MUSTANG Applications

Modular Avionics

IEEE Space Computing Conference
Pasadena, CA July 30 – August 1 2019

Art Azarbarzin

July 30 – August 1, 2019

NASA Goddard Space Flight Center

Electrical Engineering Division

To be presented by Art Azarbarzin at the IEEE Space Computing Conference, Pasadena, CA, July 30 to August 1, 2019.
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>ACE</td>
<td>Attitude Control Electronics</td>
</tr>
<tr>
<td>EGSE</td>
<td>Electrical Ground Support Equipment</td>
</tr>
<tr>
<td>IRAD</td>
<td>Internal Research and Development</td>
</tr>
<tr>
<td>ACS</td>
<td>Attitude Control System</td>
</tr>
<tr>
<td>EMI</td>
<td>Electromagnetic Interference</td>
</tr>
<tr>
<td>ISS</td>
<td>International Space Station</td>
</tr>
<tr>
<td>ADC</td>
<td>Analog to Digital Converter</td>
</tr>
<tr>
<td>ETU</td>
<td>Engineering Test Unit</td>
</tr>
<tr>
<td>JPL</td>
<td>Jet Propulsion Laboratory</td>
</tr>
<tr>
<td>ASIC</td>
<td>Application Specific Integrated Circuit</td>
</tr>
<tr>
<td>EVD</td>
<td>Engine Valve Driver</td>
</tr>
<tr>
<td>JTAG</td>
<td>Joint Test Action Group</td>
</tr>
<tr>
<td>BC/RT/BM</td>
<td>Bus Controller, Remote Terminal, Bus Monitor</td>
</tr>
<tr>
<td>FDC</td>
<td>Fault Detection and Correction</td>
</tr>
<tr>
<td>LCRD</td>
<td>Laser Communications Relay Demonstration</td>
</tr>
<tr>
<td>C&amp;DH</td>
<td>Command and Data Handling</td>
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<tr>
<td>FPGA</td>
<td>Field Programmable Gate Array</td>
</tr>
<tr>
<td>LVDS</td>
<td>Low Voltage Differential Signal</td>
</tr>
<tr>
<td>CM</td>
<td>Control Module</td>
</tr>
<tr>
<td>GEDI</td>
<td>Global Ecosystem Dynamics Investigation</td>
</tr>
<tr>
<td>MAIA</td>
<td>Multi-Angle Imager for Aerosols</td>
</tr>
<tr>
<td>COMM</td>
<td>Communications</td>
</tr>
<tr>
<td>GB</td>
<td>Gigabyte</td>
</tr>
<tr>
<td>MB</td>
<td>Megabyte</td>
</tr>
<tr>
<td>DAU</td>
<td>Data Acquisition Unit</td>
</tr>
<tr>
<td>GPM</td>
<td>Global Precipitation Mission</td>
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<tr>
<td>Mbit</td>
<td>Megabit</td>
</tr>
<tr>
<td>DDR</td>
<td>Double Data Rate</td>
</tr>
<tr>
<td>GSFC</td>
<td>Goddard Space Flight Center</td>
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<tr>
<td>DSB</td>
<td>Data Storage Board</td>
</tr>
<tr>
<td>HK</td>
<td>Housekeeping</td>
</tr>
<tr>
<td>MCE</td>
<td>Mechanism Control Electronics</td>
</tr>
<tr>
<td>DTN</td>
<td>Delay Tolerant Networking</td>
</tr>
<tr>
<td>HM</td>
<td>Heater Module</td>
</tr>
<tr>
<td>MHz</td>
<td>Megahertz</td>
</tr>
<tr>
<td>DRAM</td>
<td>Dynamic Random Access Memory</td>
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<tr>
<td>I2C</td>
<td>Inter-Integrated Circuit</td>
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<tr>
<td>MMS</td>
<td>Magnetospheric Multiscale Mission</td>
