Power Plant Selection for a Mars Surface Mission

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December 9, 1999

Agenda

Exploration Office

Summary

Background

Recommendations

Analysis

Problem Formulation

Cost Model

Decision Analysis

Sensitivity Analysis

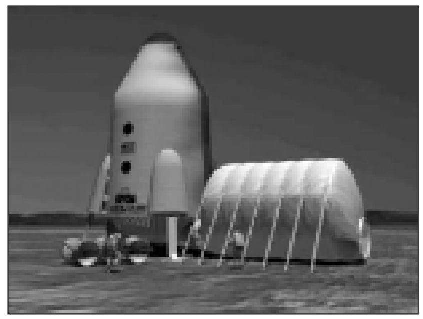
Technology Options

Conclusion

Background

Exploration Office

- Human Mars Mission plans underway for FY 2011 mission
- Deceptively short technology planning horizon to baseline
- Complex, highly integrated system requirements
  - Transit to Mars
  - Surface Activities
  - Return to Earth
- Each technology must be independent and reliable
- Technology development must be done in-house when possible



Surface Power System

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- Surface power is critical to mission success
  - Life Support
  - Habitat
  - Science manifest
  - Transportation
  - Communication
- Two in-house options for Mars power plant design
  - Nuclear thermal
  - Advanced solar electric
- Choice driven by surface weather and crew power demand
  - Sunny conditions favor advanced solar power
  - Cloudy or cold weather favor nuclear

Recommendations

Exploration Office

- If political climate remains the same,
  - Launch thermal nuclear power plant
  - Send a crew of 10 regardless of temperature
- Justification
  - Robust (all-terrain, small volume, dust storm resis't)
  - Nuclear can meet any demand, even during a nominally hot day
  - Solar is too expensive on cloudy days
  - Although solar EMV for sunny day is equal to nuclear EMV of a cold day, the nuclear is favored due to higher probability of a cold day (.7)

Recommendations (cont'd)

Exploration Office

- If Congress rejects nukes before they are baselined
  - Launch advanced solar array technology
  - If the weather is sunny, send a crew of 10 people
  - If the weather is cloudy, send a crew of 5 people
- If Congress rejects nukes after they are baselined
  - Exercise "piggyback" option to gather weather info
  - Lobby executive / legislative branches for policy change
  - Channel R&D money to mitigate nuclear fears
  - Notify other systems of possible program delay

Problem Formulation

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Development environment

- Congressional approval for Mars given: Two year R&D time
- Certification time eliminates in-house hybrid as an option
- Technology trades
  - Capability versus reliability
  - Mass versus safety
  - Risk versus cost

Operating environment

- Mars has an atmosphere: sun and temp uncoupled
- Weather and power usage for the mission are uncertain
- Cost model must account for these unknowns

Cost Model

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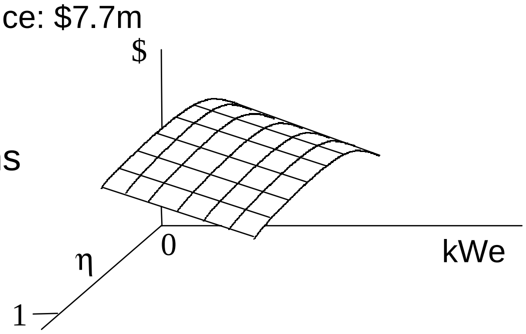
- Consists of fixed and variable
- Fixed costs distributed over mission duration
  - Research and development: higher for nuclear
  - Mass (i.e. launch costs): higher for solar
  - Fixed costs balance: $7.7m
- Variable costs ($) dependent upon nominal conditions of usage
  - Demand (kWe)
  - Efficiency (η)



Cost Model (cont'd)

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- Two primary cost drivers (decision nodes)
  - Power plant performance
  - Crew size
- Total mission cost (TMC)

$$TMC = \left(\frac{\$}{kWe}\right)\left(\frac{kWe}{day}\right)(days)$$

f(demand, weather) → $\frac{\$}{kWe}$; *f(demand)* → $\frac{kWe}{day}$; *Fixed* → $(days)$

- Once launched, no design changes possible
  - Weather at the site is unpredictable
  - Crew size provides <u>some</u> control over demand

