KSC Constellation Ground Operations Project Office

CONSTELLATION

# Integrated Testing at KSC between Constellation Systems

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KSC Constellation Ground Operations Project Office

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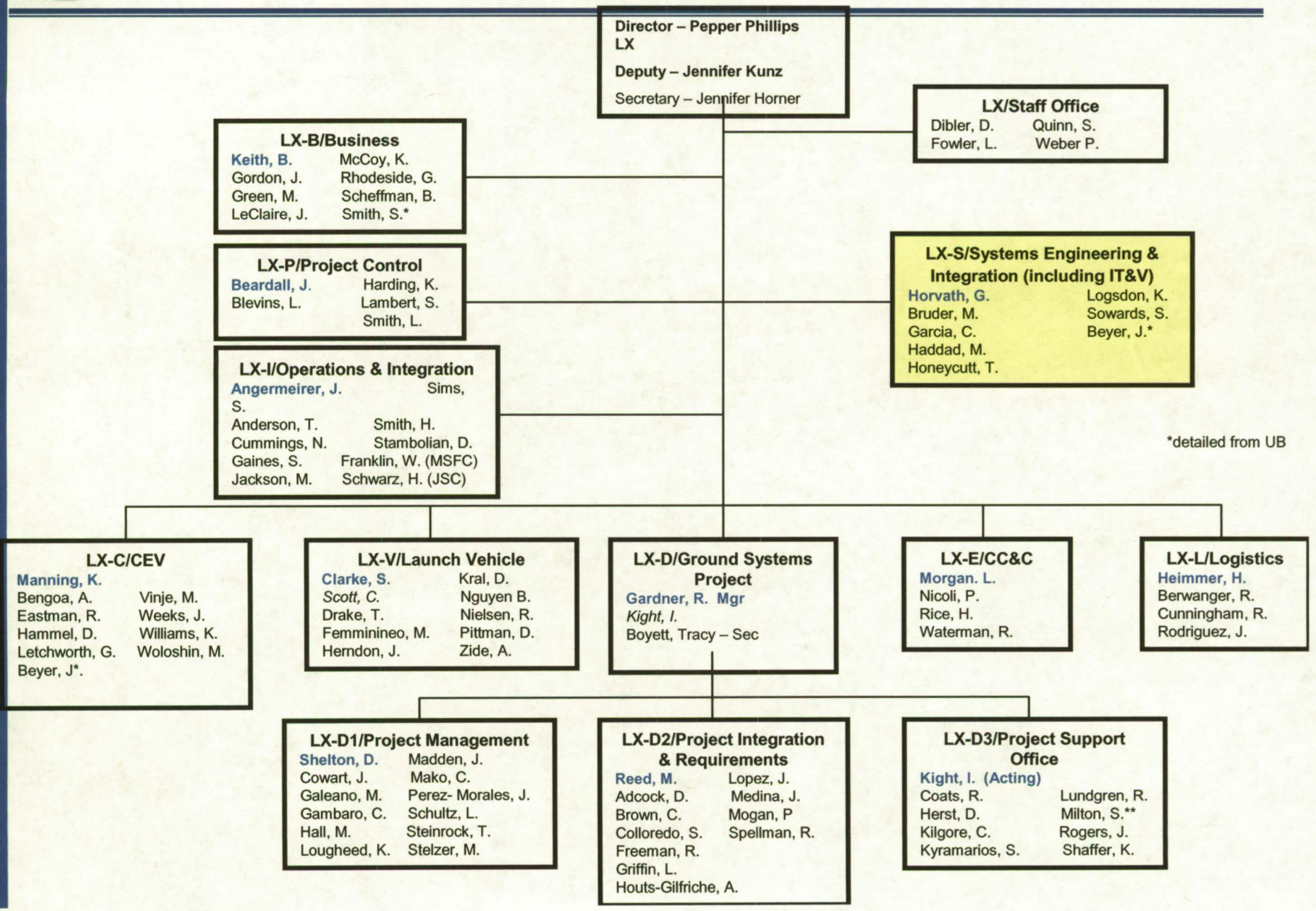

# Presentation Outline

- History of MEITs
  - MEIT Concept
  - Previous MEITs
  - Major Problems that were found by MEITs
  - Benefits of MEITs
- Integrated Testing at KSC for the Constellation Program
  - MEITs/FEITs/IVTs
  - Test Configurations
- Summary

# Multi-Element Integration Testing (MEIT)

- "Ship and shoot" was the strategy for the ISSP during the early 1990's
  - It proposed transporting flight elements directly from the factory to the launch site and begin the mission without further testing
  - Factory level testing and element interface verifications at the subsystem-level, and interface analysis were all that was planned
- Before the end of that decade a shift in testing strategy occurred within the ISSP
  - The ISSP adopted a more integrated approach for ground validation of it's flight hardware
  - Availability of elements at the launch site created a feasible opportunity to test multiple elements together
  - The notion of validation testing on the ground was presented and accepted by the ISSP due to the criticality of the on-orbit functionality, including safety concerns for the crew
- Multi Element Integration Tests (MEITs) and Integrated Systems Tests (ISTs)
  - Risk mitigation tests performed on the ground, used for validating the operation of the flight elements and their systems in an environment that is as flight-like as possible
    - Space Station element-to-element interface capability was verified as well as systems end-to-end operability with hardware and software
    - Mission Sequence Testing (MST), also known as "end-to-end" integration testing, included a full-up configuration with the Mission Control Center, TDRSS satellite communication, and the "station" operating on the ground
    - Also verified limited on-orbit system compatibility

# KSC ISS MEIT Experience

- Planned/developed and implemented the following for ISSP:
  - MEIT1:
    - U.S. Lab, Z1, P6, SSRMS, Node1 (emulated)
  - MEIT2:
    - S0/MT/MBS, S1, P1, P3/4, US Lab (emulated)
  - MEIT3:
    - JEM, Node2, US Lab (emulated)
  - Node2 Systems Test
    - Node2, US LAB & Node1 (emulated)