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<tr>
<td>EDAC</td>
<td>Error Correction and Detection</td>
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<tr>
<td>ICUD</td>
<td>Instrument Command and Data Handling Unit</td>
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<tr>
<td>MRAM</td>
<td>Magnetoresistive Random Access Memory</td>
</tr>
<tr>
<td>EDU</td>
<td>Engineering Development Unit</td>
</tr>
<tr>
<td>ILLUMA-T</td>
<td>Integrated LCRD LEO User Modem and Amplifier Terminal</td>
</tr>
<tr>
<td>MSFC</td>
<td>Marshall Space Flight Center</td>
</tr>
<tr>
<td>EEPROM</td>
<td>Electrically Erasable Programmable Read-Only Memory</td>
</tr>
<tr>
<td>IO</td>
<td>Input Output</td>
</tr>
<tr>
<td>MUSTANG</td>
<td>Modular Unified Space Technology Avionics for Next Generation</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
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</tr>
<tr>
<td>mW</td>
<td>Milli Watt</td>
</tr>
<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
</tr>
<tr>
<td>NICER</td>
<td>Neutron star Interior Composition Explorer</td>
</tr>
<tr>
<td>NVRAM</td>
<td>Nonvolatile Random Access memory</td>
</tr>
<tr>
<td>O2O</td>
<td>Optical to Orion</td>
</tr>
<tr>
<td>OCI</td>
<td>Ocean Color Instrument</td>
</tr>
<tr>
<td>PACE</td>
<td>Plankton, Aerosol, Cloud, ocean Ecosystem Mission</td>
</tr>
<tr>
<td>PROC</td>
<td>Processor</td>
</tr>
<tr>
<td>PSE</td>
<td>Power System Electronics</td>
</tr>
<tr>
<td>OM</td>
<td>Output Module</td>
</tr>
<tr>
<td>PCU</td>
<td>Power Converter Module</td>
</tr>
<tr>
<td>PM</td>
<td>Power Module</td>
</tr>
<tr>
<td>PMC</td>
<td>Power Monitor Card</td>
</tr>
<tr>
<td>PROM</td>
<td>Programmable Read Only Memory</td>
</tr>
<tr>
<td>RMAP</td>
<td>Remote Memory Access Protocol</td>
</tr>
<tr>
<td>RX</td>
<td>Receive</td>
</tr>
<tr>
<td>S/C</td>
<td>Spacecraft</td>
</tr>
<tr>
<td>SAM</td>
<td>Solar Array Module</td>
</tr>
<tr>
<td>SERDES</td>
<td>Serializer/Deserializer</td>
</tr>
<tr>
<td>SM</td>
<td>Segment Module</td>
</tr>
<tr>
<td>SPARC</td>
<td>Scalable Processor Architecture</td>
</tr>
<tr>
<td>SpW</td>
<td>SpaceWire</td>
</tr>
<tr>
<td>SRAM</td>
<td>Static Random Access memory</td>
</tr>
<tr>
<td>SSR</td>
<td>Solid State Recorder</td>
</tr>
<tr>
<td>SUROM</td>
<td>Startup Read Only Memory</td>
</tr>
<tr>
<td>TBR</td>
<td>To Be Resolved</td>
</tr>
<tr>
<td>Tbits</td>
<td>Terabits</td>
</tr>
<tr>
<td>TCC</td>
<td>Thermal Control Card</td>
</tr>
<tr>
<td>TX</td>
<td>Transmit</td>
</tr>
<tr>
<td>XAUI</td>
<td>10 Gigabit Media Independent Interface</td>
</tr>
<tr>
<td>UART</td>
<td>Universal Asynchronous Receiver/Transmitter</td>
</tr>
<tr>
<td>WFIRST</td>
<td>Wide Field Infrared Survey Telescope</td>
</tr>
</tbody>
</table>
What is MUSTANG?
(Modular Unified Space Technology Avionics for Next Generation)

