PRELIMINARY

PLANT GROWTH FACILITY – SPLIT PLENUM

END ITEM SPECIFICATION

L-9005.1

Document Approval Sheet

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Approved by:	
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ABBREVIATIONS

CDMS	Command and Data Management System
CPU	Central Processing Unit
CR	Change Request
EIS	End Item Specification
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LSLE	Life Science Laboratory Equipment
LSSC	Life Sciences Service Contract
OES	Orbiter Environment Simulator
PAR	Photosynthetically Active Radiation
PCM	Power Conditioning Module
PGC	Plant Growth Chamber
PGF-SP	Plant Growth Facility – Split Plenum
PPB	Parts per Billion
PPM	Parts per Million
RH	Relative Humidity
RTC	Real-time Clock
SCFM	Standard Cubic Feet Per Minute
TBD	To Be Determined
TBR	To Be Reviewed
VOC	Volatile Organic Compound

1. INTRODUCTION

1.1 Purpose

The End Item Specification (EIS) defines the performance characteristics of the Plant Growth Facility – Split Plenum (PGF-SP) Middeck and EXPRESS Rack payload hardware. The goal of the PGF-SP is to provide an environmental chamber that will support plant growth in microgravity as part of the Life Sciences Laboratory Equipment (LSLE) inventory. The first shuttle flight will validate performance of the PGF-SP hardware.

1.2 Applicable Documents

KHB 1700.7B	Space Transportation System Payload Ground Safety Handbook	8/99
MSFC-HDBK-527E	Materials Selection List for Space Hardware Systems	11/86
NSTS 1700.7B	Safety Policy and Requirements for Payloads Using the Space Transportation System	5/96
NSTS-21000-IDD-MDK Rev B	Middeck Interface Definition Document	6/97
SSP 52000-IDD-ERP REV C	EXPRESS Rack Interface Definition Document	8/01
NSTS-21000-SIP-MDK	Shuttle/Payload Standard Integration Plan for Middeck-Type Payloads	
NHB 1700.7B	Safety Policy and Requirements for Payloads using the Space Transportation System	
NSTS-13830 Rev.B	Implementation Procedure for NSTS Payloads System Safety Requirements	
NHB 8060.1C	Flammability, Odor and Off gassing Requirements and Test Procedures for Materials in Environments that Support Combustion	
JSC-20793	Manned Space Vehicle Battery Safety Handbook	
JSC-20793	Space Transportation System Payload Ground Safety Handbook	

ISS/EXPRESS Rack Documents
Electrical safety, interpretation of safety etc.

1.3 Change Policy

The Flight Experiment Development Manager maintains configuration control of the EIS. Changes to the Baselined EIS must be made using the formal Change Request (CR) process.

2. PAYLOAD HARDWARE OPERATING OBJECTIVES

2.1 General Hardware Performance and Requirements

2.1.1 The PGF-SP will provide a safe and flexible plant growth facility. The PGF-SP will be capable of use on long or short duration missions on the Orbiter or International Space Station (ISS).

2.1.2 The PGF-SP will provide a controlled environment within specified limits to promote plant growth. Specifically, the PGF-SP will control temperature, lighting, humidity, root moisture (TBR), Carbon Dioxide, ethylene, and other VOC's. It will provide individual control of each chamber. Control ranges are selected by the PI to achieve specific scientific comparisons particular to each experiment.

2.1.3 The PGF-SP will periodically record environmental parameters to verify control and for future scientific study, specifically temperature, lighting, humidity, root moisture (TBR), and carbon dioxide. Ethylene and other VOC's will be monitored by manually taking gas samples which will be analyzed later at ground facilities.

2.1.4 The PGF-SP will capture images of plant growth and development at various predetermined times during the mission for scientific analysis. The PGF-SP design will allow for special camera system design for experiment specific imaging requirements. For example, the PGF-SP will provide a camera array with filtered illumination and filtered image capture for the TAGES experiment. The addition of camera equipment will impact growth volume minimum cooling temperatures and weight of other materials.

2.1.5 The PGF-SP will support missions requiring continuous operations for up to 120 days.

2.2 Operational Modes- Three operational modes may be utilized during any given mission.

2.2.1 Standby- CDMS, and individual control boards are operational. All cooling fans are operational. No control devices or sensors are active. However, discrete commands and data retrieval are possible. This mode is used during testing, troubleshooting scheduled power down and loading or changing experiment configuration settings.