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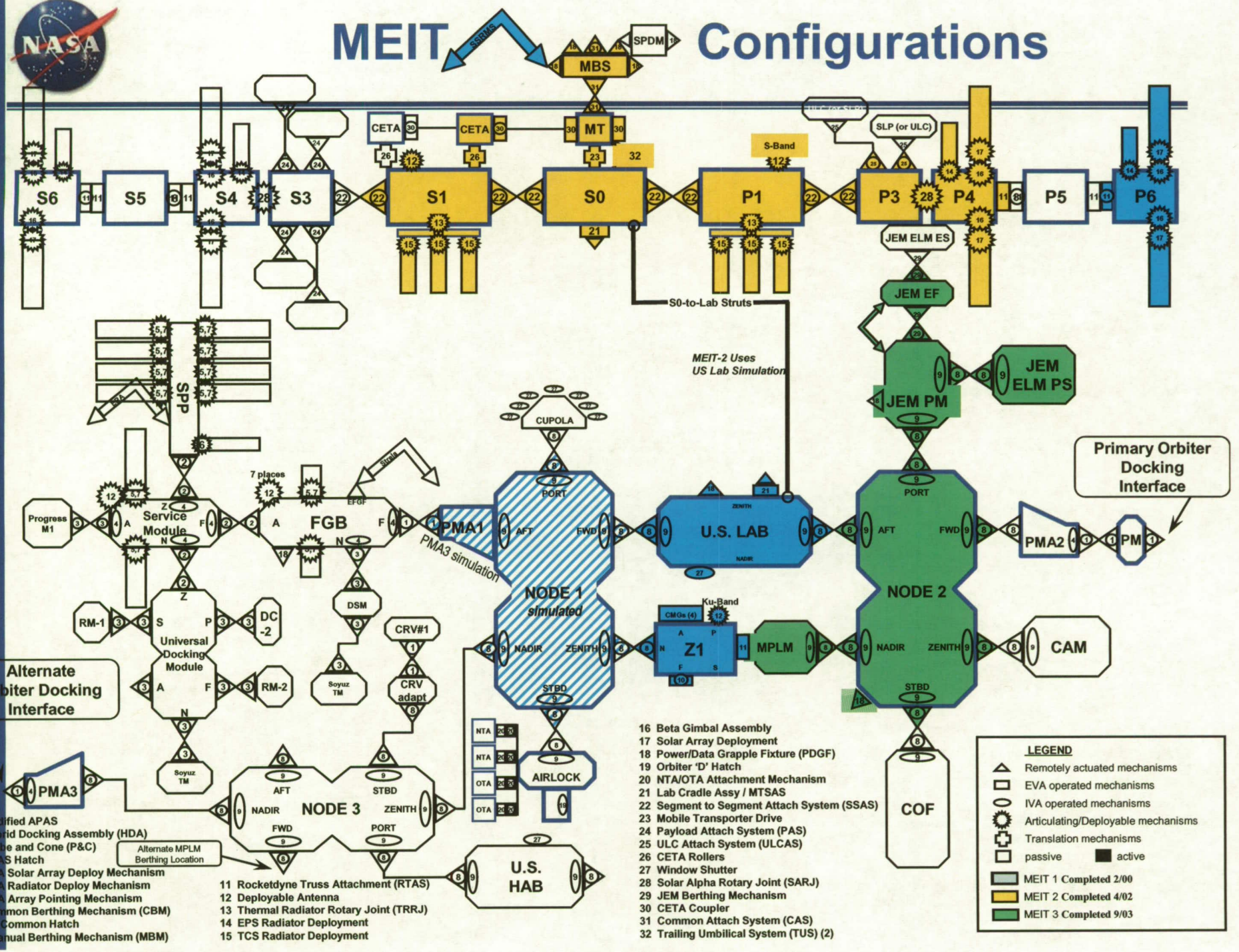
# MEIT Configurations




1 Modified APAS
2 Hybrid Docking Assembly (HDA)
3 Probe and Cone (P&C)
4 APAS Hatch
5 RSA Solar Array Deploy Mechanism
6 RSA Radiator Deploy Mechanism
7 RSA Array Pointing Mechanism
8 Common Berthing Mechanism (CBM)
9 US Common Hatch
10 Manual Berthing Mechanism (MBM)

11 Rocketdyne Truss Attachment (RTAS)
12 Deployable Antenna
13 Thermal Radiator Rotary Joint (TRRJ)
14 EPS Radiator Deployment
15 TCS Radiator Deployment

