Prepare Now for the Long Stay on Mars

Douglas W. Gage
XPM Technologies

12th International Mars Society Convention
Washington DC 30 July- 2 August 2009

XPM TECHNOLOGIES

Outline

- Assumptions/Assertions
  - Goals, constraints, approaches
- The Long Stay program/mission profile
- Required capabilities and technologies
  - Use, adapt, develop
- Programmatic Challenges
- Payoffs and spinoffs
- Conclusions

XPM TECHNOLOGIES

Assumptions/Assertions: Goals

- **Exploring a New World, not just collecting some rocks (i.e., not just one or two sorties)**
  - **A closed-end program goal: find compelling evidence for or against extinct or extant life on Mars ("put up or shut up")**
  - **An open-end program goal: develop/refine/ assess/practice lowest cost and lowest risk approaches to living on Mars, to prepare for future exploration and possible colonization**
- **Want the lowest cost, lowest risk approach to human Mars exploration**
  - **Want to avoid having future Martians saying**

    "What *were* they thinking!?!"

XPM TECHNOLOGIES

Assumptions/Assertions: Constraints

- Technology projection to 2040-2050 launch date
  - Continuing rapid electronics and sensors technology evolution (Moore's Law, etc)
  - Transport to Mars remains expensive (nominally $50K per pound), no nuclear propulsion
    - Rocket development will take about 10 years
    - Need validated approach for high-precision large payload (30-40 tonne) Mars EDL
- Resource availability (without these, it won't happen)
  - Plentiful energy (bring nuclear power plants)
  - Plentiful water (indigenous, exploitable)
  - ISRU for O_2, CH_4, and many derivatives
  - Mineral resources accessible (good site selection)

XPM TECHNOLOGIES

Assumptions/Assertions: Specific Approaches

- Hohman transfer orbits: low delta-v mission profiles
  - Conjunction, not Opposition, transits
- Pre-emplace equipment and supplies
- Minimize risks
  - Accumulate redundant assets, not a series of independent sorties
  - Survey/sample multiple diverse sites, from central base(s)
- It will be (“we can and must make it”) much safer on the surface of Mars than during transit in space
  - Abort to surface, not to space
  - Plan fewer transits, longer stays
- Maximize total duration of human presence on Mars, minimize gaps

XPM TECHNOLOGIES

Problems with a Consecutive Conjunction Missions

- Rocket production and operations dictate launching every 26 months to keep the enterprise going
- So, for the second and later crews, we launch two expensive rockets, consume an ERV, put two crews at risk for 6 months in space, and we end up with one crew on Mars, which is what we already had
- Crew (N) leaves Mars 4 months before crew (N+1) arrives, resulting in:
  - an 8 month gap in human operations on Mars
  - a 4 month overlap of two missions in space
- Initial ERV launch is required 26 months <u>before</u> first crew launch

XPM TECHNOLOGIES

The Long Stay Alternative

- First crew (launched at LW[0]) does NOT return at first Hohman opportunity (LW[0R] = 18 months), but stays N*26 months longer
- Send a second crew to join the first at the next opportunity (LW[1])
- Continue to build assets at initial base, expand to a second base only when the first has achieved critical mass

- If we want a crew to explore a site 1000 km from a site where we already have a crew, why not have that crew travel 1000 km across the surface, rather than returning them 60M km to earth and bringing a new crew 60M km from earth at the same time?
- Send robots from earth to build a habitat at the new site
- Send a rover from earth to transport the crew from the “old” site when the new habitat is ready!

