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Mars Mission Design Evaluation Criteria

Marc M. Cohen, Arch.D, Architect
NASA-Ames Research Center

Abstract

The ultimate goal of human space exploration is to discover if life exists on other worlds, to understand the genesis and evolution of the universe and to learn to live on other planets. Mars offers the closest opportunity to pursue these goals realistically. The capabilities to define, design, develop, build, test, contract out, manufacture and operate new technologies are the means to achieve this set of goals. The purpose of this set of criteria is to evaluate mission design and exploration technology proposals to ensure that the <u>*means support the goals*</u> *and do no obstruct them.*

Introduction

This paper presents a comprehensive approach to evaluating complete Mars mission designs and partial designs. It begins from current theory and methodology of design problem definition. It proposes a method of evaluating if the mission design solution answers the problem definition. A process diagram encapsulates this process as passing through two evaluation gateways: Is the problem sufficiently well-defined to allow solution seeking? And, is the solution sufficiently well -defined to begin manufacturing?

From this foundation, the paper proceeds to examine a series of crosscutting issues that affect mission design reasoning, including the mass to orbit fallacy and the comparison of exploration modes. Technical credibility is a key to mission success, consisting of completeness, consistency, new technology development, temporal design logic and cost-effectiveness. System integration places particular demands upon the design logic, leading to performance measure for every significant aspect of the design and the technology. Operational practicality is another key parameter, encompassing the ever-present cost-effectiveness issue, plus protecting human health and safety, human productivity, sustainable operational capabilities, growth path to completion and a clear stopping point. All these factors contribute to establishing meaningful life cycle cost analyses, and the understanding of how to obtain the best value for the expenditure. The paper concludes with an appraisal of participatory design process as a means to integrate the stakeholders in a complex mission, and how the program management should approach handling all these factors.

This evaluation will help us to determine not only the best designs for a First Mars Outpost but also to verify the requirements they must meet and the capabilities they must provide.[i] Perhaps the most important goal of these Mars Mission Evaluation Criteria is to move the program goals from an ill–defined to a well–structured problem state. Without such clarity, the program may wander aimlessly, in intermittent forays. Instead, this effort seeks a clear vision of both the exploration path and the exploration process. Path and process are distinct but equal imperatives. Path includes Technical Credibility and Design Selection Logic while Process includes Design Management and all its ramifications. Process is vital because ultimately, people get what the do, not what they intend.

This approach is to identify domains of evaluation. While these domains ultimately inter, mission planners can evaluate them both separately and in parallel. These criteria represent an attempt to guide that evaluation. See **Figure 1** for an

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illustration of the design evaluation process that this position paper proposes.

Design Theory

Design is a cyclical process in which the designer or the design organization iterates a sequence of conception, representation, and evaluation until arriving at a satisfactory solution. Evaluation occurs at several levels and at multiple points along the way. However, this approach to the design evaluation process concerns two major gateways that control the ***design problem definition*** and the ***design solution***. Design problem definition involves design as learning about the problem, while design solution–seeking involves design as production of a project or product. Gary Klein offers a valuable insight into the nature of ill–defined problems:

> Ill–defined problems require two simultaneous processes: 1) Goal clarification and 2) option development. Designers cannot always wait for goals to become perfectly well–specified before starting to work. They must expect to learn more about their goals during the design process itself. This helps to make the design process challenging and maddening. The designer is trying to give the sponsor/user a product, and at the same time, is trying to learn more about what the user really wants and to help the user to through this learning cycle.[ii]

While Klein's observation about two processes seems right on the mark for ill–defined problems, they appear to reinforce Herbert Simon's conclusion that ***there is no sharp boundary between well–defined and ill–defined problems***.[iii] It is difficult or impossible to know whether a problem state is ill–defined or well–defined without engaging in design as learning — to develop design ideas as a way of testing approaches to the problem.

It is essential to distinguish between the evaluation of one's own work that a designer does instinctively and the impartial evaluation of the design problem definition or the design solution. During the cognitive dynamics of the design process it is extremely difficult to prescribe evaluation techniques for the designer to use because a talented designer uses a highly subjective approach to his or her work. In this sense, the design process itself is unknowable. Because designing is unknowable, design managers and teachers attempt to rationalize design and make it transparent.

