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TEST PLAN/PROCEDURE FOR THE DPHV SYSTEM INTEGRATION

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TABLE OF CONTENTS

	Page
1 PURPOSE	1
1.1 Test Philosophy	1
2 SCOPE	1
2.1 Test System Overview	1
2.2 Document Overview	2
3 APPLICABLE DOCUMENTS	3
3.1 Vehicle Specification (PEI DCN 6004722)	3
3.2 Hydrogen Test Facility Handling Requirements	3
3.3 Hydrogen Test Facility Safety Requirements	3
4 CHARACTERIZATION TEST REQUIREMENTS	3
4.1 Hydrogen Storage Subsystem Test	3
4.2 Fuel Cell Stack Subsystem Test	4
4.3 Load Leveling Subsystem Test	4
4.4 Auxiliary Subsystem Simulation	4
4.5 Gas Management System Test	4
4.6 System Integration Test	9
5 TEST PLAN	11
5.1 Configuration/Environments	11
5.2 Support Equipment/Facility	20
5.3 Procedures	22
5.4 Test Report Requirements	22
ATTACHMENT 1 HYDROGEN STORAGE TEST PROCEDURE	23
ATTACHMENT 2 FUEL CELL STACK TEST PROCEDURE	24
ATTACHMENT 3 LOAD LEVELING TEST PROCEDURE	25
ATTACHMENT 3 AUXILIARY SIMULATION TEST PROCEDURE	26
ATTACHMENT 5 GAS MANAGEMENT TEST PROCEDURE	27
ATTACHMENT 6 SYSTEM INTEGRATION TEST PROCEDURE	28

LIST OF ILLUSTRATIONS

Figure	Title	Page
1	DPHV Integration Test Configuration	2
2	Phase I Functional Block Diagram Fuel Cell System	14
3	Gas Management System - Block Diagram	15
4	Load Leveler Subsystem Test Configuration	18
5	System Integration Test Configuration	19
6	Vehicle Test Facility	21

LIST OF TABLES

Table	Title	Page
1	DPHV Load-Leveler Characterization Tests	5
2	Fuel Cell Stack Tests	7
2-1	Static Condition Table for Fuel Cell Stack Test	8
3	DPHV Fuel Cell Module Tests	8
4	DPHV Load-Leveler Characterization Tests	9
5	Gas Management System Tests	10
5-1	Static Condition Table for Gas Management System Tests	11
6	Gas Management Subsystem Acceptance Test Measurement Parameters	12
7	DPHV System Integration Tests	13
8	Fuel Cell stack Design Point Specifications	16
9	Fuel Cell Stack Power Output	16
10	Instrumentation List	17

1. PURPOSE

The purpose of the test plan for the Direct Hydrogen-Fueled Proton-Exchange Membrane Fuel Cell powered Hybrid Vehicle (DPHV) system or subsystem is to provide a documented approach to verify the feasibility of the hardware and software designs for that system. Performance of the testing described in this test plan will verify that the functional requirements of the system and subsystems making up that system have been met.

1.1 Test Philosophy

This test plan is based upon the concept that each of the contributing subsystems will have characterization tests performed during the Research and Development (R&D) phase. These tests will provide exhaustive measurements which will determine the capability/feasibility for the subsystem design. Portions of these characterization tests for the Gas Management System will be used to verify the subsystem performance (identified as acceptance tests in the Program Management Plan) at the AlliedSignal Aerospace (ASA) facility. These tests will then be performed at the PEI facility to verify the subsystem after shipment to PEI.

After each of the subsystems have been verified at the PEI facility, the system integration test outlined in this document will be performed. Emphasis will be placed on the verification of the interactions between each of the subsystems using the Chrysler Collision Detection (CCD) communications bus. Test control will be maintained using a computer which will simulate the system controller in the DPHV. "Real-Time" data will be logged using a Data Acquisition System (DAS). All vehicle loads such as powertrain, Heating, Ventilating, Air Conditioning (HVAC) and auxiliary power requirements will be simulated using programmable resistive loads.

The integration test will be based on several different driving cycles. The FUDS Cycle will be simulated to verify vehicle power requirements. The 55 MPH Constant Speed Cycle simulation will be performed on a seven percent grade (known as the Baker Cycle) to determine the power allocations between the Fuel Cell (FC) Stack and the load leveling device. Other driving cycles will be simulated as required in order to obtain system integration data.

