# "MARS ON $300K A I) A}'": THE MARS EXPLORATION PROGRAM

Second lAA International Conference on Low-Cost Planetary Missions

Donna 1.. Shirley
Manager, Mars Exploration Program
Jet Propulsion Laboratory/California Institute of Technology
4800 Oak Grove Drive
Pasadena, C~A911 09
Fax 818-393-6800
E-Mail: dshirley@ccrnail.jpl.nasa.gov

## ABSTRACT

The Mars Exploration Program is pioneering a series of "better, faster, cheaper" missions 10 Mars over at least the next 10 years, and possibly well into the 21st century. The overall cost of the program is somewhat over $100M per year, including launch vehicles and operations, for two launches every 26 months. (This works out to about $300K per day. ) A programmatic strategy has been developed involving selection of a science theme for the program, a lonf,-term industrial partnership for spacecraft development, continuous infusion of new technology, and integration of the individual projects into an overall program so that synergy between projects can be maximized. A number of process improvements have been made in procurement, concurrent engineering, rapid prototyping, and integrated payload selection, among others.

## INTRODUCTION AND PROGRAM 1)1 NW II' I'lON

The Mars Exploration Program Office was formed at the Jet Propulsion 1 aboratory in July 1994 to integrate the robotic exploration of Mars. The two major elements of the program are Mars Pathfinder (one of the first two 1 Discovery missions) and the Mars Surveyor Program (a program to send missions to Mars every opportunity within severe cost constraints). The Mars Surveyor Program was established in the wake of the loss of Mars Observer in 1993. The first of its missions, Mars Global Surveyor, will carry six of (he eight Mars Observer instruments, and the other two instruments are planned to be flown in 1998 and 2001. The content and implementation strategy of the Mars Exploration Program arc described in Reference 1.

The Mars Exploration Program will continue the investigation of the red planet by robotic spacecraft that began in 1965. The new U.S. program of exploration will begin with launches in late 1996 of the Mars Global Surveyor and Mars Pathfinder missions and extend through at least 2005. And studies are under way for activities leading up to a human mission to Mars as early as 2018. The focus of the first 10 years of the Mars Exploration Program is on building up knowledge steadily and incrementally to a thorough characterization of the planet in terms of life, climate, and resources.

Mars Pathfinder will be the second mission in the Discovery Program of planetary exploration. It will launch in December 1996 on a McDonnell Douglas Delta "/925 rocket, and land on July 4, 199-/. It will image the terrain in 14 different spectra, monitor the weather, arid deploy a small rover to explore the region around the lander and measure the composition of the sur-face.

Mars Global Surveyor, which will launch in December 1996 (also on a Delta 79'25), will go into orbit around Mars in September 1997 and, after ac robraking into a circular polar orbit, will scan the surface of Mars for a full Martian year (about two Earth years) using six of the eight instruments that were originally flown on Mars Observer- (which was 10s1 in 1993--the first planetary spacecraft failure in 27 years).

After Mars Global Surveyor, the Mars Surveyor program will fly two missions to Mars every opportunity (about every 26

months) and, with Pathfinder, is pioneering the "better, faster, cheaper" approach to planetary missions. In late 1998 Mars Surveyor 1998 will launch an orbiter and a lander on a Delta 7325 launch vehicle (at a savings over a Delta II). The orbiter will carry an infrared spectrometer to survey the atmosphere over a yearly cycle. The lander will place a payload near the south pole to search for volatile elements such as water.

The final element of the lost Mars Observer payload (a gamma ray spectrometer) is being considered to search for water in 2001 on the Mars Surveyor 01 orbiter, and another lander payload is planned to have a rover investigate ;n-ancient highland lake bed to study the ' climate history of the planet. One of the 200' missions may be conducted in partnership with the Russians. For the 2003 opportunity the Mars Surveyor program is exploring a partnership (InterMarsNet) with the European Space Agency to place three landers on the surface. And the Mars Surveyor 2005 mission will be par( of an attempt to return a sample from the Martian surface.