J. Christopher Jones presents this dichotomy that he calls *Designers as Glass Boxes* and *Designers as Black Boxes.* Jones poses a goal to achieve from this fundamental dialectic for systematic methods: to make design process explicit by strengthening the resources and methods available to the designer operating in rationalist *Glass Box* mode so that he will not revert to the intuitive, internalized *Black Box*.[iv]

Yet, the black box plays an essential role in the creative process. Within the black box, the designer comprehends subjectively the gestalt in which his contribution must fit. According to Don Schön, designers create a whole "world" in which they construct their own protocols in the form of hypothetical rules and typologies for design solutions[v]. This form of heuristic reasoning in design is a necessary step in the solution seeking process, especially in the common situation ". . . in which it is unknown beforehand whether a particular sequence of steps will yield a solution . . ."[vi] Thus, designing is intrinsically a process of discovery and learning, but no design text can prescribe how an individual learns through design, which is the crucial feature of defining a design problem.

In contrast to black box design as learning, Herbert Simon observed the glass box phenomenon in computer science:

> . . . we as designers, or as designers of design processes, have had to be explicit as never before about what is involved in creating a design and what takes place while the creation is going on.[vii]

This emphasis upon explication of design — or design as explication — effects profoundly how the designer works. It becomes especially acute when the designer must produce rationalistic constructs to explain and justify his work.

System engineering is the quintessential glass box method. System engineering provides an excellent set of tools to select and integrate design solutions. System engineers tend to assume that all problems come well–defined, and that any design effort is susceptible to the characteristic weighted comparisons, trade studies and iterations of reference configurations. These techniques prove successful for well–structured problems but not for ill–defined ones. The ill–defined problem typically displays unclear objectives, conflicting requirements, unreduced complexity or all of these difficulties and more. The misapplication of system engineering to ill–defined problems interferes with design as learning, and may produce perfectly consistent but incorrect results.

The systematic method's literature concentrates on elaborating the glass box model through bubble diagrams, functional flow block diagrams, PERT charts, GANTT charts, flow charts and many other constructs. By describing the context and limits of design, design managers attempt to make it manageable. Ironically, because glass box methods are so persuasive and powerful, they often substitute for the actual design product. In a very large design project that imposes elaborate rituals to pass atomized design elements through many layers of review, it becomes easier for people to focus upon the bureaucratic process and not to think about the product. Witness Space Station Freedom.

Therefore, it is further important to distinguish ***control of process*** from ***control of product.*** Karl Popper, the philosopher of science, argues that "the problems of produced structure are as a rule more important than the problems of production." [viii] Thus, the mission design evaluation gateways differ from the traditional project reviews in the form of preliminary design reviews, critical design reviews, final design reviews, etc. The need to manage people and control their interactions motivates these kinds of project reviews as much — or sometimes more — than the need to find the best design solution. The design evaluation gateways control the progress of the design product alone, without reference to whom takes responsibility for which pieces of the puzzle.

These evaluation gateways offer an opportunity to step back from the whole design flow and give the project a sanity check. The experience of Space Station Freedom underscores the importance of such a sanity check, especially the necessity for a clear, well–defined problem definition before starting to seek design solutions.

Mission Design Evaluation Process

In this evaluation process, the design must satisfy three top-level criteria at each gateway. These criteria take the form of questions that demand mostly ***yes*** or ***no*** as answers. The gateways require three unequivocal yes's before opening to allow the mission design to pass on to the next cycle. This gateway approach tends to be incompatible with "fast-track" methods in which the project begins building some pieces while other pieces are not yet even sketches.

This design evaluation process differs substantially from the traditional systematic sequence of pre-Phase A "Needs, Attributes and Architectural Options" studies[ix], Phase A Concept Development, Phase B Definition Studies, and Phase C/D Design-Build. The difference between these evaluation paradigms is that in the present bureaucratized design process, designers and design managers iterate endlessly between requirements and solutions without ever passing through a problem definition. It is all too easy to become caught up in the avalanche of details and to lose all sight of the project as a whole enterprise.

Gateway 1 controls whether the mission design is ready to pass from problem definition to solution seeking. The questions at Gateway 1 ask:

1. Is the problem sufficiently well defined to allow solution seeking to begin?

2. Are the requirements clear and are they the right requirements?

3. Is this problem definition well documented?

Question 1 demands a judgment of the clarity, completeness, consistency, and credibility of the design problem definition. **Question 2** reviews whether the requirements are still correct which may shed a very different light than the early requirements review. **Question 2** may prove the most difficult because it compels the evaluators to question the fundamental reasons for the mission. **Question 3** is important to show that the solution–seeking designers will be able to understand the problem definition, especially the origin and relationship of the requirements. At **Gateway 1,** it is vital to build a consensus among all the stakeholders upon the general form and specific content of the design problem definition. Three yes's make this consensus possible (although not automatic). Without this consensus to confirm the problem definition, dissatisfied participants or stakeholders will often attack and undermine any design solution.

