Surface Power Considerations and How They Affect Latitude Choices

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Human Landing Sites Study - Google Hangouts Lecture Series
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Key Points

• The choice of Mars surface power technology is highly dependent on the human landing site decision
  ▪ The Mars surface presents a very challenging environment for power systems with reduced solar flux, 12+ hour night periods, and extended (global) dust storms
  ▪ Near-equatorial regions could accommodate solar power with energy storage
  ▪ High latitudes and/or global access may require nuclear power, particularly for long surface stays

• The preferred Mars surface power approach has not been determined
  ▪ With expected power requirements in the 10s of kilowatts, power systems used on previous robotic missions will not likely suffice
  ▪ Relevant technology development is on-going under STMD Game Changing Development Program
  ▪ Mission trade studies comparing power architectures continue under HEOMD Mars Study Capability Team

• NASA is pursuing multiple Mars surface power technology options
  ▪ Primary goal is to provide flexibility, robustness, and high reliability
  ▪ Promising technologies include nuclear fission, solar arrays, batteries/fuel cells, and radioisotope power systems
Mars Surface Power

- **No off-the-shelf options exist to power long-term human surface missions on Mars**
  - Power systems used on previous robotic missions (e.g. MSL, Phoenix) do not provide sufficient power

- **Stationary power needs...**
  - Up to 40 kW day/night continuous power
  - Power for ISRU propellant production (pre-crew arrival)
  - Power for landers, habitats, life support, rover recharging (during crew operations)
  - Technology options: Nuclear Fission or Solar PV with Energy Storage
  - Need compact stowage, robotic deployment, survivable for multiple crew campaigns (>10 yrs), long distance power transmission (1-2 km), and contingency options for extended dust storms

- **Portable power needs...**
  - 3-10 kW and up to 120 kWh for rovers, construction equipment, and thermal/heating
  - Technology options: Batteries, Fuel Cells, and Radioisotope Power Systems
  - Need reliable systems for up to 100 km traverses and remote operations; prefer cross-platform systems, interchangeable components, shared fuel cell reactants, and grid-charge compatibility

- **Mars environment represents significant challenge to systems:**
  - 3/8th gravity, 1/3rd solar flux, >12 hour night, CO2 atmosphere, long duration dust storms, wind loads, 170 to 270K temperature cycles
Kilopower

Current Project under Game Changing Development Program to design, build, and test a 1 kWe reactor with technology that is relevant for systems up to 10 kWe

- **Innovation:**
  - A compact, low cost, scalable fission power system for science and exploration
  - Novel integration of available U235 fuel form, passive sodium heat pipes, and flight-ready Stirling convertors

- **Impact:**
  - Provides Modular Option for Human Exploration Mars Surface Missions
  - Bridges the gap between Radioisotope Power Systems (RPS) and large-scale fission power technology studied in past
  - Enables Decadal Survey Planetary Science Missions
  - Reduces NASA dependence on Pu238

- **Goals:**
  - Nuclear-heated system-level test of prototype U235 reactor core coupled to flight-like Stirling convertors
  - Design concepts that verify scalability to 10 kW for Mars
Mars Radioisotope Power

Compact, reliable, and flexible power systems for solar independence. Plutonium 238 is the radioisotope of choice for heat and power for space applications. Pu-238 can supply heat to reduce heater power loads, and provide auxiliary power.

- **Proven Power System:**
  - A robust and reliable power source for robotic science for over 50 years
  - Radioisotope heat is constant and stable

- **Benefits:**
  - One element in a robust human Mars base power architecture
  - Compact and transportable, enhances mission flexibility
  - Safe for human proximity operations with minor shielding
  - Waste heat from power conversion can be used for heating

- **Mars RPS Long Poles:**
  - Limited production of Pu-238 limits large scale use
    - RPS could supply 1-3 kW_e / 4-12 kW_th, or more with adequate planning
  - Long development time needed to enhance production and develop new systems
    - High efficiency dynamic power conversion maximizes electrical power from limited heat supply
  - NASA and DOE are working to make RPS more affordable
FY17 Seedling Study under STMD Game-Changing Development (GCD) Program

- **Goal:** Develop a credible solar array/energy storage system alternative to nuclear fission for Mars surface electrical power
  - 40 kW “architecture” / 10 kW “modules”
  - Can be delivered and deployed on the 1st robotic mission and remain functional for multiple crew missions

- **Technical Approach includes 2 Elements**
  - SAWS Solar Arrays - led by LaRC with GRC support
  - SAWS Regenerative Fuel Cell & PMAD - led by JSC with GRC and JPL support

- **Study Deliverables**
  - SAWS Ground Rules and Assumptions
  - Comparison of solar array structural concepts
  - Regenerative Fuel Cell (RFC) trades and Power Management and Distribution (PMAD) concepts
  - System performance predictions and technology development investment recommendations

SAWS lander with 6-arrays, 1000 m² total, 34% efficient PV & 10 kW-class RFC
- Generates 50 kW day, 10 kW night user power over Martian sol at equator with clear skies
- Season and latitude cause variations in solar flux and daylight period
- Major dust storm at equator reduces output to 18 kW day, 5 kW night
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RFP=Request for Proposal  
SRR=System Requirements Review  
PDR=Preliminary Design Review  
CDR=Critical Design Review  
LRR=Launch Readiness Review

