-1	LSPV-1	1	S	Closed
All engine assemblies are stopped.						
When						
FAL	10	FD-1	FLB-1	10/sec	C	Off
Command and verify:						
FAL	11	EFV-1	LEFV-1	1	S	Closed
↓	↓	EFV-2	LEFV-2	↓	↓	↓
		EFV-3	LEFV-3			
FAL	11	EFV-4	LEFV-4	1	S	Closed
E.C.-1 discontinues monitoring steps 20 and 21 of Ferry Flight and step 6 of Ferry Approach and Landing.						
E.C.-2 commences monitoring						
FAL	12	FD-2	FLB-2	10/sec	M,C	On
E.C.-2 checks						
FAL	13	TF-2	TTB-2	25/sec	M	
For TBD seconds.						
When						
FAL	14		PfL-12	5/sec	C	<TBD
E.C.-2 commands and verifies T.F.-2 shutdown						
FAL	15	FCA-2	LFIV A/B-2	1	S	Closed
↓	↓	FCA-2	LCPRV-2	↓	↓	Closed
		FH-2	VFH-2			OVDC
FAL	15	FCA-2	LSPV-2	1	S	Closed
All engine assemblies are stopped.						
When						
FAL	16	FD-2	FLB-2	10/sec	C	Off

FERRY APPROACH & LANDING (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE

Command and verify:

FAL	17	EFV-5	LEFV-5	1	S	Closed
↓	↓	EFV-6	LEFV-6	↓	↓	↓
		EFV-7	LEFV-7			
FAL	17	EFV-8	LEFV-8	1	S	Closed

E.C.-2 discontinues monitoring steps 22 and 23 or Ferry Flight and 12 of Ferry Approach and Landing.

E.C.-3 commences monitoring

FAL	18	FD-3	FLB-3	10/sec	M,C	On

E.C.-3 checks

FAL	19	FT-3	TTB-3	25/sec	M	

for TBD seconds

When

FAL	20		PfL-13	5/sec	C	< TBD

E.C.-3 commands and verifies T.F.-3 shutdown.

FAL	21	FCA-3	LFIV A/B-3	1	S	Closed
↓	↓	FCA-3	LCPRV-3	↓	↓	Closed
		FH-3	VFH-3			OVDC
FAL	21	FCA-3	LSPV-3	1	S	Closed

All engine assemblies are stopped.

When

FAL	22	FD-3	FLB-3	10/sec	C	Off

Command and verify:

FAL	23	EFV-9	LEFV-9	1	S	Closed
↓	↓	EFV-10	LEFV-10	↓	↓	↓
		EFV-11	LEFV-11			
FAL	23	EFV-12	LEFV-12	1	S	Closed

E.C.-3 discontinues monitoring steps 24 and 25 of Ferry Flight and 18 of Ferry Approach and Landing.

POSTFLIGHT-FERRY

1. Tow the Orbiter into revetment. Chock and tie-down.
2. Connect Ground Power GSE.
3. Execute power transfer to Ground Power GSE.
4. Continue to monitor step 4 of Ferry Flight until the APU shutdown command is received.

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
Upon receipt of APU shutdown command						
Command and verify:						
P-F	5	G-1	VII-38	1	S	OVDC
Command and verify:						
P-F	6	GOV-1	LGOV-1	1	S	Closed
P-F	6	G-1	PC-38	1	S	
Command and verify:						
P-F	7	GFV-1	LGFV-1	1	S	Closed
P-F	7	G-1	PC-38	1	S	
Command and verify:						
P-F	8	G-1	LIOV-38	1	S	Closed
P-F	8	G-1	PC-38	1	S	
Command and verify:						
P-F	9	G-1	LIFV-38	1	S	Closed
P-F	9	G-1	PC-38	1	S	
Disengage the clutch to APU-1.						
Command and verify:						
P-F	10	GOV-1	LGOV-1I	1	S	Closed
↓	↓	GFV-1	LGFV-1I	↓	↓	↓
↓	↓	V-52	LLIV-1	↓	↓	↓
P-F	10	V-55	LFIV-1	1	S	Closed
Command and verify:						
P-F	11	G-2	VII-39	1	S	OVDC

POSTFLIGHT-FERRY (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
Command and verify:						
P-F	12	GOV-2	LGOV-2	1	S	Closed
P-F	12	G-2	PC-39	1	S	
Command and verify:						
P-F	13	GFV-2	LGFV-2	1	S	Closed
P-F	13	G-2	PC-39	1	S	
Command and verify:						
P-F	14	G-2	LIOV-39	1	S	Closed
P-F	14	G-2	PC-39	1	S	
Command and verify:						
P-F	15	G-2	LIFV-39	1	S	Closed
P-F	15	G-2	PC-39	1	S	
Disengage the clutch to APU-2.						
Command and verify:						
P-F	16	GOV-2	LGOV-2I	1	S	Closed
↓	↓	GFV-2	LGFV-2I	↓	↓	↓
↓	↓	V-53	LLIV-2	↓	↓	↓
P-F	16	V-56	LFIV-2	1	S	Closed
Command and verify:						
P-F	17	G-3	VII-40	1	S	OVDC
Command and verify:						
P-F	18	GOV-3	LGOV-3	1	S	Closed
P-F	18	G-3	PC-40	1	S	
Command and verify:						
P-F	19	GFV-3	LGFV-3	1	S	Closed
P-F	19	G-3	PC-40	1	S	
Command and verify:						
P-F	20	G-3	LIOV-40	1	S	Closed
P-F	20	G-3	PC-40	1	S	

POSTFLIGHT-FERRY (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
P-F	21	G-3	LIFV-40	1	S	Closed
P-F	21	G-3	PC-40	1	S	

Disengage the clutch to APU-3.

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
P-F	22	GOV-3	LGOV-3I	1	S	Closed
↓	↓	GFV-3	LGFV-3I	↓	↓	↓
↓	↓	V-54	LLIV-3	↓	↓	↓
P-F	22	V-57	LFIV-3	1	S	Closed

23. Perform the checks of step 1a of Ferry Flight.

24. Take a status sample of the parameters of step 1b of Ferry Flight

Check:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
P-F	25		PoL-8	1	S	19 PSIA
↓	↓		PoL-9	↓	↓	↓
↓	↓		PfL-9	↓	↓	↓
P-F	25		PfL-10	1	S	19 PSIA

26. Remove tape and hard copy, if any.
    Debrief crew as required.
    Review in-flight data and fault-isolation output.

27. Inspect all subsystems for mechanical disorders.

PURGE

Connect Drain and Purge GSE and verify status of the following couplings:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
P-F	28	C-1	LOFC-1	1	S	Open
↓	↓	C-2	LHC-1,2	↓	↓	↓
↓	↓	C-3	LFTVC-1	↓	↓	↓
↓	↓	C-4	LHC-3,4	↓	↓	↓
↓	↓	C-5	LFFC-1	↓	↓	↓
↓	↓	C-6	LHC-5,6	↓	↓	↓
↓	↓	C-8	LHC-7,8	↓	↓	↓
↓	↓	C-9	LOFC-2	↓	↓	↓
↓	↓	C-10	LFFC-2	↓	↓	↓
P-F	28	C-11	LFVC-1	1	S	Open

Also connect purge GSE to the main oxidizer and on-orbit oxidizer tank vents.

POSTFLIGHT-FERRY (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
Command and verify:						
P-F	29	V-32	LOPV-1	1	S	Closed
↓	↓	V-33	LOPV-2	↓	↓	↓
↓	↓	V-34	LFPV-1	↓	↓	↓
P-F	29	V-35	LFPV-2	1	S	Closed
Command and verify:						
P-F	30	V-70	LFFV-2	1	S	Open
When GSE indicates P = ambient at C-10, repressure with helium thru C-10 until						
P-F	31	T-10	PfT-6	1/sec	M,C	1500 PSIA
P-F	31	T-11	PfT-7	1/sec	M,C	1500 PSIA
Command GSE to hold.						
Command and verify:						
P-F	31a	V-70	LFFV-2	1	S	Closed
Command and verify:						
P-F	32	V-14	LFFV-1	1	S	Open
Pressurize T-3 with helium thru C-4.						
When:						
P-F	33	T-3	PfT-1	1/sec	M,C	35 PSIA
Command and verify:						
P-F	34	V-8	LFIV-1	1	S	Open
↓	↓	V-9	LFIV-2	↓	↓	↓
↓	↓	V-26	LFIV-3	↓	↓	↓
↓	↓	V-27	LFIV-4	↓	↓	↓
↓	↓	V-34	LFPV-1	↓	↓	↓
P-F	34	V-35	LFPV-2	1	S	Open
After 9 minutes, command GSE to open vent on C-8 for 1 minute. Command purge of L-8,9 through main engines for 3 minutes.						
Command and verify:						
P-F	35	V-28	LFTVV-5	1	S	Open
↓	↓	V-29	LFTVV-6	↓	↓	↓
↓	↓	V-30	LFTVV-7	↓	↓	↓
P-F	35	V-31	LFTVV-8	1	S	Open

POSTFLIGHT-FERRY (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE

Purge out through C-11 for 1 minute.

Command and verify:

P-F	36	V-34	LFPV-1	1	S	Closed
P-F	36	V-35	LFPV-2	1	S	Closed

Stop helium purge from C-3.

Command and verify:

P-F	37	V-10	LFTVV-1	1	S	Open
↓	↓	V-11	LFTVV-2	↓	↓	↓
↓	↓	V-12	LFTVV-3	↓	↓	↓
P-F	37	V-13	LFTVV-4	1	S	Open

Reverse purge from C-5 out through C-3 and C-11 for 10 minutes. During this time configure the main engines and command and verify:

P-F	38	V-21	LFPCV-1	1	S	Open
P-F	38	V-22	LFPCV-2	1	S	Open

To purge the H_2 autogenous lines out through C-3.

Return the main engines to initial conditions and command and verify:

P-F	39	V-21	LFPCV-1	1	S	Closed
P-F	39	V-22	LFPCV-2	1	S	Closed

Reduce helium pressure to 20 PSIA and command and verify, in sequence:

P-F	40	V-10	LFTVV-1	1	S	Closed
↓	↓	V-11	LFTVV-2	↓	↓	↓
↓	↓	V-12	LFTVV-3	↓	↓	↓
↓	↓	V-13	LFTVV-4	↓	↓	↓
↓	↓	V-8	LFIV-1	↓	↓	↓
↓	↓	V-9	LFIV-2	↓	↓	↓
↓	↓	V-26	LFIV-3	↓	↓	↓
↓	↓	V-27	LFIV-4	↓	↓	↓
↓	↓	V-14	LFFV-1	↓	↓	Closed
↓	↓	T-3	PfT-1	↓	↓	20 PSIA
P-F	40		PfL-2	1	S	20 PSIA

Command and verify:

P-F	41	V-44	LOFV-2	1	S	Open

When GSE at C-9 indicates P = ambient, repressurize the C-9 with helium until

P-F	42	T-8	PoT-6	1/sec	M,C	1500 PSIA
P-F	42	T-9	PoT-7	1/sec	M,C	1500 PSIA

POSTFLIGHT-FERRY (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
Command and verify:						
P-F	43	V-44	LOFV-2	1	S	Closed
Command and verify:						
P-F	44	V-7	LOFV-1	1	S	Open
Pressurize T-1 & T-2 through C-6 with helium.						
When:						
P-F	45	T-1	PoT-1	1/sec	M,C	35 PSIA
P-F	45	T-2	PoT-2	1/sec	M,C	35 PSIA
Command and verify:						
P-F	46	V-1	LOIV-1	1	S	Open
↓	↓	V-2	LOIV-2	↓	↓	↓
↓	↓	V-23	LOIV-3	↓	↓	↓
↓	↓	V-32	LOPV-1	↓	↓	↓
P-F	46	V-33	LOPV-2	1	S	Open
Purge for 10 minutes. After 5 minutes configure the main engines to purge L-3,4 down through the engines for 3 minutes, then return the engines to initial conditions.						
After 9 minutes Command and verify:						
P-F	47	V-24	LOTVV-1	1	S	Open
P-F	47	V-25	LOTVV-2	1	S	Open
And open the vent on C-2 for 1 minute.						
Command and verify:						
P-F	48	V-32	LOPV-1	1	S	Closed
P-F	48	V-33	LOPV-2	1	S	Closed
Terminate purge from C-6.						
Command and verify:						
P-F	49	V-3	LOVV-1	1	S	Open
↓	↓	V-4	LOVV-2	↓	↓	↓
↓	↓	V-5	LOVV-3	↓	↓	↓
P-F	49	V-6	LOVV-4	1	S	Open

POSTFLIGHT-FERRY (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE

Reverse purge at 35 PSIA from C-1 out through the main oxidizer vent.

Command and verify:

P-F	50	V-19	LOPCV-1	1	S	Open
P-F	50	V-20	LOPCV-2	1	S	Open

And configure the main engines to purge the oxidizer autogenous lines.

Command and verify:

P-F	51	V-19	LOPCV-1	1	S	Closed
P-F	51	V-20	LOPCV-2	1	S	Closed

And return the main engines to initial conditions.

Reduce the helium pressure to 20 PSIA and command and verify in sequence:

P-F	52	V-3	LOVV-1	1	S	Closed
		V-4	LOVV-2			
		V-5	LOVV-3			
		V-6	LOVV-4			
		V-1	LOIV-1			
		V-2	LOIV-2			
		V-23	LOIV-3			
		V-7	LOFV-1			Closed
		T-1	PoT-1			20 PSIA
P-F	52		PoL-1	1	S	20 PSIA

Command GSE to hold.

Command and verify:

P-F	53	GOV-1	LGOV-1I	1	S	Open
		GOV-1	LGOV-1			
		GFV-1	LGFV-1I			
		GFV-1	LGFV-1			
		G-1	LIOV-38			
		G-1	LIFV-38			
		GOV-2	LGOV-2I			
		GOV-2	LGOV-2			
		GFV-2	LGFV-2I			
		GFV-2	LGFV-2			
		G-2	LIOV-39			
		G-2	LIFV-39			
		GOV-3	LGOV-3I			
		GOV-3	LGOV-3			
		GFV-3	LGFV-3I			
		GFV-3	LGFV-3			
		G-3	LIOV-40			
P-F	53	G-3	LIFV-40	1	S	Open

POSTFLIGHT-FERRY (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE

54. After 2 seconds command and verify all the valves of the previous step closed.

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
P-F	55	GOV-4	LGOV-4I	1	S	Open
↓	↓	GOV-4	LGOV-4	↓	↓	↓
↓	↓	GFV-4	LGFV-4I	↓	↓	↓
↓	↓	GFV-4	LGFV-4	↓	↓	↓
↓	↓	GOV-5	LGOV-5I	↓	↓	↓
↓	↓	GOV-5	LGOV-5	↓	↓	↓
↓	↓	GFV-5	LGFV-5I	↓	↓	↓
↓	↓	GFV-5	LGFV-5	↓	↓	↓
↓	↓	GOV-6	LGOV-6I	↓	↓	↓
↓	↓	GOV-6	LGOV-6	↓	↓	↓
↓	↓	GFV-6	LGFV-6I	↓	↓	↓
P-F	55	GFV-6	LGFV-6	1	S	Open

56. After 2 seconds command and verify all the valves of the previous step closed.

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
P-F	57	V-70	LFFV-2	1	S	Open

When GSE at C-10 indicates P = ambient,

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
P-F	58	V-55	LFIV-1	1	S	Open
↓	↓	V-55	LPSV-4	↓	↓	↓
↓	↓	V-56	LFIV-2	↓	↓	↓
↓	↓	V-56	LPSV-5	↓	↓	↓
↓	↓	V-57	LFIV-3	↓	↓	↓
P-F	58	V-57	LPSV-6	1	S	Open

Purge for 2 minutes from C-11 out through C-10.

