Today:

- Announcements

- Team Questions?

- Guest Lecture – Spacecraft Power and Career Advice

- Launch is in 9 days
Announcements:

- Doodle poll for next Friday Check-Ins
**Announcements:**

Doodle poll for vehicles on Launch Day

<table>
<thead>
<tr>
<th>14 participants</th>
<th>YES, I have a car but all seats are full with team members</th>
<th>YES, I have a car and I can take additional students</th>
<th>NO, I don't have a car and I need a ride</th>
<th>NO, I don't have a car but I have a ride</th>
<th>NO, I don't have a car and neither does anyone on my team</th>
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<tbody>
<tr>
<td>Gabe Azcarraga</td>
<td>✔️</td>
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<td>Benjamin Hutchinson</td>
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<td>Nebiyu Sisay</td>
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<td>Elizabeth Donahoo</td>
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<td>Crawford Leeds (CA)</td>
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<td>Haleigh Flaherty</td>
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<td>Tina Nguyen</td>
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<td>Sam O'Donnell</td>
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<td>Matt Funk</td>
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<td>Trevor Barth</td>
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<td>Chris Koehler</td>
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5 1 1 3 4
Announcements:

- Community Service Approvals due today
- Turn in now and I will hand back at end of class
Announcements:

- Who needs help?

- Who doesn’t know they need help yet?

- I’m available during office hours (10:45 to 11:45 AM) and 2 to 3 today but I am out tomorrow and most of the day Monday
Tuesday 11/11...

Launch Readiness Reviews

“Big Deal”
Thursday 11/13...

Launch Logistics

Colorado Space Grant Consortium
Friday 11/14...

Team Flight Check-In

30 minute appointments
@ my office

BalloonSats Remain with me

Colorado Space Grant Consortium
Next Saturday...

Launch and Recovery!

Colorado Space Grant Consortium
Questions?

Colorado Space Grant Consortium
NASA's logo for their next generation crew exploration vehicle, Orion, was designed by Star Trek artist Mike Okuda.
WE'RE READY TO TAKE
THE NEXT GIANT LEAP.
Spacecraft
Electrical Power Subsystem (EPS)
Overview

Paul M. Anderson
Lockheed Martin Astronautics
(303) 971-4519
Future of NASA Human Exploration

Deep space extends beyond our moon, to Mars and across our solar system.

- Moon: 239,000 mi
- Near Earth Asteroid: ~3,100,000 mi
- Mars: 34,600,000 mi
- Low Earth Orbit: 220 mi
- Lagrangian Point 2: 247,000 mi
Exploration Systems Development
Space Launch System Enables Deep Space Exploration

Delta IV-Heavy
EFT-1

Space Launch System
EM-1 and EM-2
Orion Mission Timeline

- 2014 EFT-1
- 2017 EM-1
- 2018 AA2
- 2021 EM-2
The Orion Spacecraft
Orion’s First Mission
3000 Orion Team Members in 45 States
Crew Module

KENNEDY SPACE CENTER, FL
Crew Module Completion
Crew & Service Module Rollout
Launch Abort System (LAS)
Orion Move to LAS Facility

SAN DIEGO, CA
Launch Abort System
Service Module

KENNEDY SPACE CENTER, FL
Service Module Fairing Separation Test
EFT-1 Launch Vehicle
Parachute Drop Tests

ARMY YUMA PROVING GROUND, AZ
Forward Bay Cover Separation Test
Astronauts helping design Orion
Mission Control Center

JOHNSON SPACE CENTER, TX
Underway Recovery Test

SAN DIEGO, CA
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<th><a href="http://www.nasa.gov/sls">www.nasa.gov/sls</a></th>
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Practical Advice from a “Real” Engineer

Paul M. Anderson
Lockheed Martin Astronautics
(303) 971-4519
What are the Best Things About Your Job?

• Very Technically Challenging and Interesting Programs
  – Yes, this is Rocket Science

• Working with Incredibly Talented (and Under-Appreciated) Individuals

• Traveling (Some)

• Interfacing with the Public

• Launches!
What are the Worst Things About Your Job?