If a candidate problem definition fails to generate a yes to the three questions, it is not ready for solution seeking. Should the problem definition fail, two choices emerge. If, despite the failure, the problem definition is relatively within range of three yes's, design team may continue refining the "product" within the problem definition cycle.

However, should a candidate problem definition receive a resounding no — and the designers feel they made their best effort — they have no choice but to revisit the basis of the whole endeavor; the policy goals, the technology, and the objectives.

Gateway 2 controls whether the mission design is ready to pass from design solution to manufacturing. The questions at Gateway 2 ask:

1. Is the solution sufficiently well–defined to begin manufacturing?

2. How well does the design solution meet the requirements?

3. Is this design solution well–documented?

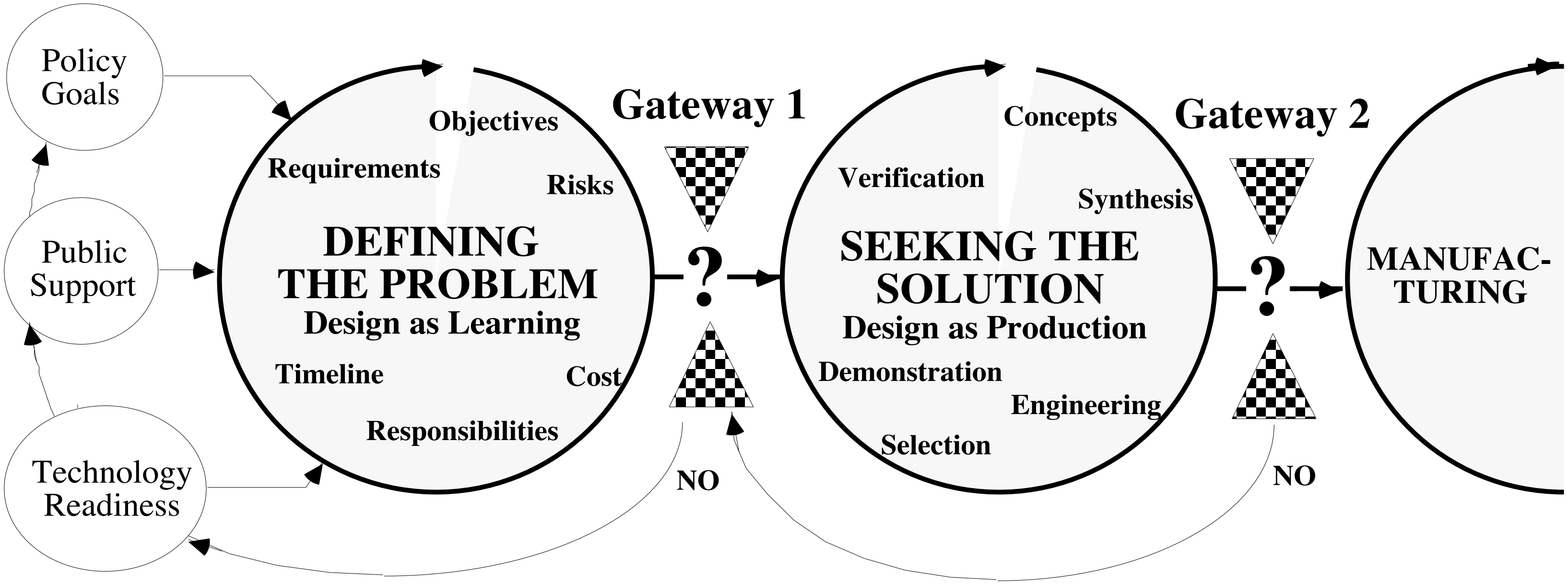
Question 1 requires a careful assessment of the totality and detail of the mission design solution. It takes the watchword clarity, completeness, consistency, and credibility several steps further by including technology verification, especially integrated technology test beds that demonstrate the functionality of the proposed systems and subsystems. **Question 2** stems from a simpler and starker inquiry: Does the design solve the problem? Is it possible for a design to meet all the requirements in a fragmented way and still not solve the problem? However, most designs that solve the problem will met the various requirements with differing degrees of success. Thus, this question accepts the most “gray scale” answer of the set. **Question 3** ensures that the design solution is ready for manufacturing, that the fabrication engineers and workers can comprehend what they need to do to produce the hardware and software. It also helps to verify that the solution solves the initial problem and will meet the project's goals and objectives.

If a design solution fails to pass gateway 2, it may continue the design cycle. However, if it fails drastically, it should return to the first cycle to reexamine whether the problem definition — as stated — is solvable.