Reduce the purge pressure to 19 PSIA and command and verify in sequence:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
P-F	59	V-70	LFFV-2	1	S	Closed
↓	↓	V-55	LFIV-1	↓	↓	↓
↓	↓	V-55	LPSV-4	↓	↓	↓
↓	↓	V-56	LFIV-2	↓	↓	↓
↓	↓	V-56	LPSV-5	↓	↓	↓
↓	↓	V-57	LFIV-3	↓	↓	↓
↓	↓	V-57	LPSV-6	↓	↓	Closed
↓	↓	T-10	PfT-4	↓	↓	19 PSIA
P-F	59	T-11	PfT-5	1	S	19 PSIA

POSTFLIGHT-FERRY (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE

Increase purge pressure at C-11 to 35 PSIA.

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
P-F	60	V-58	LFIV-4	1	S	Open
↓	↓	V-59	LPSV-7	↓	↓	↓
		V-60	LFIV-5			
		V-61	LPSV-8			
		V-62	LFIV-6			
		V-63	LPSV-9			
		EFV-1	LEFV-1			
		EFV-2	LEFV-2			
		EFV-3	LEFV-3			
		EFV-4	LEFV-4			
		EFV-5	LEFV-5			
		EFV-6	LEFV-6			
		EFV-7	LEFV-7			
		EFV-8	LEFV-8			
		EFV-9	LEFV-9			
		EFV-10	LEFV-10			
		EFV-11	LEFV-11			
P-F	60	EFV-12	LEFV-12	1	S	Open

The turbofan engine controllers command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
P-F	61	FCA-1	LFIV A/B-1	1	S	Open
↓	↓	FCA-1	LCPRV-1	↓	↓	↓
		FCA-1	LSPV-1			
		FCA-2	LFIV A/B-2			
		FCA-2	LCPRV-2			
		FCA-2	LSPV-2			
		FCA-3	LFIV A/B-3			
		FCA-3	LCPRV-3			
P-F	61	FCA-3	LSPV-3	1	S	Open

Purge for 5 minutes.
Reduce the purge pressure to 19 PSIA.

62. The A/B engine controllers command and verify closed the valves of step 61 in reverse order to which they were opened.

63. Command and verify the valves of step 60 closed in reverse order to which they were opened.

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
P-F	64	V-28	LFTVV-5	1	S	Closed
↓	↓	V-29	LFTVV-6	↓	↓	↓
		V-30	LFTVV-7			
P-F	64	V-31	LFTVV-8	1	S	Closed

POSTFLIGHT-FERRY (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE

Terminate purge from C-11.

Verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
P-F	65	T-5	PfT-2	1	S	19 PSIA
P-F	65	T-6	PfT-3	1	S	19 PSIA

Attach A/B engine covers.

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
P-F	66	V-44	LOFV-2	1	S	Open

When GSE indicates P - ambient at C-9.

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
P-F	67	V-52	LLIV-1	1	S	Open
↓	↓	V-52	LPSV-1	↓	↓	↓
		V-53	LLIV-2			
		V-53	LPSV-2			
		V-54	LLIV-3			
P-F	67	V-54	LPSV-3	1	S	Open

Purge for 2 minutes from the on-orbit oxidizer vent out through C-9. Reduce the purge pressure to 19 PSIA.

Command and verify in sequence:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
P-F	68	V-44	LOFV-2	1	S	Close
↓	↓	V-52	LLIV-1	↓	↓	↓
		V-52	LPSV-1			
		V-53	LLIV-2			
		V-53	LPSV-2			
		V-54	LLIV-3			
		V-54	LPSV-3			
		V-24	LOTVV-1			
P-F	68	V-25	LOTVV-2	1	S	Closed

Terminate purge from on-orbit oxidizer vent.

Verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
P-F	69	T-4	PoT-3	1	S	19 PSIA

70. Complete main engine purge.

Secure and disconnect the Drain and Purge GSE.

POSTFLIGHT-FERRY (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
P-F	71	C-1	LOFC-1	1	S	Closed
		C-2	LHC-1,2			
		C-3	LFTVC-1			
		C-4	LHC-3,4			
		C-5	LFFC-1			
		C-6	LHC-5,6			
		C-8	LHC-7,8			
		C-9	LOFC-2			
		C-10	LFFC-2			
P-F	71	C-11	LFVC-1	1	S	Closed

Purge complete.

Mechanically lock V-1, 2, 8, 9, 23, 26, 27.
Power down the MPS.

Verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
P-F	72	V-1	LOIV-1	1	S	Closed
		V-2	LOIV-2			
		V-8	LFIV-1			
		V-9	LFIV-2			
		V-23	LOIV-3			
		V-26	LFIV-3			
P-F	72	V-27	LFIV-4	1	S	Closed

Input flight data to processing system for trend analysis, performance evaluation, and/or maintenance report.

Power down OCMS.

MAINTENANCE

1. Tow the orbiter to the maintenance area.

2. Perform maintenance as required per maintenance procedures of Appendix C, MCR-70-306, Issue 3.

OCMS is powered up, self-checked, and used for retest.

Verify;

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
M	3	V-1	LOIV-1	1	S	Closed
		V-2	LOIV-2			
		V-3	LOVV-1			
		V-4	LOVV-2			
		V-5	LOVV-3			
		V-6	LOVV-4			
		V-7	LOFV-1			
		V-8	LFIV-1			
		V-9	LFIV-2			
		V-10	LFTVV-1			
		V-11	LFTVV-2			
		V-12	LFTVV-3			
		V-13	LFTVV-4			
		V-14	LFFV-1			
		V-19	LOPCV-1			
		V-20	LOPCV-2			
		V-21	LFPCV-1			
		V-22	LFPCV-2			
		V-23	LOIV-3			
		V-24	LOTVV-1			
		V-25	LOTVV-2			
		V-26	LFIV-3			
		V-27	LFIV-4			
		V-28	LFTVV-5			
		V-29	LFTVV-6			
		V-30	LFTVV-7			
		V-31	LFTVV-8			
		V-32	LOPV-1			
		V-33	LOPV-2			
		V-34	LFPV-1			
		V-35	LFPV-2			
		C-1	LOFC-1			
		C-2	LHC-1, 2			
		C-3	LFTVC-1			
		C-4	LHC-3, 4			
		C-5	LFFC-1			
		C-6	LHC-5, 6			
		C-8	LHC-7, 8			
		C-11	LFVC-1			Closed
		T-3	PfT-1			19 PSIA
		T-5	PfT-2			
M	3	T-6	PfT-3	1	S	19 PSIA

MAINTENANCE (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
M	3	T-1	PoT-1	1	S	19 PSIA
		T-2	PoT-2			
		T-4	PoT-3			
		L-20	PfL-1			
		L-21	PfL-4			
M	3	L-17	PoL-2	1	S	19 PSIA
Verify:						
M	4		PoL-8	1	S	19 PSIA
			PoL-9			
			PfL-9			
M	4		PfL-10	1	S	19 PSIA
Verify:						
M	5	V-36	LOPV-3	1	S	Closed
		V-37	LOPV-4			
		V-38	LOPV-5			
		V-39	LOPV-6			
		V-40	LFPV-3			
		V-41	LFPV-4			
		V-42	LFPV-5			
		V-43	LFPV-6			
		V-44	LOFV-2			
		V-70	LFFV-2			
		C-9	LOFC-2			
		C-10	LFFC-2			Closed
		T-8	PoT-4			19 PSIA
		T-9	PoT-5			
		T-10	PfT-4			
M	5	T-11	PfT-5	1	S	19 PSIA
Verify:						
M	6	GOV-1	LGOV-1I	1	S	Closed
		GOV-1	LGOV-1			
		GOV-2	LGOV-2			
		GOV-2	LGOV-2I			
		GOV-3	LGOV-3			
		GOV-3	LGOV-3I			
		GFV-1	LGFV-1			
		GFV-1	LGFV-1I			
		GFV-2	LGFV-2			
		GFV-2	LGFV-2I			
		GFV-3	LGFV-3			
		GFV-3	LGFV-3I			
		V-52	LLIV-1			
M	6	V-52	LPSV-1	1	S	Closed

MAINTENANCE (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
M	6	V-53	LPSV-2	1	S	Closed
		V-53	LLIV-1			
		V-54	LLIV-3			
		V-54	LPSV-3			
		V-55	LFIV-1			
		V-55	LPSV-4			
		V-56	LFIV-2			
		V-56	LPSV-5			
		V-57	LFIV-3			
		V-57	LPSV-6			
		G-1	LIOV-38			
		G-1	LIFV-38			
		G-2	LIOV-39			
		G-2	LIFV-39			
		G-3	LIOV-40			
M	6	G-3	LIFV-40	1	S	Closed

Verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
M	7	GFV-4	LGFV-4I	1	S	Closed
		GFV-4	LGFV-4			
		GFV-5	LGFV-5I			
		GFV-5	LGFV-5			
		GFV-6	LGFV-6I			
		GFV-6	LGFV-6			
		GOV-4	LGOV-4I			
		GOV-4	LGOV-4			
		GOV-5	LGOV-5I			
		GOV-5	LGOV-5			
		GOV-6	LGOV-6I			
		GOV-6	LGOV-6			
		V-58	LFIV-4			
		V-59	LPSV-7			
		V-60	LFIV-5			
		V-61	LPSV-8			
		V-62	LFIV-6			
		V-63	LPSV-9			
		EFV-1	LEFV-1			
		EFV-2	LEFV-2			
		EFV-3	LEFV-3			
		EFV-4	LEFV-4			
		EFV-5	LEFV-5			
		EFV-6	LEFV-6			
		EFV-7	LEFV-7			
		EFV-8	LEFV-8			
		EFV-9	LEFV-9			
		EFV-10	LEFV-10			
		EFV-11	LEFV-11			
		EFV-12	LEFV-12			Closed
			PfL-11			19 PSIA
			PfL-12			19 PSIA
M	7		PfL-13	1	S	19 PSIA

MAINTENANCE (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE

The A/B engine controllers shall verify the following:

M	8	FCA-1	LFIVAB-1	1	S	Closed
↓	↓	FCA-1	LCPRV-1	↓	↓	↓
		FCA-1	LSPV-1			
		FCA-2	LFIVA/B-2			
		FCA-2	LCPRV-2			
		FCA-2	LSPV-2			
		FCA-3	LFIVA/B-3			
		FCA-3	LCPRV-3			
M	8	FCA-3	LSPV-3	1	S	Closed

Retract the engine cradles.

V.A.B. MATE

1. Repeat step M-3.

2. Verify the following:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
V.A.B.	2	T-3	TfT-1	1	S	Ambient
↓	↓	T-5	TfT-2	↓	↓	↓
		T-6	TfT-3			
		T-1	ToT-1			
		T-2	ToT-2			
		T-4	ToT-3			Ambient
		T-3	QfT-1			uncovered
		T-3	QfT-2			↓
		T-3	QfT-3			
		T-5	QfT-4			
		T-5	QfT-5			
		T-5	QfT-6			
		T-6	QfT-7			
		T-6	QfT-8			
		T-6	QfT-9			
		T-1	QoT-1			
		T-1	QoT-2			
		T-1	QoT-3			
		T-2	QoT-4			
		T-2	QoT-5			
		T-2	QoT-6			
		T-4	QoT-7			
		T-4	QoT-8			
		T-4	QoT-9			Uncovered
			PfL-2			19 PSIA
			PfL-3			19 PSIA
		L-20	TfL-1			Ambient
			TfL-2			Ambient
V.A.B.	2		TfL-3	1	S	Ambient

V.A.B. MATE (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
V.A.B	2	L-21	TfL-4	1	S	Ambient
↓	↓		TfL-5	↓	↓	Ambient
			PoL-1			19 PSIA
		L-18	PoL-3			19 PSIA
			ToL-1			Ambient
		L-17	ToL-2			↓
		L-18	ToL-3			↓
			ToL-4			Ambient
		L-14	PgF-1			19 PSIA
		0-5	PgF-2			↓
		L-16	PgF-3			↓
		C-5	PfF-1			↓
		L-13	PgO-1			19 PSIA
		0-3	PgO-2			19 PSIA
		L-15	PgO-3			19 PSIA
		L-14	TgF-1			Ambient
		L-14	TgF-2			Ambient
		L-13	TgO-1			Ambient
		L-13	TgO-2			Ambient
		L-8	PfS-1			19 PSIA
		L-9	PfS-2			19 PSIA
		L-8	TfS-1			Ambient
		L-9	TfS-2			Ambient
		L-3	PoS-1			19 PSIA
		L-4	PoS-2			19 PSIA
		L-3	ToS-1			Ambient
		L-4	ToS-2			Ambient
↓	↓	L-7	PgRL-1	↓	↓	19 PSIA
V.A.B.	2	C-1	PoF-1	1	S	19 PSIA

PAYLOAD INSTALLATION

1. Repeat steps V.A.B. - 1, 2.

PRELAUNCH

Connect electronics coolant GSE and Ground Power GSE.

Power up OCMS and all propulsion systems.

Perform OCMS self-check.

1. Remove the mechanical stops from V-1, 2, 8, 9, 25, 26, 27.
   Verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
PL	1	V-1	LOIV-1	1	S	Closed
		V-2	LOIV-2			
		V-8	LFIV-1			
		V-9	LFIV-2			
		V-23	LOIV-3			
		V-26	LFIV-3			
PL	1	V-27	LFIV-4	1	S	Closed

Verify leak integrity:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
PL	2	T-3	PfT-1	1	S	15-20 PSIA
		T-5	PfT-2			
		T-6	PfT-3			
		T-1	PoT-1			
		T-2	PoT-2			
		T-4	PoT-3			
			PoL-1			
		L-17	PoL-2			
		L-18	PoL-3			
		L-20	PfL-1			
			PfL-2			
			PfL-3			
		L-21	PfL-4			
		L-3	PoS-1			
		L-4	PoS-2			
		L-8	PfS-1			
		L-9	PfS-2			
		L-14	PgF-1			
		0-5	PgF-2			
		L-16	PgF-3			
		L-13	PgO-1			
		0-3	PgO-2			
		L-15	PgO-3			
		C-5	PfF-1			
		C-1	PoF-1			
		L-7	PgRL-1			
		F-4	PoL-10			
PL	2	F-5	PfL-14	1	S	15-20 PSIA

PRELAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
Command and verify:						
PL	3	MEC-1		1	S	On
PL	3	MEC-2		1	S	On
PL	3	MEC-3		1	S	On
Command and verify:						
PL	4	V-1	LOIV-1	1	S	Open
↓	↓	V-2	LOIV-2	↓	↓	↓
		V-8	LFIV-1			
		V-9	LFIV-2			
		V-23	LOIV-3			
		V-26	LFIV-3			
PL	4	V-27	LFIV-4	1	S	Open
Verify:						
PL	5	V-3	LOVV-1	1	S	Closed
↓	↓	V-4	LOVV-2	↓	↓	↓
		V-5	LOVV-3			
		V-6	LOVV-4			
		V-7	LOFV-1			
		V-10	LFTVV-1			
		V-11	LFTVV-2			
		V-12	LFTVV-3			
		V-13	LFTVV-4			
		V-14	LFFV-1			
		V-19	LOPCV-1			
		V-21	LFPCV-1			
		V-22	LFPCV-2			
		V-23	LOIV-3			
		V-24	LOTVV-1			
		V-25	LOTVV-2			
		V-28	LFTVV-5			
		V-29	LFTVV-6			
		V-30	LFTVV-7			
		V-31	LFTVV-8			
		V-32	LOPV-1			
		V-33	LOPV-2			
		V-34	LFPV-1			
		V-35	LFPV-2			
		C-1	LOFC-1			
		C-2	LHC-1, 2			
		C-3	LFTVC-1			
		C-4	LHC-3, 4			
		C-5	LFFC-1			
		C-6	LHC-5, 6			
		C-8	LHC-7,8			
		C-11	LFVC-1			
PL	5	V-20	LOPCV-2	1	S	Closed

PRELAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE

6. (a) Connect hydraulic GSE.
   (b) Connect GN2 purge GSE.
   (c) M.E.C-1, 2 conduct dry main engine start and shutdown sequence.