2. SCOPE

2.1 Test System Overview

Figure 1 provides an overview of the DPHV system as it will be configured for the system integration test. The Gas Management System is comprised of the Proton Exchange Membrane (PEM) Fuel Cell Stack subsystem, the H₂ Storage subsystem, and the Gas Management controller. The Energy Management subsystem consists of the load leveling controller and the associated load leveling hardware. All auxiliary loads, powertrain loads and vehicle signals will be simulated in the programmable resistive load

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Figure 1. DPHV Integration Test Configuration

bank. The DAS will provide "real-time" measurement capability with data logging capacity TBD.

Interfaces to the CCD bus will provide an RS-232 link for both the energy management and the gas management systems. The link between the maintenance unit, the DAS, and the programmable resistive load bank will be accomplished using an IEEE-488 bus system.

The maintenance unit will provide the software controls for test performance. It simulates the operations of the system controller in the DPHV vehicle.

2.2 Document Overview

Section 3 of this test plan provides a brief description of the documents relevant to the characterization tests for each of the subsystems and for the system integration test. Section 4 provides the detailed test requirements along with success criteria for each of the subsystems and systems being tested. Section 5 describes the test configuration and the environments under which each subsystem/system will be tested. Attachments 1 through 6 to this test plan contain the specific procedures to be performed for each of the characterization tests described in Section 5.

3. APPLICABLE DOCUMENTS

This section will provide a listing of applicable industry and Governmental documents which have a bearing on the test plan. Various documents that are applicable to the DPHV testing are shown below:

- MIL-STD-810D; for environmental test methods
- ASME Boiler and Pressure Vessel Code; safety standards
- ANSI/AGA NGV-1, NGV-2; natural gas vehicle system standards
- DOT FRP-1; Federal standards for compressed gas storage on vehicles
- NFPA 50A, 50B; Fire protection standards for hydrogen usage at consumer sites
- CGA S-1.1 Pressure relief device standards for compressed gas cylinders

3.1 Vehicle Specification (PEI DCN 6004722)

The vehicle specification document defines the physical characteristics for each DPHV subsystem such as weight, size, along with environmental requirements for these units. The document further defines the interface requirements between each of these units for communications, electrical power, and mechanical interactions. Environmental concerns such as high and low temperature operating requirements, vibrational operational requirements, and safety requirements are defined in the system specification document. Finally, the system specification contains the system operational requirements as regards vehicle range, driving constraints, and verification test definition.

3.2 Hydrogen Storage Handling Requirements

TBD

3.3 Hydrogen Test Facility Safety Requirements

PEI will provide a test facility for purposes of system integration. This facility is described in Section 5.2, and complies with the following:

1993 NEC Article 500 – Hazardous Atmospheric Locations
AIRCO Pub: ADI 2028
ANSI/NFPA 50A and 50B

4. CHARACTERIZATION TEST REQUIREMENTS

This section will provide the set of test requirements necessary to verify the operation of the subsystem.

4.1 Hydrogen Storage Subsystem Test

Hydrogen storage development effort is scheduled to begin October 21, 1994. The first task is to assemble a gaseous hydrogen storage team which will immediately

address the specific requirements and test plans. A draft of the requirements and test procedures (Table 1) will be available approximately November 15, 1994.

4.2 Fuel Cell Stack Subsystem Test

The Fuel Cell Module Characterization tests will be utilized to investigate and validate key parameters of the subsystem. Table 2 shows the tests to be performed.

4.2.1 List of Tests for Fuel Cell Module. Each fuel cell module will be subjected to the tests described in Table 3. The tests may be conducted in any order.

4.2.2 Proof Pressure. The fuel cell module proof pressure shall be 1.5 times the maximum operating pressure at room temperature.

4.2.3 Voltage and Current. The fuel cell module's Open Circuit Voltage (OCV) at peak power and off-peak power operating conditions are as follows:

- Design point 1 (50 kW requirements) 200 volts
- Design point 2 (10 kW requirements) 200 volts

The fuel cell module's voltage load at peak power and off-peak power operating conditions are as follows:

- Design point 1 (50 kW requirements) 300 volts at 167 amps
- Design point 2 (10 kW requirements) 300 volts at 33 amps

4.2.4 Weight and Envelope. The fuel cell module's weight shall not exceed 28.4 kg. The length of the module shall not exceed 51 cm, and the diameter shall not exceed 21 cm.

4.3 Load Leveling Subsystem Test

4.3.1 Load Leveler Characterization Tests. The Load Leveler Characterization tests will be utilized to investigate and validate key parameters of the subsystem.