Decision Tree Example

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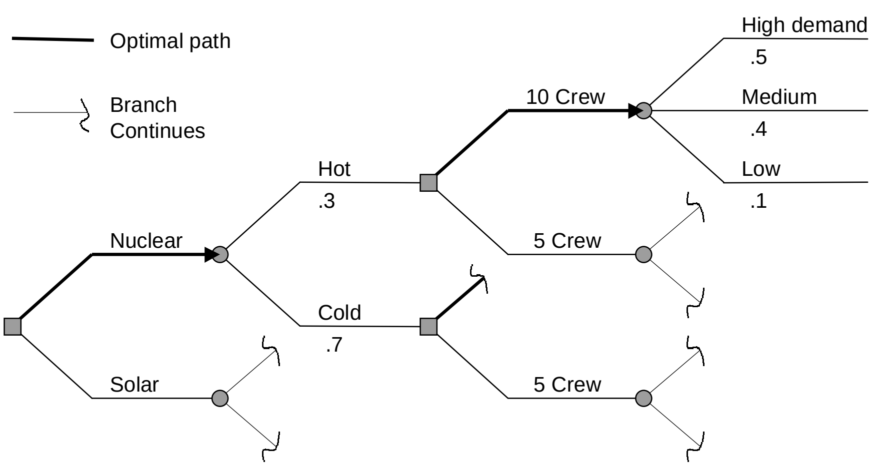

Analysis Results

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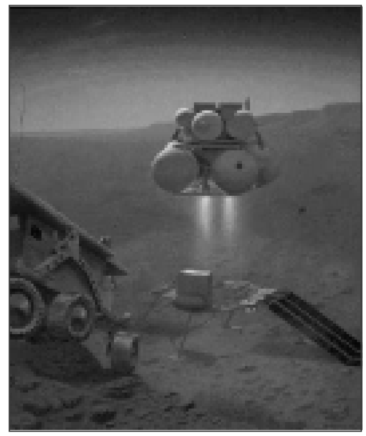
- Based on nominal weather and demand probabilities
  - Select nuclear at a cost of $8,192,938
  - Savings over solar electric: $358,808
  - Plan surface activities for a crew of 10



Sensitivity Analysis

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Three Primary Sources of Sensitivity

- Weather prediction
  - How do deviations in the nominal values [P(hot)=.3, P(cloudy)=.5] affect the strategy?
- Demand prediction
  - Are power usage probabilities well-correlated to crew size?
- Congressional approval
  - How does the likelihood of congressional approval effect the decision to “go nuclear?”

Sensitivity Results

Exploration Office

- Crew demand
  - Strategy insensitive to demand probabilities
  - High confidence in #'s (Apollo, Skylab databases)
  - P(demand) is same regardless of technology
- Technology choice
  - Cost of solar sensitive to P(sunny)
  - Nuclear decision
    - Very robust to weather relative to solar
    - Highly sensitive to P(congressional approval)
  - Need options if congress rejects "all-nuclear" plan

Options

Exploration Office

- Hybrid solar/nuclear power plant
  - Military technology in development
  - Acquire from NRO
- Send scout probe on fast transfer orbit for weather info
  - Planetary Orbiter: Climate data
  - Lander: Site weather data
- Leverage robotic precursors
  - Missions already in development by contractors
  - Manifest science instruments on orbiter or lander

Options Analysis

Exploration Office

- Hybrid Option: $6,500,000 acquisition cost
  - Nuclear component may be rejected by constituents
  - Dual-use technology may be regulated by Congress
  - Not “in-house” research and development
- In-house space craft too expensive
  - Orbiter: $75 m Lander: $125 m
  - Both options > Expected Value of Perfect Information
- ✓ Piggyback on mission currently under development
  - Orbiter: $100,000 on U.S. 2001 Mars Orbiter Mission
  - Lander: $200,000 on Russian 2001 Mars Lander

Conclusions

Exploration Office

- Selecting a power plant for Mars exploration is critical to its success
- Nuclear (with piggyback option) supports “better, faster, cheaper” approach
  - Low Sensitivity to weather
  - No sensitivity to usage probabilities
  - Highly sensitive to Washington, DC policy makers
- Solar is difficult to justify as a viable first choice

Back-up Slides

Decision Analysis

Exploration Office

Plant efficiency for various surface conditions

Power Source	Sunny	Cloudy	Hot	Cold
Nuclear	N/A	N/A	90%	100%
Solar	100%	70%	N/A	N/A

- Probabilities of nominal conditions (over mission duration)
  - Sunny Day: 50% Cloudy Day: 50%
  - Hot Day: 30% Cold Day: 70%
- Insufficient power (e.g. high demand, cloudy day) reduces the science capability by an amount equivalent to $10,000 for every kWe short of demand

Decision Analysis (cont'd)

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Demand probabilities for two possible crew sizes

Crew Size	High (180 kWe)	Medium (140 kWe)	Low (80 kWe)
5 member	.3	.65	.05
10 member	.5	.4	.1

- "High demand" is slightly more likely with large crew
- Probability of "low demand" is larger for larger groups
  - Team work increases task efficiency
  - Reliance on robotic power reduced