   Status is reported to CCC.

Verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
PL	7	TR-(1-37)	LBIV-(1-37)	1	S	Closed
		TR(1-37)	LMBV-(1-37)			
		TR(1-37)	LIOV-(1-37)			
		TR(1-37)	LIFV-(1-37)			Closed
		TR(1-37)	VII-(1-37)			0 VDC
PL	7	TR(1-37)	IIE-(1-37)	1	S	0

Simulate:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
PL	7	TC-(1-37)	PC-(1-37)	1	C/O	300 PSIA

Verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
PL	8	V-36	LOPV-3	1	S	Closed
		V-37	LOPV-4			
		V-38	LOPV-5			
		V-39	LOPV-6			
		V-40	LFPV-3			
		V-41	LFPV-4			
		V-42	LFPV-5			
		V-43	LFPV-6			
		V-44	LOFV-2			
		V-70	LFFV-2			
		C-9	LOFC-2			
		C-10	LFFC-2			Closed
		T-8	PoT-4			19 PSIA
		T-9	PoT-5			
		T-10	PfT-4			
		T-11	PfT-5			
			PoL-8			
			PoL-9			
PL	8		PfL-10,9	1	S	19 PSIA

And simulate:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
PL	8		PoL-6	1	C/O	400 PSIA
		F-6	PoL-4			1500 PSIA
		T-8	PoT-6			1500 PSIA
		T-8	ToT-4			
		T-9	ToT-5			
		T-9	PoT-7			1500 PSIA
		F-7	PoL-5			1500 PSIA
			PoL-7			400 PSIA
PL	8		PfL-7	1	C/O	400 PSIA

PRELAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
PL	8	F-8	PfL-5	1	C/O	1500 PSIA
		T-10	PfT-6			1500 PSIA
		T-10	TfT-4			
		T-11	TfT-5			
		T-11	PfT-7			1500 PSIA
		F-9	PfL-6			1500 PSIA
PL	8		PfL-8	1	C/O	400 PSIA

Verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
PL	9	GOV-1	LGOV-1	1	S	Closed
		GOV-1	LGOV-1I			
		GOV-2	LGOV-2			
		GOV-2	LGOV-2I			
		GOV-3	LGOV-3			
		GOV-3	LGOV-3I			
		GFV-1	LGFV-1			
		GFV-1	LGFV-1I			
		GFV-2	LGFV-2			
		GFV-2	LGFV-2I			
		GFV-3	LGFV-3			
		GFV-3	LGFV-3I			
		V-52	LLIV-1			
		V-52	LPSV-1			
		V-53	LLIV-2			
		V-53	LPSV-2			
		V-54	LLIV-3			
		V-54	LPSV-3			
		V-55	LFIV-1			
		V-55	LPSV-4			
		V-56	LFIV-2			
		V-56	LPSV-5			
		V-57	LFIV-3			
PL	9	V-57	LPSV-6	1	S	Closed

and:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
PL	9	G-1	LIOV-38	1	S	Closed
		G-1	LIFV-38			
		G-2	LIOV-39			
		G-2	LIFV-39			
		G-3	LIOV-40			
		G-3	LIFV-40			Closed
		G-1	VII-38			OV
		G-2	VII-39			OV
		G-3	VII-40			OV
		G-1	VIEO-1			OVDC
		G-2	VIEO-2			OVDC
		G-3	VIEO-3			OVDC
		G-1	IIE-38			0
		G-2	IIE-39			0
PL	9	G-3	IIE-40	1	S	0

PRELAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
PL	9	PT-1	QPTL-1	1	S	
PL	9	PT-2	QPTL-2	1	S	
PL	9	PT-3	QPTL-3	1	S	

and simulate:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
PL	9	G-1	PC-38	1	C/O	
		G-2	PC-39			
		G-3	PC-40			
		G-1	TC-1			
		G-2	TC-2			
		G-3	TC-3			
		V-46	PCV-1			1500 PSIA
		V-49	PCV-4			
		H-4	PHEO-1			
		H-7	PHEO-4			1500 PSIA
		H-4	THE-1			
		H-7	THE-4			
		P-1	PPD-1			1500 PSIA
		P-4	PPD-4			
		V-47	PCV-2			
		V-50	PCV-5			
		H-5	PHEO-2			
		H-8	PHEO-5			1500 PSIA
		H-5	THE-2			
PL	9	H-8	THE-5	1	C/O	

and:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
PL	9	P-2	PPD-2	1	C/O	1500 PSIA
		P-5	PPD-5			
		V-48	PCV-3			
		V-51	PCV-6			
		H-6	PHEO-3			
		H-9	PHEO-6			1500 PSIA
		H-6	THE-3			
		H-9	THE-6			
		P-3	PPD-3			1500 PSIA
		P-6	PPD-6			1500 PSIA
		U-1	NT-1			
		U-1	AT-1			
		U-2	NT-2			
		U-2	AT-2			
		U-3	NT-3			
		U-3	AT-3			
		P-1	NP-1			
		P-1	AP-1			
PL	9	P-2	NP-2	1	C/O	

PRELAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
PL	9	P-2	AP-2	1	C/O	
		P-3	NP-3			
		P-3	AP-3			
		P-4	NP-4			
		P-4	AP-4			
		P-5	NP-5			
		P-5	AP-5			
		P-6	NP-6			
		P-6	AP-6			
		PT-1	NS-1			
		PT-2	NS-2			
		PT-3	NS-3			
		CL-1	AC-1			
		CL-2	AC-2			
		CL-3	AC-3			
		CL-4	AC-4			
		CL-5	AC-5			
		CL-6	AC-6			
		CL-7	AC-7			
		CL-8	AC-8			
		CL-9	AC-9			
PL	9	P-1	TPB-1	1	C/O	

And:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
PL	9	P-2	TPB-2	1	C/O	
		P-3	TPB-3			
		P-4	TPB-4			
		P-5	TPB-5			
		P-6	TPB-6			
		PT-1	TPTB-1			
		PT-2	TPTB-2			
		PT-3	TPTB-3			
		PT-1	TPTL-1			
		PT-2	TPTL-2			
		PT-3	TPTL-3			
		PT-1	PPTL-1			
		PT-2	PPTL-2			
PL	9	PT-3	PPTL-3	1	C/O	

OCMS will conduct a dry A/B start.

Verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
PL	10	V-58	LFIV-4	1	S	Closed
		V-60	LFIV-5			
		V-62	LFIV-6			
		V-59	LPSV-7			
		V-61	LPSV-8			
PL	10	V-63	LPSV-9	1	S	Closed

PRELAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
PL	10	G-4	VII-41	1	S	OVDC
↓	↓	G-4	IIE-41	↓	↓	0
↓	↓	G-4	VIEO-4	↓	↓	OVDC
↓	↓	GFV-4	LGFV-4I	↓	↓	Closed
↓	↓	GFV-4	LGFV-4	↓	↓	↓
↓	↓	GOV-4	LGOV-4I	↓	↓	↓
↓	↓	GOV-4	LGOV-4	↓	↓	Closed
PL	10	PT-4	QTPL-1	1	S	

Simulate:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
PL	10	U-4	NT-4	1	C/O	
↓	↓	PT-4	AT-4	↓	↓	
↓	↓	PT-4	PTPL-1	↓	↓	
↓	↓	PT-4	TTPL-1	↓	↓	
↓	↓	P-7	PPD-7	↓	↓	50 PSIA
PL	10	P-7	AP-7	1	C/O	

Verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
PL	11	G-5	VII-42	1	S	OVDC
↓	↓	G-5	IIE-42	↓	↓	0
↓	↓	G-5	VIEO-5	↓	↓	OVDC
↓	↓	GFV-5	LGFV-5I	↓	↓	Closed
↓	↓	GFV-5	LGFV-5	↓	↓	↓
↓	↓	GOV-5	LGOV-5I	↓	↓	↓
↓	↓	GOV-5	LGOV-5	↓	↓	Closed
PL	11	PT-5	QTPL-2	1	S	

Simulate:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
PL	11	U-5	NT-5	1	C/O	-
↓	↓	U-5	AT-5	↓	↓	
↓	↓	PT-5	PTPL-2	↓	↓	
↓	↓	PT-5	TTPL-2	↓	↓	
↓	↓	P-8	PPD-8	↓	↓	50 PSIA
PL	11	P-8	AP-8	1	C/O	

Verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
PL	12	G-6	VII-43	1	S	OVDC
↓	↓	G-6	IIE-43	↓	↓	0
↓	↓	G-6	VIEO-6	↓	↓	OVDC
↓	↓	GFV-6	LGFV-6I	↓	↓	Closed
↓	↓	GFV-6	LGFV-6	↓	↓	↓
↓	↓	GOV-6	LGOV-6I	↓	↓	↓
↓	↓	GOV-6	LGOV-6	↓	↓	Closed
PL	12	PT-6	QTPL-3	1	S	

PRELAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
Simulate:						
PL	12	U-6	NT-6	1	C/O	
		U-6	AT-6			
		PT-6	PTPL-3			
		PT-6	TTPL-3			
		P-9	PPD-9			50 PSIA
PL	12	P-9	AP-9	1	C/O	
Verify:						
PL	13	EFV-1	LEFV-1	1	S	Closed
		EFV-2	LEFV-2			
		EFV-3	LEFV-3			
		EFV-4	LEFV-4			
		EFV-5	LEFV-5			
		EFV-6	LEFV-6			
		EFV-7	LEFV-7			
		EFV-8	LEFV-8			
		EFV-9	LEFV-9			
		EFV-10	LEFV-10			
		EFV-11	LEFV-11			
		EFV-12	LEFV-12			Closed
			PfL-11			19 PSIA
			PfL-12			19 PSIA
PL	13		PfL-13	1	S	19 PSIA
Simulate:						
PL	13		TfL-6	1	C/O	
PL	13		TfL-7	1	C/O	
PL	13		TfL-8	1	C/O	

A/B E.C.-1 will conduct a dry start of T.F.-1 by verifying:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
PL	14	FCA-1	LFIVA/B-1	1	S	Closed
		FCA-1	LCPRV-1			Closed
		FH-1	VFH-1			OVDC
		FH-1	IFH-1			OADC
		IGN-1	VIIA/B-1			OVDC
		IGN-1	III-1			O
		IGN-1	VIEO-1			OVDC
		LA-1	QLO-1			
PL	14	FCA-1	LSPV-1	1	S	Closed

PRELAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE

and simulating:

PL	14	FCA-1	NVDVP-1	1	C/O	
		FCA-1	PDVDVP-1			
		LA-1	PSPD-1			
		LA-1	TSPD-1			
		FM-1	FfF-1			
		TF-1	NHPT-1			
		FD-1	FLB-1			
		TF-1	PFI-1			
		TF-1	TIA-1			
		TF-1	NF-1			
		TF-1	PHPT-1			
		TF-1	THPT-1			
		TF-1	PED-1			
		TF-1	TED-1			
		TF-1	TLPTD-1			
		TF-1	TCI-1			
PL	14	LA-1	PG-1	1	C/O	
PL	14	LA-1	PLPD-1	1	C/O	

As well as:

PL	14	TF-1	PfCCI-1	1	C/O	
		TF-1	TfCCI-1			
		TF-1	TTB-1			
		FCA-1	TFH-1			
		FCA-1	NVDVP-1			
		TF-1	AFFB-1			
		TF-1	AFCB-1			
		TF-1	ALPRB-1			
		COMP-1	FIC-1			
PL	14	COMP-1	ACEC-1	1	C/O	

A/B E.C.-2 will conduct a dry start of T.F.-2 by verifying:

PL	15	FCA-2	LFIVA/B-2	1	S	Closed
		FCA-2	LCPRV-2			Closed
		FH-2	VFH-2			OVDC
		FH-2	IFH-2			OADC
		IGN-2	VIIA/B-2			OVDC
		IGN-2	III-2			0
		IGN-2	VIEO-2			OVDC
		LA-2	QLO-2			
PL	15	FCA-2	LSPV-2	1	S	Closed

And simulating:

PL	15	FCA-2	NVDVP-2	1	C/O	
		FCA-2	PDVDVP-2			
		LA-2	PLPD-2			
		LA-2	PSPD-2			
		LA-2	TSPD-2			
		FM-2	FfF-2			
PL	15	TF-2	NHPT-2	1	C/O	

PRELAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
PL	15	FD-2	FLB-2	1	C/O	
		TF-2	PFI-2			
		TF-2	TIA-2			
		TF-2	NF-2			
		TF-2	PHPT-2			
		TF-2	THPT-2			
		TF-2	PED-2			
		TF-2	TED-2			
		TF-2	TLPTD-2			
		TF-2	TCI-2			
PL	15	LA-2	PG-2	1	C/O	

As well as:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
PL	15	TF-2	PfCCI-2	1	C/O	
		TF-2	TfCCI-2			
		TF-2	TTB-2			
		FCA-2	TFH-2			
		FCA-2	NVDVP-2			
		TF-2	AFFB-2			
		TF-2	AFCB-2			
		TF-2	ALPRB-2			
		COMP-2	FIC-2			
PL	15	COMP-2	ACEC-2	1	C/O	

A/B E.C.-3 will conduct a dry start of T.F.-3 by verifying:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
PL	16	FCA-3	LFIVA/B-3	1	S	Closed
		FCA-3	LCPRV-3			Closed
		FH-3	VFH-3			OVDC
		FH-3	IFH-3			OADC
		IGN-3	VIIA/B-3			OVDC
		IGN-3	III-3			O
		IGN-3	VIEO-3			OVDC
		LA-3	QLO-3			
PL	16	FCA-3	LSPV-3	1	S	Closed

And simulating:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
PL	16	FCA-3	NVDVP-3	1	C/O	
		FCA-3	PDVDVP-3.			
		LA-3	PLPD-3			
		LA-3	PSPD-3			
		LA-3	TSPD-3			
		FM-3	FfF-3			
		TF-3	NHPT-3			
		FD-3	FLB-3			
		TF-3	PFI-3			
		TF-3	TIA-3			
		TF-3	NF-3			
		TF-3	PHPT-3			
PL	16	TF-3	THPT-3	1	C/O	

PRELAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
PL	16	TF-3	PED-3	1	C/O	
↓	↓	TF-3	TED-3	↓	↓	
		TF-3	TLPTD-3			
		TF-3	TCI-3			
PL	16	LA-3	PG-3	1	C/O	

As well as:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
PL	16	TF-3	PfCCI-3	1	C/O	
↓	↓	TF-3	TfCCI-3	↓	↓	
		TF-3	TTB-3			
		FCA-3	TFH-3			
		FCA-3	NVDVP-3			
		TF-3	AFFB-3			
		TF-3	AFCB-3			
		TF-3	ALPRB-3			
		COMP-3	FIC-3			
PL	16	COMP-3	ACEC-3	1	C/O	

Remove all solid start cartridges.

