Overview of Avionics and Electrical Ground Support Equipment

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49th AIAA Aerospace Sciences Meeting
Orion Pad Abort 1 Flight Test
January 4-7 2011
Avionics Overview: Relevant Test Objectives

• Primary Objectives
  
  AC01p. Demonstrate the capability of the LAS to propel the CM to a safe distance from a launch vehicle during a pad abort.
  S01p. Demonstrate abort event sequencing from abort initiation through LAS jettison.
  AC03p. Demonstrate ground-initiated abort.
  DS02p. Demonstrate stability and control characteristics of the LAV due to the LAS.
  P02p. Demonstrate the ability of the LAS to jettison from the CM.
  P01p. Determine the performance of the abort motor.
  P04p. Determine the performance of the ACM.
  S07p. Demonstrate jettison of the forward bay cover.
  S09p. Obtain data on ground impact locations for LAV modules and elements.
  
• Secondary Objectives
  
  R01s. Demonstrate parachute assembly system event sequencing.
  R02s. Demonstrate the deployment of the drogue parachute system.
  R03s. Obtain data on performance of the drogue system.
  R04s. Demonstrate the deployment of the main parachute pilot chute.
  R05s. Demonstrate the performance of the main parachute system.

Avionics and FSW supported these objectives
Avionics Overview: Palletized Packaging

AV2

AV3

AV1
System Overview: Avionics & EGSE
Avionics Overview: Components

- **Remote Interface Unit** (Honeywell)
- **Vehicle Management Computer** (Honeywell)
- **Flight Data Recorder** (Teletronics)
- **Master Data Acquisition Unit** (Teletronics)
- **Main Vehicle Battery** (EaglePicher)
- **Power Distribution Unit** (Lockheed)
- **RF Transmitter** (Teletronics)
- **RF Hybrid** (Merrimac)
- **Tri-Band Antenna** (Haigh-Farr)
- **SIGI–INS unit without GPS** (Honeywell)
Avionics Overview: Component Layout

CM BUS HARNESSSES ROUTED IN FWD BAY

CM BUS HARNESSSES ROUTED IN FWD BAY

DFI

SiGI 2

SiGI 1

AV1

Bus Couplers (BC2A/B)

AV2

AV3

Bus Couplers (BC1A/B)
System Overview – Closed Loop Control

FT-RIU1
FT-VMC1 (Primary)
FT-RIU2
FT-VMC2
FT-RIU1
FT-VMC1 (Primary)
FT-RIU2
FT-VMC2

FT-SIGI1
FT-SIGI2

INERTIAL DATA FEEDBACK

PRIMARY FT-SIGI DATA USED BY BOTH FT-VMCs IF PRIMARY FT-SIGI DATA IS VALID
PRIMARY FT-VMC COMMANDS ARE PASSED ON TO ACM CONTROLLER VIA BOTH FT-RIUs
SECONDARY FT-VMC CMDS ARE IGNORED BY FT-RIUs

INERTIAL DATA FEEDBACK

ACTIVE CTRL
STDBY CTRL

OUTER LOOP
INNER LOOP
STDBY CTRL

CM/LAS MOVEMENT

BIG LOOP (INERTIAL)

PRESS XDCRS (x3)

PINTLE ACTUATORS
POSITION INDICATORS
SMALL LOOP (POSITION)

ACM CTRLR A
ARBITER

ACM CTRLR B

PINTLE ACTUATORS
POSITION INDICATORS
SMALL LOOP (THRUST)

ACTUATORP
OSITION

POSITION & THRUST CMDS

INTRA-FPGA COMM

PINTLES (x8)

CHAMBER PRESSURE FEEDBACK

KEY

ACTIVE CTRL
STDBY CTRL

LINEAR ACCEL, LINEAR & ANGULAR VELOCITY, POSITION, ATTITUDE (ROLL, PITCH & TRUE HEADING), ATTITUDE RATE, INERTIAL ALTITUDE, AND BODY ANGULAR RATES
Flight SIGI

- PA-1 large angle of attack knowledge error; attributed to design of PA-1 orientation
  - Environmental testing resulted in vertical velocity and altitude errors which affected angle of attack
  - Tests at high steady g in vertical channel plus random vibration saturated sensors
- Solution: Mount SIGI with diagonal axis vertical. Instead of 19 g on a single vertical channel, 11 g will be sensed by all 3 channel
Antenna Analysis

Abort plume assumed to be opaque

Interference pattern between Antenna 1 & 2

Antennas clocked between Abort nozzles

Tri-Band Antennas
Battery Cycle Life / Recharge Logistics

- Vendor recommended charging algorithm: Charge at 7.5 A until battery terminal voltage reaches 38V, then reduce current limit to 2.0 A until terminal voltage reaches 38V again
- Two battery charging tests conducted; resulted in algorithm bypassing high current charge and entering top-off phase immediately
- Additional tests and consultation with EaglePicher concluded that a period of inactivity produced a passivation layer, and, combined with the high state of charge (SOC), resulted in an elevated charging terminal voltage.