XPM TECHNOLOGIES

Return from Long Stay

- **Assume N=3, resulting in each crew spending 8 years on the surface of Mars and about 9 years total away from earth**
- **No need to send ERV early, since it will not be used for years**
  - **Use early launch opportunities to send additional cargo (equipment and supplies) to increase effectiveness and reduce risk**
  - **Send crew to Mars <u>before</u> completing the ERV!**
  - **Send ERV to Mars at LW[2] to perform an unmanned test returning samples to earth at LW[2R]**
  - **Send ERVs to Mars at LW[3] to return first crew at LW[3R] and at LW[4] to return second crew at LW [4R]**

XPM TECHNOLOGIES

Long Stay Program Profile

- LW[-2]: 1 launch to set up initial infrastructure
- LW[-1]: 2 launches, robots build underground habitat
- LW[0]: 2 launches, first crew plus more cargo
- LW[1]: 2 launches, second crew plus more cargo
- LW[2]: 2 launches, ERV plus more cargo
- LW[2R]: ERV returns samples in unmanned test
- LW[4]: 2 launches, ERV plus more cargo
- LW[3R]: ERV returns first crew
- LW[4]: 1 launch, ERV
- LW[4R]: ERV returns second crew
- Each crew spends 8 years on Mars, 9 years off earth
- Total program is 12 launches over 7 windows, 15+ years from first unmanned launch to return of second crew

XPM TECHNOLOGIES

Comparison: Long Stay vs Sequence of Conjunction Missions

	2 N=3 Long Stay missions	**5 Conjunction missions**
Time from first crew arrival to last departure	122 mo	122 mo
2 crews on Mars	70 mo (1@70 mo)	--
1 crew on Mars	52 mo (2@26 mo)	90 mo (5@ 18 mo)
Gap: 0 crews on Mars	--	32 mo (4@8 mo)
# crews	2	5
Total launches	12	11
Habitat launches	2	5
ERV launches/returns	3/3* (*one unmanned)	6*/5 (* one final backup)
Cargo launches	7	--
Leave behind	2 semi-used tuna cans	5 depleted tuna cans
	+ 3 ERV stages	+ 5 ERV stages
	+ **"Mars Base 1"**	+ 1 ERV (spare)

XPM TECHNOLOGIES

Assumptions/Assertions: More Specific Approaches

- It will be ("we can and must make it") much safer indoors than outdoors on Mars
  - Use robots to construct underground habitat
    - Use tuna can habitat as backup
  - Use tele-present robotic geology to preview EVAs
  - Use robots to explore wide areas, bring samples back to base lab

- Must enable "spur of the moment" EVAs with low pressure high O2 % habitat atmosphere, low pressure (MCP?) suits ("EMUs")

- Minimize entropy growth: recycle, don't incinerate

XPM TECHNOLOGIES

Why Underground Habitat?

- Live in Underground caverns
  - Constructed on Mars (ISRU)
  - Need EDL only for "crew capsule" (<< 40 mT)
  - Expandable interior space
  - Strong radiation protection
  - Loosely integrated systems -- easy to repair/upgrade
- Live in "Tuna Can" on Surface
  - Brought from earth
  - Need EDL for complete hab (nominally 40 mT)
  - Fixed limited interior space
  - Limited radiation protection
  - Tightly integrated systems -- hard to repair/upgrade

- Command center
- Living and dining areas, galley, pantry, garden
- Medical/dental clinic, ICU, gym, track, spa, swimming pool
- Medical, biological, chemical, and geological labs
- Supply and specimen storage
- Manufacturing/repair shop, supplies & parts storage, garage
- Thermal, air, water, waste, IT, comms, etc systems
- …

XPM TECHNOLOGIES

Choices in Building Underground

- **Use Roman-style barrel vault construction**
  - **5 meters of regolith overburden as radiation shielding**
- **Cut and cover tunneling, or boring**
- **Role of water ice (resource? problem? both?)**
  - **Cold ice is hard and strong!**
  - **Build in permafrost, on permafrost, or "dry"?**
  - **Use ice as mortar, concrete, "glue" for brick, or ???**
- **Pressure shell vs thermal shell**
  - **Same, thermal inside, or pressure inside?**