A/B E.C.-1, 2, 3 will command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
PL	17	SC-1	VC-1	1	C/O	28 VDC
PL	17	SC-2	VC-2	1	C/O	28 VDC
PL	17	SC-3	VC-3	1	C/O	28 VDC

Then command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
PL	17	SC-1	VC-1	1	C/O	OVDC
PL	17	SC-2	VC-2	1	C/O	OVDC
PL	17	SC-3	VC-3	1	C/O	OVDC

Connect Zero-G lube pressurization GSE

A/B E.C.- 1, 2, 3 will verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
PL	18	LA-1	PZGL-1	1	C/O	
PL	18	LA-2	PZGL-2	1	C/O	
PL	18	LA-3	PZGL-3	1	C/O	

Stop and disconnect Zero-G lube GSE.
Replace all solid start cartridges.
Command all propulsion systems off.

Command all engine controllers off.

Power down OCMS.

Disconnect all GSE.

Tow orbiter to pad.

LAUNCH

1. Connect orbiter to pad electrical interfaces.
   Connect Electronic collant GSE.

2. Power up OCMS. Command OCMS self-check.
   Power up all engine controllers. Command controller self-checks.
   Power up all propulsion systems.

3. Verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	3	V-1	LOIV-1	1	S	Open
		V-2	LOIV-2			Open
		V-3	LOVV-1			Closed
		V-4	LOVV-2			
		V-5	LOVV-3			
		V-6	LOVV-4			
		V-7	LOFV-1			Closed
		V-8	LFIV-1			Open
		V-9	LFIV-2			Open
		V-10	LFTVV-1			Closed
		V-11	LFTVV-2			
		V-12	LFTVV-3			
		V-13	LFTVV-4			
		V-14	LFFV-1			
		V-19	LOPCV-1			
		V-20	LOPCV-2			
		V-21	LFPCV-1			
		V-22	LFPCV-2			Closed
		V-23	LOIV-3			Open
		V-24	LOTVV-1			Closed
		V-25	LOTVV-2			Closed
		V-26	LFIV-3			Open
		V-27	LFIV-4			Open
		V-28	LFTVV-5			Closed
		V-29	LFTVV-6			
		V-30	LFTVV-7			
		V-31	LFTVV-8			
		V-32	LOPV-1			
		V-33	LOPV-2			
		V-34	LFPV-1			
		V-35	LFPV-2			
		C-1	LOFC-1			
		C-2	LHC-1,2			
		C-3	LFTVC-1			
		C-4	LHC-3,4			
		C-5	LFFC-1			
		C-6	LHC-5,6			
		C-8	LHC-7,8			
		C-11	LFVC-1			Closed
		T-3	PfT-1			15-20 PSIA
		T-5	PfT-2			
L	3	T-6	PfT-3	1	S	15-20 PSIA

LAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	3	T-1	PoT-1	1	S	15-20 PSIA
		T-2	PoT-2			
		T-4	PoT-3			
			PoL-1			
		L-17	PoL -2			
		L-18	PoL -3			
		L-20	PfL-1			
			PfL -2			
			PfL -3			
		L-21	PfL -4			
		L-3	POS-1			
		L-4	POS -2			
		L-8	PfS-1			
		L-9	PfS-2			
		C-5	PfF-1			
		C-1	PoF-1			
		L-7	PgRL-1			
		F-4	PoL-10			
		F-5	PfL-14			
		L-14	PgF-1			
		0-5	PgF -2			
		L-16	PgF -3			
		L-13	Pg0-1			
		0-3	Pg0 -2			
L	3	L-15	Pg0 -3	1	S	15-20 PSIA

M.E.C.-1,2,3 will verify actuators locked, and igniters de-energized.

4. Remove all protective covers.

5. Verify RCS doors closed

Verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	6	TR-(1-37)	LBIV-(1-37)	1	S	Closed
		TR-(1-37)	LMBV-(1-37)			
		TR-(1-37)	LIOV-(1-37)			
		TR-(1-37)	LIFV-(1-37)			Closed
		TR-(1-37)	VII-(1-37)			OVDC
		V-36	LOPV-3			Closed
		V-37	LOPV-4			
		V-38	LOPV-5			
		V-39	LOPV-6			
		V-40	LFPV-3			
		V-41	LFPV-4			
		V-42	LFPV-5			
		V-43	LFPV-6			
		V-44	LOFV-2			
		V-70	LFFV-2			
		C-9	LOFC-2			
		C-10	LFFC-2			Closed
		T-8	PoT-4			19 PSIA
L	6	T-9	PoT-5	1	S	19 PSIA

LAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	6	T-10	PfT-4	1	S	19 PSIA
↓	↓	T-11	PfT-5	↓	↓	↓
			PoL-8			
			PoL-9			
			PfL-9			
L	6		PfL-10	1	S	19 PSIA

Verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	7	GOV-1	LGOV-1	1	S	Closed
↓	↓	GOV-1	LGOV-1I	↓	↓	↓
		GOV-2	LGOV-2			
		GOV-2	LGOV-2I			
		GOV-3	LGOV-3			
		GOV-3	LGOV-3I			
		GFV-1	LGFV-1			
		GFV-1	LGFV-1I			
		GFV-2	LGFV-2			
		GFV-2	LGFV-2I			
		GFV-3	LGFV-3			
		GFV-3	LGFV-3I			
		V-52	LLIV-1			
		V-52	LPSV-1			
		V-53	LLIV-2			
		V-53	LPSV-2			
		V-54	LLIV-3			
		V-54	LPSV-3			
		V-55	LFIV-1			
		V-55	LPSV-4			
		V-56	LFIV-2			
		V-56	LPSV-5			
		V-57	LFIV-3			
		V-57	LPSV-6			
		G-1	LIOV-38			
		G-2	LIOV-39			
		G-3	LIOV-40			
		G-1	LIFV-38			
		G-2	LIFV-39			
		G-3	LIFV-40			Closed
		G-1	VII-38			OV
		G-2	VII-39			OV
L	7	G-3	VII-40	1	S	OV

Verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	8	GFV-4	LGFV-4I	1	S	Closed
↓	↓	GFV-4	LGFV-4	↓	↓	↓
		GOV-4	LGOV-4I			
		GOV-4	LGOV-4			
		GFV-5	LGFV-5I			
L	8	GFV-5	LGFV-5	1	S	Closed

LAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	8	GOV-5	LGOV-5I	1	S	Closed
		GOV-5	LGOV-5			
		GFV-6	LGFV-6I			
		GFV-6	LGFV-6			
		GOV-6	LGOV-6I			
		GOV-6	LGOV-6			
		V-58	LFIV-4			
		V-59	LPSV-7			
		V-60	LFIV-5			
		V-61	LPSV-8			
		V-62	LFIV-6			
		V-63	LPSV-9			Closed
		G-1	VII-41			OVDC
		G-2	VII-42			
		G-3	VII-43			OVDC
		EFV-1	LEFV-1			Closed
		EFV-2	LEFV-2			
		EFV-3	LEFV-3			
		EFV-4	LEFV-4			
		EFV-5	LEFV-5			
		EFV-6	LEFV-6			
		EFV-7	LEFV-7			
		EFV-8	LEFV-8			
		EFV-9	LEFV-9			
		EFV-10	LEFV-10			
		EFV-11	LEFV-11			
		EFV-12	LEFV-12			Closed
			PfL-11			19 PSIA
			PfL-12			
L	8		PfL-13	1	S	19 PSIA

A/B E.C.-1,2,3 will verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	9	FCA-1	LFIVA/B-1	1	S	Closed
		FCA-1	LCPRV-1			
		FCA-1	LSPV-1			Closed
		IGN-1	VIIA/B-1			OVDC
		FCA-2	LFIVA/B-2			Closed
		FCA-2	LCPRV-2			
		FCA-2	LSPV-2			Closed
		IGN-2	VIIA/B-2			OVDC
		FCA-3	LFIVA/B-3			Closed
		FCA-3	LCPRV-3			
		FCA-3	LSPV-3			Closed
		IGN-3	VIIA/B-3			OVDC

10 Connect helium servicing GSE to each main engine purge accumulator and service with 2000 Psia dry helium.

LAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE

Connect the Propellant-Servicing and Pressurization GSE to the following couplings and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	11	C-1	LOFC-1	1	S	Open
		C-2	LHC-1,2			
		C-3	LFTVC-1			
		C-4	LHC-3,4			
		C-5	LFFC-1			
		C-6	LHC-5,6			
		C-8	LHC-7,8			
		C-9	LOFC-2			
		C-10	LFFC-2			
L	11	C-11	LFVC-1	1	S	Open

Command pre-propellant loading purge sequence of the main engines.

When the main engine controllers indicate "ready for propellants",

command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	12	V-1	LOIV-1	1	S	Closed
		V-2	LOIV-2			Closed
		V-7	LOFV-1			Open
		V-24	LOTVV-1			
L	12	V-25	LOTVV-2	1	S	Open

Command LOX transfer to slow mode.

Verify operations by checking:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	13	L-17	ToL-2	1	S	$<200^{o}R$

When:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	14	T-4	QoT-7	10/sec	C	Covered

Command LOX recirculation helium on at C-2, and command LOX transfer to fast fill.

When:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	15	T-4	QoT-8	10/sec	C	Covered

Command LOX transfer to slow fill and command termination of helium recirculation.

When:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	16	T-4	QoT-9	10/sec	C	Covered

LAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE

Command LOX to mode hold.

Verify:

L	17	T-4	ToT-3	1	S	$164 \pm 3^{o}R$
		L-17	ToL-2			
		L-3	ToS-1			
		L-4	ToS-2			
		L-17	PoL-2			
		L-3	PoS-1			
		L-4	PoS-2			
L	17	L-7	PgRL-1	1	S	

Visually check for leakage with scan cameras.

Commence monitoring for leakage with compartment gas analyzers.

Command and verify:

L	18	V-3	LOVV-1	1	S	Open
		V-4	LOVV-2			
		V-5	LOVV-3			
		V-6	LOVV-4			
		V-1	LOIV-1			Open
L	18	V-23	LOIV-3	1	S	Closed

Command LOX transfer to slow mode.

Verify operation by checking:

L	19		ToL-1	1	S	$< 200^{o}R$

When:

L	20	T-1	QoT-1	10/sec	C	Covered

Command LOX Recirculation helium on at C-2, and command LOX transfer to fast fill.

When:

L	21	T-1	QoT-2	10/sec	C	Covered

Command LOX transfer to slow fill and command termination of helium recirculation.

When:

L	22	T-1	QoT-3	10/sec	C	Covered

LAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE

Command LOX to mode hold.

Verify:

L	23	T-1	ToT-1	1	S	164±3°R
↓	↓		ToL-1	↓	↓	164±3°R
L	23	T-1	PoL-1	1	S	

Command and verify:

L	24	V-1	LOIV-1	1	S	Closed
L	24	V-2	LOIV-2	1	S	Open

Command LOX transfer to slow mode.

Verify operation by checking:

L	25	L-18	ToL-3	1	S	<200°R

When

L	26	T-2	QoT-4	10/sec	C	Covered

Command LOX recirculation helium on at C-2, and command LOX transfer to fast fill.

When:

L	27	T-2	QoT-5	10/sec	C	Covered

Command LOX transfer to slow fill and command termination of helium recirculation.

When:

L	28	T-2	QoT-6	10/sec	C	Covered

Command LOX to mode hold.

Verify:

L	29	T-2	ToT-2	1	S	164±3°R
↓	↓	L-18	ToL-3	↓	↓	164±3°R
L	29	L-18	PoL-3	1	S	

Command and verify:

L	30	V-2	LOIV-2	1	S	Closed
L	30	V-7	LOFV-1	1	S	Closed

LAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
Command and verify:						
L	31	V-44	LOFV-2	1	S	Open
When:						
L	32	T-8	PoT-4	1/sec	S	14.7 PSIA
L	32	T-9	PoT-5	1/sec	S	14.7 PSIA
Commence servicing T-8, 9 with GO2.						
Monitor:						
L	33	T-8	PoT-6	1/sec	C	1500 PSIA
↓	↓	T-8	ToT-4	↓	↓	
↓	↓	T-9	PoT-7	↓	↓	1500 PSIA
L	33	T-9	ToT-5	1/sec	C	
Compute accumulator quantity, and send hold command to GSE at full load.						
Command and verify:						
L	34	V-44	LOFV-2	1	S	Closed
Monitor:						
L	35	T-8	PoT-6	1	M	1500 PSIA
↓	↓	T-8	ToT-4	↓	↓	
↓	↓	T-9	PoT-7	↓	↓	1500 PSIA
L	35	T-9	ToT-5	1	M	
For decay.						
Command and verify:						
L	36	V-70	LFFV-2	1	S	Open
When:						
L	37	T-10	PfT-4	1/sec	S	14.7 PSIA
L	37	T-11	PfT-5	1/sec	S	14.7 PSIA
Commence servicing T-10, 11 with GH2.						
Monitor:						
L	38	T-10	PfT-6	1/sec	C	1500 PSIA
↓	↓	T-10	TfT-4	↓	↓	
↓	↓	T-11	PfT-7	↓	↓	1500 PSIA
L	38	T-11	TfT-5	1/sec	C	

LAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE

Compute accumulator quantity, and send hold command to GSE at full load.

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	39	V-70	LFFV-2	1	S	Closed

Monitor:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	40	T-10	PfT-6	1/sec	M	1500 PSIA
↓	↓	T-10	TfT-4	↓	↓	
↓	↓	T-11	PfT-7	↓	↓	1500 PSIA
L	40	T-11	TfT-5	1/sec	M	

For decay.

Reverify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	41		PoL- 8	1	S	19 PSIA
↓	↓		PoL-9	↓	↓	↓
↓	↓		PfL-9	↓	↓	↓
L	41		PfL-10	1	S	19 PSIA

Connect vents to TR-15 and TR-9.

Connect vents to TR-2 and TR-3.

Verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	42	F-6	PoL-4	1	S	1500 PSIA
↓	↓	F-7	PoL-5	↓	↓	↓
↓	↓	F-8	PfL-5	↓	↓	↓
L	42	F-9	PfL-6	1	S	1500 PSIA

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	43	TR-2	LBIV-2	1	S	Open
↓	↓	TR-2	LMBV-2	↓	↓	↓
↓	↓	TR-2	LIFV-2	↓	↓	↓
↓	↓	TR-2	LIOV-2	↓	↓	↓
↓	↓	TR-3	LBIV-3	↓	↓	↓
↓	↓	TR-3	LMBV-3	↓	↓	↓
↓	↓	TR-3	LIFV-3	↓	↓	↓
↓	↓	TR-3	LIOV-3	↓	↓	↓
↓	↓	TR-9	LBIV-9	↓	↓	↓
↓	↓	TR-9	LMBV-9	↓	↓	↓
↓	↓	TR-9	LIFV-9	↓	↓	↓
↓	↓	TR-9	LIOV-9	↓	↓	↓
↓	↓	TR-15	LBIV-15	↓	↓	↓
↓	↓	TR-15	LMBV-15	↓	↓	↓
↓	↓	TR-15	LIFV-15	↓	↓	↓
L	43	TR-15	LIOV-15	1	S	Open

LAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	44		PoL-8	1/sec A.R.	C	Ambient
↓	↓		PoL-9	↓	↓	↓
			PfL-9			
L	44		PfL-10	1/sec A.R.	C	Ambient

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	45	TR-2	LBIV-2	1	S	Closed
↓	↓	TR-2	LMBV-2	↓	↓	↓
		TR-2	LIFV-2			
		TR-2	LIOV-2			
		TR-3	LBIV-3			
		TR-3	LMBV-3			
		TR-3	LIFV-3			
		TR-3	LIOV-3			
		TR-9	LBIV-9			
		TR-9	LMBV-9			
		TR-9	LIFV-9			
		TR-9	LIOV-9			
		TR-15	LBIV-15			
		TR-15	LMBV-15			
		TR-15	LIFV-15			
L	45	TR-15	LIOV-15	1	S	Closed

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	46	V-36	LOPV-3	1	S	Open
↓	↓	V-38	LOPV-5	↓	↓	↓
		V-40	LFPV-3			
L	46	V-42	LFPV-5	1	S	Open

Verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	47		PoL-6	1	S	375-400 PSIA
↓	↓		PoL-7	↓	↓	↓
			PfL-7			
L	47		PfL-8	1	S	375-400 PSIA

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	48	V-36	LOPV-3	1	S	Closed
↓	↓	V-38	LOPV-5	↓	↓	↓
		V-40	LFPV-3			
L	48	V-42	LFPV-5	1	S	Closed

Repeat steps L-43, 44, 45.