Table 4 shows the tests to be performed at both high and low temperature extremes.

4.4 Auxiliary Subsystem Simulation

TBD

4.5 Gas Management System Test

Overall characterization testing of the gas management subsystem will be conducted at AlliedSignal Aerospace Systems and Equipment and at Pentastar Electronics, Inc. The characterization tests will be used to demonstrate the safe and reliable operation of the gas management subsystem at three levels of operation. Critical parameters of interest in the gas management system are shown in Table 5.

Table 1. DPHV Load-Leveler Characterization Tests

Test Requirement	Paragraph	Test Procedure
Development Effort		
Safety Assessment		
Auto-Ignition	TBD	TBD
Leakage	TBD	TBD
Long-term Compatibility	TBD	TBD
Accelerated Environments	TBD	TBD
Refueling	TBD	TBD
Other	TBD	TBD
CNG Vessel Evaluation		
Weight	TBD	TBD
Capacity	TBD	TBD
H ₂ Permeability	TBD	TBD
Leakage	TBD	TBD
Long-term Compatibility	TBD	TBD
Accelerated Environments	TBD	TBD
Refueling	TBD	TBD
Ancillary Equipment	TBD	TBD
Other	TBD	TBD
Structural Materials		
H ₂ Permeability	TBD	TBD
Yield Strength	TBD	TBD
Ultimate Strength	TBD	TBD
Modulus of Elasticity	TBD	TBD
Accelerated Environments	TBD	TBD
Other	TBD	TBD

Table 1. DPHV Load-Leveler Characterization Tests (Continued)

Test Requirement	Paragraph	Test Procedure
Advanced Prototype		
Weight	TBD	TBD
Capacity	TBD	TBD
Operating Pressure	TBD	TBD
Burst Pressure	TBD	TBD
Bonfire	TBD	TBD
Gunfire	TBD	TBD
Fatigue Cycle	TBD	TBD
Accelerated Environments	TBD	TBD
Refueling	TBD	TBD
Ancillary Equipment	TBD	TBD
Other	TBD	TBD
System Delivered to Pentastar		
Total weight	TBD	TBD
Total External Volume	TBD	TBD
Delivery Pressure Regulation	TBD	TBD
Remaining Fuel Measurement	TBD	TBD
Hot Day Refueled Capacity	TBD	TBD
Cold Day Refueled Capacity	TBD	TBD
Refueling Time	TBD	TBD
Hot Day Delivery	TBD	TBD
Cold Day Delivery	TBD	TBD
Diurnal Temperature Variation	TBD	TBD
Other	TBD	TBD

Table 2. Fuel Cell Stack Tests

Test	Specification	Procedure	Equipment Required	Range	Accuracy
H ₂ Pressure Proof	4.5 Bar pressure for 5 minutes – no permanent deformation	Attach pressure lines and gages to hydrogen inlet fittings. Seal the hydrogen output fittings. Apply nitrogen gas pressure at 4.5 Bar.	Pressure Gage (3) Timer	0-5 Bar 0-10 min	± 1% at 80 C ± 5 sec at 5 min
H ₂ Pressure Leakage	4.5 Bar pressure for 5 minutes – no visible signs of leakage, no indication of leakage on gages	Attach pressure lines and gages to hydrogen inlet fittings. Seal the hydrogen output fittings. Apply nitrogen gas pressure at 4.5 Bar.	Pressure Gage (3) Timer	0-5 Bar 0-10 min	± 1% at 80 C ± 5 sec at 5 min
Air Pressure Proof	4.5 Bar pressure for 5 minutes – no permanent deformation	Attach pressure lines and gages to hydrogen inlet fittings. Seal the air output fittings. Apply nitrogen gas pressure at 4.5 Bar.	Pressure Gage (3) Timer	0-5 Bar 0-10 min	± 1% at 80 C ± 5 sec at 5 min
Air Pressure Leakage	4.5 Bar pressure for 5 minutes – no visible signs of leakage, no indication of leakage on gages	Attach pressure lines and gages to air inlet fittings. Seal the air output fittings. Apply nitrogen gas pressure at 4.5 Bar.	Pressure Gage (3) Timer	0-5 Bar 0-10 min	± 1% at 80 C ± 5 sec at 5 min
Coolant Pressure Proof	4.5 Bar pressure for 5 minutes – no permanent deformation	Attach pressure lines and gages to air inlet fittings. Seal the air output fittings. Apply nitrogen gas pressure at 4.5 Bar.	Pressure Gage (3) Timer	0-5 Bar 0-10 min	± 1% at 80 C ± 5 sec at 5 min
Coolant Pressure Leakage	4.5 Bar pressure for 5 minutes – no visible signs of leakage, no indication of leakage on gages	Attach pressure lines and gages to air inlet fittings. Seal the air output fittings. Apply nitrogen gas pressure at 4.5 Bar.	Pressure Gage (3) Timer	0-5 Bar 0-10 min	± 1% at 80 C ± 5 sec at 5 min
Voltage	Produce a minimum of 50 KW steady state in accordance with Design Point 1 specifications. Produce minimum of 10 KW in accordance with Design Point 2 specifications	Establish proper flow, pressure and temperature conditions as described in Table 2-1 for two steady state performance points. Measure voltage load and current data, calculate power.	Digital Multimeter, IEEE-488 Interface	0-500 V	± 1% at 200 V
Current	Produce a minimum of 50 KW steady state in accordance with Design Point 1 specifications. Produce minimum of 10 KW in accordance with Design Point 2 specifications	Establish proper flow, pressure and temperature conditions as described in Table 2-1 for two steady state performance points. Measure voltage load and current data, calculate power.	Digital Multimeter, IEEE-488 Interface	0-500 amp	± 1% at 100 V