Cross–Cutting Issues

Within the overarching design evaluation approach, a number of Mars mission–specific evaluation criteria apply to the two gateways. In addition, a number of other issues cut across the design process itself. These cross-cutting issues include: technical credibility, operational practicality, participatory process (consensus) and program management.

Mission Design Evaluation Process



Evaluation Gateway 1
1. Is the problem sufficiently well-defined to allow solution-seeking?

2. Are the requirements clear and are they the right ones?

3. Is this problem definition well-documented?

Evaluation Gateway 2
1. Is the solution sufficiently well-defined to begin manufacturing?

2. How well does the design solution meet the requirements?

3. Is this design solution well-documented?

The Mass to Orbit Fallacy

The great -- and perhaps unique -- difficulty in developing a design problem definition for a space mission is that so much depends upon launch capability and the subsequent diminutions in a payload capacity as it approaches its destination. The system engineer asks: “What could you do with 100 kg on the surface of Mars?” This mode of thinking places the delivery system ahead of the mission objectives.

This paradox is the space age equivalent of “putting the cart before the horse.” This approach is so ingrained in the NASA and Space culture that any discussion of exploring Mars with most engineers quickly degenerates into a comparison of reconstituted or resurrected heavy launch vehicle systems. This way of thinking is unlikely to produce either the human Mars exploration mission *or* the HLLV system anytime soon.

Instead, it is vital to take a new approach that looks at each major part of the problem separately and determines what is the best way to conduct each one, without prejudging how the technology for one major portion should influence the technology for another portion. The key questions in this instance are:

To what extent is the design problem definition independent of any specific design solution or technology application?

Does the candidate design (either problem definition or design solution) offer a significant reduction in complexity over other approaches?

Exploration Modes

Each Mars exploration mode poses a potentially valuable contribution: human or machine; orbital, atmospheric or surface; autonomous robot or telepresence; manned sprint or permanent base. Each specific exploration mode raises the key questions:

1. What is the best mode for a general or specific reconnaissance to pursue scientific exploration or to prepare for a permanent base?

2. Does a manned mission offer any advantages over unmanned Mars site examination, selection, survey or preparation?

3. Does a sprint mission offer any advantages over a permanent base approach as a first manned Mars mission?

4. Does the Mars surface Habitat share common hardware with the space station, the lunar surface habitat, the TMIV, or the TEIV?

5. Is this commonalty between entities a benefit or a penalty?

6. What is the appropriate safety philosophy and strategy for a Mars surface mission?

Technical Credibility

The essence of technical credibility is that a proposed Mars Mission design should be capable of doing what its proponents claim it will do. This criterion differs from judging proposals on whether they appear to be the smartest or best way to go to Mars. If a mission design proposal is fundamentally credible, it is important to evaluate it fairly on the broader aspects of technical credibility: completeness, temporal design and cost–effectiveness.

Completeness

To achieve completeness, a Mars Mission Architecture must address both participatory process and system engineering. These planning criteria include:

1. The objectives to accomplish on Mars, particularly science,

2. The most efficient and productive way to accomplish them,

3. The best way to deliver this capability to Mars.

Completeness means an explicit approach to consistency and continuity in the design and conduct of Mars exploration. Continuity implies that the exploration continues steadily over a sufficiently long period to accomplish all the scientific goals. Consistency implies providing rigorous and reliable treatment for each aspect of exploration, without burdening individual investigations with unnecessary components. Finally, the directness of the approach will be crucial to implementing complete and timely Mars missions. Technical credibility means internal consistency from end to end for each mission and program.

Consistency

Is the mission design consistent in handling the issues -- or does it make the exceptions outnumber the rules?

<u>For example:</u>

How many NASA engineers does it take to screw in a light bulb?

Answer: Two **--** One to screw in the light bulb and one to sign the waiver.

This little joke illustrates a profound problem in the way the bureaucracy can constrain a program so that predictable and necessary changes become “discrepancies” or “contingencies,” or “exceptions” that require ”waivers and sign-offs.” These shortsighted constraints go a great way toward keeping thousands of civil servants and contractors in secure jobs processing paper, but they can make it difficult or impossible for the working technical people -- the designers, engineers, manufacturers, and astronauts -- to do their jobs. Safety should be the highest priority throughout the program, but often the ritual observances for trivial matters can obstruct the more significant factors that affect safety.

New Technology Development

Does the mission design treat technology development as a wasted cost or as an investment opportunity?

Should technology development occur in a focused technology program? Should this effort happen before selecting a “point design” or after selecting one? Since one can rarely determine impartially beforehand which alternative will serve best over the long run, this approach encourages the parallel development and testing of multiple options. No one can know or specify all requirements before undertaking these design and development activities. Rather, this technology development serves as inquiry by design research that will help to discover new requirements and technical possibilities.