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	49	V-37	LOPV-4	1	S	Open
↓	↓	V-39	LOPV-6	↓	↓	↓
		V-41	LFPV-4			
L	49	V-43	LFPV-6	1	S	Open

LAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
Repeat step L-47.						
Command and verify:						
L	50	V-37	LOPV-4	1	S	Closed
↓	↓	V-39	LOPV-6	↓	↓	↓
		V-41	LFPV-4			
L	50	V-43	LFPV-6	1	S	Closed
Monitor:						
L	51		PoL-6	5/sec	M	375-400 PSIA
↓	↓		PoL-7	↓	↓	↓
			PfL-7			
L	51		PfL-8	5/sec	M	375-400 PSIA
For decay.						
Command and verify:						
L	52	V-36	LOPV-3	1	S	Open
↓	↓	V-37	LOPV-4	↓	↓	↓
		V-38	LOPV-5			
		V-39	LOPV-6			
		V-40	LFPV-3			
		V-41	LFPV-4			
		V-42	LFPV-5			
L	52	V-43	LFPV-6	1	S	Open
Command and verify:						
L	53	TR-1	LBIV-1	1	S	Open
Through:						
L	53	TR-37	LBIV-1	1	S	Open
Verifying:						
L	53		PoL-6	1 samp/step	S	375-400 PSIA
↓	↓		PoL-7	↓	↓	↓
			PfL-7			
L	53		PfL-8	1 samp/step	S	375-400 PSIA
Between each valve opening.						
54. Commence monitoring the pressures of step L-53 at 5 samples/sec.						
Command and verify:						
L	55	V-44	LOFV-2	1	S	Open

LAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
		Top T-8, 9 with GO2 from C-9, until				
L	56	T-8	PoT-6	1/sec	C	1500 PSI
L	56	T-9	PoT-7	1/sec	C	1500 PSI
		Command GSE to Hold, and				
L	57	V-44	LOFV-2	1	S	Closed
L	57	V-70	LFFV-2	1	S	Open
		Top T-10, 11 with GH2 from C-10 until				
L	58	T-10	PfT-6	1/sec	C	1500 PSI
L	58	T-11	PfT-7	1/sec	C	1500 PSI
		Command GSE to hold, and				
L	59	V-70	LFFV-2	1	S	Closed
		Disconnect the GSE vents from TR-2, 3, 9, 15.				
		Command and verify:				
L	60	V-8	LFIV-1	1	S	Closed
↓	↓	V-9	LFIV-2	↓	↓	Closed
↓	↓	V-28	LFTVV-5	↓	↓	Open
↓	↓	V-29	LFTVV-6	↓	↓	↓
↓	↓	V-30	LFTVV-7	↓	↓	↓
↓	↓	V-31	LFTVV-8	↓	↓	↓
L	60	V-14	LFFV-1	1	S	Open
		Command fuel transfer to slow fill.				
		Verify operation by checking:				
L	61	L-20	TfL-1	1	S	<50°R
↓	↓	L-21	TfL-4	↓	↓	↓
L	61		TfL-5	1	S	<50°R
		When both:				
L	62	T-5	QfT-4	10/sec	C	Covered
L	62	T-6	QfT-7	10/sec	C	Covered
		Command helium recirculation from C-8 on, and LH2 transfer to fast fill.				
		When:				
L	63	T-5	QfT-5	10/sec	C	Covered
		Or				
L	63	T-6	QfT-8	10/sec	C	Covered

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<u>LAUNCH</u> (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE

Terminate helium recirculation, and command transfer to slow fill.

When:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	64	T-5	QfT-6	10/sec	C	Covered

Or:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	64	T-6	QfT-9	10/sec	C	Covered

Command fuel transfer to mode hold when the other one covers, or TBD seconds after the first one covers.

65. Monitor compartment analyzers for leakage.
Monitor compartment fire detectors.

Verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	66	T-5	TfT-2	1	S	36-40°R
↓	↓	T-6	TfT-3	↓	↓	↓
		L-20	TfL-1			
		L-21	TfL-4			
		L-8	TfS-1			
		L-9	TfS-2			
		L-8	PfS-1			
L	66	L-9	PfS-2	1	S	

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	67	V-26	LFIV-3	1	S	Closed
↓	↓	V-27	LFIV-4	↓	↓	Closed
		V-8	LFIV-1			Open
		V-9	LFIV-2			↓
L	67	V-(10-13)	LFTVV-(1-4)	1	S	Open

Command fuel transfer to slow fill.

Verify operation by checking:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	68		TfL-2	1	S	$< 50^oR$
L	68		TfL-3	1	S	$<50^oR$

When:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	69	T-3	QfT-1	1	S	Covered

Command helium recirculation on from C-8 and command fuel transfer to fast fill.

When:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	70	T-3	QfT-2	1	S	Covered

LAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
	Terminate helium recirculation, and command fuel transfer to slow fill.					
	When:					
L	71	T-3	QfT-3	1	S	Covered
	Command fuel transfer to mode hold.					
	Verify:					
L	72	T-3	TfT-1	1	S	36-40°R
↓	↓		TfL-2	↓	↓	↓
L	72		TfL-3	1	S	36-40°R
	Command and verify:					
L	73	V-14	LFFV-1	1	S	Closed
	Command and verify:					
L	74	V-1	LOIV-1	1	S	Open
L	74	V-7	LOFV-1	1	S	Open
	Top T-1 until:					
L	75	T-1	QoT-3	10/sec	C	Covered
	Terminate topping.					
	Command and verify:					
L	76	V-1	LOIV-1	1	S	Closed
L	76	V-2	LOIV-2	1	S	Open
	Top T-2 until					
L	77	T-2	QoT-6	10/sec	C	Covered
	Terminate topping.					
	Command and verify:					
L	78	V-2	LOIV-2	1	S	Closed
L	78	V-23	LOIV-3	1	S	Open
	Top T-4 until:					
L	79	T-4	QoT-9	10/sec	C	Covered

LAUNCH (Continued)

Terminate topping.

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	80	V-23	LOIV-3	1	S	Closed
		V-7	LOFV-1			Closed
		V-1	LOIV-1			Open
L	80	V-2	LOIV-2	1	S	Open

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	81	V-14	LFFV-1	1	S	Open

Top T-3 until:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	82	T-3	QfT-3	10/sec	C	Covered

Terminate topping.

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	82	V-8	LFIV-1	1	S	Closed
		V-9	LFIV-2			Closed
		V-26	LFIV-3			Open
L	82	V-27	LFIV-4	1	S	Open

Top T-5, 6 until:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	83	T-5	QfT-6	10/sec	C	Covered
L	83	T-6	QfT-9	10/sec	C	Covered

Terminate topping.

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	84	V-26	LFIV-3	1	S	Closed
		V-27	LFIV-4			Closed
		V-8	LFIV-1			Open
		V-9	LFIV-2			Open
L	84	V-14	LFFV-1	1	S	Closed

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	85	V-3	LOVV-1	1	S	Closed
		V-4	LOVV-2			
		V-5	LOVV-3			
		V-6	LOVV-4			
		V-10	LFTVV-1			
		V-11	LFTVV-2			
		V-12	LFTVV-3			
		V-13	LFTVV-4			
L	85	V-24	LOTVV-1	1	S	Closed

LAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	85	V-25	LOTVV-2	1	S	Closed
↓	↓	V-28	LFTVV-5	↓	↓	↓
		V-29	LFTVV-6			
		V-30	LFTVV-7			
L	85	V-31	LFTVV-8	1	S	Closed
Verify:						
L	86	T-8	PoT-6	1	S	1500 PSIA
↓	↓	T-9	PoT-7	↓	↓	1500 PSIA
L	86	T-4	PoT-3	1	S	<30 PSIA
Command and verify:						
L	87	V-33	LOPV-2	1	S	Open
Verify:						
L	88	T-4	PoT-3	1	S	35-40 PSIA
Command and verify:						
L	89	V-33	LOPV-2	1	S	Closed
Command and verify:						
L	90	V-24	LOTVV-1	1	S	Open
L	90	V-25	LOTVV-2	1	S	Open
Verify:						
L	91	T-4	PoT-3	1	S	Ambient
Command and verify:						
L	92	V-24	LOTVV-1	1	S	Closed
L	92	V-25	LOTVV-2	1	S	Closed
Command and verify:						
L	93	V-32	LOPV-1	1	S	Open
Check:						
L	94	T-4	PoT-3	1	S	35-40 PSIA
Command and verify:						
L	95	V-32	LOPV-1	1	S	Closed

LAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
Monitor:						
L	96	T-4	PoT-3	1/sec	M	35-40 PSIA
For decay.						
Verify:						
L	97	T-10	PfT-6	1	S	1500 PSIA
↓	↓	T-11	PfT-7	↓	↓	1500 PSIA
↓	↓	T-5	PfT-2	↓	↓	< 30 PSIA
L	97	T-6	PfT-3	1	S	<30 PSIA
Command and verify:						
L	98	V-34	LFPV-1	1	S	Open
Verify:						
L	99	T-5	PfT-2	1	S	35-40 PSIA
L	99	T-6	PfT-3	1	S	35-40 PSIA
Command and verify						
L	100	V-34	LFPV-1	1	S	Closed
Command and verify:						
L	101	V-28	LFTVV-5	1	S	Open
↓	↓	V-29	LFTVV-6	↓	↓	↓
↓	↓	V-30	LFTVV-7	↓	↓	↓
L	101	V-31	LFTVV-8	1	S	Open
Verify:						
L	102	T-5	PfT-2	1	S	Ambient
L	102	T-6	PfT-3	1	S	Ambient
Command and verify:						
L	103	V-28	LFTVV-5	1	S	Closed
↓	↓	V-29	LFTVV-6	↓	↓	↓
↓	↓	V-30	LFTVV-7	↓	↓	↓
L	103	V-31	LFTVV-8	1	S	Closed
Command and verify:						
L	104	V-35	LFPV-2	1	S	Open
Verify:						
L	105	T-5	PfT-2	1	S	35-40 PSIA
L	105	T-6	PfT-3	1	S	35-40 PSIA

LAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
Command and verify:						
L	106	V-35	LFPV-2	1	S	Closed
Monitor:						
L	107	T-5	PfT-2	1/sec	M	35-40 PSIA
L	107	T-6	PfT-3	1/sed	M	35-40 PSIA
For decay. If none, command and verify:						
L	108	V-32	LOPV-1	1	S	Open
↓	↓	V-33	LOPV-2	↓	↓	↓
↓	↓	V-34	LFPV-1	↓	↓	↓
L	108	V-35	LFPV-2	1	S	Open
Command Pressurization of T-1 and T-2 with helium from C-6 until:						
L	109	T-1	PoT-1	10/sec	C	35-40 PSIA
L	109	T-2	PoT-2	10/sec	C	35-40 PSIA
Terminate pressurization from C-6. Continue Monitoring:						
L	110	T-1	PoT-1	10/sec	M	35-40 PSIA
L	110	T-2	PoT-2	10/sec	M	35-40 PSIA
For decay. Command pressurization T-3 with helium from C-4, until						
L	111	T-3	PfT-1	10/sec	C	35-40 PSIA
Terminate pressurization from C-4. Continue monitoring:						
L	112	T-3	PfT-1	10/sec	M	35-40 PSIA

for decay.

113. Repeat steps L-55 through L-59. (Top gas accumulators, T-8,9,10, 11.)

Load and pressurization complete.

LAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE

Commence monitoring:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	114	T-8	PoT-6	1/sec	S	1500 PSIA
↓	↓	T-8	ToT-4	↓	↓	
		T-9	PoT-7			1500 PSIA
		T-9	ToT-5			
		T-10	PfT-6			1500 PSIA
		T-10	TfT-4			
		T-11	PfT-7			1500 PSIA
L	114	T-11	TfT-5	1/sec	S	

Compute and display accumulator quantity on request.

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	115	GOV-1	LGOV-1I	1	S	Open
↓	↓	GOV-2	LGOV-2I	↓	↓	↓
		GOV-3	LGOV-3I			
		GFV-1	LGFV-1I			
		GFV-2	LGFV-2I			
		GFV-3	LGFV-3I			
		V-52	LLIV-1			
		V-53	LLIV-2			
		V-54	LLIV-3			
		V-55	LFIV-1			
		V-56	LFIV-2			
L	115	V-57	LFIV-3	1	S	Open

Command the APU shaft clutches to engage on all three sections.

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	116	G-1	VII-38	1	S	28 VDC
↓	↓	G-2	VII-39	↓	↓	↓
L	116	G-3	VII-40	1	S	28 VDC

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	117	G-1	LIOV-38	1	S	Open

Initiate igniter spark, verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	118	G-1	IIE-38	1	S	Pulses
L	118	G-1	PC-38	1	S	

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	119	G-1	LIFV-38	1	S	Open
L	119	G-1	PC-38	1	S	

LAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
Command and verify:						
L	120	GOV-1	LGOV-1	1	S	Open
L	120	G-1	PC-38	1	S	
Command and verify:						
L	121	GFV-1	LGFV-1	1	S	Open
L	121	G-1	PC-38	1	S	
Check:						
L	122	G-1	TC-1	1	S	
↓	↓	U-1	NT-1	2/sec	C	
↓	↓	PT-1	QPTL-1	1	S	
↓	↓	PT-1	QPTL-1	↓	↓	
L	122	PT-1	TPTL-1	1	S	
L	122	PT-1	NS-1	1	S	
When NT-1 reaches steady-state, command igniter sparkoff, and verify:						
L	123	G-1	IIE-38	1	S	OADC
Command and verify:						
L	124	G-2	LIOV-39	1	S	Open
Initiate igniter spark, verify:						
L	125	G-2	IIE-39	1	S	Pulses
L	125	G-2	PC-39	1	S	
Command and verify:						
L	126	G-2	LIFV-39	1	S	Open
L	126	G-2	PC-39	1	S	
Command and verify:						
L	127	GOV-2	LGOV-2	1	S	Open
L	127	G-2	PC-39	1	S	
Command and verify:						
L	128	GFV-2	LGFV-2	1	S	Open
L	128	G-2	PC-39	1	S	
Check:						
L	129	G-2	TC-2	1	S	
↓	↓	U-2	NT-2	2/sec	C	
↓	↓	PT-2	NS-2	1	S	
↓	↓	PT-2	QPTL-2	↓	↓	
↓	↓	PT-2	PPTL-2	↓	↓	
L	129	PT-2	TPTL-2	1	S	

LAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE

When NT-2 reaches steady-state, command igniter spark off, and verify:

L	130	G-2	IIE-39	1	S	OADC

Command and verify:

L	131	G-3	LIOV-40	1	S	Open

Initiate igniter spark; verify:

L	132	G-3	IIE-40	1	S	Pulses
L	132	G-3	PC-40	1	S	

Command and verify:

L	133	G-3	LIFV-40	1	S	Open
L	133	G-3	PC-40	1	S	

Command and verify:

L	134	GOV-3	LGOV-3	1	S	Open
L	134	G-3	PC-40	1	S	

Command and verify:

L	135	GFV-3	LGFV-3	1	S	Open
L	135	G-3	PC-40	1	S	

Check:

L	136	G-3	TC-3	1	S	
↓	↓	U-3	NT-3	2/sec	C	
↓	↓	PT-3	NS-3	1	S	
↓	↓	PT-3	QPTL-3	↓	↓	
↓	↓	PT-3	PPTL-3	↓	↓	
L	136	PT-3	TPTL-3	1	S	

When NT-3 reaches steady-state, command igniter spark off, verify:

L	137	G-3	IIE-40	1	S	OADC

Commence monitoring:

L	138	G-1	PC-38	1/sec	M	
↓	↓	G-1	TC-1	1/sec	↓	
↓	↓	U-1	NT-1	2/sec	↓	
↓	↓	PT-1	QPTL-1	1/2 sec	↓	
↓	↓	PT-1	PPTL-1	1/2 sec	↓	
↓	↓	PT-1	TPTL-1	1/2 sec	↓	
↓	↓	PT-1	NS-1	1/2 sec	↓	
↓	↓	G-2	PC-39	1/sec	↓	
↓	↓	G-2	TC-2	1/sec	↓	
L	138	U-2	NT-2	2/sec	M	
L	138	PT-2	TPTL-2	1/2 sec	M	

LAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	138	PT-2	QPTL-2	1/2sec	M	
↓	↓	PT-2	PPTL-2	1/2sec	↓	
		PT-2	NS-2	1/2sec		
		G-3	PC-40	1/sec		
		G-3	TC-3	1/sec		
		U-3	NT-3	2/sec		
		PT-3	QPTL-3	1/2sec		
		PT-3	PPTL-3	1/2sec		
		PT-3	TPTL-3	1/2sec		
L	138	PT-3	NS-3	1/2sec	M	

139 Verify vehicle power.

140 Execute power transfer.

141 Disconnect all remaining GSE.

Take final status.

Verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	142	V-1	LOIV-1	1	S	Open
↓	↓	V-2	LOIV-2	↓	↓	Open
		V-3	LOVV-1			Closed
		V-4	LOVV-2			↓
		V-5	LOVV-3			
		V-6	LOVV-4			
		V-7	LOFV-1			Closed
		V-8	LFIV-1			Open
		V-9	LFIV-2			Open
		V-10	LFTVV-1			Closed
		V-11	LFTVV-2			↓
		V-12	LFTVV-3			
		V-13	LFTVV-4			
		V-14	LFFV-1			
		V-19	LOPCV-1			
		V-20	LOPCV-2			
		V-21	LFPCV-1			
		V-22	LFPCV-2			
		V-23	LOIV-3			
		V-24	LOTVV-1			
		V-25	LOTVV-2			
		V-26	LFIV-3			
		V-27	LFIV-4			
		V-28	LFTVV-5			
		V-29	LFTVV-6			
		V-30	LFTVV-7			Closed
		V-31	LFTVV-8			Closed
		V-32	LOPV-1			Open
		V-33	LOPV-2			↓
		V-34	LFPV-1			
L	142	V-35	LFPV-2	I	S	Open

LAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	142	C-1	LOFC-1	1	S	Closed
		C-2	LHC-1,2			
		C-3	LFTVC-1			
		C-4	LHC-3,4			
		C-5	LFFC-1			
		C-6	LHC-5,6			
		C-8	LHC-7,8			
		C-11	LFVC-1			Closed
		T-3	PfT-1			35-40 PSIA
		T-3	QfT-2			
		T-3	QfT-3			
		T-1	PoT-1			35-40 PSIA
		T-1	ToT-1			164±3°R
		T-1	QoT-1			Covered
		T-1	QoT-2			
		T-1	QoT-3			Covered
		T-2	PoT-2			35-40 PSIA
		T-2	ToT-2			164±3°R
		T-2	QoT-4			Covered
		T-2	QoT-5			
		T-2	QoT-6			Covered
		T-4	PoT-3			35-40 PSIA
		T-4	ToT-3			164±3°R
		T-4	QoT-7			Covered
		T-4	QoT-8			
		T-4	QoT-9			Covered
		T-5	PfT-2			35-40 PSIA
		T-5	TfT-2			36-40°R
		T-5	QfT-4			Covered
		T-5	QfT-5			
		T-5	QfT-6			Covered
		T-6	PfT-3			35-40 PSIA
		T-6	TfT-3			36-40°R
		T-6	QfT-7			Covered
		T-6	QfT-8			
		T-6	QfT-9			
			PoL-1			
		L-17	PoL-2			
		L-18	PoL-3			
			ToL-1			164±3°R
		L-17	ToL-2			
		L-18	ToL-3			
			ToL-4			
		L-20	PfL-1			
			PfL-2			
			PfL-3			
		L-21	PfL-4			
		L-20	TfL-1			36-40°R
			TfL-2			
L	142		TfL-3	1	S	36-40°R
L	142	T-3	TfT-1	1	S	36-40°R
L	142	T-3	QfT-1	1	S	Covered

LAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	142	L-21	TfL-4	1	S	36-40°R
			TfL-5			36-40°R
		L-3	PoS-1			
		L-4	PoS-2			
		L-3	ToS-1			164 ± 3°R
		L-4	ToS-2			164 ± 3°R
		L-8	PfS-1			
		L-9	PfS-2			
		L-8	TfS-1			36-40°R
		L-9	TfS-2			36-40°R
		C-5	PfF-1			
		C-1	PoF-1			
		L-14	PgF-1			
		0-5	PgF-2			
		L-16	PgF-3			
		L-13	Pg0-1			
		0-3	Pg0-2			
		L-15	Pg0-3			
		L-7	PgRL-1			
		L-14	TgF-1			
		L-14	TgF-2			
		L-13	Tg0-1			
L	142	L-13	Tg0-2	1	S	

and:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	143	C-9	LOFC-2	1	S	Closed
		C-10	LFFC-2			
		V-44	LOFV-2			
L	143	V-70	LFFV-2	1	S	Closed

and:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	144	GOV-4	LGOV-4I	1	S	Closed
		GOV-4	LGOV-4			
		GOV-5	LGOV-5I			
		GOV-5	LGOV-5			
		GOV-6	LGOV-6I			
		GOV-6	LGOV-6			
		GFV-4	LGFV-4I			
		GFV-4	LGFV-4			
		GFV-5	LGFV-5I			
		GFV-5	LGFV-5			
		GFV-6	LGFV-6I			
		GFV-6	LGFV-6			
		V-58	LFIV-4			
		V-59	LPSV-7			
		V-60	LFIV-5			
		V-61	LPSV-8			
L	144	V-62	LFIV-6	1	S	Closed

LAUNCH (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
L	144	V-63	LPSV-9	1	S	Closed
↓	↓	EFV-1	LEFV-1	↓	↓	↓
↓	↓	EFV-2	LEFV-2	↓	↓	↓
↓	↓	EFV-3	LEFV-3	↓	↓	↓
↓	↓	EFV-4	LEFV-4	↓	↓	↓
↓	↓	EFV-5	LEFV-5	↓	↓	↓
↓	↓	EFV-6	LEFV-6	↓	↓	↓
↓	↓	EFV-7	LEFV-7	↓	↓	↓
↓	↓	EFV-8	LEFV-8	↓	↓	↓
↓	↓	EFV-9	LEFV-9	↓	↓	↓
↓	↓	EFV-10	LEFV-10	↓	↓	↓
↓	↓	EFV-11	LEFV-11	↓	↓	↓
↓	↓	EFV-12	LEFV-12	↓	↓	Closed
↓	↓		PfL-11	↓	↓	20 PSIA
↓	↓		PfL-12	↓	↓	↓
L	144		PfL-13	1	S	20 PSIA

145 Command the main and turbofan engine controllers to take final status.

BOOST

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
Verify readiness:						
B	1	V-1	LOIV-1	1	S	Open
		V-2	LOIV-2			Open
		V-3	LOVV-1			Closed
		V-4	LOVV-2			
		V-5	LOVV-3			
		V-6	LOVV-4			
		V-7	LOFV-1			Closed
		V-8	LFIV-1			Open
		V-9	LFIV-2			Open
		V-10	LFTVV-1			Closed
		V-11	LFTVV-2			
		V-12	LFTVV-3			
		V-13	LFTVV-4			
		V-14	LFFV-1			
		V-19	LOPCV-1			
		V-20	LOPCV-2			
		V-21	LFPCV-1			
		V-22	LFPCV-2			
		V-23	LOIV-3			
		V-24	LOTVV-1			
		V-25	LOTVV-2			
		V-26	LFIV-3			
		V-27	LFIV-4			
		V-28	LFTVV-5			
		V-29	LFTVV-6			
		V-30	LFTVV-7			
		V-31	LFTVV-8			Closed
		V-32	LOPV-1			Open
		V-33	LOPV-2			
		V-34	LFPV-1			
		V-35	LFPV-2			Open
		C-1	LOFC-1			Closed
		C-2	LHC-1,2			
		C-3	LFTVC-1			
		C-4	LHC-3,4			
		C-5	LFFC-1			
		C-6	LHC-5,6			
		C-8	LHC-7,8			
		C-11	LFVC-1			Closed
		T-3	PfT-1			35-40 PSIA
		T-3	TfT-1			36-40°R
		T-3	QfT-1			Covered
		T-3	QfT-2			
		T-3	QfT-3			Covered
		T-1	PoT-1			35-40 PSIA
		T-1	ToT-1			164±3°R
		T-1	QoT-1			Covered
		T-1	QoT-2			
B	1	T-1	QoT-3	1	S	Covered

BOOST (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
B	1	T-2	PoT-2	1	S	35-40 PSIA
		T-2	ToT-2			$164\pm3^{\circ}R$
		T-2	QoT-4			Covered
		T-2	QoT-5			↓
		T-2	QoT-6			Covered
		T-4	PoT-3			35-40 PSIA
		T-4	ToT-3			$164\pm3^{\circ}R$
		T-4	QoT-7			Covered
		T-4	QoT-8			↓
		T-4	QoT-9			Covered
		T-5	PfT-2			35-40 PSIA
		T-5	TfT-2			$36-40^{\circ}R$
		T-5	QfT-4			Covered
		T-5	QfT-5			↓
		T-5	QfT-6			Covered
		T-6	PfT-3			35-40 PSIA
		T-6	TfT-3			$36-40^{\circ}R$
		T-6	QfT-7			Covered
		T-6	QfT-8			↓
		T-6	QfT-9			Covered
			PoL-1			
		L-17	PoL-2			
		L-18	PoL-3			
			ToL-1			$164\pm3^{\circ}R$
		L-17	ToL-2			↓
		L-18	ToL-3			↓
			ToL-4			$164\pm3^{\circ}R$
		L-20	PfL-1			
			PfL-2			
			PfL-3			
		L-21	PfL-4			
		L-20	TfL-1			$36-40^{\circ}R$
		L-21	TfL-4			↓
			TfL-5			$36-40^{\circ}R$
		L-3	PoS-1			
		L-4	PoS-2			
		L-3	ToS-1			$164\pm3^{\circ}R$
		L-4	ToS-2			$164\pm3^{\circ}R$
		L-8	PfS-1			
		L-9	PfS-2			
		L-8	TfS-1			$36-40^{\circ}R$
		L-9	TfS-2			$36-40^{\circ}R$
		C-5	PfF-1			
		C-1	PoF-1			
		L-14	PgF-1			
		0-5	PgF-2			
		L-16	PgF-3			
		L-13	PgO-1			
↓	↓	0-3	PgO-2	↓	↓	
B	1	L-15	PgO-3	1	S	

BOOST (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
B	1	L-7	PgRL-1	1	S	
↓	↓	L-14	TgF-1	↓	↓	
		L-14	TgF-2			
		L-13	TgO-1			
B	1	L-13	TgO-2	1	S	

Continue to monitor:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
B	2		PoL-6	5/sec	M	375-400 PSIA
↓	↓		PoL-7	↓	↓	↓
			PfL-7			
B	2		PfL-8	5/sec	M	375-400 PSIA

Continue to monitor:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
B	3	T-8	PoT-6	1/sec	S	1500 PSIA
↓	↓	T-8	ToT-4	↓	↓	
		T-9	PoT-7			1500 PSIA
		T-9	ToT-5			
		T-10	PfT-6			1500 PSIA
		T-10	TfT-4			
		T-11	PfT-7			1500 PSIA
B	3	T-11	TfT-5	1/sec	S	

Continue to monitor:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
B	4	G-1	PC-38	1/sec	M	
↓	↓	G-1	TC-1	1/sec	↓	
		U-1	NT-1	2/sec		
		PT-1	QPTL-1	1/2 sec		
		PT-1	PPTL-1	1/2 sec		
		PT-1	TPTL-1	1/2 sec		
		PT-1	NS-1	1/2 sec		
		G-2	PC-39	1/sec		
		G-2	TC-2	1/sec		
		U-2	NT-2	2/sec		
		PT-2	QPTL-2	1/2 sec		
		PT-2	PPTL-2	1/2 sec		
		PT-2	TPTL-2	1/2 sec		
		PT-2	NS-2	1/2 sec		
		G-3	PC-40	1/sec		
		G-3	TC-3	1/sec		
		U-3	NT-3	2/sec		
		PT-3	QPTL-3	1/2 sec		
		PT-3	PPTL-3	1/2 sec		
		PT-3	TPTL-3	1/2 sec		
B	4	PT-3	NS-3	1/2 sec	M	

5. At T+153 seconds, command extension of main engine nozzles.

SEPARATION (T+173 sec)

1. The CCC commands main engine start.

   At FS + 0.9 seconds, the main engine igniters are turned off.

   At Pc = 90%, the main engine gimbal actuators are unlocked.

   At TBD, command and verify.

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
S	2	V-19	LOPCV-1	1	S	Open
↓	↓	V-20	LOPCV-2	↓	↓	↓
↓	↓	V-21	LFPCV-1	↓	↓	↓
S	2	V-22	LFPCV-2	1	S	Open

In addition to the main engine data, monitor.

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
S	3	T-3	PfT-1	10/sec	M	35-40 PSIA
↓	↓	T-3	TfT-1	1/sec	M	36-40°R
↓	↓	T-3	QfT-2	10/sec	S	C/U
↓	↓	T-3	QfT-1	10/sec	C	C/U
↓	↓	T-1	PoT-1	10/sec	M	35-40 PSIA
↓	↓	T-1	ToT-1	1/sec	M	164±3°R
↓	↓	T-1	QoT-2	10/sec	S	C/U
↓	↓	T-1	QoT-1	10/sec	C	C/U
↓	↓	T-2	PoT-2	10/sec	M	35-40 PSIA
↓	↓	T-2	ToT-2	1/sec	M	164±3°R
↓	↓	T-2	QoT-5	10/sec	S	C/U
↓	↓	T-2	QoT-4	10/sec	C	C/U
↓	↓	L-8	PfS-1	20/sec	M	
↓	↓	L-9	PfS-2	20/sec	↓	
↓	↓	L-8	TfS-1	1/sec	↓	36-40°R
↓	↓	L-9	TfS-2	1/sec	↓	36-40°R
↓	↓	L-3	PoS-1	20/sec	↓	
↓	↓	L-4	PoS-2	20/sec	↓	
↓	↓	L-3	ToS-1	1/sec	↓	164±3°R
S	3	L-4	ToS-2	1/sec	M	164±3°R

Continue to monitor:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
S	4		PoL-6	5/sec	M	375-400 PSIA
↓	↓		PoL-7	↓	↓	↓
↓	↓		PfL-7	↓	↓	↓
S	4		PfL-8	5/sec	M	375-400 PSIA

Continue to monitor:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
S	5	T-8	PoT-6	1/sec	S	1500 PSIA
↓	↓	T-8	ToT-4	↓	↓	
↓	↓	T-9	PoT-7	↓	↓	1500 PSIA
↓	↓	T-9	ToT-5	↓	↓	
↓	↓	T-10	PfT-6	↓	↓	1500 PSIA
↓	↓	T-10	TfT-4	↓	↓	
↓	↓	T-11	PfT-7	↓	↓	1500 PSIA
S	5	T-11	TfT-5	1/sec	S	

SEPARATION (Continued)

Continue to monitor:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
S	6	G-1	PC-38	1/sec	M	
		G-1	TC-1	1/sec		
		U-1	NT-1	2/sec		
		PT-1	QPTL-1	1/2 sec		
		PT-1	PPTL-1	1/2 sec		
		PT-1	TPTL-1	1/2 sec		
		PT-1	NS-1	1/2 sec		
		G-2	PC-39	1/sec		
		G-2	TC-2	1/sec		
		U-2	NT-2	2/sec		
		PT-2	QPTL-2	1/2 sec		
		PT-2	PPTL-2	1/2 sec		
		PT-2	TPTL-2	1/2 sec		
		PT-2	NS-2	1/2 sec		
		G-3	PC-40	1/sec		
		G-3	TC-3	1/sec		
		U-3	NT-3	2/sec		
		PT-3	QPTL-3	1/2 sec		
		PT-3	PPTL-3	1/2 sec		
		PT-3	TPTL-3	1/2 sec		
S	6	PT-3	NS-3	1/2 sec	M	

ASCENT

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE

When:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
A	1	T-1	QoT-2	10/sec	S	UNC
A	1	T-2	QoT-5	10/sec	S	UNC
A	1	T-3	QfT-2	10/sec	S	UNC

The central computer makes an update of the engine cutoff prediction.

