Seminar 12
Social & Political Aspects of Space Flight
Spacecraft Power & Thermal Control
FRS 104, Princeton University
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Spacecraft Power & Thermal Control
[Understanding Space] Sec 13.2, 13.3
Social & Political Aspects of Space Flight:
[Societal Impact of Space Flight, NASA-SP-4801] Ch 4, 8, and 9

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http://www.princeton.edu/~stengel/FRS.html

Typical Electrical Power Requirements

- Generate electrical power for s/c systems
- Store power for “fill-in”
- Distribute power to loads
- Condition power (e.g., voltage regulation)
- Protect power bus from faults
- Provide clean, reliable, uninterrupted power

Live from the Moon: The Societal Impact of Apollo

- Apollo 8
- Apollo 11
- Continuing turmoil in the US, Vietnam War
- Arthur Clarke, Ray Bradbury quotes
- “If they can put a man on the Moon, why can’t they ...

- Beginning and the end of the Space Race
- Strangeness of events, cultural divide between technologists and the general public
- Apollo 13

Andrew Chaiken, Ch. 4, NASA-SP-4801

Live from the Moon: The Societal Impact of Apollo

- 1970s: “the Me decade”
- The astronauts revealed, beliefs, family life, depression, “The Right Stuff”
- Conrad: “Do you know me?”
- History doesn’t repeat
- Bush 41: Space Exploration Initiative fizzles. “I was set up.”
- Apollo as a multi-generational experience: movies, HBO series, catch phrases

Andrew Chaiken, Ch. 4, NASA-SP-4801
Live from the Moon: The Societal Impact of Apollo

- John Noble Wilford: … when people took risks to reach grand goals”
- The Moon hoax, not embraced
  - Mailer: “the impossibility of carrying out such a hoax”
  - Armstrong: “It would have been harder to fake it than to do it.”
- Ahead of its time; populace was unprepared
- Bush 43: Vision for Space Exploration (cancelled in 2011)
- Momentous punctuation mark
- Humans as a multi-planet species?
- TBD

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Commercial and Economic Impact of Spaceflight: An Overview

- “Little to show (for manned spaceflight) except circus.”
- “Real payoff in space (unmanned spacecraft) has been funded by the remaining on-third of the civilian space budget”
- What is spaceflight actually for?
- NASA Technology Utilization Program (1962)
- Value in the eye of the beholder

Philip Scranton, Ch. 8, NASA-SP-4801
Commercial and Economic Impact of Spaceflight: An Overview

- Expectation of wider contributions to society
- Indirect impact of NASA on American industry
- Spacefaring innovations embedded in a transnational culture of technological experimentation
- NASA projects as exploratory development
- NASA, military, industry, and university innovations entwined

*Philip Scranton, Ch. 8, NASA-SP-4801*

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Commercial and Economic Impact of Spaceflight: An Overview

- NASA as the largest dispersed technology developer, shaping aspirations into form and function
- NASA as the hub of Big Engineering
- NASA’s domains
  - Impact on space operations
  - Impact on enterprise for producing and managing space projects
  - Impact on operations derived from space experimentation
- Communications

*Philip Scranton, Ch. 8, NASA-SP-4801*
Commercial and Economic Impact of Spaceflight: An Overview

- Materials processing, absence of commercial use of space; however, impetus for improved manufacturing methods and materials on Earth
- Advances in instrumentation, measurements, and navigation
- New management techniques
- Quality control and reliability

*Philip Scranton, Ch. 8, NASA-SP-4801*

The Political Economy of Spaceflight

- Complex relationships between politics and the economy
- Appropriateness of government stimulus
- Government-industry nexus
- Role of the free market
- Why pay to into space?
- Institutional structure
- Sector view

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The Political Economy of Spaceflight

- Transportation
- Technology, research, and development
- Astronomy and planetary science
- Communications
- Reconnaissance, remote sensing, electronic intelligence, and early warning
- Weapons
- Navigation
- Human spaceflight
- Microgravity research

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The Political Economy of Spaceflight

- Support services
- Insurance
- Capital
- Burial services
- Management, economics, and policy
- Education
- Professional and advocacy groups
- Media

*Stephen B. Johnson, Ch. 9, NASA-SP-4801*
Solar Cell Types and Characteristics

- Silicon (Efficiency < 15%)
- Gallium Arsenide (GaAs)
  - Dual Junction (~22%)
  - Triple Junction (~28%)
  - Quad Junction (>30%)