The MSM critical technologies are: propulsion, aerobraking, regenerative life support, EVA, robotics, human factors, and crew health maintenance.[x] In situ resource generation, storage, and utilization are emerging also as essential elements of the Mars Surface Mission. The vital step is comparing promising new technologies to off–the–shelf items for cost and improved performance, maintainability, producibility, reliability, quality and safety. The burden of proof should rest with the developers of new technology, although the mission design managers should adopt an openness to being persuaded that a new technology may be equal or better than an existing flight technology.

System Integration

System Integration, particularly the integration of multiple technologies, raises two sets of issues: Design Logic and Temporal Design. The mission design must resolve both sets of issues together.

<u>Design Logic:</u> The design logic articulates the assumptions about the MSM design approach and the interface constraints between the transportation and surface systems. It also applies at lower and more detailed levels to the whole chain of design decision-making and evaluation.

The Design Logic must satisfy these six questions (or tests):

1. Does the technology and system integration approach accurately respond to the design problem definition and decomposition?

2. Does the system integration occur at “natural” intersections of the architectural elements and technologies or is it forced?

3. Do the partitions or separations of technologies occur at “natural break points?” Do these break points give the program “clean interfaces?”

4. Are there any artificial or forced integrations that reflect external bias rather than the design problem definition, the mission design solution and the technology selection (e.g. pork barrel politics or parochial turf claims)?

5. Are the mission elements modular, interchangeable and replaceable or are they so highly integrated as to negate a real availability/maintainability strategy?

6. What approach to availability, maintainability, redundancy, reliability,

reparability and safety suits best the MSM objectives and requirements? How does this strategy correspond to the system integration approach?

Temporal Aspect of System Integration: When and how should system integration occur in the design, development, test & engineering process? The traditional approach, based primarily upon the strictures of federal procurement law and a cultural tradition, places the system integration process late in the Phase C/D Design-Build phase of a hardware contract. Any changes or corrections in integration so late in the manufacturing cycle are extremely expensive and difficult. These questions concern the fundamental approach to system integration and its relation to technology development.

1. While Phase C/D is unavoidable for flight hardware integration, is it the best time to begin system integration?

2. Can the system integration occur early — "pre-Phase A" — to establish the functionality desired for the mission?

3. When can the Mission to Mars start?

4. What rationale determines when a technology is ready?

5. Is NASA's traditional 8 point Technology Readiness Scale an appropriate gauge for a mission-oriented technology development program?

Temporal design also concerns the long-term conduct of the whole Mars exploration program. A successful Mars Mission architecture should reflect a sustained commitment to exploring Mars. The MSM design will approach the temporal aspect of exploration, not as a series of arbitrary target dates, but as an assessment of appropriate and deliberate speed. This assessment involves meaningful milestones with a vigorous pursuit of precursor exploration and technology development missions. For each exploration activity, will a time delay allow the development of a new enabling, safer or more cost–effective technology within a reasonable time? To what extent should technology development pace Mars exploration? To what extent are missions repeatable — not just single flight opportunities — but for a plan for efficient, reliable and timely follow-on expeditions?

Performance Measures

All these considerations under Technical Credibility boil down to establishing performance measures for every significant aspect of the design and the technology. Performance measures require clear indices to evaluate both if the design succeeds or fails and how well it succeeds or how badly it fails. Then the program management must decide whether to continue pursuing that approach or to try an alternative. This decision often requires courage, first to admit making a mistake and second to write off the costs of an unsuccessful design or unsatisfactory technology investment. The ability and willingness to make these evaluation decisions imply that the mission design program must study several alternative designs and technologies for many of the critical performance measures. This approach requires the willingness to devote more people and resources up front to ensure choosing the best approach instead of paying greater penalties downstream in the design process to correct poor decisions.

An example of an architectural design performance measure comes from the American Institute of Architects Handbook of Professional Practice. The Guideline for the Architectural Areas and Volumes or Buildings provides specific rules for measuring different attributes of tenant–usable areas versus infrastructural or common areas and volumes.[xi] The evaluation of each Habitat design concept should adopt a similar consistent approach to measuring spatial efficiency.

Operational Practicality

Operational practicality involves several issues: cost–effectiveness, crew health and safety, human productivity, and life cycle costs.