Over the next 10 years the Mars Exploration Program will result in a detailed understanding of Mars, which is of interest not only to Mars scientists but will help in understanding more about the Earth's environment, and can eventually provide the basis for human exploration of Mars. The entire program will be conducted for about one-third the cost of the Viking missions, which orbited and landed on Mars 20 years ago. 1 lath mission costs about the same as a major motion picture, and the total cost of 10 missions to Mars is about the same as that of a single major military aircraft,

Figure 1 graphically illustrates the program---including a U.S.-only mission set (on the bottom)- -which can be augmented by international partnerships (on the top). 1 Each launch year is shown across the top from 1996 through 2005.

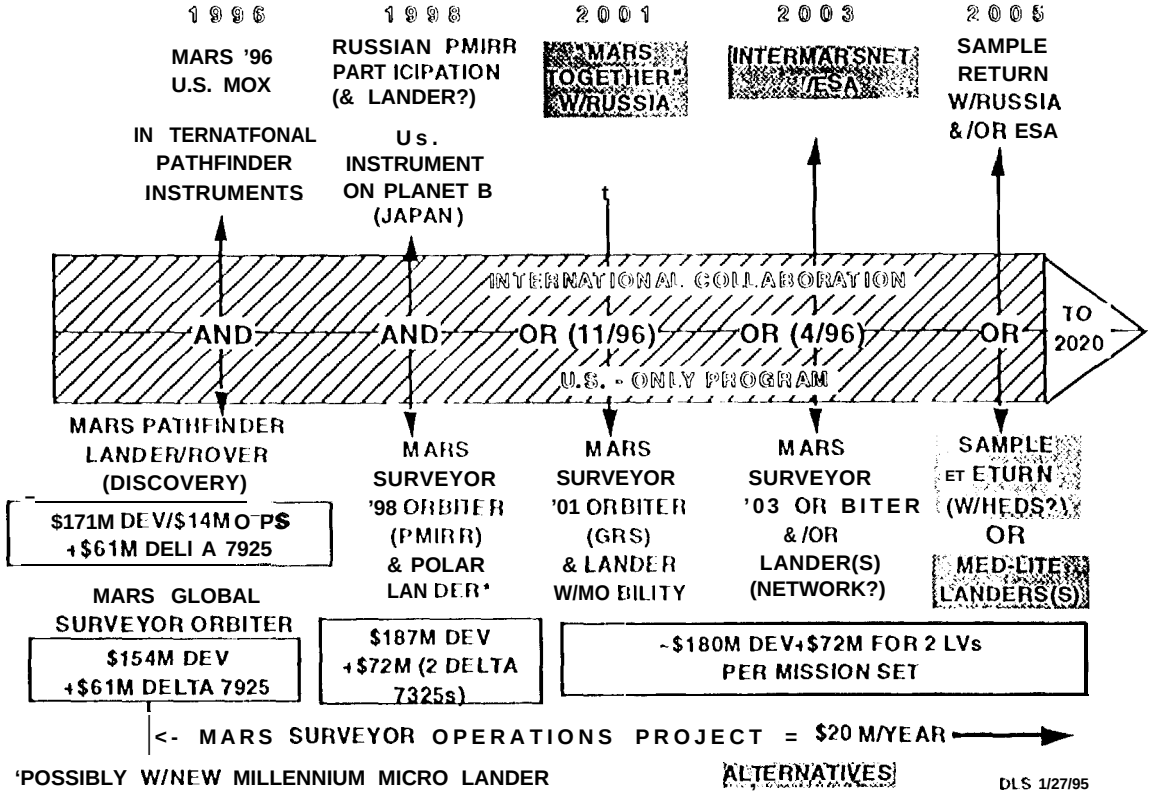


Figure 1. Mars Exploration Program Strategy

The funding available for each mission is shown in the boxes in real-year dollars: the first number is development cost, the second is launch vehicle cost. (The assumption here is that Delta 7325s cost only $36M each, but this may not be the case when the "Med-Lite" contract is finally negotiated.) For Pathfinder, a $14M operations cost is shown for the 7-month cruise and a year of surface operations. For the Mars Surveyor Program, a project has been formed to operate all the missions, and there is $20M per year available for this (not including tracking and data acquisition costs of the Deep Space Network).