DCN 6004710 (Draft)
October 21, 1994

Table 2-1. Static Condition Table for Fuel Cell Stack Test

Parameter	Design Point 1 (50 KW)	Design Point 2 (10 KW)	Equipment Required
H ₂ Inlet Temp °C	85 ± 1 °C	85 ± 1 °C	Thermocouple and Digital Multimeter
H ₂ flow L/min	1.12 ± 1	TBD ± TBD	Flowmeter and Digital Multimeter
H ₂ pressure bar	3.0 ± 1	3.0 ± 1	Pressure Sensor and Digital Multimeter
Air Inlet Temp °C	75 ± 1 °C	75 ± 1 °C	Thermocouple and Digital Multimeter
Air flow L/min	TBD ± TBD	TBD ± TBD	Airflow Sensor and Digital Multimeter
Air pressure bar	3.0 ± 1	3.0 ± 1	Pressure Sensor and Digital Multimeter
Coolant Inlet Temp °C	70 ± 1 °C	70 ± 1 °C	Thermocouple and Digital Multimeter
Coolant flow L/min	TBD ± TBD	TBD ± TBD	Flowmeter and Digital Multimeter
Coolant pressure bar	3.0 ± 1	3.0 ± 1	Pressure Sensor and Digital Multimeter
Open circuit voltage v	300 ± TBD	300 ± TBD	Digital Multimeter
Voltage load v	50 ± .5	50 ± .5	Digital Multimeter
Current Amp	167 ± 1	33 ± 1	Digital Multimeter

Table 3. DPHV Fuel Cell Module Tests

Test	Paragraph
Fuel Cell Stack Proof Pressure and Leakage	5.1.2.1
Voltage and Current	5.1.2.2
Weight and Envelope	5.1.2.3

Characterization tests will be conducted using a simulated fuel cell. The three levels of operation pertain to the fuel cell stack power output. One level is at the rated stack power tentatively set at 50 kW (gross) and 200 volts. Another level is at a nominal power of 10 kW (gross) which is near expected vehicle cruising conditions. The third level of operation is during startup where the fuel cell is expected to produce less than 10 kw of power using ambient condition air and hydrogen. The gas management subsystem, using a simulated fuel cell stack and hydrogen storage system, will undergo testing to simulate these three different operational scenarios. Parameters to be measured mainly include the temperature, pressure, and flowrate for both air and hydrogen that would enter the

Table 4. DPHV Load-Leveler Characterization Tests

Test	Requirement Paragraph (6004722 DPHV Vehicle Specification)	Test Procedure Paragraph (Attachment 3)
Communications Tests	TBD	TBD
CCD Protocol	TBD	TBD
Command/Response tests	TBD	TBD
Diagnostic Tests	TBD	TBD
BIT	TBD	TBD
Polled Response	TBD	TBD
Operational Tests	TBD	TBD
Bus load vs. Commanded Response	TBD	TBD
Weight Tests	TBD	TBD
Dimensional Tests	TBD	TBD
Vibration Tests	TBD	TBD

fuel cell stack. Output stack measurements are not needed in the gas management acceptance test since these conditions will be reflected via the hydrogen recirculation loop, the gas/water separators, and the stack cooling system. Subsystem measurements are needed for the following parameters shown in Table 6. The acceptable ranges of operation are also shown in this table.