Solution:
- To avoid charging, developed go/no-go SOC criteria of 25% (25AH; 200% estimated usage for day of flight). Equates to approx 4 scrubs before the batteries need to be recharged in addition to planned pre-launch tests
  - 87 AH initial SOC (after the 3 planned tests)
  - 10.6 AH used per launch scrub
  - 15.01 AH used for worst case launch scenario
- No change to battery charging algorithm. If charging is required, discharge the batteries to 25AH or less prior to charging
FT-VMC Issues and Resolution

- FT-VMC BGA Black pad Issue (Risk #3941)
  - Black pad evidence on high vibration failed test unit (unmodified rugged chassis) in development testing
  - Black pad phenomenon occurs when the ball grid array on a device soldered to the printed wire board fractures or has debonded (open pads)
  - The root issue is anomalies in the inter-metallic bonds during the manufacturing process. This leads to a weaken joint and potential premature failure at these points
  - Industry phenomenon
  - Second test shows no black pad
  - Part is Altera Stratix 3 FPGA

- Conclusion: accepted risk for PA1
EGSE Overview: Launch Configuration

- **Concrete Pad**
- **CM**
- **LAS**
- **J-Box**
- **Berm**
- **MOF at Cox Range Control Center**
- **Range Comm**
- **4.5+ Miles Between MOF and VIV**
- **Long (155 ft) Umbilical**
- **Short (25 ft) Umbilical with 7 connectors located at CM Umbilical plate**
- **Cable Distribution Unit**
- **Vehicle Interface Van (VIV) (NASA provided / LM Modified)**
- **Mobile Operations Facility (MOF) Housing CCMS Back End**

**Overview:**
- **Launch Configuration**
EGSE Overview
Open Avionics Issues at T-0

• At T-27d, Remote Interface Unit 2 (RIU2) failed to respond correctly on all interfaces upon power up.
  • Telemetry (MDAU serial link) and VMC point-to-point unresponsive
  • Ethernet interface degraded (intermittent ICMP response, no command response)
  • Voltage and Currents were nominal
  • RIU1 behaved nominally
  – Lab units never showed this behavior, even after an aggressive power-cycle test (power cycled approx 100 times consecutively)
  – Project team elected not to attempt the power cycle test on flight units to reduce risk of damage or further degradation.
  – Root cause has not been isolated. May be grounding problem. Power cycle test was performed post-flight, no recurrence of symptoms observed.
Open Avionics Issues at T-0

• SIGI2 exhibited increasing drift in the position solution throughout the vehicle integration and system testing phase. Requirement was “< 0.6 ft/s”
  – Altitude Go/No-Go limits exceeded (-41% margin), accepted as this is not used by the GNC control loop
  – Drift error disappeared on Day of Flight

• CM Main Vehicle Battery 1 (MVB1) voltage was slow to recover following brief (< 1 minute) load test at T-24 hours
  – Test and performance history of this battery indicated that the activation acceptance testing at the manufacturer showed similar behavior on this particular serial number. It was within acceptance criteria so it wasn’t flagged.
**Open EGSE Issues at T-0**

- Vehicle Interface Unit ‘Voter Card’ shorted intermittently.
  - At T-18d, routine checks found that the CM skin had become energized by the VIV ground reference.
  - Upon investigation, root cause found to be jack screw not installed according to drawing and a failure of the PCB conformal coating.
  - Replaced failed board with spare. Inspected remaining 8 boards for similar failures, replaced all post-flight.

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*Coating failed, energizing this screw via the 28VDC plane*

*This washer should have been installed on the other side*

*Intermittent contact between screws*
Open EGSE Issues at T-0

- Command and Control Server failed to enumerate RIUs correctly for the first time at T-2h25m
  - Prevented automatic verification of avionics built in test (cursory inspection found no avionics problems)
  - Analyzed all the logfiles available in real time using system experts in the Mission Engineering Room and the engineering teams standing by in Denver and Houston
  - At T-39m, decided to reinitialize the EGSE command server and rerun avionics built in test to verify no avionics issues were masked by the EGSE failure.
  - Had not happened before or since
Avionics Flight data: Abort Enable

- **Abort Enable**
- **Mission Mode**
- **ACMC A ACM Mode**
- **ACMC A 140V Battery Voltage**
Avionics Flight data: Abort Enable

- w_mca10sw00012f: ADL_Abort_Enable_Cmd_Recvd
- w_mca13sw00122f: NAV_SIGI_ModeCommanded
- w_mca13sw00121f: NAV_Mode
- w_mca13sw00123f: NAV_IsSigIReady
Avionics Flight data: Abort Enable