2.2.2 Park- The growing environment is actively being controlled to programmed preset values. Environmental data is being stored in volatile memory (TBR). Moving camera systems and hard drives are not operating. This mode is used during ascent, and descent to protect moving parts from high random vibration loads and shock.

2.2.3 Normal- Environment is actively being controlled to programmed preset values. Environmental data is stored on non-volatile hard drives (TBR). Moving cameras operate in accordance with preset algorithms. This mode is used during all normal experiment modes.

2.2.4 Switching between modes will normally be accomplished by an operator command from the user interface.

2.2.5 In the case of excessive air inlet or exit temperatures the PGF-SP will enter standby mode automatically.

2.3 Mission Descriptions: The PGF-SP will be designed to meet four specific mission descriptions.

2.3.1 Orbiter based Experiment- The PGF-SP will be capable of use as a single Middeck locker capable of supporting normal science missions. It will be capable of controlling and recording environmental parameters during handover operations, pre-launch, launch, orbit, descent, and removal. It will be capable of capturing images while on orbit or when specifically commanded during pre and post flight operations.

2.3.2 ISS Based Basic Mission- The PGF-SP will be capable of being transported to the ISS on the orbiter, transferred to the ISS (powered down) and installed in the EXPRESS Rack. Experiments may be carried out for longer periods of time. The PGF-SP would then be returned using the Orbiter.

2.3.3 Live Sample Transport- The PGF-SP will be capable of transporting live plant samples to the ISS in a controlled and monitored environment.

2.3.4 ISS Based Extended Mission- The PGF-SP will be capable of being installed on the ISS and receiving live specimens from the Orbiter. New environmental control parameters may be added to the PGF-SP data base and gathered data downloaded to ground control operations.

2.3.5 Ground Based Control- The PGF-SP will be capable of being installed in an orbiter simulator as a control for experiments being run on the orbiter or ISS.

2.3.6 Middeck Transport Only- The PGF-SP will not be designed for transport in Research Double Module, the MPLM or other non-Middeck launch and landing scenarios.

3. Payload General Specifications

The following sections state the functional specifications for the design and fabrication of the PGF-SP. Individual specifications mandated by the Middeck and EXPRESS Rack interface are not listed in these sections but will be implemented in the payload design and fabrication

3.1 Payload General Specifications

3.1.1 The PGF-SP payload shall be designed in accordance with the requirements Middeck and EXPRESS Rack interface requirements

3.1.2 The PGF-SP flight hardware shall be capable of standard loading at L-3 days.

3.1.3 Hardware Scrub/turn-around procedures shall not be required for hardware operation unless launch is delayed for greater than 2 days.

> **Note:** Experiment specific requirements may require later installation or scrub/turn-around operations at less than 2 days.

3.1.4 The payload shall support an experiment duration from one (1) to one hundred and twenty (120) days with a 90% reliability at 120 days.

3.1.5 All functions of the experiment shall be automatically controlled by the CDMS with the exception of gas sampling, harvesting and fixation.

3.1.6 The PGF-SP payload shall operate and meet all of its functional requirements when exposed to ambient temperatures within the range 15 to 30^{o}C.

3.1.7 The PGF-SP shall operate (standby mode) in a safe manner when exposed to ambient temperatures within the range 10 – 35^{o}C

3.1.8 Nominal weight of the PGF-SP without consumables will be less than 60 lbs.

3.1.9 The PGF-SP shall accommodate up to 5 lbs of water, nutrients, live samples and special equipment installed within the PGF-SP

3.1.10 The growing area for each plant growth chamber will be 0.031 m^2 (48 in^2) (TBR) as shown in Figure TBD

3.1.11 The growing height for each chamber shall be 216 mm (8.5 in) (TBR) as shown in Figure TBD

3.1.12 The nominal root tray/growth medium depth is 51 mm (2 in) as shown in Figure 3.1

> **Note:** Plants and growth media may be arranged in any fashion which meets the limitations of the chamber volume, orientation, and available interfaces.