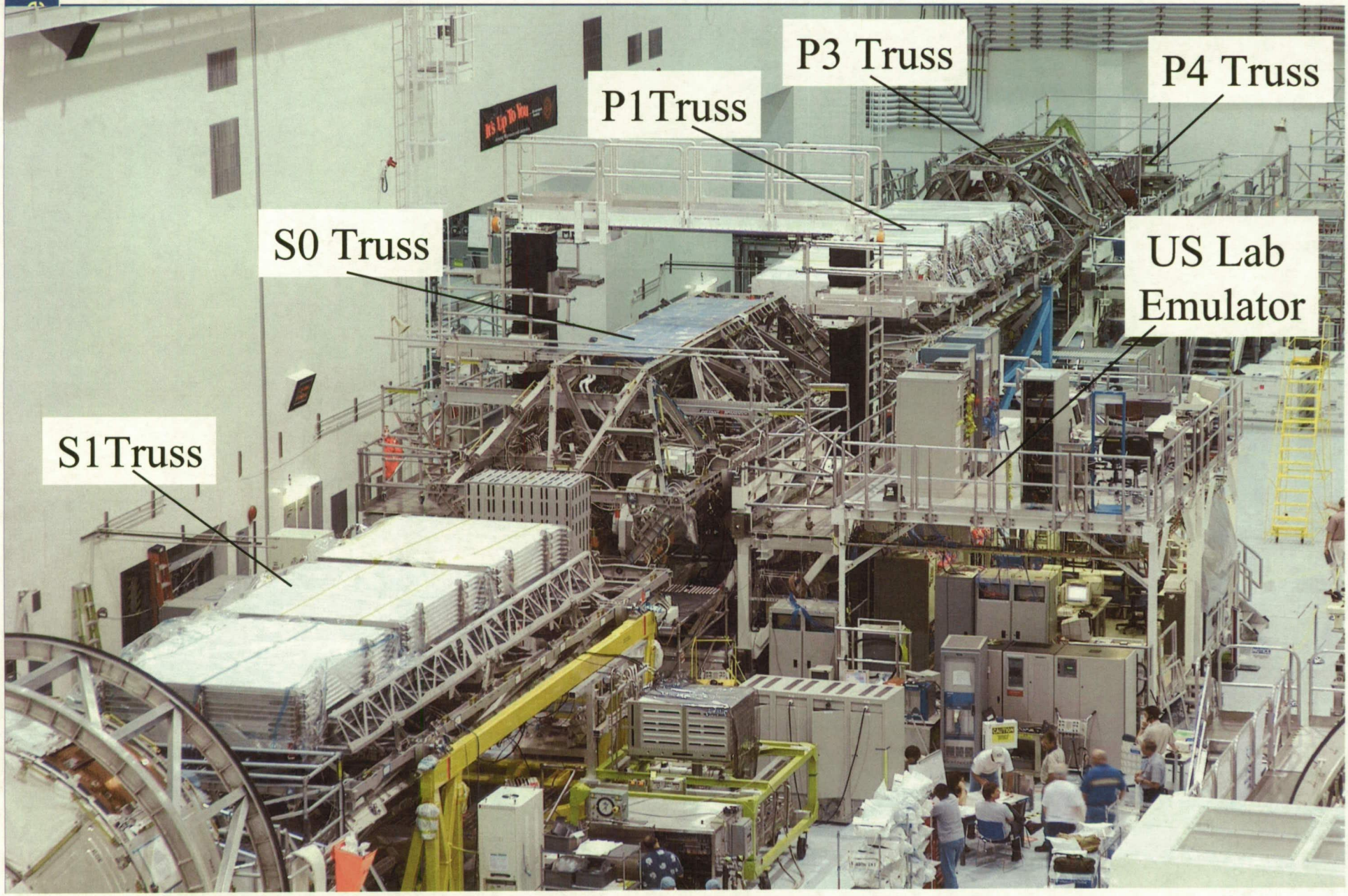
16 Beta Gimbal Assembly
17 Solar Array Deployment
18 Power/Data Grapple Fixture (PDGF)
19 Orbiter 'D' Hatch
20 NTA/OTA Attachment Mechanism
21 Lab Cradle Assy / MTSAS
22 Segment to Segment Attach System (SSAS)
23 Mobile Transporter Drive
24 Payload Attach System (PAS)
25 ULC Attach System (ULCAS)
26 CETA Rollers
27 Window Shutter
28 Solar Alpha Rotary Joint (SARJ)
29 JEM Berthing Mechanism
30 CETA Coupler
31 Common Attach System (CAS)
32 Trailing Umbilical System (TUS) (2)

**LEGEND**

- Remotely actuated mechanisms
- EVA operated mechanisms
- IVA operated mechanisms
- Articulating/Deployable mechanisms
- Translation mechanisms
- passive / active

MEIT 1 **Completed 2/00**
MEIT 2 **Completed 4/02**
MEIT 3 **Completed 9/03**

# MEIT 2 Hardware at KSC



# ISS MEIT Top Examples

- P6 failed to power up due to Auxiliary Power Converter Unit (APCU) under voltage trip condition
  - Impact: Unable to start P6 on Orbit
- US Lab Critical Activation took 36 Hrs first MEIT Power-up (MDM/Procedure problems), Requirement <2 hrs. During MEIT regression Mission Sequence Test, Critical Activation took 1 hr, 15 minutes
  - Impact: Loss of Lab element during on-orbit activation due to thermal loading
- C&C computers failed several times due to task overrun problems (CPU utilization problems)
  - Impact: Significant operational issues (Loss of Vehicle commanding, Vehicle health visibility, visibility to crew/ground) would occur because of continued loss of C&C MDM's
- Video lines were swapped between Trailing Umbilical Systems 1,2 (US) and Mobile Base System (CSA)
  - Impact: Significant operational impact to manually route video signals from SSRMS to RWS. EVA would have been required to replace two harnesses to correct the problem
- C&C failed when performing Sync to GPS time
  - Impact: Loss of accurate GPS capability, degraded attitude control capability until development /testing and on-orbit upload of new software patch
- Quality of Space to Ground Audio was unacceptable
  - Impact: Operation and potential safety impact to crew due to lack of understanding between Crew/Ground

# MEIT Benefits

- **Significant findings from MEIT have created an opportunity to correct major operational problems which would have resulted in:**
  - Cost/Schedule Slip
    - Major milestone slippage in the Program
  - Critical On-orbit Operations impacts
    - Safety concerns for the crew
    - Loss of mission objectives
    - Loss of flight hardware
  - Nominal Operations impacts
    - Unknown operation risks (loss of redundancy capability)
  - Unplanned EVA's

**The Cumulative effect of identifying/resolving integrated HW/SW/Procedure problems before flight has proven to save the Program major On-orbit issues**

# Integrated Testing at KSC for Constellation

- Testing that occurs between two or more individual Constellation Systems to verify the interfaces between those Systems and to validate the integrated Systems' functionality and interoperability
- Includes testing mechanical, electrical, data and fluid interfaces
- Integrated testing applies to the in-space flight and integrated vehicle stack configurations
  - Multi-Element Integration Testing (MEIT)
  - Flight Element Integration Testing (FEIT)
  - Interface Verification Testing (IVT)

# Multi-Element Integration Test (MEIT)

An integration test between two or more flight systems that will be launched on separate launch vehicles and integrated together for the first time in space. Interfaces between the flight systems, mission systems, and other appropriate CxP/ISS and external systems may be also tested as part of each MEIT.