Characterization testing on the gas management controls will be verified by testing and, hence, control of the parameters in Table 6.

4.6 System Integration Test

The System Integration Characterization tests will be utilized to investigate and validate key parameters of the subsystem.

Table 7 shows the tests to be performed at both high and low temperature extremes.

The entire set of subsystems may be characterized under both static and dynamic conditions. The same set of characterization tests may also be run while the various system elements are being subject to environmental constraints (vibration tests or ambient temperature tests). In these cases, existing acquisition system instrumentation channels, sensors, instruments) will be provided to acquire shake stand or thermal

Table 5. Gas Management System Tests

Test	Specification	Procedure	Equipment Required	Range	Accuracy
H ₂ Pressure Proof					
H ₂ Pressure Leakage	Software detection of hydrogen leakage	Program the simulation computer to simulate a hydrogen leakage of TBD psi/sec. Software in the Gas Management system passes this information to the CCD bus and is detected by the Maintenance Unit computer.	Computer to digitally simulate signals from the Fuel Cell indicating hydrogen leakage and connections to the Gas Management System.	N/A	N/A
Air Pressure Proof					
Air Pressure Leakage	Software detection of air leakage	Program the simulation computer to simulate an air leakage of TBD psi/sec. Software in the Gas Management system passes this information to the CCD bus and is detected by the Maintenance Unit computer.	Computer to digitally simulate signals from the Fuel Cell indicating air leakage, and connections to the Gas Management System.	N/A	N/A
Coolant Pressure Proof					
Coolant Pressure Leakage	Software detection of coolant leakage	Program the simulation computer to simulate coolant leakage of TBD psi/sec. Software in the Gas Management system passes this information to the CCD bus and is detected by the Maintenance Unit computer	Computer to digitally simulate signals from the Fuel Cell indicating air leakage, and connections to the Gas Management System.	N/A	N/A
Voltage	Produce a minimum of 50 KW steady state in accordance with Design Point 1 specifications. Produce minimum of 10 KW in accordance with Design Point 2 specifications.	Simulate voltage from the fuel cell in accordance with Design Point 1 and Design Point 2 specifications (Table 5-1).	Computer to digitally simulate the design point signals and the voltage produced by the fuel cell.	N/A	N/A
Current	Produce a minimum of 50 KW steady state in accordance with Design Point 1 specifications. Produce minimum of 10 KW in accordance with Design Point 2 specifications.	Simulate current from the fuel cell in accordance with Design Point 1 and Design Point 2 specifications (Table 5-1).	Computer to digitally simulate the design point signals and the voltage produced by the fuel cell.	N/A	N/A

DCI 0004710 (Rev. 10)
October 21, 2004

Table 5-1. Static Condition Table for Gas Management System Tests

Parameter	Design Point 1 (50 KW)	Design Point 2 (10 KW)	Equipment Required
H ₂ Inlet Temp °C	85 ± 1 °C	85 ± 1 °C	Computer to digitally simulate this parameter to the Gas Management system.
H ₂ flow L/min	1.12 ± 1	TBD ± TBD	Computer to digitally simulate this parameter to the Gas Management system.
H ₂ pressure bar	3.0 ± 1	3.0 ± 1	Computer to digitally simulate this parameter to the Gas Management system.
Air Inlet Temp °C	75 ± 1 °C	75 ± 1 °C	Computer to digitally simulate this parameter to the Gas Management system.
Air flow L/min	TBD ± TBD	TBD ± TBD	Computer to digitally simulate this parameter to the Gas Management system.
Air pressure bar	3.0 ± 1	3.0 ± 1	Computer to digitally simulate this parameter to the Gas Management system.
Coolant Inlet Temp °C	70 ± 1 °C	70 ± 1 °C	Computer to digitally simulate this parameter to the Gas Management system.
Coolant flow L/min	TBD ± TBD	TBD ± TBD	Computer to digitally simulate this parameter to the Gas Management system.
Coolant pressure bar	3.0 ± 1	3.0 ± 1	Computer to digitally simulate this parameter to the Gas Management system.
Open circuit voltage v	100 ± TBD	100 ± TBD	Computer to digitally simulate this parameter to the Gas Management system.
Voltage load v	50 ± .5	50 ± .5	Computer to digitally simulate this parameter to the Gas Management system.
Current Amp	150 ± 1	50 ± 1	Computer to digitally simulate this parameter to the Gas Management system.

chamber data that can be used for later time correlation with various actions of the subsystem. These environmental tests are described in the System Control Specification.