• **Failures**
  – Good Way to End Up on Leno & Letterman

• **Long Hours**
  – 50-60 Hours / Week During a Program is Typical

• **High Stress**
  – Lots of Technical Problems (without them we have no jobs)
  – Lots of Cost/Schedule Problems
  – High Visibility Programs (Company and General Public)

• **Lots of Traveling**
  – Most Business Trips are a Drag

• **Personnel Problems**
  – Very Few, but They’re Your Worst Nightmare
What do I Need to do to become a Successful Engineer?

• **Apply and Get Accepted to a Respected Engineering School**
  – Transfers from 2 Year Community Colleges are Now Widely Accepted and an Excellent, Cost-Effective Route
  – Does Not Have to be the #1 School in the World
    • But Should be Respected
  – Masters Degrees are Preferred, but can be Obtained Post-Employment
    • Good Tool to Help Avoid the Engineering and/or Management Glass Ceiling

• **Good Grades (within Reason)**
  – Extra-Curricular Activities are Also Strong Hiring Discriminators

• **Get Some Real-World Work Experience Before Graduating**
  – Taco Bell Doesn’t Count

• **Interview Well!**
  – If you can’t Write or Speak, Learn to do So
What do I Need to do to become a Successful Engineer?

- Get Along Well with People / Be a Good Team Player
- Be Diverse & Willing to do Multiple Things – Continually Broaden!
- Have a Positive Attitude
- Be Willing to Make Hard Decisions
- Be Thick Skinned but not Calloused
EPS Subsystem - What is it and What does it do?
• **(4) Major Functions of the Electrical Power Subsystem**
  
  – **Produces / Collects Electrical Power**
    
    • Nuclear
      – Plutonium-Based Radioisotope Thermoelectric Generators (RTGs) – Planetary Spacecraft
      – Uranium-Based Fission Reactors – Very Few (SNAP; TOPAZ)
    
    • Solar
      – Silicon Solar Cells (Standard & High Efficiency) – Commercial & Low Cost Applications
      – Gallium Arsenide Solar Cells (1, 2, 3 Junction) – Commercial, LEO, GEO, Planetary Applications
      – Rigid, Flexible, Concentrating Arrays
  
  – **Stores Electrical Power**
    
    • Batteries
      – NiCd (Low-Cost; Short Mission Life Applications)
      – NiH₂ (Workhorse Technology for LEO, GEO, Planetary Applications)
      – AgZn (Limited Life Cycle Applications – Mars Pathfinder)
      – Lithium Ion (Upcoming Technology – Mars Exploration Rover; DOD Experimental Applications)
  
  – **Controls & Conditions Electrical Power**
    
    • Power Regulators
    • Battery Chargers
    • Power Converters
  
  – **Distributes Electrical Power**
    
    • Power Switches (Mechanical or Electrical)
    • Fuses / Electronic Circuit Breakers
How Much Power Does a Spacecraft Need?
How Much Power Does a Spacecraft Need?

• **Small (Light-Bulb Sized)**
  – Mars Climate Orbiter; Mars Odyssey: 300W
  – Mars Polar Lander; Mars Exploration Rover: 150W
  – Stardust; Genesis: 200W

• **Medium (Hair Dryer Sized)**
  – Mars Reconnaissance Orbiter (1kW)
  – Commercial & Military Communication Satellites (1kW - 15kW)
  – Weather Satellites (2kW - 5kW)
  – Classified Satellites (Can’t Say)

• **Large (House-Sized)**
  – Hubble Space Telescope (25kW)
  – NASA / International Space Station (50kW)
  – Project Prometheus / Jupiter Icy Moon Orbiter (JIMO) – In Work

• **Monster (City-Sized)**
  – Lunar & Martin Outposts (100kW - 1MW)
  – SDI Weapons Platforms (100MW+)
What Gets Powered on a Spacecraft?
What Gets Powered on a Spacecraft?

• Computer

• Power (Battery, Electronics)

• Attitude Control Equipment (Star Cameras, IMUs, Reaction Wheels)

• Telecommunication Equipment (RF Amplifiers)

• Thermal Control (Heaters)

• Propulsion Thruster Valves

• Payload (What the Spacecraft Actually Does)
What Does a Solar Powered EPS Look Like & How Does it Work?