XPM TECHNOLOGIES

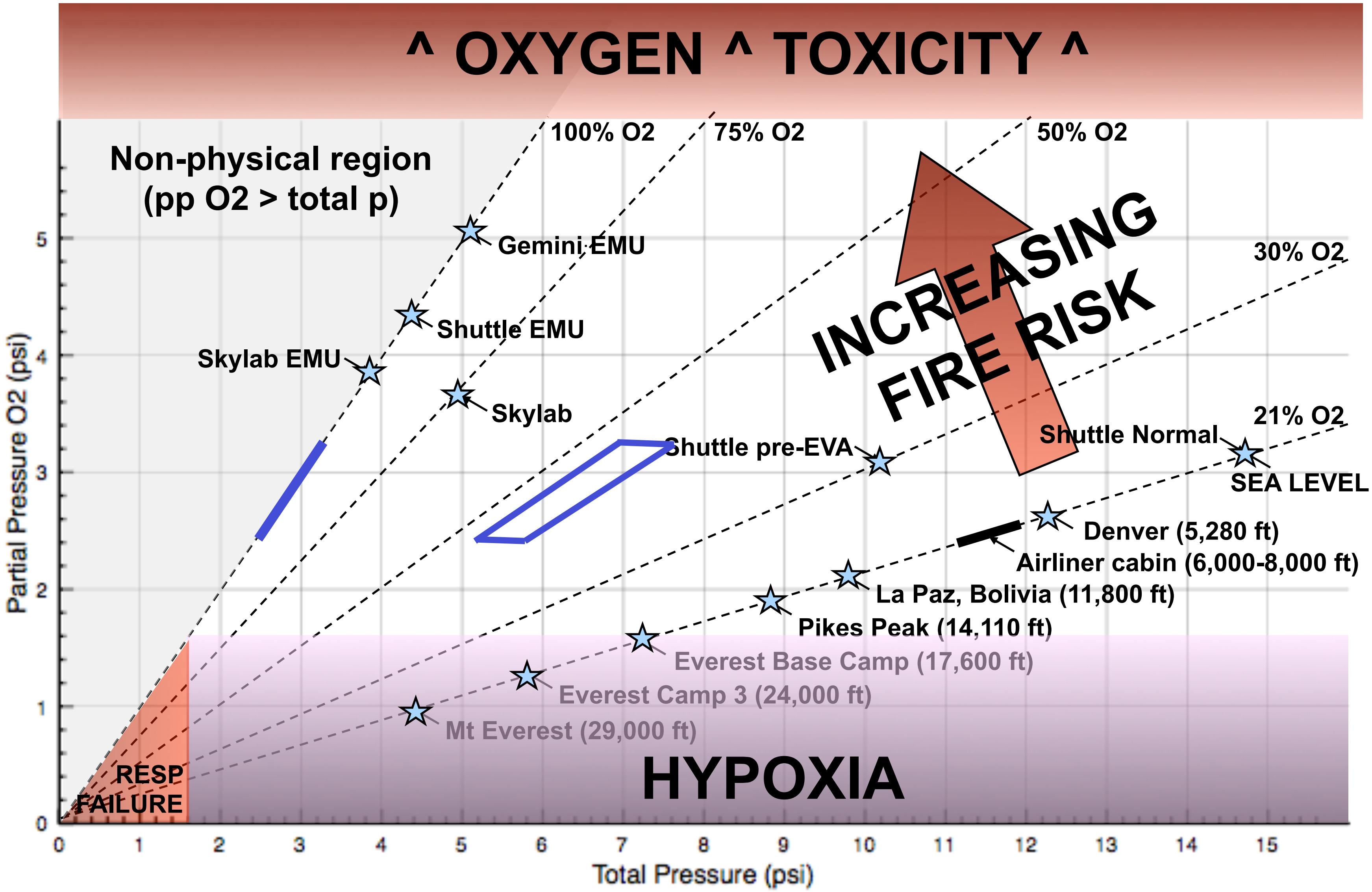
Low Pressure High O2 Habitat to Prevent Decompression Sickness (DCS)