- The primary objectives of MEIT are:
  - Demonstrate the interoperability, functionality, and stability of the flight systems, elements/modules, and sub-systems as an integrated "in-space" vehicle assembly on the ground before they are assembled in space for the first time.
  - Validate critical mission sequence activities and flight procedures prior to their first-time execution in-flight.
- A secondary objective of MEIT is:
  - To collect functional and performance data from the integrated flight systems to support validation of the different interface test tool sets, emulators, and simulators used by the Projects in accepting future serial numbers of those flight systems.
- MEIT serves a training ground:
  - Flight Crew and Trainers
  - Mission Operations Division (MOD) and MCC personnel
  - Constellation System Engineers (includes ISS System Engineers for MEIT1)

# MEIT (continued)

- MEITs are executed after all of the system-level requirements have been satisfied by the involved Project Offices and those offices declare their system designs as verified for flight.
- MEITs are one time tests with a potential for a follow-on regression test
  - Performed prior to first crewed missions
- Use of flight-like emulators and cables/connectors may be used when integration between the flight systems is not practical (i.e. ISS Flight Emulator for the CEV-ISS MEIT configuration).
- Planned MEITs:
  - CEV to International Space Station (emulated) (Orion/ISS)
  - CEV to Lunar Lander/EDS (emulated) (Orion/LSAM)

# Flight Element Integration Test (FEIT)

An integration test between the new or significantly modified systems, elements, and modules being assembled into an integrated launch vehicle for the first time. Interfaces between the flight systems, ground systems, mission systems, and other appropriate CxP and external systems may be also tested as part of each FEIT.

- The primary objectives of the FEIT are:
  - Demonstrate the interoperability, functionality, and stability of the flight systems, elements/modules, and sub-systems as an integrated "launch vehicle" assembly prior to the first operational test flight of that particular launch vehicle configuration (including first flight of significantly modified systems, elements, and modules);
  - Validate critical mission sequence activities and flight procedures prior to their first-time execution.
- A secondary objective of the FEIT is:
  - To collect functional and performance data from the integrated flight systems to support validation of the different interface test tool sets, emulators, and simulators used by the Projects in accepting future serial numbers of those flight systems.

# FEIT (continued)

- FEITs are executed after all of the system-level requirements have been satisfied by the involved Project Offices and those offices declare their system designs as verified for flight.
- FEITs are planned and scheduled as part of the assembly and preparation of the integrated launch vehicle.
- FEITs are currently planned for every test flight (except for Ares 1-X)
- Planned FEITs:
  - CEV/CLV (Orion/Ares I)
  - Lunar Lander/EDS/CaLV (LSAM/EDS/Ares V)

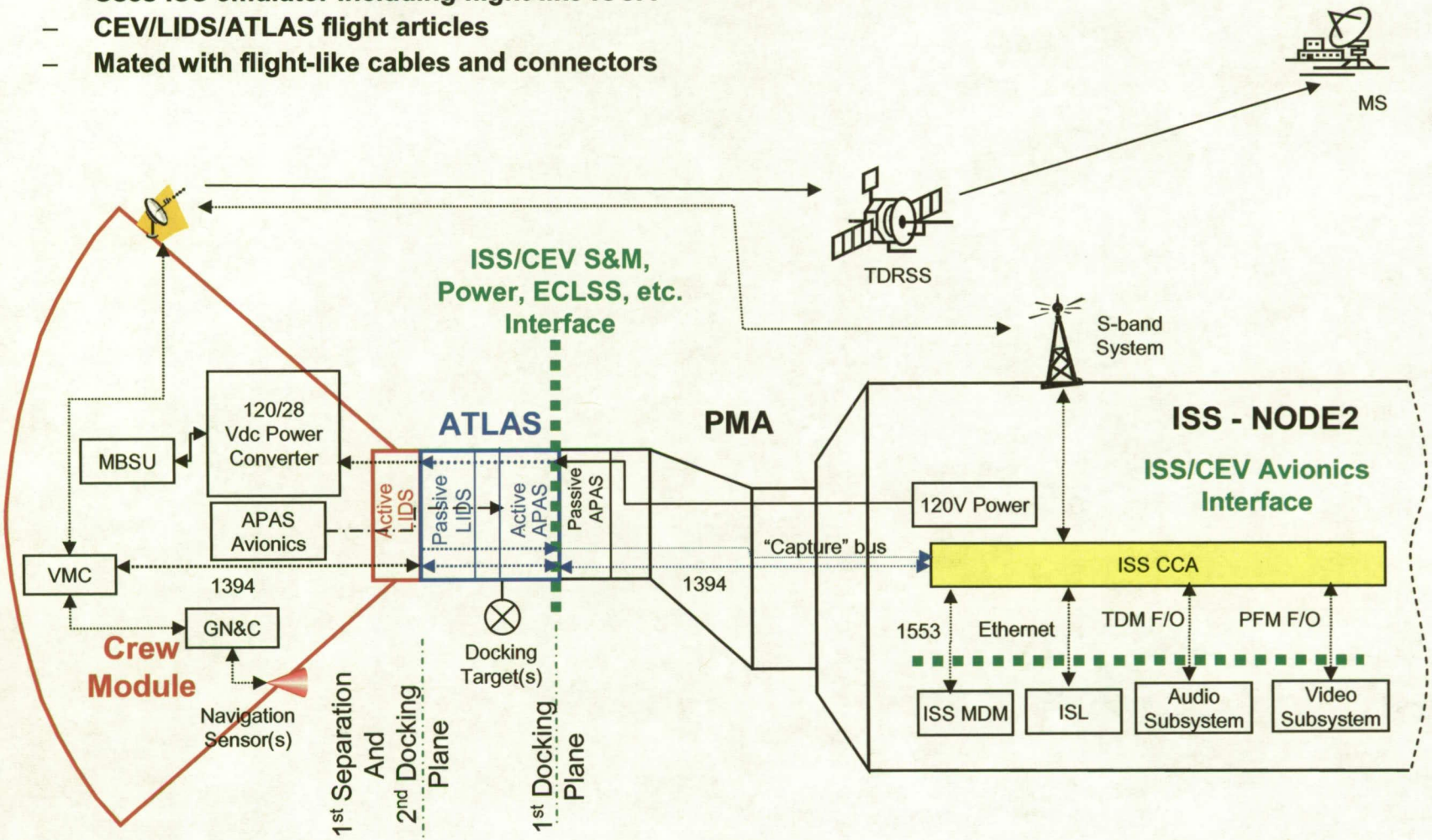
# Interface Verification Testing (IVT)