Cost–Effectiveness

What is the appropriate criterion for cost-effectiveness? Every Mars mission proposal and technology is analyzable for cost, pay–off and risk. The analytical criteria shall be fair and impartial both as written and as applied. The benchmarks for assessing cost and benefit include: mass in Earth orbit as a cost, mass delivered to Mars as a benefit, and delivery time as a variable. This evaluation must compare each specific exploration step for the risk of failure against the risk (to the next phase of exploration) of not taking it. The key cost question is whether the size of the infrastructural investment for humans to go to Mars implies that a base–building approach from the first landing will be most cost–effective.

Does the Mission design "trip over a pound to save a penny?" This question is particularly important for ideas of system integration and commonalty. On Space Station Freedom, it was an article of faith that commonalty and standardization would yield substantial "cost avoidances." However, standardization most often meant eliminating a capability that did not fit within a framework of what should be common or whose hardware should be common and who's should not.

Protect Human Health and Safety

How well does the mission design provide protection, support and multiple solutions to ensure the crew's health and safety? What criterion does the mission design use to baseline these protections, and are they the appropriate performance measures? The mission design logic identifies these crew health milestones as interface constraints, but they also arise as design evaluation criteria insofar as they constitute performance criteria for the crew habitats on the TMIV, the Mars Surface and on the return TEIV. Thus, the mission design logic provide clear assessment measures or criteria for crew health at each of the four major way points:

1. What is the baseline condition of the crew upon launch from earth?
   (+0 days)

2. What is the crew's condition upon arriving on Mars?
   (+120 to +200 days)

3. What is the crew's condition before lift-off from Mars?
   (+720 to +800 days)

4. What is the condition of the crew upon return to Earth?
   (+920 to +1100 days)

Human Productivity

In assessing cost–benefit considerations, especially for science, the conventional input–output profit model of productivity is neither appropriate nor relevant. Rather, the evaluation must look to new values in productivity including: long term–returns, making opportunities for creativity, discovery and serendipity, the growth of capabilities and skills, planned reliability and quality, and enhancing the lives of the explorers and the people on Earth. Human performance will determine the success of manned missions of 1000 days or longer more critically than any other element. The definition of cost-effectiveness must incorporate human factors, habitability and sustained performance as the highest priority. Habitability, the qualities of work life, crew autonomy, democracy and teamwork are all components of productivity in the high technology environment. For the architectural design of Mars spacecraft and habitats, this priority means that the human performance quality of the living and working environment takes precedence over short–sighted economies such as maximizing equipment packaging or shortening utility runs.

Sustainable Operational Capability

The purpose of this technology development is to ensure thoroughness in the study of Mars through a substantial operating capability. The benchmarks of this capability will include self–sufficiency, mobility and the benefit of a variety of human skills. This mix of capabilities should attain a harmony in working together to accomplish the exploration objectives.

Is this mission a "flag & footsteps" enterprise that sows the seeds of its own demise even as it achieves its highest goal, or does it present persuasive long-term benefits and staying power?

Growth Path

An important aspect of both credibility and design decision–making is the mission growth path. Is it an evolutionary capability; that allows the project technology to grow and mature? Or, is it a stable or closed-end approach in which accommodating a new technology means a whole new mission start?

Pre-judging this question is difficult at best. Design decisions should examine which future options they foreclose and which they keep open. However, evolution is not an absolute value; it is important to recognize that after a particular lifetime, the Mars surface habitat and associated hardware may become obsolete or too expensive to maintain. Then it will be time to build the next generation, rather than limp along with the status quo.

Evolutionary capability also means a progression in thinking about using machine missions to prepare for human missions. Increasing international cooperation may be another measure of evolutionary capability and reduction of the support staff on Earth may be another such measure. These two measures may conflict; resolving such contradictions is an essential aspect of planning for evolutionary capability.

Completion and Stopping Point

When is the build up of a Mars habitat or Mars base complete? How is the completion of construction different from the completion of exploration -- at a particular site or region -- or as part of a particular program?

Life Cycle Costs

Life–cycle costs, especially for logistics, operations and resupply, are equally important as initial costs for early explorations and even more important for the permanent Mars Base. This analysis will compare the economics of short-term projects against other short-term projects and the economics of a permanent base against other permanent base ideas.

1. Does the Mission design reduce Mission resupply cost through ISRU? How effective is this reduction in cost and mass?

2. Does the Mission design use Space Resources or In-Situ Resources to enhance the safety and viability of the mission as a whole?

3. How do the life cycle costs for a series of short expeditions compare to fewer but much longer missions?

4. How do the comparative mass budgets compare for renewable versus nonrenewable consumables, especially for life support and energy systems?