## STRATEGIC PLANNING--THINKING LIKE A BUSINESS

Because the new Mars exploration missions were to be conducted at only a fraction of the cost of previous missions, cost became the major driver--with performance and risk being the dependent variables --- a major paradigm shift for NASA missions. Consequently, it was decided to approach planning for the program as though it were a business. This approach was based on a methodology for business planning described in Reference 2. A diagram of the approach is shown in Figure 2, mapped as a series of questions.

Since Mars Global Surveyor and Pathfinder (including the rover technology experiment being funded by NASA's technology program) were in existence when the Mars Exploration Program was formed, they were our "current business." Businesses of the future were the remainder of the U.S. Mars Surveyor Program, plus international missions that could augment Surveyor. We investigated several "businesses" which we must be in to conduct a program of Mars exploration in today's environment, and arrived at five: knowledge generation, exploration, education, inspiration, and technology development/transfer. For each

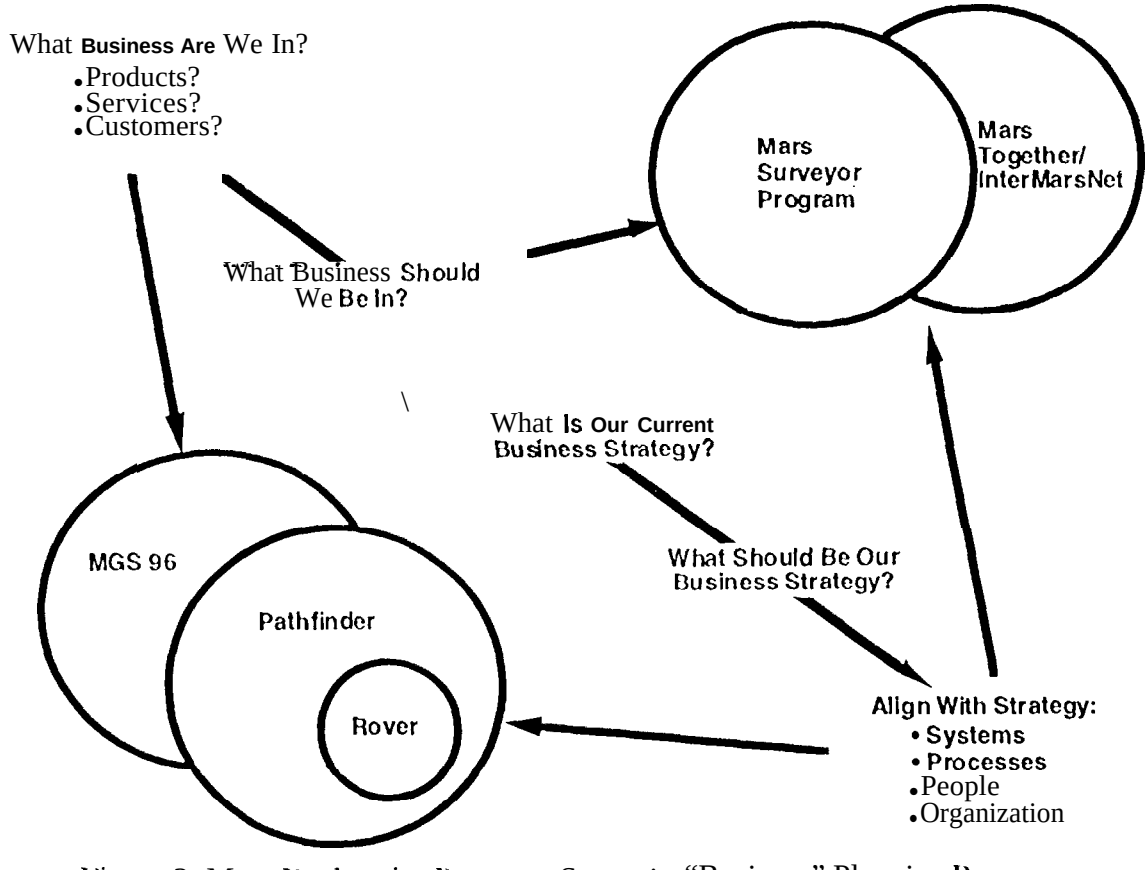


Figure 2. Mars Exploration Program Strategic "Business" Planning Process

business we identified the customers and the specific products and services we would be providing these customers. We identified how we were currently meeting the needs of these customers; that is, what our current business strategy is. Then we identified what our business strategy should be to meet the customer's needs. We selected which businesses should be our primary focus, and which should be primarily carried out by "partner" organizations at JPL. We identified the systems, technology, and processes needed to carry out our business strategy. Then we staffed the program office, and, finally, we evolved an organization to conduct the selected businesses.

Table 1 shows the selected "businesses" with their descriptive information (summarized).

This business analysis showed us that the "knowledge" and "exploration" businesses are very similar in terms of the missions needed to produce the knowledge products. These knowledge products (an understanding of Mars, plus knowledge about the technology and processes of conducting missions to Mars) could be produced synergistically by current and future Mars Exploration Program missions, provided the missions are conducted properly. If the information received from the missions can be synthesized and translated into products suitable for the classroom, the needs of the "education" business can be met. And if the information is presented in a clear and exciting way, the Mars Exploration Program can provide "inspiration" to the public.