- Interface Verification Testing (IVT) verifies the mechanical and/or electrical interfaces between two or more flight systems after these systems have been mated
- IVT consists of the minimal set of activities to verify the integrity of all physical and functional interfaces between the systems involved for each specific vehicle stack configuration
- Performed every time after Full Operational Capability (FOC) has been obtained with the flight and ground Systems
- MEITs/FEITs would be required if any significant design upgrades or modifications have occurred

# MEIT 1 Test Configuration

# MEIT 1: CEV to ISS (emulator)

- **CEV-ISS interoperability/functionality MEIT (2013, prior to first human flight)**
  - **All functional interfaces: data, audio, video, RF, power**
  - **End to end with Mission Control and communications including TDRSS**
  - **Uses ISS emulator including flight-like ICCA**
  - **CEV/LIDS/ATLAS flight articles**
  - **Mated with flight-like cables and connectors**



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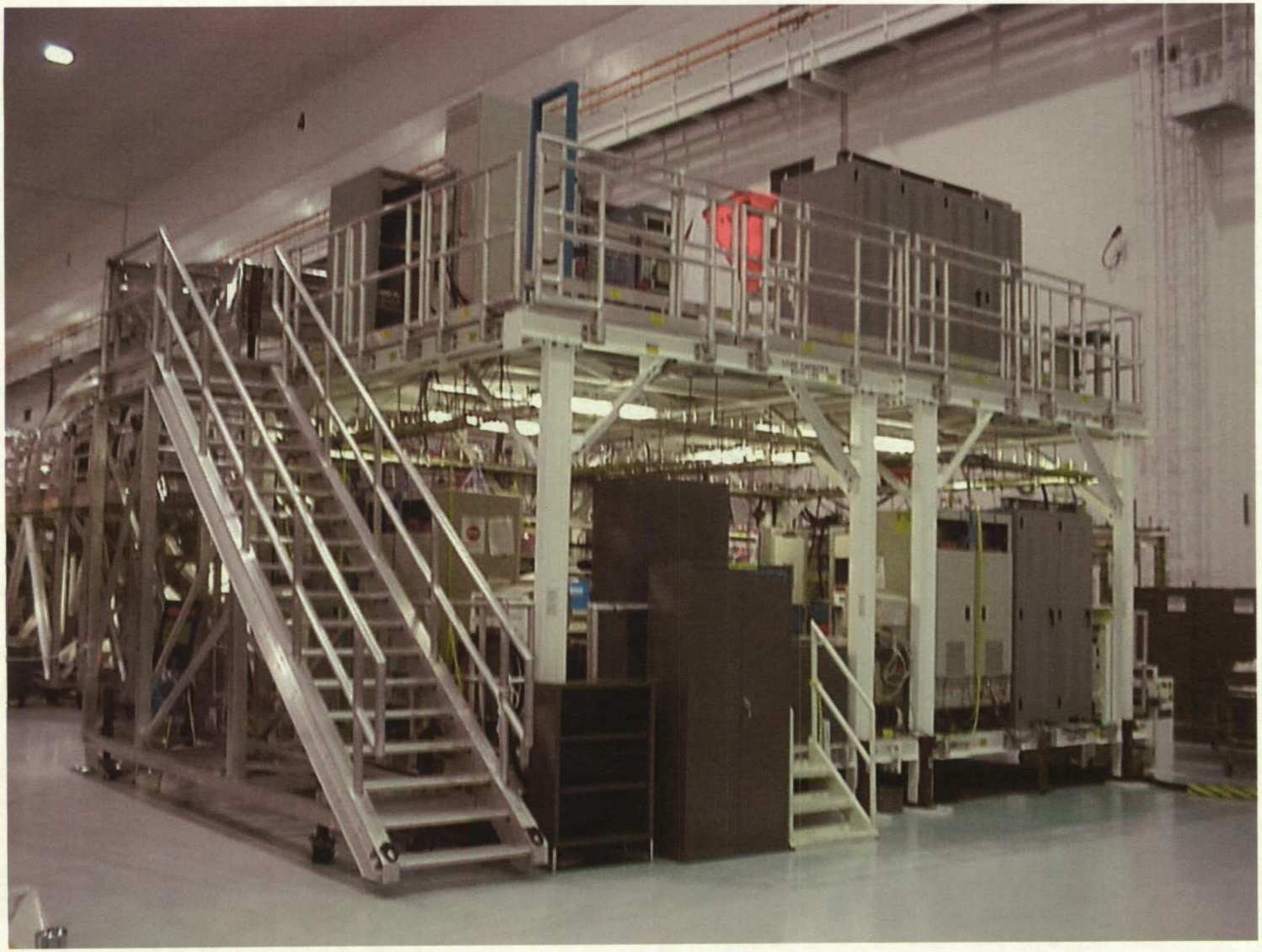
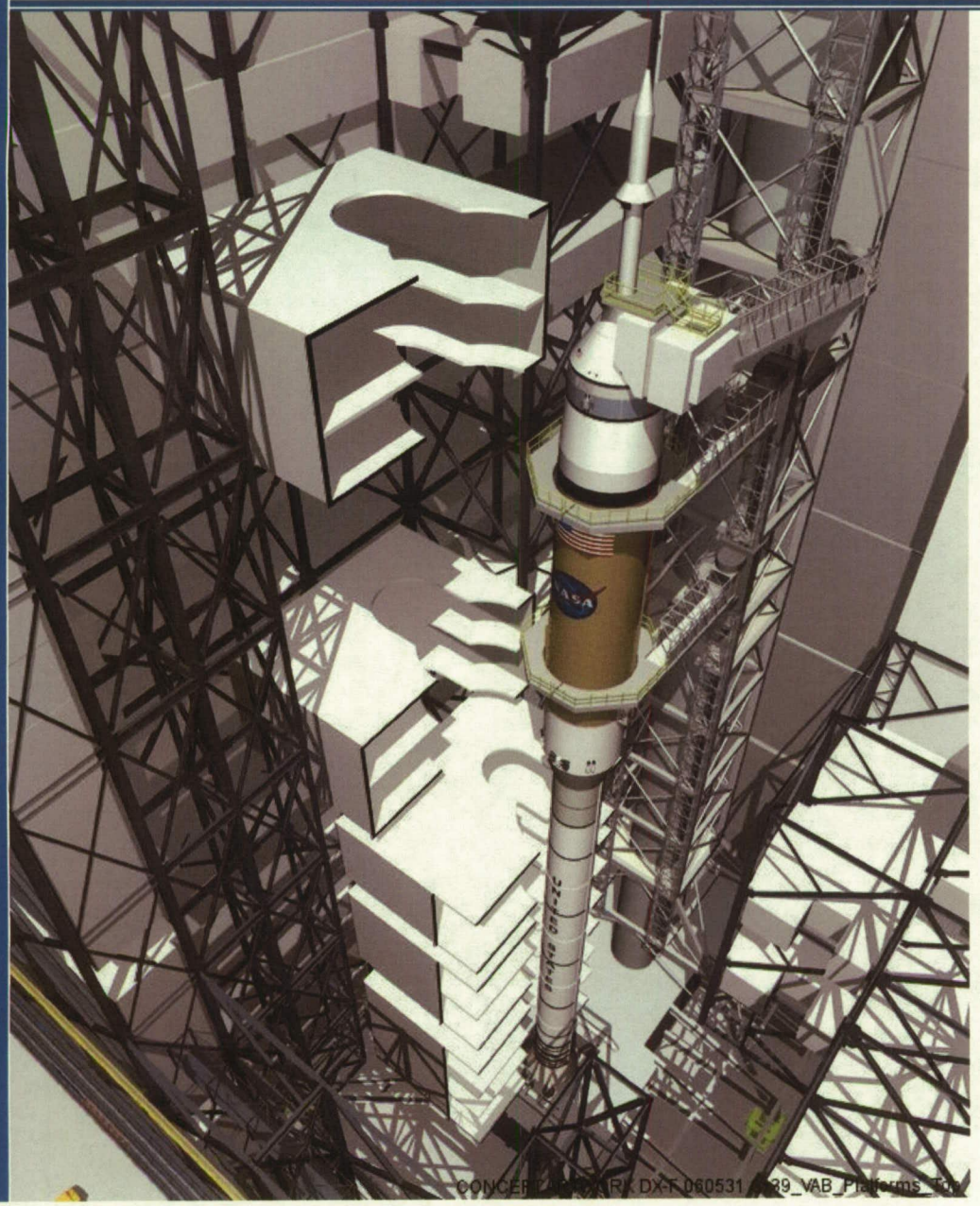
# ISS Flight Emulator



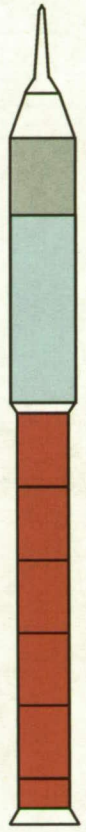



# MEIT 2 Test Configurations

# FEIT 1 – Ares 1 Launch Vehicle Stack



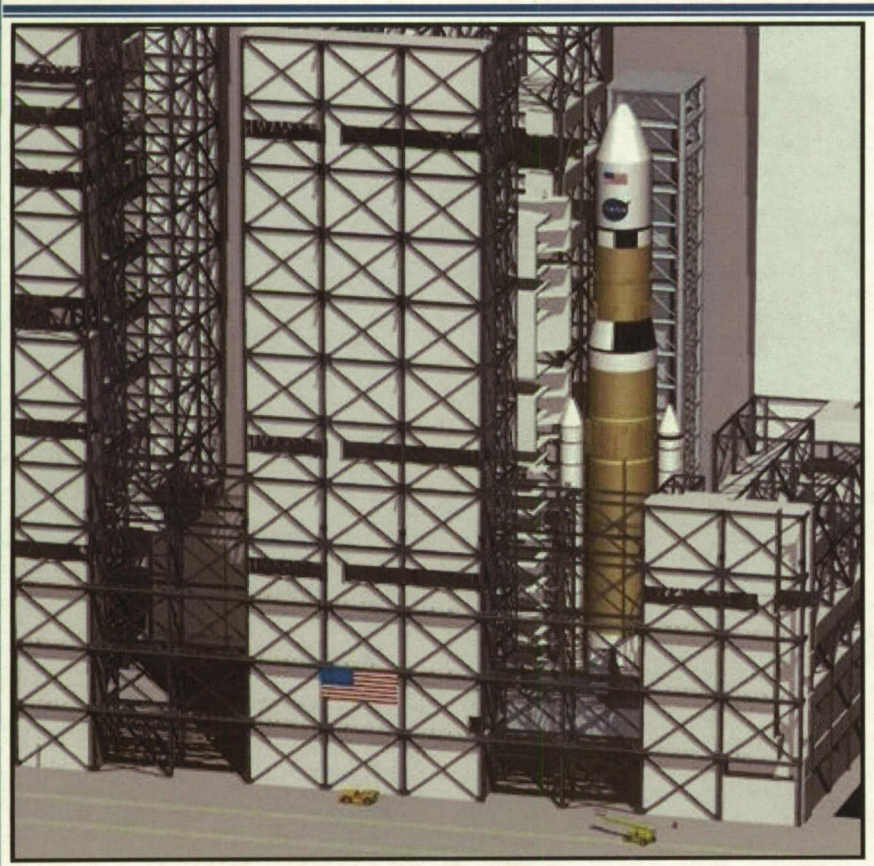
- **Test Configuration:**
  - CEV/CLV Integrated Stack
  - Ground Systems
  - Missions Systems
  - SCaN (Space Communications and Navigation)