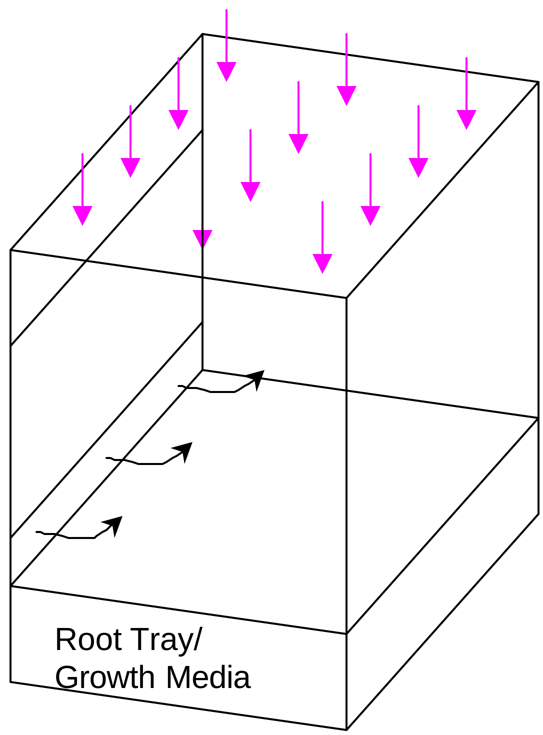

Figure 3.1 – Plant Growth Chamber Layout and Dimensions

3.2 Plant Growth Chamber (PGC) Environmental Control

3.2.1 General

3.2.1.1 The PGF-SP shall provide housing for 2 Plant Growth Chambers (PGC).
3.2.1.2 Each PGC shall be isolated and have independent environment controls.
3.2.1.3 Each PGC shall be monitored separately.
3.2.1.4 Air circulation shall be provided in the PGC's to prevent any air stratification or chamber "dead zones".
3.2.1.5 A gas sampling port and septum shall be provided on each PGC for on-orbit gas sampling. The gas sampling port interface shall be in accordance with Figure TBD
3.2.1.6 Carbon Dioxide removal will be accomplished using a sacrificial scrubbing agent and will require replacement at pre-set intervals.
3.2.1.7 Carbon Dioxide makeup will be accomplished by drawing in cabin air.
3.2.1.8 Volatile Organic Compounds (VOC's) including Ethylene will be removed using sacrificial scrubbing agent filters which will be replaced when the Carbon Dioxide filters are replaced.
3.2.1.9 Water provided to the plants will be a combination of reclaimed moisture from the dehumidification process and stowed water from a reservoir.

3.2.2 Control set points and accuracy

3.2.2.1 Each PGC shall be capable of controlling environmental variables within an accuracy given in table 3.2.2. This is the error between the measured value and the set point value

3.2.2.2 Carbon Dioxide will be controlled to the setpoint or 80% (TBR) of ambient, whichever is lower. The PGF-SP will not be designed to produce carbon dioxide.

3.2.2.3 The control value for photosynthetic active radiation will be determined by (TBD).

3.2.2.4 Ethylene and VOC's will be controlled using an open loop system. The system will be designed to meet the values in table 3.2.2 during normal expected usage. The PGF-SP will also offer the option of removing or not removing VOC's and ethylene as an experimental variable.

Table 3.2.2 - Control set points and accuracy

Environmental Variable	Set point Range	Control Accuracy
Temperature	23 – 26 °C (TBR)	+/- 0.5 °C
Relative Humidity	60 – 85% RH	+/- 5% RH
Carbon Dioxide	700 – 3,000 PPM	+/- 75 PPM
Photosynthetic Active Radiation	50 – 300 μmoles/m2/sec.	5% of set point
Root Zone Moisture (TBR)	25 – 75% saturated	+/- 20% of saturation
VOC's	<25% ambient	N/A
Ethylene	<50 ppb	N/A

3.2.3 Environmental variability within each PGC

3.2.3.1 The PGF-SP will minimize environmental variability within each chamber. Variability will be within the limits given in table 3.2.3

3.2.3.2 Photosynthetic active radiation variability will be measured at the top surface of the root tray. Additional variability will be introduced along the PGC growing axis

Table 3.2.3 - Environmental variability

Environmental Variable	Variability within PGC
Temperature	+/-0.5 °C
Relative Humidity	+/- 5% RH
Carbon Dioxide	+/- 75 ppm
Photosynthetic Active Radiation	+/- 10%
Root Zone Moisture	+/- 15% of saturation

3.2.4 Environmental Data Recording

3.2.4.1 Environmental data will be recorded and stored by the CDMS. Measurements will be taken within the accuracy described in table 3.2.4.

3.2.4.2 All measurements will represent the local value except the photosynthetically active radiation which will be calibrated to represent the average light level at the plane of the growth tray.