5. How long is a realistic “life” on which to base life-cycle costs?

6. Is the baseline life cycle the same across the entire Mars mission?

7. Is it possible to factor scientific return or accomplishment of mission goals into the cost-benefit equation?

Participatory Design Process

A design problem definition or a design solution can live through the design process only so long as all the people involved agree to it. This design lifetime becomes the province of participatory process. The ideal outcome is a consensus upon the products of the two design evaluation gateways that will sustain the project all the way through to completion. Participatory process helps ensure that the stakeholders “buy into” both the problem definition and the design solution.

Dimensions of Problem Solving

This overarching criterion distinguishes between the two dimensions of problem solving: technical difficulty and participatory complexity. Technical difficulty is the domain of system engineering, and social or participatory complexity is the domain of participatory and democratic process. The relationship between these domains is that the participatory design research process will reduce ill–defined Mars exploration complexity to well–structured goals upon which systems engineering can operate. A rigorous system engineering method will then focus upon specific analysis of technical requirements and capabilities to produce the mission design.

Participatory Process is also key to persuading all investigators who wish to explore Mars have an opportunity to contribute their ideas and resources to the Mars exploration program. It can also ensure -- indeed, it may be the only way to ensure -- that an appropriate and innovative problem definition can lead to a creative Mission Design solution. The absence or failure of participatory process that leads to a national or international consensus means that “business as usual” will smother any new human space program in its cradle under bureaucratic overload. Participatory process in support of a clear consensus upon a design solution may be the only way to build the momentum to go to Mars.

Participation in Mars exploration involves developing agreement upon both national and international goals. Building trust, consensus and openness among domestic and international partners is a key to optimizing the use of Earth resources. Participation in Mars exploration leads us to develop new educational, technical training and employment opportunities. The exploration program must serve to educate the public to appreciate the scientific objectives and benefits of Mars exploration and to provide the competent people to carry the work through future generations. Participation includes sharing technology development efforts with less developed economies on Earth to broaden the base of communities and nations that can play a role in Mars exploration that will be meaningful to them and that will help them develop economically.

Professionalism in Design

However, it is essential to maintain the highest professional standards of objectivity to avoid a rush to judgment about mission strategies or technologies. The main goal of design methodology for future space missions may be to avoid a premature division of the work into packages before defining the problem (on the model of the space station program). However, neither is it reasonable to wait until the program can identify every requirement for every mission situation. Rather, the best hope is to discover and better understand requirements through design synthesis. This design research strategy encourages the most innovative engineering and architectural design approaches including: concurrent engineering, designing–in quality, multidisciplinary teamwork, peer review, democratic–participatory (instead of hierarchical) decision–making, and research in design method and process. These innovations can serve as a competitive and cooperative strategy to gain the positive technical benefits of both competition and cooperation while avoiding their negative aspects.

International Cooperation

Peaceful cooperation and exploration beyond the Earth are symbiotic. They demand international trust and openness to cooperate successfully. Both national goals and international goals can strengthen all the partners and be mutually reinforcing. Technology development and technology transfer can help a number of potential participating nations to develop their own industrial base and train Mars exploration candidates and scientific and technical interns. In this context, the Mars program should help revitalize educational systems around the Earth and increase industrial efficiency. Ultimately, however, the design and execution the Mars exploration objectives will determine how well the participants meet these goals.

How will various exploration modes require different technology development efforts? Conversely, how would a particular new technology enable different exploration modes than currently are possible? What do particular technology mixes imply for international cooperation? Will international participation be an asset or an added difficulty to designing or conducting Mars exploration? How might this participation vary over time? It is important for Mars mission architecture proponents to be explicit about these questions.

Program Management

What is the most appropriate approach to Mars Exploration Program management?

Judging from the most recent human space project experiences in NASA, it would be easy to erect an immense bureaucracy that produces tons of reports and studies and but does nothing to go to Mars. Consider that the Space Shuttle Program has three “levels,” and has struggled with turf problems, including the Challenger accident. The Space Station Program consisted of four complete levels of “management,” spread over five locations. The prospect of multi-agency collaboration on a Mars expedition (NASA, DOD, DOE) raises the specter of a five-tiered bureaucracy. Substantial international participation raises the ante to a six-tiered bureaucracy. Without a radical change in the approach to program management, a Mars exploration enterprise will become a nightmare for everyone involved -- except the paper and copier industries.