Solar Array

Lander Cruise
- 30 Strings
- 7.5 mil GaAs/Ge 1J

Lander Landed
- 31 Strings
- 7.5 mil GaAs/Ge 1J

Orbiter
- 72 Strings
- 7.5 mil GaAs/Ge 1J

Battery Assembly
- Single NiH2 Battery
- (11) 16 A-Hr CPVs
- “Extra” IPV Cell (L)
- Telemetry

Charge Control Unit (CCU)

CCU Card “A”
CCU Card “B”

Power
Discrete Commands & Telemetry

Power Distribution & Drive Unit (PDDU)

DC-DC HKPS Card
EPS Switch Card
Switch Logic Card
Load Switch Card (2)
28V DC-DC Converter Card
Slave I/O Card
Motor Driver Card
EPS Module I/F Card
EPS Backplane

Command & Data Handling (C&DH)

Unregulated Loads
- Propulsion
- Telecom
- AD&C
- Thermal
- Cameras
- MVACS (L)

Power
Telemetry

Motor Loads
- S/A’ s (O & L)
- HGA (O), MGA (L)

Regulated Loads
- DST/CDU/ TMU
- PMIRR (O)

Pyro Initiator Unit (PIU)

Pyro Initiator Card (1-O; 2-L)
Prop Valve Driver Card (1-O; 1-L)

MFB
Secondary Pwr

PIU Power

Telemetry

Power

Optical Encoders

Power

Telemetry

Power

NSIs
G&H Actuators
Thrusters
What Does an Nuclear Powered EPS Look Like & How Does it Work?

(2) Advanced Radioisotope Power System (ARPS) - GFE

- Current
- Voltage
- (4) General Purpose Heat Sources (GPHS)
- (16) AMTEC Cells
- 4.7V per Cell
- 19 kg
- 15.3” (Diameter)
- 105We @ EOL

16 A-Hr Battery Assy
8 CPVs

Power Control & Distribution Module (PCDM) - LMA

- Shunt Control Module
- Battery Control Module
- Boost Regulator Module
  - Switch Logic Card
  - EPS Switch Card
  - Load Switch Card #1
  - Load Switch Card #2
  - Dual Slave I/O Card
- High Efficiency HKPS Card
- EPS Module I/F Card
- EPS Backplane

PVDM Power
SSPA Power

Safety Relay Assy

Pyro Initiator Unit (PIU) (LMA)

- Pyro Initiator Card (1)
- Prop Valve Driver Card (1)

Shunt Resistor Banks (16 Legs)

Command & Data Handling (C&DH)

Loads
- Prop & Batt Xdcrs
- SDST
- IMU, Star Tracker
- Payloads
- Thermal
- Star 48

Shuttle/IUS/T0 I/Fs
28V Power/RSense
Trickle Charge
Hardline Tlm
Safety Inhibits

Latch Valve Thrusters
S/C NSIs
Star48 NSIs

Power
Telemetry

Power
Telemetry

Power
Telemetry

Power
Telemetry
What Sort of Tasks does an EPS S/C Engineer Perform?

• Technical
  – Calculate How Much Power is Required to Operate the Spacecraft
  – Calculate How Big a Solar Array or Nuclear Source is Required
    • Predict Power Variations on a Day to Day / Hour to Hour Basis
  – Calculate How Big a Battery is Needed for Eclipse Periods
    • Depth of Discharge / Life Cycles
  – Design & Test the Circuitry to Control, Condition and Distribute Power
    • Both Digital and Analog Circuit Design and Analysis
  – Derive the Software Requirements Necessary to Manage the EPS
  – Support Spacecraft Level Integration & Testing
  – Troubleshoot Problems as they Occur
  – Support Launch Operations @ KSC or VAFB
  – Operate the Spacecraft During the Mission
What Sort of Tasks does an EPS S/C Engineer Perform?

• **Programmatic**
  – Manage Large Budgets and Complex Schedules
  – Manage Subcontractor Suppliers
  – Present Status to Management and the Customer
    • Both Technical and Programmatic
  – Supervise the Supporting Engineering Staff
  – Give the Final GO for Launch
  – Write Technical Papers, Give Presentations to Industry & the Public
What Sort of College Majors do EPS Engineers Have?

- Electrical Engineering
- Mechanical Engineering
- Physics
- Chemical Engineering
- Nuclear Engineering
- Aerospace Engineering
- Computer Science
- Engineering (General)
- Engineering Management
Spacecraft
Electrical Power Subsystem (EPS)
Overview

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