3.2.4.3 VOC and Ethylene concentrations will be monitored using occasional gas samples which will be examined post-flight using ground based equipment.

Table 3.2.4 – Recording Accuracy

Environmental Variable	Measurement Accuracy
Temperature	+/-0.2 °C (TBR)
Relative Humidity	+/- 2% RH
Carbon Dioxide	+/- 20 ppm + 2% of reading
Photosynthetic Active Radiation	+/- 3 µmoles/m2/sec
Root Zone Moisture	+/- 20% of saturation

3.3 Thermal Management

3.3.1 Orbiter Middeck Rear Cooling

3.3.1.1 Rear-ducted air cooling will be utilized for payload thermal exchange. The PGF-SP will draw 36 +/-5 SCFM for cooling of internal components.

3.3.1.2 Electromechanical loads shall be monitored for over temperature and be capable of automatic shut-down.

3.3.1.3 The payload exhaust temperature shall be monitored to ensure it does not exceed 46°C. The PGF-SP will enter standby mode if inlet temperature exceeds 32°C or if outlet temperature exceeds 45°C. The PGF-SP will shut down if exhaust temperature reaches 46°C.

3.3.2 Orbiter Middeck Front Cooling Option

3.3.2.1 The PGF-SP shall be designed to minimize the impact to the existing hardware if it must be flown as a cabin-air cooled payload.

3.3.3 EXPRESS Rack Rear Cooling and Water Loop

3.3.3.1 The PGF-SP shall be capable of using Avionics air from the EXPRESS Rack for cooling.

3.3.3.2 The PGF-SP shall be capable of using the Moderate Temperature Water Loop for thermal management in order to offset the difference in cooling air between the EXPRESS Rack and the Orbiter Middeck.

3.4 Imaging System (Camera)

3.4.1 The image system will be capable of storing time-elapsed images of the plant development within each PGC for post-mission evaluation.

3.4.2 The image recording system shall be capable of storing a minimum of 1080 (90 days x 12) images per PGC throughout the mission duration.

3.4.3 The camera will be controlled discretely (i.e., on/off) via commands issued by the CDMS.

3.4.4 The camera resolution shall be at least 640 lines (H) x 350 lines (V).

3.4.5 The imaging system will capture and store color images.

3.4.6 The imaging system will support experiment specific requirements which may include special illumination, special filtering and camera motion.

3.5 Payload Container

3.5.1 The PGF-SP will use a single Middeck locker replacement container.

Note: In the case of a cabin cooled payload is required a double locker may be used to provide air flow to the electronics located in the rear of the locker.

3.5.2 The PGF-SP will be capable of on-orbit transport from the orbiter Middeck to the ISS EXPRESS Rack.

3.5.3 The locker structure will meet all of the safety requirements associated with the orbiter Middeck and the EXPRESS Rack.

3.5.4 The payload container will provide access to the PGF-SP hardware and the biological samples.

3.5.5 The payload container will provide a mount for the PGF-SP interface panel.

3.6 Command and Data Management System (CDMS)

3.6.1 General

3.6.1.1 The CDMS shall control the operation of the cooling system, lighting system, crew interface, data archival, condensate control, power monitoring, and image capture.

3.6.1.2 A watchdog circuit shall be implemented to ensure that the CDMS is functioning properly or issue a system reset.

3.6.1.3 The CDMS shall be capable of restoring normal operation in the event of an unexpected system shut-down.

3.6.1.4 The CDMS will normally start in a standby mode in the event of an emergency shutdown and restart.

3.6.2 CDMS Mother Board

3.6.2.1 The CDMS Mother Board will provide top level control for all PGF-SP systems

3.6.2.2 The CDMS Mother Board will act as the primary interface for crew operations and network communications.

3.6.3 Interface Panel

3.6.3.1 LCD (TBR) - A Liquid Crystal Display (LCD) mounted on the payload interface panel displays messages to the user as the payload operates.

3.6.3.1.1 The LCD shall be used to display nominal status and nominal error messages.

3.6.3.1.2 Messages on the LCD shall be clearly visible and formatted as defined in the PGF-SP Crew Procedures. Messages will be formatted in accordance with ISS requirements.

3.6.3.1.3 A touch screen or individual switches shall be used to transfer actions to the CDMS for payload commanding.

3.6.3.2 Power On/Off – A circuit breaker attached to the payload status panel is used to apply/withdraw power to the payload. The breaker is engaged to initiate payload operation.