Since the only way to conduct a series of Mars missions on the very low budgets allocated is to use new techniques, processes, and technologies, the "technology" business becomes a by-product of the knowledge and exploration businesses. The step of transferring technology developed or transformed by the Mars Exploration Program is needed to infuse that technology into other applications (preferably commercial). We decided to focus on the knowledge and exploration businesses as primary, with education, inspiration, and technology as secondary businesses. We then began developing a strategic plan to conduct our "businesses." The following is from a draft of this plan.

Table 1. Mars Exploration Program Business Analysis (Summary)

| Business | Product | Technology in Product | Technology to Produce Product | Features of Product | Customers |
|---|---|---|---|---|---|
| Knowledge | Information about Mars | Information management | Mars Missions | Understandable information | Scientists, everyone |
| Exploration | Information about Mars | Information management | Mars Missions | Synthesized information | NASA |
| Education | Educational products | Information presentation | Translation Of knowledge | in curricula | Educators, students |
| Inspiration | Inspiring information | Information presentation | Computer graphics, etc | Exciting | The Public |
| Technology Development & Transfer | Advanced technology | Technology itself | Techniques for technology production | Cost-effective | Missions, industry |

MARS EXPLORATION PROGRAM
STRATEGIC PLAN

## ~fla~~.exploration Program (MEP) Vision

**To Know Mars**

## MEP Mission

Explore Mars to understand it in terms of life, climate, and resources.

Provide a first step in the search for life beyond Earth.

Better understand the processes that shape the solar system, including the Earth.

Pave the way for human exploration of Mars.

## MEP Goals

1. Pave the way for human exploration of Mars.
2. Find evidence of past or present life (or find evidence that life never existed on Mars) to understand the potential for life elsewhere in the universe.
3. Better understand the climate- -the weather, processes, anti history—in order to understand the relationship to Earth's cl imate change processes.
4. Identify and learn to utilize the resources available on Mars- understand the solid planet, how it evolved, and what resou rccs it provides for fut urc exploration.
5. Identify and characterize safe, interesting, and productive sites for human landings.
6. Find and learn to usc water and other resources.
7. Characterize Mars' atmosphere, surface environment, and other factors that bear on the design of human missions.
8. Pioneer technologies for low-cost, high-return planetary exploration.

## MEP Strategies

Strategies are specific actions anti approaches wc wili take to guide the Mars Program toward our customers' goals.