Decision: Solar or Nuclear or Both  
Flight Demo: 2026?  
Human Rating:  
Flight Qual.: 2033?
Environment Impacts on Mars Surface Solar Arrays

Tom Kerslake
NASA Glenn Research Center
Solar Arrays on Mars Right Now

- Robotic missions with flexible power conops
  - Pathfinder (19°N, 1.5m², 0.25 m²/<20 W)
  - MER Spirit & Opportunity (15°S/2°S, 2m², <200 W)
  - Phoenix (68°N, 3m² wings, <150 W)
Mars Surface Solar Fluxes

• Flux on top of atmosphere (AM0) depends on:
  • Season (Mars Sun distance changes by 18.5%, flux by 38%)

• Total surface flux depends on:
  • Mars season
  • Landing site latitude (sun angles, clear sky & dust storm OD)
    • OD = optical depth (opacity)
  • Landing site longitude (local surface albedo)
Yearly Mars Surface Solar Flux

- **50° North latitude** landing site, clear skies

- **30° South latitude** landing site, clear skies
Major (Global) Dust Storms

No Global Dust Storm | During Dust Storm

Dust Haze Hiding the Martian Surface in 2001
Major Dust Storms - Frequency

- 0, 1, 2 major dust storms may occur per Mars year
  - Dust storm covers the globe, 3 month duration, high OD values
  - Occur during summer in the southern hemisphere
  - OD modeled as f(season, latitude, time)
    - Highest OD in the South, lower in the North
  - Historically, ~1/3\(^{rd}\) chance each for 0, 1, 2 major dust storms/yr
  - For these 3 years, MER encountered 1 major dust storm (Jul 2007)
Major Dust Storm Loss in Solar Flux

- From ~30% to 3X reduction in maximum flux – single storm
Mars Surface Solar Array Configuration

- Must be deployable for high power applications
- Desire planar solar panels (not concentrators)
- Fixed horizontal/tilted panels, tracking panels
  - Fixed horizontal panels are simple, maximize power generation for low latitude sites; but lower power at high latitude, highest dust collection rate, passive dust control insufficient
  - Fixed tilted panels (or tents) are simple, can enhance power for high latitude sites, East-West facing panel pairs broaden daily power generation hump, can achieve more strength/stiffness, effective passive dust abatement possible; but have azimuth dependence, reduced power generation (by 20-25%)
  - Tracking panels (typically 1-DOF, N-S or E-W) offer modest power enhancement (5-15%), offer tilting for dust removal / wind load management; but have strong azimuth dependence and mechanisms introduce risk, cost, mass penalties
- Panels should be kept ~0.5m above the irregular Mars surface to avoid regolith saltation, string current limiting (possible major/complete loss in power)
Mars Surface Solar Array
Power Degradation Factors

• Even for long missions (6 Mars years), Mars surface environment is mostly benign for solar arrays
  • No concern for proton/electron radiation or GCRs
  • No micro-meteor strike damage
  • Paschen discharge damage eliminated by design
  • Modest thermal cycling, aero-flutter fatigue, NUV/VUV darkening

• Dust collection on solar cell coverglass is a major power degradation challenge that must be managed
  • Resident dust blocks sunlight, degrades current output
  • High speed wind blown dust could scratch covers/optical coatings, increase reflectance (degrades current output)
  • Dust could contain corrosive peroxide or perchlorate (need H₂O?)
  • Solar arrays for a high value mission (human life, $100B’s) cannot rely on probabilistic Aeolian dust cleaning, i.e. dust devils
MER solar panel dust collection

- 0.14% loss per sol
- No power after ~1 year
Dust Management (Abatement, Removal)

• Fine dust (micron scale) is an aerosol in the Mars atmosphere constantly precipitating
  • Dust clings via Van der Waals, electrostatic forces

• Human Mars surface base will have many sensitive surfaces (need dust management)
  • Solar arrays, radiators, windows, antennas, lights, nav aides

• “Abatement” avoids dust collection
  • Electrostatic, tilted surfaces, anti-soiling coatings

• “Removal” allows dust to collect for periodic removal
  • Piezoelectric shakers, mechanical wipers, electrodynamic, peel-n-discard films, high speed jets (leaf blower, dust devil)
  • Piezoelectric dust removal demonstrated very high effectiveness in ground tests with rigid panels; low mass/power/conops penalties

• Long duration in situ Mars surface demonstration of dust management will be required
Summary

- Mars surface power for human-scale missions (10s of kW) represents a major development challenge/long-pole
  - No off-the-shelf options exist
  - Mars environment and distributed landing sites pose significant challenges on power architecture
- **Primary options include Solar PV with Energy Storage or Nuclear Fission**
  - Solar PV option could leverage SEP investments
  - Kilopower will demonstrate multi-kW reactor class with 2017 nuclear test in Nevada
- **Technology Gap can be closed with focused, sustained investments**
  - STMD GCD Program provides good starting point with Kilopower & SAWS
  - Funding augmentation needed to accelerate technology maturation to allow informed decision on flight system approach
  - Mars simulated environment testing is crucial for technology validation
  - A mid/late 2020s robotic surface demo of ISRU/power is highly desirable to reduce risk for human missions
  - Must start now to assure technology readiness for 2030s human landings!