5. TEST PLAN

5.1 Configuration/Environments

This section contains the general features of the test plan environment, schedule, and personnel description.

5.1.1 H₂ Storage Configuration/Environments. TBD

5.1.2 Fuel Cell Stack Configuration/Environments. TBD

Table 6. Gas Management Subsystem Acceptance Test Measurement Parameters

Parameter	Acceptable Parameter Ranges		
	Start-up	Normal Cruise	Peak Power
H ₂ Stack Inlet Temperature	10-100°C	50-95°C	50-95°C
H ₂ Stack Inlet Pressure	1-3 Bar	1-3 Bar	1-3 Bar
H ₂ Stack Inlet Flowrate	0-1.0 kg/hr	0.5-1.0 kg/hr	2.3-4.6 kg/hr
Air Stack Inlet Temperature	10-100°C	50-85°C	50-85°C
Air Stack Inlet Pressure	1-3 Bar	1-3 Bar	1-3 Bar
Air Stack Inlet Flowrate	0-30 kg/hr	0-30 kg/hr	80-160 kg/hr
Coolant Inlet Temperature	10-100°C	70-90°C	70-90°C

5.1.2.1.1 **Setup.** Attach pressure lines to the hydrogen, air, and coolant inlet fittings. Seal the hydrogen, air, and coolant outlet fittings. The setup shall include a pressure gage as shown in Figure 2.

5.1.2.1.2 **Procedure.** Simultaneously apply a nitrogen gas pressure of 4.5 (+.5, -0) bar to all inlet fittings, at room temperature and hold for a five minute period. Observe all gages for displacement indicating leakage. There shall be no visible external leakage. After simultaneously releasing of applied pressure, visually examine the unit for permanent deformation. There shall be no evidence of permanent deformation.

5.1.2.2 **Voltage and Current.**

5.1.2.2.1 **Setup.** Install the fuel cell module into the setup shown in Figure 3. Connect the hydrogen inlet side to a hydrogen source capable of providing a humidified fluid temperature of 85°C and TBD L/min flow rate. Connect the air inlet side to an air source capable of providing a humidified fluid temperature of 75°C and TBD L/min flow rate. Connect the coolant inlet side to a coolant source capable of providing a fluid temperature of 70°C and TBD L/min flow rate. Connect the power terminals to the load bank. Connect the cell voltage pin connector to TBD.

5.1.2.2.2 **Procedure.** Establish the flow, pressure, and temperature conditions described in Table 8 for the two steady state performance points.

From the voltage load and current data acquired, calculate the power. The minimum power shall be as described in Table 9.

Table 7. DPHV System Integration Tests

Test	Requirement Paragraph (6004722 DPHV Vehicle Specification)	Test Procedure Paragraph (Attachment 3)
Communications Tests		
CCD Protocol to each subsystem	TBD	TBD
Command/Response tests to each subsystem	TBD	TBD
Diagnostic Tests		
BIT from each subsystem	TBD	TBD
Polled Response from each subsystem	TBD	TBD
Operational Tests		
Bus load vs. Commanded Response	TBD	TBD
TBD	TBD	TBD
TBD	TBD	TBD
TBD	TBD	TBD
Weight Tests	TBD	TBD
Dimensional Tests	TBD	TBD
Vibration Tests	TBD	TBD

5.1.2.3 Weight and Envelope

5.1.2.3.1 Setup. Position scale capable of weighing up to 300 kg on flat level surface. Measuring device to have a minimum length 100 cm.

5.1.2.3.2 Procedure. Place fuel cell module on scale and record weight value. Measure and record the fuel cell length and outer diameter.

5.1.2.4 Ambient Conditions. Unless specified otherwise in an individual test procedure, all testing shall be conducted with the test unit at the laboratory ambient pressure and temperature existing at the time of test. The instrumentation required to perform the tests described in this document shall meet the requirements listed in Table 10.

Figure 2. Phase I Functional Block Diagram Fuel Cell System

DCN 6004710 (Draft)
October 21, 1994

IG-23283

Figure 3. Gas Management System - Block Diagram

5.1.2.5 Test Fluids. Except where otherwise indicated in the individual test descriptions, the test fluids will conform to the following specifications:

Hydrogen side	Commercial Grade
Air Side	Commercial Grade
Coolant Side	TBD
Water	Deionized

5.1.2.6 Test Surveillance and Witnessing. The tests required herein shall be conducted under the surveillance of the Pentastar TBD or designee.