- MEP will operate in the manner of a business, determining the needs of our customers and developing "contracts" with thcm for meeting those needs.
- Our primary products are knowl edge and exploration. Our secondary products ----- technology, education, and inspiration-- will be produced in partnership with other elements of J]'].
- Wc will employ best business practices and will create technical and managerial innovations to manage our projects within the terms of the "contracts."
- We will implement our projects with common processes anti support operations to minimize costs.
- Wc will partner with NASA, industry, the science community, the educational community, anti other elements of J]']. to accomplish our goals.
- international participation will be sought for each MEP mission within the program constraints.

Top-level Program strategies arc supported by specific thematic emphases in knowl edge, exploration, technology, education, anti inspiration.

### Knowledge St rategy

- Build a progressively deeper knowledge of Mars by implementing a series of missions that build on the knowledge gained by previous missions.
- Partner with other countries to acquire and analyze information.
- Maintain a global compendium of the state of knowledge of Mars.
- Provide a steady stream of new Mars informational and educational products that summarize the state of knowl edge and the remaining unanswered questions about Mars.

### Exploration Strategy

- Implement a series of missions focused on discovery.

- Use new instruments and instrument deployment techniques.
- 1 and at different sites.
- Investigate more of the Martian surface and more aspects of the atmosphere over longer periods of time with more capable sensors as the MEP progresses.
- Return samples to the Earth.
- Tailor investigations to support future human exploration of Mars.

### Technology Strategy

- Utilize new technology at every opportunity.
- Promote cos(-effective.ncss by integrating MEP technology needs with the needs of other J]'], flight projects.
- Partner with the JPL Technology and Applications Program (TAP) Office to develop technology products tailored to Ml 3P needs.
- Partner with industry to develop and demonstrate technology and infuse it into our projects.
- Support "l'Al' in the transfer of our technology outside JPl ..

### Education Strategy

- Transform our knowledge of Mars into educational products.
- Partner with universities to disseminate these products and to train educators to understand and use them.
- Partner with the JPL Public Education Office to insert these products into curricula.

### Inspiration Strategy

- Share the excitement and knowledge generated by discoveries about Mars with the world.
- Partner with JPL Public Affairs Office and with museums, NASA Centers, and other organizations to disseminate our information products widely and in innovative ways.
- Partner with industry to develop commercial products based on our program.

## ORGANIZING TO CONDUCT OUR BUSINESSES

Figure 3 shows the Mars Exploration Program office organization that has evolve.d over the last 20 months. Before the J]']. rc.organization that created the office, preprojects were in one organization, ongoing projects in another. Now the preprojects and flight projects have been brought together so that there can be maximum benefit to the ncw projects by close association with the old projects. ']'here is considerable personnel sharing. At the program level, the Business Operations anti Outreach offices were created to allow resource sharing between the projects. The program office staff is very small, and this has enabled our overhead to bc reduced from about 1570 of the project business base to under 6%, of which Icss than 1 % is program office overhead. (The rest supports the J]']. technical infrastructure..)

The Mars Pathfinder spacecraft is being developed by JPL in a subsystem mode. All Mars Surveyor spacecraft will be system contracted. Mars Global Surveyor selected Martin Marietta Astronautics in Denver as its spacecraft system contractor, and Martin Marietta also won the contract to build both Mars Surveyor 98 spacecraft. J]']. and (the now) Lockheed Martin Astronautics (1 .MA) arc thus in a long-term partnership. Wc are working to "mirror" our organizations to facilitate teaming and communication. Spacecraft design and operations arc to bc conducted at I.MA, with mission design and operations being at J]'],.

Payloads for the spacecraft arc procured through the announcement of opportunity process from NASA 1 leadquarters, with support from the projects in defining the allowable envelopes for accommodation of the payloads.