• A form factor for building future avionics/electronics small/mid size instruments and spacecraft
  – 5.25” x 8“ (board size)
• No-backplane; enables size optimization for available volume and mix and match the portfolio of the card designs to meet the mission needs
  – 22 designs
• Circuits and designs can be re-laid out for larger Flagship class missions (and less frequent) that currently envision needing larger 6U cards
  – WFIRST (GSFC Mission) has re-laid out two boards worth of circuits into one 6U-220 in a Modular Form (GPM size boards shown in orange)

Note; Acronym list will be provided at the time of presentation

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<table>
<thead>
<tr>
<th></th>
<th>MUSTANG design portfolio</th>
<th>Design Heritage</th>
<th>Programs Baselined</th>
<th>Design</th>
<th>Schematic</th>
<th>Layout</th>
<th>FPGA</th>
<th>EDU Assy Completion</th>
<th>EDU Test Completion</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Processor (PROC)</td>
<td>IRAD</td>
<td>PACE/OCI/MAIA</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>✓ Complete</td>
<td>✓ Complete</td>
<td>6 Processors built and delivered (2 for MAIA); Processor #2 completed Vibe and Tvac. Flight Unit under test</td>
</tr>
<tr>
<td>2</td>
<td>Communication (COMM)</td>
<td>MMS, LRO, GPM/SDO</td>
<td>PACE</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>80%</td>
<td>✓ Complete</td>
<td>✓ Complete</td>
<td>Flight build planned for Spring 2020</td>
</tr>
<tr>
<td>3</td>
<td>Housekeeping (HK)</td>
<td>MMS</td>
<td>PACE/OCI/MAIA</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>✓ Complete</td>
<td>✓ Complete</td>
<td>Flight Unit under test</td>
</tr>
<tr>
<td>4</td>
<td>Engine Valve Drive (EVD) &amp; Deployment</td>
<td>MMS</td>
<td>PACE</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>✓ Complete</td>
<td>✓ Complete</td>
<td>Flight build planned for Spring 2020</td>
</tr>
<tr>
<td>5</td>
<td>Power Monitor Card (PMC)</td>
<td>MMS/GPM</td>
<td>PACE/WFIRST</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>✓ Complete</td>
<td>✓ Complete</td>
<td>Flight Unit under test</td>
</tr>
<tr>
<td>6</td>
<td>Output Module (OM) B2C</td>
<td>MMS/GPM</td>
<td>PACE/OCI/WFIRST</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>NA</td>
<td>✓ Complete</td>
<td>✓ Complete</td>
<td>Flight Build on progress</td>
</tr>
<tr>
<td>7</td>
<td>Low Voltage Power Convertor (LVPC) B2C and I2C</td>
<td>MMS</td>
<td>PACE/OCI/MAIA/WFIRST</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>NA</td>
<td>✓ Complete</td>
<td>✓ Complete</td>
<td>Flight Unit under test</td>
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<tr>
<td>8</td>
<td>Segment Module (SM)</td>
<td>LRO, SDO, MMS, GPM</td>
<td>PACE</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>NA</td>
<td>✓ Complete</td>
<td>✓ Complete</td>
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<tr>
<td>9</td>
<td>Solar Array Module (SAM)</td>
<td>MESSENGER/STEREO</td>
<td>PACE/WFIRST</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>NA</td>
<td>✓ Complete</td>
<td>✓ Complete</td>
<td>Flight Unit under test</td>
</tr>
<tr>
<td>10</td>
<td>Data Storage Board (DSB)</td>
<td>MMS</td>
<td>PACE/MAIA</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>✓ Complete</td>
<td>✓ Complete</td>
<td>Flight Unit under test</td>
</tr>
<tr>
<td>11</td>
<td>Attitude Control System IO (ACS IO)</td>
<td>GPM</td>
<td>PACE</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>✓ Complete</td>
<td>✓ Complete</td>
<td>Flight build planned for Spring 2020</td>
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<tr>
<td>12</td>
<td>Mechanism (MCE)</td>
<td>GPM</td>
<td>PACE/OCI</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>✓ Complete</td>
<td>✓ Complete</td>
<td>Flight Build on progress</td>
</tr>
<tr>
<td>13</td>
<td>Deployment B2C and I2C</td>
<td>MMS</td>
<td>PACE/OCI</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>NA</td>
<td>✓ Complete</td>
<td>✓ Complete</td>
<td>Flight build planned for Spring 2020</td>
</tr>
</tbody>
</table>
## MUSTANG General Status 6/25/2019 (cont’d)