5.1.2.7 Data Record. A record of all test data shall be kept by the test technician on the data sheets provided in the back of this document. As each test is performed, the test technician will observe the test data and record that data on the applicable data sheet using black ink (erasures are not permitted). Each completed data sheet shall be signed

Table 8. Fuel Cell Stack Design Point Specifications

	Design Point 1 (30 kW)	Design Point 2 (10 kW)
H ₂ Inlet Temp °C	85 (± 1 °C)	85 (± 1 °C)
H ₂ Flow (L/min)	1.12 (± .1)	TBD (± TBD)
H ₂ Pressure Bar	3.0 (± .1)	3.0 (± .1)
Air Inlet Temp °C	75 (± 1 °C)	75 (± 1 °C)
Air Flow L/min	TBD (± TBD)	TBD (± TBD)
Air Pressure Bar	3.0 (± .1)	3.0 (± .1)
Coolant Inlet Temp °C	70 (± 1 °C)	70 (± 1 °C)
Coolant Flow L/min	TBD (± TBD)	TBD (± TBD)
Coolant Pressure Bar	3.0 (± .1)	3.0 (± .1)
Open Circuit Voltage V	100 (± TBD)	100 (± TBD)
Voltage Load V	50 (± .5)	50 (± .5)
Current Amp	150 (± .1)	150 (± .1)

Table 9. Fuel Cell Stack Power Output

	Design Point 1	Design Point 2
Power kW	TBD	TBD

and dated by the test technician and stamped in the appropriate place by the cognizant Quality Assurance representative, signifying that the test result is either accepted or rejected. If the test result is rejected, a statement describing the problem should be written in the REMARKS block.

5.1.3 Load Leveling Configuration/Environments. The Load Leveler will be an integral part of the Energy Management System and will be tested as a single unit using a set of characterization tests designed by PEI and configured as shown in Figure 4. The configuration for these tests will be designed to simulate the following:

- Bilateral data flow between the CCD bus and the EMS/LL device to establish proper communication between the Maintenance Unit used to drive the CCD and the Energy Management System itself

Table 10. Instrumentation List

Test	Instrument	Required Range	Accuracy
Hydrogen Proof Pressure	Pressure gage timer	0-5 Bar 0-10 Min	$\pm 1\%$ at 80°C ± 5 sec at 5 min
Air Proof Pressure	Pressure gage timer	0-5 Bar 0-10 Min	$\pm 1\%$ at 80°C ± 5 sec at 5 min
Coolant Proof Pressure	Pressure gage timer	0-5 Bar 0-10 Min	$\pm 1\%$ at 80°C ± 5 sec at 5 min
Hydrogen Pressure Drop	Flow Meter Thermocouple ΔP gage	0-5 sl/min 0-150°C 0-5 Bar	$\pm 3\%$ at 4 sl/min $\pm 5^\circ\text{C}$ $\pm 1\%$ at 4 bar
Air Pressure Drop	Flow Meter Thermocouple ΔP gage	0-5 sl/min 0-150°C 0-5 Bar	$\pm 3\%$ at 4 sl/min $\pm 5^\circ\text{C}$ $\pm 1\%$ at 4 bar
Coolant Pressure Drop	Flow Meter Thermocouple ΔP gage	0-5 sl/min 0-150°C 0-5 Bar	$\pm 3\%$ at 4 sl/min $\pm 5^\circ\text{C}$ $\pm 1\%$ at 4 bar
Voltage	Voltmeter	0-500 volt	$\pm 1\%$ at 200 volt
Current	Ammeter	0-500 amp	$\pm 1\%$ at 100 amp
Weight	Scale	0-200 kg	$\pm 1\%$ at 50 kg

- Electrical bus load conditions for the EMS/LL as simulated by a programmable system of resistive loading
- Driving profile to simulate dynamic conditions by programming the resistive load concurrently with the commands and data on the CCD bus (FUDS cycle and Baker Cycle).

Data will be gathered on a small data acquisition system in real time and stored on disk. Data stored during these tests will consist of such parameters as time (for correlation with the driving cycle), voltages at the output of the Load Leveler as well as key internal voltage monitoring points, currents at the same, or additional, points, and various key temperatures.

The configuration above will allow the entire EMS/LL to be tested under both static and dynamic conditions as an independent unit.