As personnel roll off Pathfinder and Mars Global Surveyor, some arc going to Mars Surveyor 98 and Mars Preprojects, while

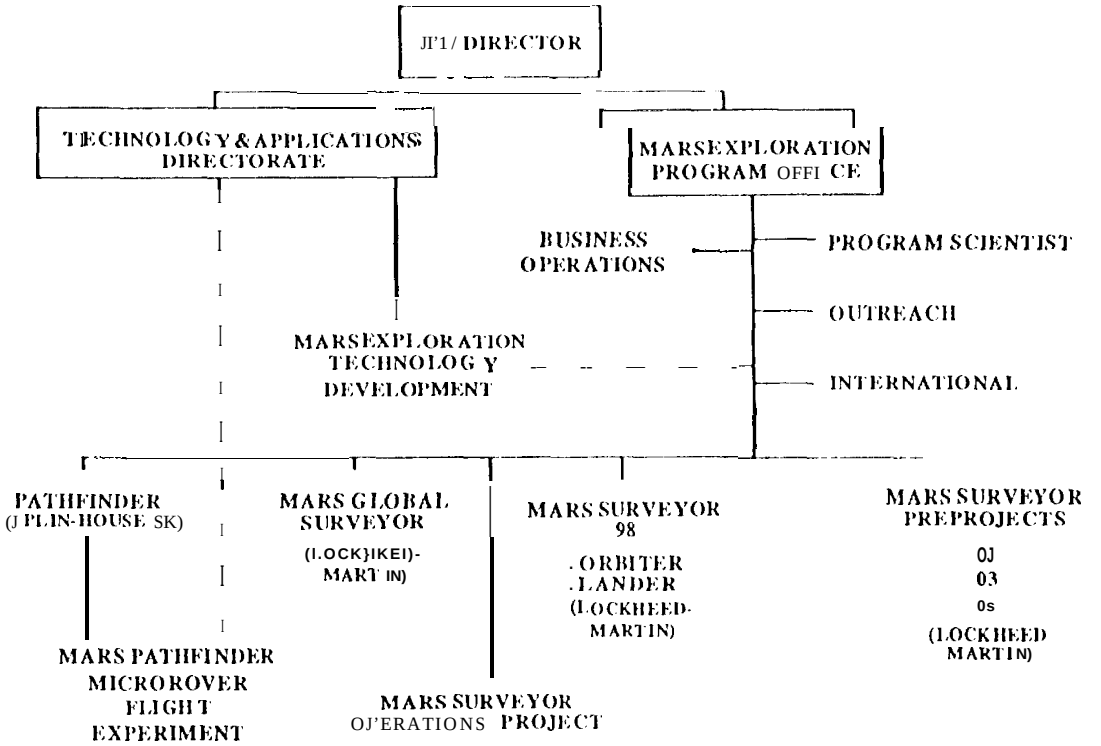


Figure3. Mars Exploration Program Organization Chart

others are transferring their knowledge of "better, faster, cheaper" to other programs. For example, the project manager of the first New Millennium mission was formerly the task manager for the Pathfinder Attitude and Information Management subsystem. Because of the relatively short development times for Mars projects, this training anti knowledge diffusion can be efficiently done.

## PARTNERSHIP WITH INDUSTRY

The Mars Surveyor Program is built around an industry partnership for the space.craft (both orbiters and landers). Payloads arc procured through an announcement of opportunity process, except for the reflight of the Mars Observer instruments on Mars Global Surveyor and the 1998 and 2001 orbiters. So not only has the overall cost of Mars exploration declined drastically, but there has been a major shift from in-house JPL spacecraft workforce to contractor workforce. in real-year dollars, Mars Observer (not counting launch vehicle and operations) cost about $460M, of which 54% was spent in industry (mostly through a system contract). Mars Global Surveyor, carrying six of the eight Mars Observer instruments, costs $154M, with 69% going to industry. Mars Surveyor 1998 has $187M for two missions, and 83% Of the money is spent by industry. Figure 4 shows the continuing decline in overall funds for the follow-on missions, and the continued trend to spend the. lion's share of the money with industry.