- **w_mca10sw00012f**: ADL Abort Enable_Cmd_Rsvd
- **w_mce03pd10001v**: PDU Bus 2 ORD Voltage
- **w_mce03pd10002c**: PDU Bus 2 ORD Current
- **w_mca16ru00095f**: [RHU_HS] Discrete IO Pad Abort_Rdy_Status

Project Orion Abort Flight Test
Avionics Flight data: Abort Enable

Video from [http://www.youtube.com/watch?v=lKzAZY2tTk](http://www.youtube.com/watch?v=lKzAZY2tTk)
Due to PEC and MDAU design, erroneous telemetry can be recorded during ordnance firing events. When a channel is fired, PwrSpply indicates 0V and all channels firing.

Similar signature observed in EDL during validation testing with live NSIs.

This does not affect the performance of the PECs themselves, all ordnance did fire as designed (verified by post-flight continuity test).

Had there been an anomaly, the lack of telemetry would impede troubleshooting.

Solution: provide dedicated, isolated sense lines for each channel.
• Avionics design had no true time reference; clocks were synced to free-running time signal on board
• SIGI had no GPS. Would not have improved position reckoning during boost phase of PA-1, but could have provided an accurate clock and reduced drift errors prior to launch. VIV had GPS time reference, but no IRIG signal to CM.
• WSMR data path included an RF Best Source Selector. Path delay is variable.

<table>
<thead>
<tr>
<th>Product</th>
<th>Time Offset</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOF wideband recorded telemetry</td>
<td>+00:00:00.000</td>
</tr>
<tr>
<td>VIV logged data files</td>
<td>+00:00:00.114±0.006</td>
</tr>
<tr>
<td>DFI recorder segment 1</td>
<td>-04:22:37.873±0.005</td>
</tr>
<tr>
<td>DFI recorder segment 2</td>
<td>-04:22:44.440±0.005</td>
</tr>
<tr>
<td>DFI recorder segment 3</td>
<td>-04:22:53.415±0.005</td>
</tr>
<tr>
<td>OFI recorder segment 1</td>
<td>-02:53:06.654±0.005</td>
</tr>
<tr>
<td>OFI recorder segment 2</td>
<td>-02:53:12.533±0.005</td>
</tr>
<tr>
<td>OFI recorder segment 3</td>
<td>-02:53:19.532±0.005</td>
</tr>
<tr>
<td>CM tunnel film camera</td>
<td>+11:20:54.963±0.006</td>
</tr>
<tr>
<td>CM tunnel video camera</td>
<td>+12:34:53.680±0.032</td>
</tr>
<tr>
<td>WSMR optics</td>
<td>+00:00:00.114±0.006</td>
</tr>
<tr>
<td>WSMR radar</td>
<td>+00:00:00.114±0.006</td>
</tr>
<tr>
<td>BET</td>
<td>+13:00:00.203</td>
</tr>
</tbody>
</table>
• Abort motor blast competed with vehicle motion to demate umbilical connectors from the Crew Module.
• Lanyards failed, although may have been after connectors demated.
T-0 Cable Failure Post Launch

Blast forces depinned the smallest connector

Lanyard anchor
Conclusions / Lessons Learned

- Avionics survived the flight
  - SIGI2 position error turned out to be less than 3 ft
  - RF Telemetry Link maintained lock via at least one receiver throughout the flight (best source selector switched as needed)
  - Parachute cutters fired successfully at T+8 minutes
  - All transmitters and auxiliary systems powered down as scheduled by T+14 minutes, VMCs and RIUs powered down when ground crew removed the Battery Enable Plugs.
  - Passed full suite of post-flight tests (functional checkout and mission simulations) with no issues.
  - No evidence of BGA/Black Pad failure
- Data time tagging plan must account for entire data path, should be considered early so that post flight analysis is practical. Requirements must be clear and understood
- Launch schedule pressure can lead to sub-optimized solutions if decisions are based on unrealistic launch date (mid- or long-term solutions may be rejected unnecessarily)
BACKUP
## Command Log (Operator Station in the MOF): PA-1 Launch command

<table>
<thead>
<tr>
<th>Time</th>
<th>Message</th>
</tr>
</thead>
<tbody>
<tr>
<td>05/06/2010 12:59:55:921</td>
<td>Sending Command CGF01GV00010B - VIU Pad Abort Execute</td>
</tr>
<tr>
<td>05/06/2010 12:59:55:921</td>
<td>RTE: Release HOLD on Task scriptid 2881 restore to COMPUTABLE</td>
</tr>
<tr>
<td>05/06/2010 13:00:00:473</td>
<td>ALRT: Command Response Error</td>
</tr>
<tr>
<td>05/06/2010 13:00:00:473</td>
<td>ALRT: Abort heartbeat was turned off or lost, it is ok to re-enable RIU cmding</td>
</tr>
<tr>
<td>05/06/2010 13:00:02:171</td>
<td>MSG: CMD Response Verified: VIU Pad Abort Execute</td>
</tr>
</tbody>
</table>