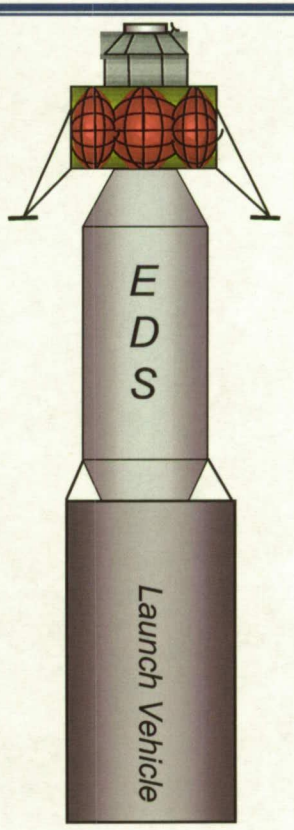




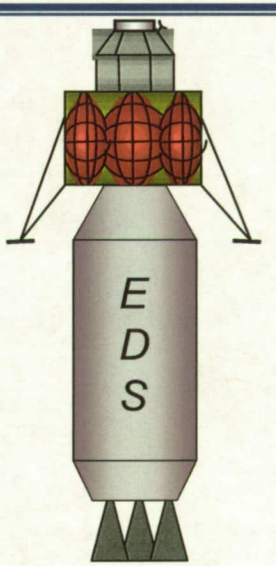

# FEIT 2 Test Configurations

# FEIT 2 – Ares V Launch Vehicle Stack






TC1




TC2

- **Test Configurations:**
  - LSAM/EDS/CaLV (TC1)
    - Integrated Stack
  - LSAM/EDS (TC2)
    - On-orbit Configuration

- **Both test configurations include:**
  - Ground Systems
  - Missions Systems
  - SCaN (Space Communications and Navigation)

# Summary

- Based on the previous success' of MEITs for the ISSP, these type of integrated tests have also been planned for the Constellation Program
  - MEIT
    - CEV to ISS (emulated)
    - CEV to Lunar Lander/EDS (emulated)
  - FEIT
    - CEV/CLV
    - Lunar Lander/EDS/CaLV
  - IVT
    - Performed every time after Full Operational Capability (FOC) has been obtained with the flight and ground systems