<table>
<thead>
<tr>
<th>MUSTANG design portfolio</th>
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<th>EDU Assy Completion</th>
<th>EDU Test Completion</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>14 Dark Star</td>
<td>IRAD</td>
<td>OCI/GEDI</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>NA</td>
<td>✓ Complete</td>
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<td>15 Digital I/O (M1)</td>
<td>LCRD/SpaceFrame</td>
<td>PACE/OCI</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
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<td>✓ Complete</td>
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<td>16 Thermal Control Card (TCC)</td>
<td>TIRS</td>
<td>PACE/OCI</td>
<td>100%</td>
<td>10%</td>
<td>100%</td>
<td>100%</td>
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<td>17 Heater Module (HM)/I2C</td>
<td>MMS</td>
<td>OCI/MAIA/WFIRST</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>NA</td>
<td>✓ Complete</td>
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<tr>
<td>18 PPT Controller</td>
<td>MESSENGER</td>
<td>*</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>NA</td>
<td>✓ Complete</td>
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<tr>
<td>19 PPT Power Card</td>
<td>MESSENGER</td>
<td>*</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>NA</td>
<td>✓ Complete</td>
<td>✓ Complete</td>
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<tr>
<td>20 OM I2C</td>
<td>MMS</td>
<td>PACE/WFIRST</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>NA</td>
<td>✓ Complete</td>
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<td>21 Application Specific DarkStar</td>
<td>IRAD</td>
<td>OCI</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>NA</td>
<td>✓ Complete</td>
<td>✓ Complete</td>
<td></td>
</tr>
<tr>
<td>22 ISS Power Convertor Unit (120 to 28 V plus distribution) 2 modules PM and CM</td>
<td>NICER</td>
<td>GEDI/ ILLUMA-T/O2O</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>NA</td>
<td>✓ Complete</td>
<td>✓ Complete</td>
<td></td>
</tr>
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</table>

**Future Plans**
- DTN Card (Integrating DSB & Proc designs)
- Processor upgrade with HPSC chiplet upgrade
- High Voltage Card
- Custom ADC (for multi-channel Instruments)

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To be presented by Art Azarbarzin at the IEEE Space Computing Conference, Pasadena, CA, July 30 to August 1, 2019.
GEDI Flight PCU with EMI cover  
(operating on ISS since Nov 2018)
MUSTANG Processor Card Features (Dual Leon 3)

- GR712RC Dual-Core LEON3FT SPARC V8 Processor ASIC (200 MIPS)
  - Memory controller for SRAM, PROM, MRAM, and parallel IO (FPGA)
  - 6 UARTS, GPIO, 6 SpW ports - 2 with RMAP, 1553 BC/RT/M
  - 1.8V Core Voltage
- RTG4 Catch all FPGA
  - FLASH memory controller with onboard EDAC
  - Time Management and Distribution with external clock input
  - 2 additional SpW ports with RMAP
  - Watchdog and other FDC
  - LEON3 Core for CFDP
  - 10 Mb ETHERNET Core available with IPLEON3
  - Up to 20 LVDS/RS422 Discretes
  - 1.2V FPGA Core Voltage

- General
  - Up to 32 MB SRAM (16 MB Shared SRAM with FPGA)
  - 8-16 GB FLASH, 8 MB MRAM (EEPROM functionality), 64K PROM
  - Daughter card capability with custom functionality
- Mass: 0.986 Kg
- Power: 12.6W full card. Can be tailored to lower power per application depending on clock frequency and IO needed.
- Volume: 2"W x 7.24"H x 9.605"D