In addition to the main engine data, continue to monitor:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
A	2	T-3	PfT-1	10/sec	M	35-40 PSIA
↓	↓	T-3	TfT-1	1/sec	M	36-40°R
		T-3	QfT-2	10/sec	S	C/U
		T-3	QfT-1	10/sec	C	C/U
		T-1	PoT-1	10/sec	M	35-40 PSIA
		T-1	ToT-1	1/sec	M	164±3°R
		T-1	QoT-2	10/sec	S	C/U
		T-1	QoT-1	10/sec	C	C/U
		T-2	PoT-2	10/sec	M	35-40 PSIA
		T-2	ToT-2	1/sec	M	164±3°R
		T-2	QoT-5	10/sec	S	C/U
		T-2	QoT-4	10/sec	C	C/U
		L-8	PfS-1	20/sec	M	
		L-9	PfS-2	20/sec	↓	
		L-8	TfS-1	1/sec		36-40°R
		L-9	TfS-2	1/sec		36-40°R
		L-3	PoS-1	20/sec		
		L-4	PoS-2	20/sec		
		L-3	ToS-1	1/sec		164±3°R
A	2	L-4	ToS-2	1/sec	M	164±3°R

3. When the 4g limit is reached, command the main engines to MPL.

4. At T + 200 seconds, command the RCS thermal protective doors open.

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
A	5	TR-(1-37)	VII-(1-37)	1	S	28 VDC
A	5	TR-(1-37)	IIE-(1-37)	1	S	0 ADC

Continue to monitor:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
A	6		PoL-6	5/sec	M	375-400 PSIA
↓	↓		PoL-7	↓	↓	↓
			PfL-7			
A	6		PfL-8	5/sec	M	375-400 PSIA

ASCENT (Continued)

Continue to monitor:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
A	7	T-8	PoT-6	1/sec	S	1500 PSIA
		T-8	ToT-4			
		T-9	PoT-7			1500 PSIA
		T-9	ToT-5			
		T-10	PfT-6			1500 PSIA
		T-10	TfT-4			
		T-11	PfT-7			1500 PSIA
A	7	T-11	TfT-5	1/sec	S	

Continue to monitor:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
A	8	G-1	PC-38	1/sec	M	
		G-1	TC-1	1/sec		
		U-1	NT-1	2/sec		
		PT-1	QPTL-1	1/2 sec		
		PT-1	PPTL-1	1/2 sec		
		PT-1	TPTL-1	1/2 sec		
		PT-1	NS-1	1/2 sec		
		G-2	PC-39	1/sec		
		G-2	TC-2	1/sec		
		U-2	NT-2	2/sec		
		PT-2	QPTL-2	1/2 sec		
		PT-2	PPTL-2	1/2 sec		
		PT-2	TPTL-2	1/2 sec		
		PT-2	NS-2	1/2 sec		
		G-3	PC-40	1/sec		
		G-3	TC-3	1/sec		
		U-3	NT-3	2/sec		
		PT-3	QPTL-3	1/2 sec		
		PT-3	PPTL-3	1/2 sec		
		PT-3	TPTL-3	1/2 sec	M	
A	8	PT-3	NS-3	1/2 sec		

When:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
A	9	T-1	QoT-1	10/sec	S	UNC
A	9	T-2	QoT-4	10/sec	S	UNC

A shutdown command is sent to the main engine controllers.

(nominally T + 357 sec.)

Conduct Post-Shutdown monitoring checks on the main engines and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
A	10	V-1	LOIV-1	1	S	Open
		V-2	LOIV-2			Open
		V-3	LOVV-1			Closed
		V-4	LOVV-2			
		V-5	LOVV-3			
		V-6	LOVV-4			
A	10	V-7	LOFV-1	1	S	Closed

ASCENT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
A	10	V-8	LFIV-1	1	S	Open
		V-9	LFIV-2			Open
		V-10	LFTVV-1			Closed
		V-11	LFTVV-2			
		V-12	LFTVV-3			
		V-13	LFTVV-4			
		V-14	LFFV-1			Closed
		V-19	LOPCV-1			Open
		V-20	LOPCV-2			
		V-21	LFPCV-1			
		V-22	LFPCV-2			Open
		V-23	LOIV-3			Closed
		V-24	LOTVV-1			
		V-25	LOTVV-2			
		V-26	LFIV-3			
		V-27	LFIV-4			
		V-28	LFTVV-5			
		V-29	LFTVV-6			
		V-30	LFTVV-7			
		V-31	LFTVV-8			Closed
		V-32	LOPV-1			Open
		V-33	LOPV-2			
		V-34	LFPV-1			
		V-35	LFPV-2			Open
		C-1	LOFC-1			Closed
		C-2	LHC-1, 2			
		C-3	LFTVC-1			
		C-4	LHC-3, 4			
		C-5	LFFC-1			
		C-6	LHC-5, 6			
		C-8	LHC-7, 8			
A	10	C-11	LFVC-1	1	S	Closed

ON-ORBIT

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
0-0	1	V-1	LOIV-1	1	S	Closed
		V-2	LOIV-2			
		V-8	LFIV-1			
0-0	1	V-9	LFIV-2	1	S	Closed

2. Retract the main engine nozzles.

3. Command the main engines secure.

Commence monitoring:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
0-0	4	V-1	LOIV-1	1/hr	S	Closed
		V-2	LOIV-2			
		V-3	LOVV-1			
		V-4	LOVV-2			
		V-5	LOVV-3			
		V-6	LOVV-4			
		V-7	LOFV-1			
		V-8	LFIV-1			
		V-9	LFIV-2			
		V-10	LFTVV-1			
		V-11	LFTVV-2			
		V-12	LFTVV-3			
		V-13	LFTVV-4			
		V-14	LFFV-1			
		V-19	LOPCV-1			
		V-20	LOPCV-2			
		V-21	LFPCV-1			
		V-22	LFPCV-2			
		V-23	LOIV-3			
		V-24	LOTVV-1			
		V-25	LOTVV-2			
		V-26	LFIV-3			
		V-27	LFIV-4			
		V-28	LFTVV-5			
		V-29	LFTVV-6			
		V-30	LFTVV-7			
		V-31	LFTVV-8			Closed
		V-32	LOPV-1			Open
		V-33	LOPV-2			
		V-34	LFPV-1			
		V-35	LFPV-2			Open
		C-1	LOFC-1			Closed
		C-2	LHC-1, 2			
		C-3	LFTVC-1			
		C-4	LHC-3, 4			
		C-5	LFFC-1			
		C-6	LHC-5, 6			
		C-8	LHC-7, 8			
0-0	4	C-11	LFVC-1	1/hr	S	Closed

ON-ORBIT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
0-0	4	T-1	PoT-1	1/hr	S	19 PSIA
		T-2	PoT-2			19 PSIA
		T-3	PfT-1			19 PSIA
		L-8	PfS-1			< X
		L-9	PfS-2			
		L-3	PoS-1			
		L-4	PoS-2			
		C-5	PfF-1			
0-0	4	C-1	PoF-1	1/hr	S	< X

Commence monitoring:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
0-0	5	T-4	PoT-3	1/sec	S	35-40 PSIA
		T-4	ToT-3	1/sec A.R.		$164 \pm 3^{\circ}R$
		T-4	QoT-7 *	10/sec A.R.		C/U
		T-4	QoT-8 *	10/sec A.R.		C/U
		T-4	QoT-9 *	10/sec A.R.		C/U
		T-5	PfT-2	1/sec		35-40 PSIA
		T-5	TfT-2	1/sec A.R.		$36-40^{\circ}R$
		T-5	QfT-4 *	10/sec A.R.		C/U
		T-5	QfT-5 *	10/sec A.R.		C/U
		T-5	QfT-6 *	10/sec A.R.		C/U
		T-6	PfT-3	1/sec		35-40 PSIA
		T-6	TfT-3	1/sec A.R.		$36-40^{\circ}R$
		T-6	QfT-7 *	10/sec A.R.		C/U
		T-6	QfT-8 *	10/sec A.R.		C/U
0-0	5	T-6	QfT-9 *	10/sec A.R.	S	C/U

* While accelerating in the proper attitude.

When required to perform an RCS burn, verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
0-0	6	TR-X	LBIV-X	1	S	Open

Initiate igniter spark, verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
0-0	7	TR-X	VII-X	1	S	28 VDC
0-0	7	TR-X	IIE-X	1	S	Pulses

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
0-0	8	TR-X	LIOV-X	1	S	Open
0-0	8	TR-X	PC-X	1	S	

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
0-0	9	TR-X	LIFV-X	1	S	Open
0-0	9	TR-X	PC-X	1	S	

ON-ORBIT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE

For small bit impulses, this would be the end of the thruster start sequence. For larger burns, command and verify:

0-0	10	TR-X	LMBV-X	1	S	Open
0-0	10	TR-X	PC-X	A.R.	S	

At steady-state terminate igniter spark, verify:

0-0	11	TR-X	IIE-X	1	S	0 ADC

During burn, monitor:

0-0	12	TR-X	PC-X	10/sec	S	300 PSIA

To shutdown, command and verify:

0-0	13	TR-X	LMBV-X	1	S	Closed
↓	↓	TR-X	LIOV-X	↓	↓	Closed
		TR-X	LIFV-X			Closed
0-0	13	TR-X	PC-X	1	S	Ambient

Continue to monitor:

0-0	14		PoL-6	5/sec	S	375-400 PSIA
↓	↓		PoL-7	↓	↓	↓
			PfL-7			
0-0	14		PfL-8	5/sec	S	375-400 PSIA

Continue to monitor:

0-0	15	T-8	PoT-6	1/sec	C	1500 PSIA
↓	↓	T-8	ToT-4	↓	S	
		T-9	PoT-7		C	1500 PSIA
		T-9	ToT-5		S	
		T-10	PfT-6		C	1500 PSIA
		T-10	TfT-4		S	
		T-11	PfT-7		C	1500 PSIA
0-0	15	T-11	TfT-5	1/sec	S	

When:

0-0	16	T-8	PoT-6	1/sec	C	1500-X PSIA

Or:

0-0	17	T-9	PoT-7	1/sec	C	1500-X PSIA

Verify:

0-0	18	V-52	LLIV-1	1	S	Open
0-0	18	V-53	LLIV-2	1	S	Open
0-0	18	V-54	LLIV-3	1	S	Open

ON-ORBIT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE

Command and verify:

0-0	19	V-52	LPSV-1	1	S	Open
0-0	19	V-53	LPSV-2	1	S	Open
0-0	19	V-54	LPSV-3	1	S	Open

Engage the clutches to P-1, 2, 3.

During G02 resupply, monitor the following additional parameters:

0-0	20	P-1	PPD-1	2/sec	S	1500 PSIA
		H-4	THE-1	1/2 sec		
		H-4	PHEO-1	1/2 sec		1500 PSIA
		P-2	PPD-2	2/sec		1500 PSIA
		H-5	THE-2	1/2 sec		
		H-5	PHEO-2	1/2 sec		1500 PSIA
		P-3	PPD-3	2/sec		1500 PSIA
		H-6	THE-3	1/2 sec		
0-0	20	H-6	PHEO-3	1/2 sec	S	1500 PSIA

When:

0-0	21	T-8	PoT-6	1/sec	C	1500 PSIA
0-0	21	T-9	PoT-7	1/sec	C	1500 PSIA

Disengage the clutches to P-1, 2, 3.

Discontinue resupply monitors.

Command and verify:

0-0	22	V-52	LPSV-1	1	S	Closed
0-0	22	V-53	LPSV-2	1	S	Closed
0-0	22	V-54	LPSV-3	1	S	Closed

When:

0-0	23	T-10	PfT-6	1/sec	C	1500-X PSIA

Or:

0-0	24	T-11	PfT-7	1/sec	C	1500-X PSIA

Verify:

0-0	25	V-55	LFIV-1	1	S	Open
0-0	25	V-56	LFIV-2	1	S	Open
0-0	25	V-57	LFIV-3	1	S	Open

ON-ORBIT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
Command and verify:						
0-0	26	V-55	LPSV-4	1	S	Open
0-0	26	V-56	LPSV-5	1	S	Open
0-0	26	V-57	LPSV-6	1	S	Open
Engage the clutches to P-4, 5, 6.						
During GH2 resupply, monitor the following additional parameters:						
0-0	27	P-4	PPD-4	2/sec	S	1500 PSIA
↓	↓	H-7	THE-4	1/2 sec	↓	
		H-7	PHEO-4	1/2 sec		1500 PSIA
		P-5	PPD-5	2/sec		1500 PSIA
		H-8	THE-5	1/2 sec		
		H-8	PHEO-5	1/2 sec		1500 PSIA
		P-6	PPD-6	2/sec		1500 PSIA
		H-9	THE-6	1/2 sec		
0-0	27	H-9	PHEO-6	1/2 sec	S	1500 PSIA
When:						
0-0	28	T-10	PfT-6	1/sec	C	1500 PSIA
0-0	28	T-11	PfT-7	1/sec	C	1500 PSIA
Disengage clutches to P-4, 5, 6.						
Discontinue resupply monitors.						
Command and verify:						
0-0	29	V-55	LPSV-4	1	S	Closed
0-0	29	V-56	LPSV-5	1	S	Closed
0-0	29	V-57	LPSV-6	1	S	Closed
Continue to monitor:						
0-0	30	G-1	PC-38	1/sec	M	
↓	↓	G-1	TC-1	1/sec	↓	
		U-1	NT-1	2/sec		
		PT-1	QPTL-1	1/2 sec		
		PT-1	PPTL-1	1/2 sec		
		PT-1	TPTL-1	1/2 sec		
		PT-1	NS-1	1/2 sec		
		G-2	PC-39	1/sec		
		G-2	TC-2	1/sec		
		U-2	NT-2	2/sec		
		PT-2	QPTL-2	1/2 sec		
		PT-2	PPTL-2	1/2 sec		
		PT-2	TPTL-2	1/2 sec		
		PT-2	NS-2	1/2 sec		
0-0	30	G-3	PC-40	1/sec	M	