## Vehicle Interface Unit Log (VIV): Launch Command Received

<table>
<thead>
<tr>
<th>Time</th>
<th>Message</th>
</tr>
</thead>
<tbody>
<tr>
<td>13:00:00.014</td>
<td>ViuExec processCcsCommand msgNum=659 CmdId=1033 Arg 1=276 Arg 2=277 Arg 3=0</td>
</tr>
<tr>
<td>13:00:00.014</td>
<td>ViuExec, buildLocalCmd, pipename=/tmp/sendAbsPipe syncWord=64203 cmdId=1</td>
</tr>
<tr>
<td>13:00:00.014</td>
<td>ViuCmdAbsLog:EricAbstractCmd(482) viuCmdAbs readCmdIO - cmdId 1033, msgNum 659, cmdval[0]=276, cmdval[1]=0</td>
</tr>
<tr>
<td>13:00:00.014</td>
<td>ViuCmdAbsLog:EricAbstractCmd(257) viuCmdAbs sendToDiscreteDriver - wrote a 0, to dio brd num 0, chan num 1</td>
</tr>
<tr>
<td>13:00:00.014</td>
<td>ViuCmdAbsLog:EricAbstractCmd(659) viuCmdAbs readCmdIO - Sent stat to viuCmdEx - num byte 16, cmdId 1033, c</td>
</tr>
<tr>
<td>13:00:00.014</td>
<td>ViuCmdAbsLog:EricAbstractCmd(482) viuCmdAbs readCmdIO - cmdId 1033, msgNum 659, cmdval[0]=277, cmdval[1]=0</td>
</tr>
<tr>
<td>13:00:00.014</td>
<td>ViuCmdAbsLog:EricAbstractCmd(257) viuCmdAbs sendToDiscreteDriver - wrote a 0, to dio brd num 1, chan num 1</td>
</tr>
<tr>
<td>13:00:00.014</td>
<td>ViuCmdAbsLog:EricAbstractCmd(659) viuCmdAbs readCmdIO - Sent stat to viuCmdEx - num byte 16, cmdId 1033, c</td>
</tr>
<tr>
<td>13:00:00.019</td>
<td>send tlm name: MGF01GV30038K value 1</td>
</tr>
<tr>
<td>13:00:00.019</td>
<td>send tlm name: MGF01GV30050K value 1</td>
</tr>
<tr>
<td>13:00:00.019</td>
<td>send tlm name: MGF01GV30002V value 1105568640</td>
</tr>
<tr>
<td>13:00:00.019</td>
<td>send tlm name: MGF01GV30014V value 1105528000</td>
</tr>
<tr>
<td>13:00:00.019</td>
<td>send tlm name: MGF01GV30004D value 1</td>
</tr>
<tr>
<td>13:00:00.019</td>
<td>SetRuleFire, NORM, Fired rule 1.10 Monitor_RIU1_Enable_Execute_On_Rule1.</td>
</tr>
<tr>
<td>13:00:00.019</td>
<td>SetRuleFire, NORM, Fired rule 1.11 Monitor_RIU2_Enable_Execute_On_Rule1.</td>
</tr>
<tr>
<td>13:00:00.019</td>
<td>send tlm name: MGF01GV30038K value 0</td>
</tr>
<tr>
<td>13:00:00.019</td>
<td>send tlm name: MGF01GV30050K value 0</td>
</tr>
<tr>
<td>13:00:00.019</td>
<td>send tlm name: MGF01GV30002V value 0</td>
</tr>
<tr>
<td>13:00:00.019</td>
<td>send tlm name: MGF01GV30014V value 0</td>
</tr>
<tr>
<td>13:00:00.019</td>
<td>send tlm name: MGF01GV30004D value 0</td>
</tr>
</tbody>
</table>

## Command Log (Operator Station in the MOF): PA-1 Launch command

- SCL: send command "abortexecute"
- RTE: Release HOLD on Task scriptid 2881 restore to COMPUTABLE
- MSG: VIU1 command accepted. MsgNum: 659 CmdId: 1033
- MSG: VIU3 command accepted. MsgNum: 659 CmdId: 1033
- ALRT: Command Response Error
- ALRT: Abort heartbeat was turned off or lost, it is ok to re-enable RIU cmding
- MSG: 05/06/2010 13:00:02:171 CMD Response Verified: VIU Pad Abort Execute