Mike Griffin and James French emphasize this point:

> It is too easy in the modern era to be seduced into creating overly complex and unnecessary paper systems. (The computer is particularly dangerous in this case with the multitude of software systems to “help the manager manage.”) Once created, these paper systems seem to take on a life of their own and expand and propagate. Even with computerized concepts, huge amounts of time and money can be wasted in excessive documentation. The systems engineer should think through the documentation requirements for his activity and implement a plan to meet the requirements. Avoid unnecessary “bells and whistles” that sound great but do not contribute. They will exact their price later.[xii]

Program Management for Mars exploration will not succeed as “Business as Usual.” Instead, the Mars exploration program must seek out new approaches to design, management and planning that will accommodate the new challenges of Mars exploration. These approaches most likely will include extensive international participation, vast complexity, sustained design and operations effort over several decades, and great technical difficulty. The key to approaching this challenge is to understand the nature of problem solving, particularly the relative advantages and disadvantages of participatory process and system engineering, and to frame them in the context of international cooperation.

All the great, successful aircraft and spacecraft programs share a single factor: a great design idea. Usually there was a small group of designers or even a single designer who provided the intellectual and goal-seeking leadership that kept the program on track, and out of the paralyzing detours of top-heavy project management. Stated simply: once there is a consensus upon a design problem definition -- and that consensus is completely independent of special interests -- the designers should specify the requirements for program management.

Questions for Mission Design Management

1. Who are the Participants?
2. Who are the Stakeholders?
3. What scientific and technical disciplines are necessary to provide analysis, design, engineering and management capabilities?
4. What governmental organizations should play a role -- and what role should each play?
5. What industries can contribute to producing hardware, software & systems integration?
5. How well does the management shape the design organization to fit the design problem and to develop its solution?
6. To what extent does the management map the design work packages onto existing organizations as welfare programs, without regard for the mission characteristics?
7. How should program management respond to all these factors?

Conclusion

The ultimate test of a space mission architecture is the degree to which it responds directly to the mission objectives as embodied in the design problem definition. Factors that may detract from success include: mapping the solution onto the performing organizations rather than addressing the design problem, pork-barrel distribution of tasks rather than picking the best people for the job, and subordinating critical design judgments to external considerations. The success of a Mars Mission architecture depends on how well it defines the problem and then solves it.

Contact Information

Marc M. Cohen
Advanced Projects Branch, Space Projects Division
Mail Stop 244-14
NASA Ames Research Center
Moffett Field, CA 94035-1000

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[i] This effort to define a Mission Design Evaluation approach for Human mission to Mars began at the Case for Mars IV Conference at the University of Colorado in the summer of 1990. Larry Lemke led a small working group in exploring various evaluation approaches and metrics. These design evaluation criteria are the inheritance from that effort, further developed and revised in light several subsequent Mars exploration studies.

[ii] Klein, Gary A. (1987), “Analytical versus Recognitional Approaches to Design Decision Making,” in William Rouse and Kenneth Boff, editors, System Design: Behavioral Perspectives on Designers, Tools and Organizations , New York: North–Holland, Elsevier Publishing Co., p. 179.

[iii] Simon, Herbert (1973), “The Structure of Ill–Structured Problems,” in Nigel Cross, editor (1984), pp. 145–166. Developments in Design Methodology, Chichester UK: John Wiley and Sons Ltd. [verify citation].

[iv] Jones, J. Christopher (1970), DESIGN METHODS: Seeds of Human Futures, New York: Wiley–Interscience.

[v] Schön, Donald A. (July, 1988), “Designing: Rules, Types and Worlds,” Design Studies, Vol. 9. No. 3, London: Butterworth & Co. Publishers Ltd.,.

[vi] Rowe, Peter G.(1987), Design Thinking, Cambridge, MA: MIT Press. p. 75.

[vii] Simon, Herbert (1973) The Science of the Artificial, Cambridge, MA: MIT Press. [check page]

[viii] Miller, D. (1985) editor, Popper Selections, Princeton NJ: Princeton University Press, p. 62.

[ix] This term derives from the Space Station Needs, Attributes and Architectural Options Studies by eight aerospace companies working in parallel but separately before the Space Station Phase A began in May of 1983.

[x] Gross, A. R., Harper, L. D., Shafto, Michael G., Vernikos, J., Webbon, B. W., and Berry, W. E., (1992) “Human Support for Mars Exploration: Issues and Approaches,” in Pritchard, E. B., Mars: Past, Present and Future, Volume 145, Progress in Astronautics and Aeronautics, Washington DC: American Institute of Aeronautics and Astronautics. pages 269-296.

[xi] “Guideline for the Architectural Area and Volume of Buildings, AIA D101,” (1980 edition ?) in Architect’s Handbook of Professional Practice, Volume III, Washington DC: American Institute of Architects. [check for most recent]

[xii] Griffin, Michael D., and French, James R. (1991) Space Vehicle Design, Washington DC: American Institute of Aeronautics and Astronautics, pages 8-9.