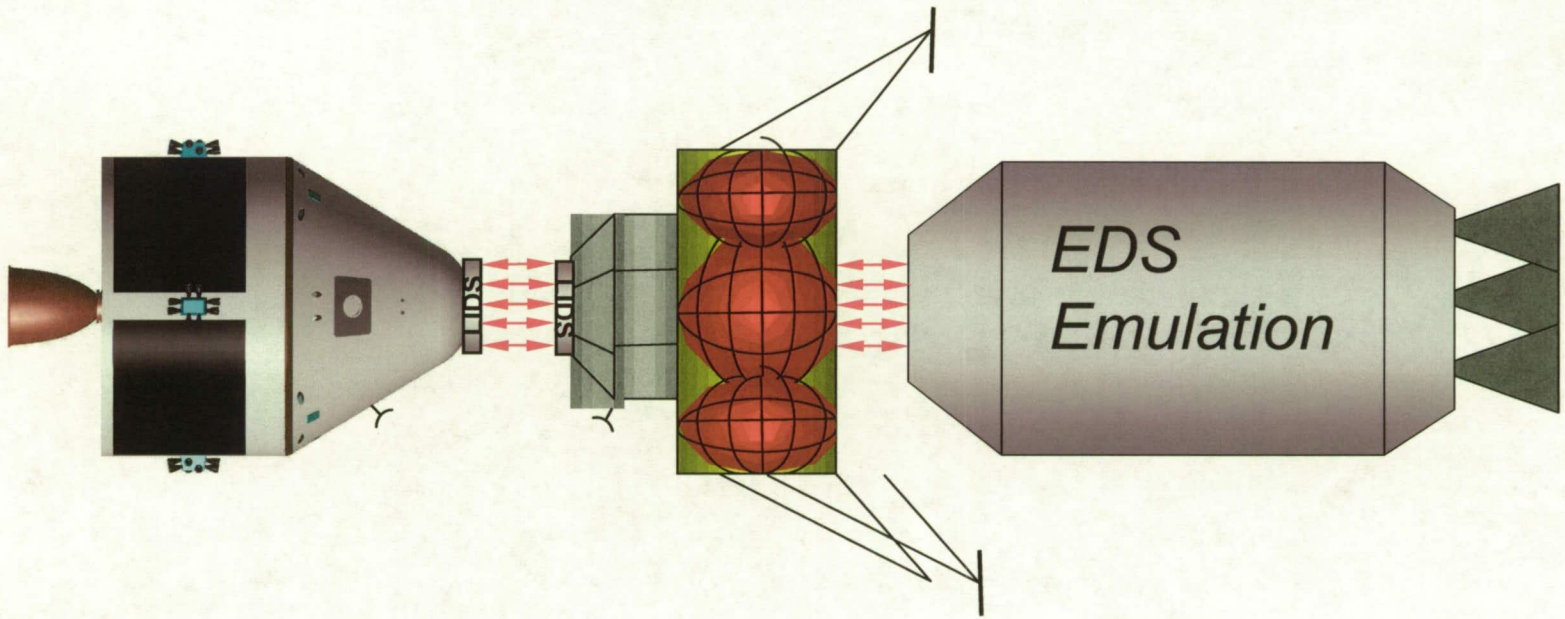

# Backup

# CEV-ISS MEIT Interfaces

- Mechanical
  - CxP will utilize newly developed Low Impact Docking System (LIDS)
  - LIDS is not compatible with ISS Docking System (APAS)
  - CxP will construct two APAS To LIDS Adapter Segments (ATLAS)
  - ATLAS will be installed permanently on PMAs 2 and 3 (APAS side)
  - Provides power and data pass through capability compatible with APAS 'X' connectors
- Power
  - ISS will provide 120 VDC to CEV via two redundant power feeds
  - Maximum continuous allocation of 1 kW; maximum peak load of 2 kW (combined)
  - CEV will convert 120 VDC ISS power to 28 VDC for internal buses
- Fluids/Gases
  - Only requirements are for Inter Module Ventilation (IMV) air circulation – essentially same as for SSP orbiter
- Avionics
  - Audio, video, and data are distributed internally to CEV over a network of IEEE 1394b data buses (Firewire)
  - Current concept is to extend one or more 1394 bus through ATLAS and PMAs into USL via existing ISS cable harnesses
  - CEV bus would connect to CxP provided C3I Communications Adapter (CCA – also called a Common Communications Adapter) which would provide conversion to legacy ISS networks.
    - CCA required for 1553 (ISS) and 1394 (CEV) data conversions
    - CCA installed on ISS
    - CCA can be integrated into ISS emulator and tested, or at SDIL in Houston
    - CCA or prototype may be integrated into ISS emulator and tested with CEV
  - Separate CEV to ISS Operational (S-Band) RF link would be implemented for rendezvous/ proximity ops similar to SSOR/SSSR

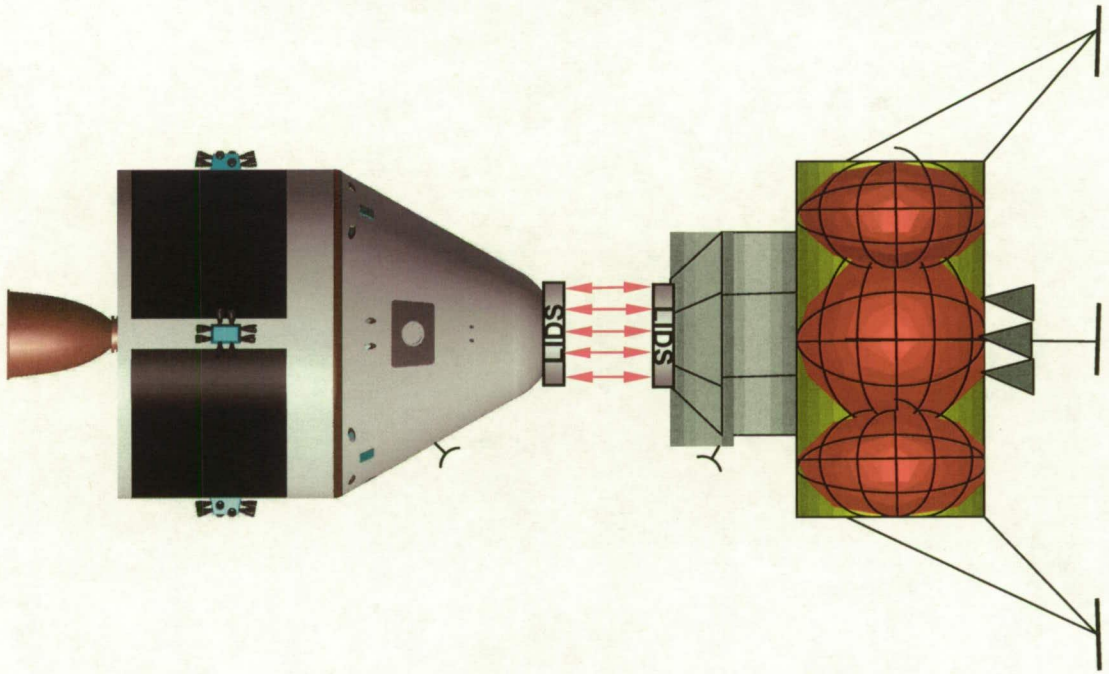
# MEIT 2: Test Configuration #1 (TC1)

## CEV to Lunar Lander with EDS Emulation



# MEIT 2: Test Configuration #2 (TC2)

## CEV to Lunar Lander



# FEIT 1 Test Configuration

# ISS Emulator

## INTERFACES

- Avionics/Data interfaces:
  - Analog/discrete sensors and effectors – to/from SSMB MDMs
  - MIL-STD-1553 data – SSMB C&DH data bus network
  - Ethernet – MRDL telemetry and OPS LAN data
  - Video – baseband (NTSC) and fiber optic (PFM)
  - Audio – baseband and ISS fiber optic audio bus
  - High Rate data – video, bitstream, and CCSDS data packets
- Electrical Power interfaces:
  - Primary/Secondary power (160VDC/120VDC)
  - Flight quality secondary power provided by FEUs of appropriate power distribution ORUs
  - Simulated load banks (PLRPC)
  - DDCU/RPCM
- Fluid or gas interfaces can be supported by other GSE equipment