The same set of characterization tests may also be run while the EMS/LL system is being subject to various environmental constraints (vibration tests or ambient temperature tests). In these cases, existing acquisition system instrumentation channels, sensors, instruments will be provided to acquire shake stand or thermal chamber data that

M94J027

Figure 4. Load Leveler Subsystem Test Configuration

can be used for later time correlation with various actions of the subsystem. These environmental tests are described in the System Control Specification.

5.1.4 Auxiliary Simulation Configuration/Environments

5.1.5 Gas Management System Configuration/Environments

5.1.6 System Integration Configuration/Environments. For a full-up systems integration test, all the elements of the control system will be connected together as shown functionally in Figure 5. The Maintenance Unit computer will be responsible for simulating the required driving cycles, providing the driving input simulations, and for providing the simulated outputs to the CCD bus for all the data required by the control system.

The elements to be tested during this integration test are:

- The Maintenance Unit
- The Gas Management System
- The Energy Management System/Load Leveler
- The DC Power Bus
- The CCD Bus

Auxiliary equipment required for this test are a programmable resistive load unit, capable of dissipating approximately 120 kW of electrical power for up to three minutes,

M94J026

Figure 5. System Integration Test Configuration

and a data acquisition system, which is connected by means of an IEEE-488 bus to the Maintenance Unit computer. Data will be gathered on this acquisition system in real time and stored on disk. Data stored during these tests will consist of such parameters as time (for correlation with the driving cycle), voltages on the DC bus, at the output of the fuel stack, at the output of the Load Leveler as well as key internal voltage monitoring points, currents at the same, or additional, points, and various key temperatures, flow rates etc.

The configuration shown in Figure 5 will allow the entire control system to be tested under both static and dynamic conditions as an independent unit.

The same set of characterization tests may also be run while the various system elements are being subject to environmental constraints (vibration tests or ambient temperature tests). In these cases, existing acquisition system instrumentation channels, sensors, instruments will be provided to acquire shake stand or thermal chamber data that can be used for later time correlation with various actions of the subsystem. These environmental tests are described in the System Control Specification.

5.2.1 AlliedSignal. TBD

5.2.1.1 Hydrogen Storage. TBD

5.2.1.2 Fuel Cell Stack. TBD

5.2.1.3 Gas Management System. TBD

5.2.2 PEI. TBD

5.2.2.1 Load Leveling. TBD

5.2.2.2 Auxiliary Simulation. TBD

5.2.2.3 System Integration. TBD

5.2.2.3.1 Support Equipment. Support equipment for the System Integration will consist of primarily, two major pieces of equipment.

A programmable resistive load will connect to the DC power bus, and will be capable of dissipating 120 kW for up to three minutes. This will allow the Maintenance Unit to program the value of the load during dynamic tests before it generates the appropriate stimulus messages on the CCD bus, and to measure the responses of the various subsystems to these changes.

A data acquisition system will be provided to gather various parametric information from each portion of the subsystems during the integration tests. These consist primarily of voltages, currents, resistances, temperatures which are pertinent to the system tests. This system will be connected to the Maintenance Unit via an IEEE-488 bus connection.

5.2.2.3.2 Support Facility. PEI will provide the necessary building for the Vehicle Test Facility. This facility will be located in a newly constructed building on the property of the present PEI complex. The fuel cell and storage area will be located outdoors on a 40' X 40' concrete pad, with the fuel cell itself located 4-5 feet below ground level with a concrete roof and earth berm surrounding it. Power and data cables will be run from the fuel cell area into the electric vehicle development area. All conduit to and from the area will have explosion proof seal offs and fittings. The entire concrete pad will be enclosed by a chain link fence approximately eight feet high. Metal and concrete bumpers will be installed around the hydrogen storage area for added safety.

A preliminary building layout is shown in Figure 6.

5.3 Procedures

All possible system/subsystem test configurations will be described in this section.

5.4 Test Report Requirements

Figure 6. Vehicle Test Facility

5.3 Procedures

All possible system/subsystem test configurations will be described in this section.

5.4 Test Report Requirements

This section will detail the format and data requirements to be used in the test report for this acceptance test.

ATTACHMENT 1
HYDROGEN STORAGE TEST PROCEDURE

ATTACHMENT 2
FUEL CELL STACK TEST PROCEDURE

ATTACHMENT 3
LOAD LEVELING TEST PROCEDURE

ATTACHMENT 4
AUXILIARY SIMULATION TEST PROCEDURE

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ATTACHMENT 5
GAS MANAGEMENT TEST PROCEDURE

ATTACHMENT 6
SYSTEM INTEGRATION TEST PROCEDURE