To be presented by Art Azarbarzin at the IEEE Space Computing Conference, Pasadena, CA, July 30 to August 1, 2019.
MUSTANG Processor Design upgraded for WFIRST Mission

- Quad Leon 4 ASIC (MUSTANG + size module form factor)- Board size 6U-220
  - 3 Engineering Board assembled tested; 1 delivered to the JPL Coronagraph Team to be used in the Instrument for a tech Demo on WFIRST Observatory (2 more deliveries planned for JPL)
- MUSTANG Team is planning on lifting the Quad Leon 4 design/layout and create an upgraded version of MUSTANG Processor Card
- WFIRST Processor Board features listed below

  Processor: GR740, Quad Core LEON4 SPARC V8 Processor and 250MHz-Rev 1
  - FPGA: RTG4
  - SUROM 64KB
  - SDRAM 256MB(+128MB FEC)
  - DDR2 4GB(+2GB FEC)
  - MRAM 2X16MB

  Oscillator QT194(50MHz)+QT2020
  - Peripherals:
    - SpaceWires: 20(8 GR740,12 RTG4)
    - 1553B: 1(1 GR740)
    - RS422: 16 TX and 16RX
    - UART: 3 (2 GR740,1 RTG4)
    - Debug ports: SPW Debug port and RTG4 JTAG

To be presented by Art Azarbarzin at the IEEE Space Computing Conference, Pasadena, CA, July 30 to August 1, 2019.
WFIRST Processor Board; Quad Leon 4
Digital I/O Card Features
(SERDES 3.125 Gbits)

- Unbuffered SERDES, from RTG4
  - 16 pairs xmit, 16 pairs rec.
  - Each pair capable of 3.125 Gbits
  - Each set of 4 pairs can be used in XAUI mode (10G Ethernet)
- LVDS and/or RS422
  - 20 pairs in / 20 pairs out
  - Splits between LVDS and RS422 every 4 pairs (one chip handles 4 pairs)
  - LVDS 100 MHz, RS422 10 Mbps
- LVDS using repeaters
  - High speed LVDS from RTG4
  - 36 pairs in, 18 pairs out, 200 MHz rate

- DDR2 memory, Two independent banks, 128Mx32, 4 Gbit
- SRAM memory, 8Mx32, 256 Mbit
- MRAM memory, 4Mx32, 128 Mbit
- RTG4 150 FPGA
- Mass; 1.070 Kg
- Volume; 2.5"W x 7.24"H x 9.605"D
- Power; 8W

To be presented by Art Azarbarzin at the IEEE Space Computing Conference, Pasadena, CA, July 30 to August 1, 2019.
Data Storage Board Features
(3.5 Tbps Storage using Flash)

- Up to 3.5 Tbit (448 Gbyte) Flash SSR
  - Sizeable in 512 Gbit (64 GB) banks
- 7 banks of 64 GB
  - 8 3D-Plus Flash stacks per bank
  - 8 Flash die per stack
  - 8 Gbit per die
  - Independently powered or in groups (TBR)
- 8 MB Rad-Hard MRAM
  - Sizeable in 16 Mbit (2 MB) banks
- Interfaces
  - 4 SpW interfaces, buffered
  - 4 1-3.125 Gbps SerDes interfaces (unbuffered)
- Power
  - Internally derived 2.5V and 1.2V
- Mass: 1.3 Kg
- Power Consumption: 3.7W for fully populated board
- Volume: 2"W x 7.24"H x 9.605"D