- "Bends" and "Chokes"- pain in joints or lungs due to bubbles formed from N_2 dissolved in body tissues when atmospheric pressure is reduced - can have serious complications
- A statistical measure of DCS risk when moving from hab to suit, assuming oxygen/nitrogen atmospheres, is

  $$R = (\text{initial pp } N_2) / (\text{final total pressure})$$

  - R = 1.2 is deemed "low risk"
- Bottom line
  - EMU: 100% O_2 at 2.4-3.4 psi
  - Habitat: 40-45% O_2 with total pressure 6-7 psi
  - MUST pay careful attention to fire prevention and suppression (and change NASA policy of 30% O_2 max)

Atmospheric Pressure and Composition



XPM TECHNOLOGIES

Mars Robotic Applications

- Robots (unmanned vehicles) will be used to support:
  - Exploration: preview areas before humans visit
    - Identify hazards, to reduce risk
    - Identify areas of highest interest, to maximize efficient use of human attention
  - Logistics: transportation of supplies, equipment, people
    - Including fuel, oxygen, water, food
  - Construction: physical work
    - Excavation, manufacture of bricks
    - Construction of structures
    - Possibly working alongside humans
- "Optionally manned" vehicles
  - Humans as pilots and/or as passengers

XPM TECHNOLOGIES

Differences from Today's Mars Rovers

- Human "hands-on" allows proactive maintenance and repair
  - So design to be easily repairable, rather than super-reliable
- Human "nearby" allows intervention, teleoperation
  - by "nearby" mean low communications latency
  - variable/dynamic levels of autonomy
  - eliminate once-per-day rover command cycle
  - can accept mistakes that simply waste time (but don't harm the vehicle)
- Work robots require much more power than rovers
  - Methane-oxygen fuel? (ISRU, same as for rockets)
  - Refueling will be both possible and necessary
- Installation of communications/navigation infrastructure can support repetitive operations within a "familiar" area with minimum operator attention

Mars Robotic Capabilities, Technologies, Challenges

- Autonomous excavation, drilling, site preparation
- Road clearing (bulldozer, plow)
- Autonomous nuclear powerplant deployment, operation
- Autonomous ISRU: fuel and O2 production
- Autonomous cryo-fluid handling, transfer
- Dynamic / adjustable robotic autonomy
- High power methane-oxygen engines, compact light-weight fuel cells
- Perception-based route learning, replay, retroplay
- Manage variable communications latency, link outages

XPM TECHNOLOGIES

Some of the Technologies/Systems Needed on Martian Surface

- Surface nuclear power plant (electrical, thermal)
- Cryogenic storage and handling tools
- Thermal control systems (including insulation)
- Methane-oxygen power sources (electrical, thermal, motive; very small to very large)
- Vehicles (manned and unmanned, ground and air, pressurized and unpressurized, all sizes)
- Construction technologies and equipment
  - Including robots, autonomous or supervised
- Communications and navigation systems (intra-base, off-base, off-planet; systems, vehicles, people)
- Ultra-reliable IT support (redundant, radiation-hard; wearables, etc)
- Medical strategies/tools: auto-, para-, and tele-

XPM TECHNOLOGIES

It’s Not (Just) Rocket Science!

- It’s not even just technology

- It’s construction, physiology, and robotics…
- …and psychology and sociology,
- …and nutrition, gardening, and medicine,
- …and architecture, history, insulation, and HVAC,
- …and power distribution, IT, sensors, and AI,
- …and biology, chemistry, geology, and seismology,
- …and…

- What on Mars does this have to do with NASA?

Exploring Mars is Two Efforts

- Mars Transportation System
  - NEO-mission capability plus 40 tonne Mars EDL
  - NASA Apollo-style program focused on rockets and spacecraft – nominally 10 years, intensive, expensive
- Living and Working on Mars
  - Developing and refining effective approaches to maintaining human life on Mars
  - NASA integration of systems to be deployed – NTE 10 years, intensive, expensive…
  - …preceded by a long-term low-level distributed effort using all the time we've got – starting now!
    - Get it right on Earth, to reduce risk on Mars
    - Not necessarily NASA! Not necessarily US Govt!