3.6.3.2.1 The circuit breaker shall operate freely and enable power to the payload.

3.6.4 Status LED (TBR) – A bicolor LED attached to the payload status panel displays the CDMS operating condition.

3.6.4.1 The LED shall provide green light to indicate normal operating conditions and the yellow/amber light to indicate all off nominal conditions.

3.6.4.2 The status LED shall be capable of activation/deactivation via commands issued by the CDMS.

3.6.5 Power Conditioning Module (PCM)

3.6.5.1 The PGF-SP payload shall derive its main electrical power from the orbiter's Middeck 28 Vdc (Nom.) + 4 Vdc source.

3.6.5.2 The PGF-SP payload power consumption shall be limited to:

3.6.5.2.1 180 W maximum continuous power

3.6.5.2.2 Power peaks limited to 200 W for a duration of less than 10 sec.

3.6.6 Data Storage

3.6.6.1 The CDMS shall archive the experiment data to a nonvolatile storage media.

3.6.6.2 The CDMS shall archive a minimum of 90 days of data.

3.6.6.3 The CDMS shall store a redundant copy of the experiment's archived data with the exception of the camera images.

3.6.7 Serial Communication

3.6.7.1 The CDMS shall be capable of RS 422 serial communications via the front panel serial port. (TBR)

3.6.7.2 The serial port shall be capable of operating with a baud rate of at least 38,400 bps.

3.6.7.3 The CDMS shall be capable of USB communications via a USB connector in the front panel (TBR)

3.6.8 Real Time Clock

3.6.8.1 A Real Time Clock (RTC) shall be located on the CDMS CPU board.

3.6.8.2 The RTC shall continue to keep time when power is removed from the PGF-SP payload.

3.6.8.3 The battery shall provide power to the RTC for a minimum of one (1) year.

3.6.8.4 The RTC shall maintain a local real time base, with accuracy better than 5 minutes over the entire mission.

3.6.9 Data Archival

3.6.9.1 The CDMS shall monitor the vital signs and environmental parameters of the payload in the range and to the accuracy indicated in Table 3.2.2.

3.6.9.2 The CDMS shall be capable of storing data acquired over the entire mission including vital signs, environmental parameters, time-base correlation, and captured images.

3.6.9.3 The data acquisition rate shall be adjustable between 10 sample/minute. and 1 sample/hour, with a nominal rate of 1 sample/10 minute.

3.6.9.4 Images will be logged based on a predetermined schedule.

4. HARDWARE DEVELOPMENT AND PROJECT MANAGEMENT

NASA-KSC Flight Experiments Project Managers, YA-E, will provide overall project management. NASA-KSC Life Science Service Contractor (LSSC) will coordinate all phases of payload design, documentation, fabrication, integration, and testing.

4.1 Design

The PGF-SP payload will be designed by the NASA-KSC Life Science Sevice Contractor (LSSC) in accordance with applicable NASA specifications and standards. The design process will include structural, thermal, and airflow analysis. Detailed electrical, electronic, acoustic, and vibration examinations will also be performed. The design process will include preliminary and critical design reviews at approximately 30% and 90% completion levels, respectively.

4.2 Specifications and Drawings

Detailed Mechanical and Electrical drawings define physical dimensions, materials, and fabrication methods of the payload. The top level mechanical and electrical assembly drawing numbers are 1020-M-0000-00 and 1020-E-0000-00, respectively. Technical specifications will augment drawings to completely describe payload performance requirements.

4.3 Fabrication

Specifications and drawings described in Section 4.2 will be used to fabricate the payload hardware. Fabrication will be subcontracted by the LSSC to qualified mechanical, electronic, and electrical companies. Subcontractors will be selected based on technical qualifications, cost estimates and delivery schedules.

4.4 Integration and Functional Testing

Payload systems described in section 3.0 will be integrated by the LSSC after fabrication. Individual systems will be functionally tested prior to acceptance from a subcontractor. The integrated payload will be tested to verify compliance with applicable NASA specifications and standards.

4.5 Flight Certification Testing

The following tests shall be performed on the payload systems described in section 3.0:

- EMI Test
- Vibration Test
- Acoustic Test
- Offgas Test
- Design Validation Test – Final hardware test to ensure that the payload complies with this specification.
- Software Validation Test – Final software test to verify the functionality of the software.