To be presented by Art Azarbarzin at the IEEE Space Computing Conference, Pasadena, CA, July 30 to August 1, 2019.
• GEDI PCU  6 Modules (120V to 28V convertor) operating on ISS since Nov 2018:  1 EDU + 1 Flight Unit
• Illuma-T PCU (copy of GEDI PCU with 3 modules) in production; 1 EDU + 1 Flight Unit
• O2O PCU (Orion) (identical to Illuma-T) – share EDU with Illuma-T + 1 Flight Unit
• OCI Instrument; Avionics CDR complete and flight build in progress
  – ICDU (7 module assembly)
    • 2 EDUs delivered to flight software team
    • 1 ETU used for box qualification (delivery on target in April 2019)
    • 1 Flight Unit (delivery Fall 2019)
  – MCE (4 module assembly) (1 EDU, 2 ETUs and 1 Flight)
  – DAU (4 MUSTANG modules delivered to custom box) – 1 EDU, 1 ETU, 1 Flight
• PACE spacecraft bus – EDU build complete and delivered (preparing for flight build)
  – C&DH Unit (5 Modules) 1 EDU; DTN implementation
  – C&DH-ACE (7 Modules) 1 ETU and 1 Flight
  – PSE (Power Subsystem Electronics) 12 Modules; 1 ETU + 1 Flight

To be presented by Art Azarbarzin at the IEEE Space Computing Conference, Pasadena, CA, July 30 to August 1, 2019.
• MAIA Instrument Electronics – Collaboration with JPL
  – 2 EDUs plus 2 EGSEs
    • EDU#1 delivered July 2018 (2-Module Unit) Processor/Data Storage plus EGSE #1
    • EDU#2 delivered September 2018 (5-Module Unit) including Processor/Data Storage plus EGSE #2
  – 1 Flight Unit plus 1 EGSE; Flight Build completed and under test, EGSE 90% complete
    • 2-Module delivery and 3-Module delivery plus EGSE #3; October 2019 (on target)
• Lunar Platform Lander (renamed VIPER) - Collaboration with MSFC (tentative launch date 2023)
  a tech demo
  – MUSTANG hardware was selected- criteria; lower power, best fit for available volume, “Extendability”
    (modular feature) and comparable cost (copies of existing designs)
  – 1 ETU plus 2 Flight Units
    • 18 modules (2 boxes) to manage power subsystem, power distribution and flight data system
    • Total of 54 modules to deliver
MUSTANG OCI Instrument C&DH Unit (ICDU)
(OCI is main Instrument for the PACE Mission at Goddard)

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• MUSTANG modular Avionics can be used for fast development by mix and matching hardware
• There flexibility to adapt the interfaces without relaying out the board
• Adaptability for adjusting voltages for Application Specific Card
• Adaptability for power distribution with different power requirements
• Also the flexibility of combining the modules in any order that fits the available volume
Back-up Charts
MUSTANG Production

• MUSTANG will produce over 132 Boards for PACE Mission and MAIA Instrument including delivered EDUs & ETUs
  – 20 Boards for OCI Instrument
  – 100 Boards for PACE spacecraft (including Mechanism and Instrument Tilt platform)
  – 12 Boards for MAIA

• Mechanical and Electronics assemblies produces at multiple manufacturing houses in several States and ahead of schedule to avoid "Bottlenecks” during production cycle
  – Mechanical housing; Minnesota & Maryland
  – Bare Board fabrication houses in multiple States; Colorado, California, Texas & Arizona
  – Electronic Assemblies
    • Irvine Electronics – California
    • Cobham – Colorado
    • Genesis Engineering Solution – Maryland
    • GSFC in-house assembly (ISO certified; operated by the certified contractor-partner)
    • Other potential assemblies houses to be used;
      – Flextronics (CA)

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MUSTANG Cards

Engine Valve Driver Card
Digital IO Card
PSE Monitor Card
Output Module Card

Housekeeping Card
Communication Card
Processor Card
Data Storage Board (not fully populated)
Full capacity 3.5Tb

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MUSTANG Cards

Deployment Card

Power Converter Unit (PCU) – Used in ISS Applications (Power Module – PM & Control Module – CM)

Segment Module

Heater Module

Mechanism Control Card

Dark Star Power Converter Card

Low Voltage Power Converter Card