Functional Blocks of Electrical Power System

- Energy generation
- Energy storage
- Power management and distribution
Solar Arrays

- Generate power during sunlit periods for
  - Payload
  - Operation of power bus
  - Charging batteries
- Typical power output: 2kW – 15kW

Solar Array Design

- Each solar cell produces
  - < 2 W
  - 0.7 – 3 V
- Series arrangement to produce voltage
- Parallel arrangement to produce current
Batteries

- **Nickel Cadmium (NiCd)**
  - Heavier, older tech
  - Lower volume
- **Nickel Hydrogen (NiH2)**
  - Present tech
  - Pressurized vessels
- **Lithium Ion (Li Ion)**
  - State of the art
  - ½ the mass, 1/3 the volume of NiH2
  - Extra care required

*MAE 342 Lecture, Bob Danielak, Lockheed-Martin, 2008*

Definitions

- **Capacity**: fully charged amount of energy
- **State of Charge (SOC)**: How much charge remains in battery
- **Depth of Discharge**: How much charge is taken out of battery
- **Charge Rate**: Rate (current) at which charge (Ah) is put into battery
- **Charge Efficiency**: How much charge energy is stored
- **Charge/Discharge Ratio**: Charge required to restore beginning SOC following discharge
- **Self Discharge**: Low-level leakage
- **Trickle Charge**: Continuing charge to counter self-discharge
- **Balancing**: Equalizing the SOC of each cell in a battery

*MAE 342 Lecture, Bob Danielak, Lockheed-Martin, 2008*
**Power Management and Distribution**

- Solar array control
- Battery charge control
- Battery discharge control
- Power distribution and protection
- Bus voltage regulation and conditioning
- Power switching
- Power telemetry
- Requirements driven by power system architecture, bus voltage, and power levels

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**MAE 342 Lecture, Bob Danielak, Lockheed-Martin, 2008**

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**Power Management and Distribution**

![Diagram](image-url)
Power System Architectures

• Unregulated (battery-dominated) bus
  – Bus voltage determined by battery voltage
• Sunlight regulated bus
  – Bus voltage regulated during sunlit period
  – Bus voltage determined by battery voltage during eclipse
• Fully regulated bus
  – Bus voltage regulated in sunlight and eclipse
  – Power converter boosts variable battery voltage to bus voltage

Power System Sizing

• Power system must
  – Support the spacecraft through entire mission
  – Recharge batteries after longest eclipse
  – Accommodate electric propulsion loads
  – Accommodate failures to assure reliability
  – Account for margins and contingencies
• Factors affecting sizing include
  – Satellite orbit
  – Time of year/seasonal variation
  – Life degradation/environmental effects
  – Total eclipse load
  – Number of discharges
Power System Analysis

• Power budget
  – Payload, bus, and charge loads
  – Error margins

• Energy balance
  – Dynamic simulation over multiple duty cycles

• Stability Analysis
  – Small-signal AC stability
  – Bus impedance
  – Bus ripple
  – Transient response

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Power System Tradeoffs

![Graph showing cost vs. solar array size](image-url)

- Total Cost
- Solar Cell Cost
- Energy Storage Cost

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*MAE 342 Lecture, Bob Danielak, Lockheed-Martin, 2008*
Thermal Control

Typical Temperature Requirements

- Maximum & minimum operational/non-operational temperatures
- Maximum diurnal swing
- Maximum gradients
- Survival/safe state temperature
- Allowable rate of change
- Control requirements of sub-systems
Thermal Design Environments

- Pre-launch (shipping, on pad)
- Launch and transfer orbit
- Mission characteristics
  - On orbit
  - On surface
- Sun exposure
- Shadow
Heat Sources

Fairing Inner Surface
Maximum Temperatures
Thermal Design Constraints

- Equipment utilization philosophy
- Design margin philosophy
- Failure mode philosophy
- Power system margin
- Mass budget
- Temperature specifications
- Sun/shadow duty cycle
- Equipment redundancy


Thermal Control Types

- Passive
  - Coatings and paints
  - Thermal isolation
  - Heat sinks
  - Phase Change Materials

- Active
  - Heaters
  - Heat pipes
  - Thermoelectric devices
  - Thermal louvers

Thermal Analysis

- Steady state (thermal equilibrium)
- Transient
- Thermal network models
  - Nodes
    - Elements that can be characterized by a single temperature
    - Energy storage devices
  - Conductors
    - Energy transport
  - Energy sinks
- Closed-form idealizations
- Finite element/difference software

The End