ON-ORBIT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
0-0	30	G-3	TC-3	1/sec	M	
		U-3	NT-3	2/sec		
		PT-3	QPTL-3	1/2 sec		
		PT-3	PPTL-3	1/2 sec		
		PT-3	TPTL-3	1/2 sec		
0-0	30	PT-3	NS-3	1/2 sec	M	
When required to perform an OMS burn, verify:						
0-0	31	TR-1	LBIV-1	1	S	Open
		TR-2	LBIV-2			
		TR-3	LBIV-3			
0-0	31	TR-4	LBIV-4	1	S	Open
Initiate igniter spark, verify:						
0-0	32	TR-1	IIE-1	1	S	Pulses
		TR-2	IIE-2			
		TR-3	IIE-3			
0-0	32	TR-4	IIE-4	1	S	Pulses
Command and verify:						
0-0	33	TR-1	LIOV-1	1	S	Open
		TR-1	PC-1			
		TR-2	LIOV-2			Open
		TR-2	PC-2			
		TR-3	LIOV-3			Open
		TR-3	PC-3			
		TR-4	LIOV-4			Open
0-0	33	TR-4	PC-4	1	S	
Command and verify:						
0-0	34	TR-1	LIFV-1	1	S	Open
		TR-1	PC-1			
		TR-2	LIFV-2			Open
		TR-2	PC-2			
		TR-3	LIFV-3			Open
		TR-3	PC-3			
		TR-4	LIFV-4			Open
0-0	34	TR-4	PC-4	1	S	
Command and verify:						
0-0	35	TR-1	LMBV-1	1	S	Open
		TR-1	PC-1	A.R.		
		TR-2	LMBV-2	1		Open
		TR-2	PC-2	A.R.		
		TR-3	LMBV-3	1		Open
		TR-3	PC-3	A.R.		
		TR-4	LMBV-4	1		Open
0-0	35	TR-4	PC-4	A.R.	S	

ON-ORBIT (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
		At steady-state Pc, terminate spark, verify:				
0-0	36	TR-1	IIE-1	1	S	OADC
↓	↓	TR-2	IIE-2	↓	↓	↓
↓	↓	TR-3	IIE-3	↓	↓	↓
0-0	36	TR-4	IIE-4	1	S	OADC
		During burn, monitor:				
0-0	37	TR-1	PC-1	10/sec	S	300 PSIA
↓	↓	TR-2	PC-2	↓	↓	↓
↓	↓	TR-3	PC-3	↓	↓	↓
0-0	37	TR-4	PC-4	10/sec	S	300 PSIA
		To shutdown, command and verify:				
0-0	38	TR-1	LMBV-1	1	S	Closed
↓	↓	TR-2	LMBV-2	↓	↓	↓
↓	↓	TR-3	LMBV-3	↓	↓	↓
0-0	38	TR-4	LMBV-4	1	S	Closed
		Command and verify:				
0-0	39	TR-1	LIOV-1	1	S	Closed
↓	↓	TR-2	LIOV-2	↓	↓	↓
↓	↓	TR-3	LIOV-3	↓	↓	↓
0-0	39	TR-4	LIOV-4	1	S	Closed
		Command and verify:				
0-0	40	TR-1	LIFV-1	1	S	Closed
↓	↓	TR-2	LIFV-2	↓	↓	↓
↓	↓	TR-3	LIFV-3	↓	↓	↓
↓	↓	TR-4	LIFV-4	↓	↓	Closed
↓	↓	TR-1	PC-1	↓	↓	Ambient
↓	↓	TR-2	PC-2	↓	↓	↓
↓	↓	TR-3	PC-3	↓	↓	↓
0-0	40	TR-4	PC-4	1	S	Ambient
		Commence monitoring:				
0-0	41	LA-1	PZGL-1	1/hr	S	
↓	↓	LA-2	PZGL-2	↓	↓	
↓	↓	LA-3	PZGL-3	↓	↓	
↓	↓	PT-4	QTPL-1	↓	↓	
↓	↓	PT-5	QTPL-2	↓	↓	
↓	↓	PT-6	QTPL-3	↓	↓	
↓	↓	PT-4	PTPL-1	↓	↓	
↓	↓	PT-5	PTPL-2	↓	↓	
0-0	41	PT-6	PTPL-3	1/hr	S	

DOCKING

1. Continue monitoring the Main Propulsion System as in steps On-Orbit 4, 5.

2. To execute and RCS or OMS burn
   repeat steps On-Orbit (6-13) or (31-40) respectively.

3. Continue to monitor APS gas pressures and temperatures as in
   steps On-Orbit - 14, 15.

4. To execute resupply of the APS accumulators, perform steps
   On-Orbit - (16-29).

5. Continue to monitor Propellant Conditioning System operation as in step
   On-Orbit - 30.

6. Continue to monitor A/B lube pressurization systems as in step
   On-Orbit - 41.

DOCKED

1. Continue monitoring the Main Propulsion System as in Docking step 1.

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
	Command and verify:					
DD	2	TR-(1-37)	VII-(1-37)	1	S	OVDC
	Command and verify:					
DD	3	TR-(1-37)	LBIV-(1-37)	1	S	Closed

Command the RCS doors closed.

4. Continue to monitor as APS gas pressures and temperatures as in steps On-Orbit - 14, 15.

5. Continue to monitor A/B lube systems as in step On-Orbit -41.

6. Continue operation of the Propellant Conditioning Subsystem until command is received for APU shutdown. Continue monitoring as in Docking step 30 until shutdown. Upon command to shutdown, perform steps P-F-(5-22).

7. The Propellant Conditioning Subsystem will be operated 10 minutes per day while on orbit for hydraulic system conditioning. To perform this operation,or to restart the subsystem prior to undocking, perform steps L-115 through L-138.

DOCKED

8. Before undocking, open the RCS doors, and command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
DD	9	TR-(1-37)	VII-(1-37)	1	S	28 VDC

and,

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
DD	10	TR-(1-37)	LBIV-(1-37)	1	S	Open

DESCENT - Same as Docking

REENTRY

1. Continue monitoring the Main Propulsion System as in steps on-orbit- 4, 5.

2. Secure the RCS and OMS subsystems as in steps Docked - 2, 3.

3. Continue monitoring APS pressures and temperatures as in steps on-orbit - 14, 15.

4. Operate the Propellant Conditioning Subsystem in the resupply mode as in steps on-orbit - (16-29) as required, otherwise monitor as in step on-orbit 30

Terminate zero-g pressurization of the turbofan lube systems and command readiness checks on the turbofan engines:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
R	5	FCA-1	LFIV A/B-1	1	R	Closed
↓	↓	FCA-1	LCPRV-1	↓	↓	Closed
		FCA-1	LSPV-1			Closed
		LA-1	QLO-1			
		FCA-2	LFIV A/B-2			Closed
		FCA-2	LCPRV-2			Closed
		FCA-2	LSPV-2			Closed
		LA-2	QLO-2			
		FCA-3	LFIV A/B-3			Closed
		FCA-3	LCPRV-3			Closed
↓	↓	FCA-3	LSPV-3	↓	↓	Closed
R	5	LA-3	QLO-3	1	R	

Terminate zero-g pressurization of the A/B Propellant Management Power Train Lube Systems and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
R	6	GFV-4	LGFV-4I	1	S	Closed
↓	↓	GFV-4	LGFV-4	↓	↓	↓
		GOV-4	LGOV-4I			
		GOV-4	LGOV-4			
		GFV-5	LGFV-5I			
		GFV-5	LGFV-5			
		GOV-5	LGOV-5I			
		GOV-5	LGOV-5			
		GFV-6	LGFV-6I			
		GFV-6	LGFV-6			
		GOV-6	LGOV-6I			
		GOV-6	LGOV-6			
		V-58	LFIV-4			
		V-59	LPSV-7			
		V-60	LFIV-5			
		V-61	LPSV-8			
↓	↓	V-62	LFIV-6	↓	↓	↓
R	6	V-63	LPSV-9	1	S	Closed

REENTRY (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
R	6	G-1	VII-41	1	S	OVDC
		G-2	VII-42			
		G-3	VII-43			OVDC
		EFV-1	LEFV-1			Closed
		EFV-2	LEFV-2			
		EFV-3	LEFV-3			
		EFV-4	LEFV-4			
		EFV-5	LEFV-5			
		EFV-6	LEFV-6			
		EFV-7	LEFV-7			
		EFV-8	LEFV-8			
		EFV-9	LEFV-9			
		EFV-10	LEFV-10			
		EFV-11	LEFV-11			
		EFV-12	LEFV-12			Closed
			PfL-11			
			PfL-12			
			PfL-13			
		PT-4	QTPL-1			
		PT-5	QTPL-2			
R	6	PT-6	QTPL-3	1	S	

APPROACH & LANDING - (Orbital)

1. Continue to monitor the Main Propulsion System as in steps on-orbit- 4, 5.

2. Continue to monitor APS gas parameters as in step on-orbit - 15.

3. To resupply the APS gas accumulators execute steps on-orbit - (16-29), otherwise monitor the Propellant Conditioning Subsystem parameters as in step on-orbit - 30.

4. Command the A/B engine cradles to be lowered.

5. The A/B Propulsion System is activated and monitored as in Ferry Pre-flight, steps 92 through 136 except that windmilling is the primary mode of start, with solid start cartridges as back-up, instead of ground start GSE.

6. After landing, taxi to the revetment area.

7. Shutdown the A/B Propulsion System as in steps 3 through 23 of Ferry Approach and Landing.

POSTFLIGHT - (Orbital)

1. Tow the Orbiter into the revetment. Chock and tie down.

2. Connect ground power GSE.

3. Execute power transfer.

4. Continue monitoring Propellant Conditioning Subsystem operation as in step on-orbit - 30, until the APU shutdown command is received. Upon receipt of the APU shutdown command, execute steps 5 - 22 of Postflight-Ferry.

5. Take a final status sample of the Main Propulsion System parameters of steps on-orbit - 4, 5.

6. Remove tape and hard copy, if any.
Debrief crew as required.
Review in-flight data and fault-isolation output.

7. Connect Drain and Purge GSE and verify as in step 28, Postflight-Ferry, (P-F).

8. Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
P-0	8	V-32	LOPV-1	1	S	Closed
		V-33	LOPV-2			
		V-34	LFPV-1			
P-0	8	V-35	LFPV-2	1	S	Closed

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
P-0	9	V-36	LOPV-3	1	S	Closed
		V-37	LOPV-4			
		V-38	LOPV-5			
		V-39	LOPV-6			
		V-40	LFPV-3			
		V-41	LFPV-4			
		V-42	LFPV-5			
P-0	9	V-43	LFPV-6	1	S	Closed

10. Perform a purge of the main LH_2 system by executing steps 30 through 40 of Postflight-Ferry.

11. Perform a purge of the main LOX system by executing steps 41 through 52 of Postflight-Ferry.

Command and verify:

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
P-0	12	V-36	LOPV-3	1	S	Open
		V-37	LOPV-4			
P-0	12	V-38	LPOV-5	1	S	Open

POSTFLIGHT - (Orbital) (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
P-O	12	V-38	LOPV-5	1	S	Open
↓	↓	V-39	LOPV-6	↓	↓	↓
↓	↓	V-40	LFPV-3	↓	↓	↓
↓	↓	V-41	LFPV-4	↓	↓	↓
↓	↓	V-42	LFPV-5	↓	↓	↓
P-O	12	V-43	LFPV-6	1	S	Open
Command and verify:						
P-O	13	TR-(14-28)	LBIV-(14-28)	1	S	Open
Command and verify:						
P-O	14	TR-(14-28)	LMBV-(14-28)	1	S	Open
↓	↓	TR-(14-28)	LIOV-(14-28)	↓	↓	↓
P-O	14	TR-(14-28)	LIFV-(14-28)	1	S	Open
After two seconds, command and verify:						
P-O	15	TR-(14-28)	LMBV-(14-28)	1	S	Closed
↓	↓	TR-(14-28)	LIOV-(14-28)	↓	↓	↓
P-O	15	TR-(14-28)	LIFV-(14-28)	1	S	Closed
Command and verify:						
P-O	16	V-38	LOPV-5	1	S	Closed
↓	↓	V-39	LOPV-6	↓	↓	↓
↓	↓	V-42	LFPV-5	↓	↓	↓
P-O	16	V-43	LFPV-6	1	S	Closed
Command and verify:						
P-O	17	TR-21	LIOV-21	1	S	Open
P-O	17	TR-21	LIFV-21	1	S	Open
Until:						
P-O	18		PoL-9	A.R.	C	19PSIA
P-O	18		PfL-10	A.R.	C	19PSIA
Then, command and verify:						
P-O	19	TR-21	LIOV-21	1	S	Closed
↓	↓	TR-21	LIFV-21	↓	↓	↓
P-O	19	TR-(14-28)	LBIV-(14-28)	1	S	Closed
Command and verify:						
P-O	20	TR-(1-13)	LBIV-(1-13)	1	S	Open
P-O	20	TR-(29-37)	LBIV-(29-37)	1	S	Open

POSTFLIGHT - (Orbital) (Continued)

PHASE	STEP	ELEMENT	MEASUREMENT	SAMPLES	USE	EXPECTED VALUE
Command and verify:						
P-O	21	TR-(1-13)	LMBV-(1-13)	1	S	Open
↓	↓	TR-(1-13)	LIOV-(1-13)	↓	↓	↓
		TR-(1-13)	LIFV-(1-13)			
		TR-(29-37)	LMBV-(29-37)			
		TR-(29-37)	LIOV-(29-37)			
P-O	21	TR-(29-37)	LIFV-(29-37)	1	S	Open
After two seconds, command and verify:						
P-O	22	TR-(1-13)	LMBV-(1-13)	1	S	Closed
↓	↓	TR-(1-13)	LIOV-(1-13)	↓	↓	↓
		TR-(1-13)	LIFV-(1-13)			
		TR-(29-37)	LMBV-(29-37)			
		TR-(29-37)	LIOV-(29-37)			
P-O	22	TR-(29-37)	LIFV-(29-37)	1	S	Closed
Command and verify:						
P-O	23	V-36	LOPV-3	1	S	Closed
↓	↓	V-37	LOPV-4	↓	↓	↓
		V-40	LFPV-3			
P-o	23	V-41	LFPV-4	1	S	Closed
Command and verify:						
P-O	24	TR-1	LIOV-1	1	S	Open
P-O	24	TR-1	LIFV-1	1	S	Open
Until:						
P-O	25		PoL-8	A.R.	C	19PSIA
P-O	25		PfL-9	A.R.	C	19PSIA
Then command and verify:						
P-O	26	TR-1	LIOV-1	1	S	Closed
↓	↓	TR-1	LIFV-1	↓	↓	↓
		TR-(1-13)	LBIV-(1-13)			
P-O	26	TR-(29-37)	LBIV-(29-37)	1	S	Closed

27. Purge the gas lines of the Propellant Conditioning Subsystem and A/B Propellant Management Subsystem by executing steps 53-56 of Postflight-Ferry.

28. Purge remaining LH_2 system, less main engines, by executing steps 57-65 of Postflight-Ferry.

POSTFLIGHT - (Orbital) (Continued)

29. Purge remaining LOX system, less main engines, by executing steps 66-69 of Postflight-Ferry.

30. Complete main engine purge.

31. Secure and disconnect the Drain and Purge GSE. Verify propellant coupling status as in step 71 or Postflight-Ferry. Purge complete.

32. Inspect all subsystems for mechanical disorders.

33. Attach covers and install desicants where required.

34. Command RCS doors closed.

35. Secure and verify the MPS isolation valves as in step 72 of Postflight-Ferry.

36. Power down all propulsion systems and OCMS.

37. Input flight data to processing system for trend analysis, performance evaluation, and/or maintenance report.