XPM TECHNOLOGIES

Living on Mars: Programmatic Challenges

- How?
  - Develop overall plan, model of system, subsystems
  - Assess technologies, adapt or develop
  - Validate through simulation on Earth
  - Iterate until it's time to go…
- Who?
  - Many agencies/entities = "many cooks"
    - Example: DOE: nuclear powerplant (exploit thermal as well as electrical)
- When?
  - Begin process now
  - Long term time challenge: choose/harvest technologies only when appropriate
  - Short term time challenge: mission length precludes complete testing

XPM TECHNOLOGIES

Time Scales, Long Term:
Pick a Date… How about 30 years from now?

- **For reference, 30 years ago:**
  - **No: Mac, Windows, cellphones, DVDs, PDAs, iPODs, etc**
  - **300/1200/2400 bps telephone modems (monolithic AT&T)**
  - **ARPANET becoming Internet, WWW a decade in future**
  - **1977: PET computer with 4 KB RAM, analog tape, no disk, for $595**
- **What to expect 30 years from now, in 2039:**
  - **Rules of Thumb say that processing power, RAM and disk memory, and link bandwidth will all be about 50Kx current (2007) levels!**
  - **10,000 TB (10 petabyte, or PB) disks, incredible processing, etc**
  - **Cellphones, laptops will be subsumed into wearable (body network?) devices/systems… who knows!!**
- **Our mission commander, 40 years old in 2039, is currently a 10 year old in fourth grade**
  - **She is growing up with all aspects of rapidly evolving IT**
  - **She “won’t leave home without IT”**

XPM TECHNOLOGIES

Time Scales, Short Term

- Characteristic Times
  - 26 months - time between launch opportunities for conjunction missions
  - 30+ months - length of conjunction mission (6+ mo to Mars, 18 mo stay, 6+ mo return)
  - 12-24? months - unmanned spacecraft Assembly-Test-Launch (ATL) cycle time
  - 12-18 months - COTS IT/electronics technology generation
- Impossible to perform a full-mission-duration system test (bring redundant repairable systems)
- Loose coupling enables rapid system evolution, reduces obsolescence
  - Deploy a new generation of IT for each successive mission

XPM TECHNOLOGIES

Technology Spinoffs from Mars Preparation Program

- Technologies for distributed, loosely coupled, self-contained, intensively recycling, communities/ homesteads
  - Analysis of and attention to all the considerations
  - Coping with and exploiting extreme pressures and temperatures
    - Effective cold weather clothing
    - Instrumentation
  - Water and waste recycling strategies and processes
- Portable nuclear and methane-oxygen power plants
- Medical strategies/technologies/tools

XPM TECHNOLOGIES

Conclusions

- **Living and working on the surface of Mars presents a much broader range of challenges than just developing the rockets to get there and back**
- **It is feasible, cost-effective, and imperative to reduce surface stay risk through extensive preparation**
- **Risk to crew during surface stay is lower than in space – so even the First Stay should be a Long Stay!**
- **Developing rockets requires crisp focus, is expensive, and must be done intensively and quickly**
- **Preparation for the surface stay is diffuse, comprises many factors, technologies, and strategies, is relatively inexpensive (compared to rockets), and should be done over many years – starting now!**
- **The real challenge is to manage a complicated program with a relatively small budget, across multiple agencies and over a period of many years**

A “Virtuous Cycle”

- The safer it is on the surface of Mars, the longer we should plan to stay

- The longer we are planning to stay on Mars, the safer we can and should make it, starting now!

XPM TECHNOLOGIES

Alternate Titles / Future Papers

- Space: All that Stands between Us and Mars
- NOT Rocket Science: A Rational Program for the Human Exploration of Mars
- Learn to Live on Mars, Learn to Live on Earth
- Lifestyles of the Rich and Martian