The Pathfinder spacecraft is king built in subsystem mode and assembled at JPL. LMA is the contractor for both the MGS and Mars Surveyor 1998 spacecraft. These were two separate procure.lncnts, with the second being for both the orbiter and lander. Under the terms of the Mars Surveyor 98 contract, LMA can be selected as the contractor for follow-on missions, provided their performance is adequate for Mars Surveyor 98. JPL and LMA arc developing a teaming relationship. The JPL/LMA partnership entails a division of labor rather than oversight of the contractor by JPL. For instance, on Mars Surveyor 98, JPL personnel arc located in Denver as part of the Lockheed Martin spacecraft team, where JPL skills can augment LMA skills. This enables a very small JPL project office. The LMA

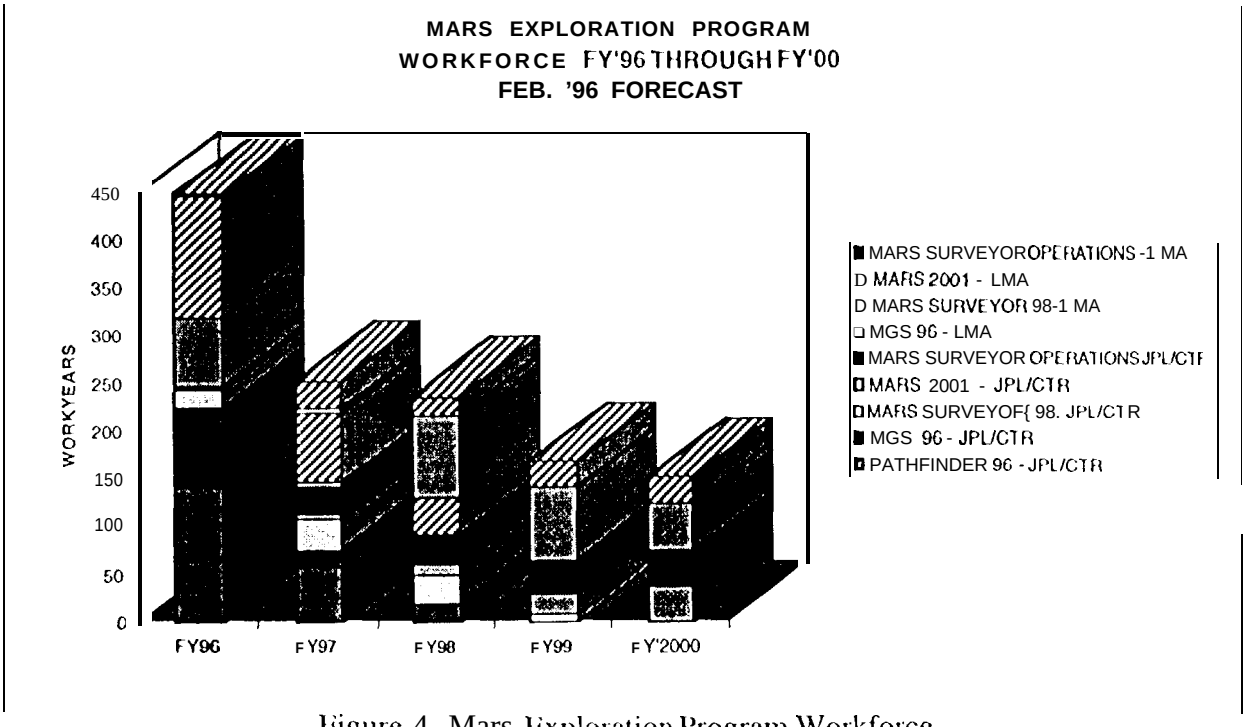


Figure 4. Mars Exploration Program Workforce

spacecraft team will operate the Mars Surveyor 98 spacecraft from Denver, while JPL will operate the mission.

## PARTNERING WITH SCIENTISTS

Science instruments are procured through the announcement of opportunity process, but are then managed by the projects. in some cases JPL is also partnered with the scientists to develop payload elements. For example, the Mars Surveyor 98 lander payload includes an integrated instrument/robotarm suite where the arm is being developed at JPL and the payload is being integrated by JPL, while the instruments are developed outside JPL. The principal investigator for the integrated payload is at a university. in these cases the announcement of opportunity proposals that involve JPL are kept carefully segregated within JPL, from the Mars Exploration Program Office or any of its projects.

## SOME COST CONTAINING PRACTICES

The Mars Exploration Program is pioneering several practices required to contain costs while still conducting rewarding missions. These include the following (with a few examples):

Rapid, goal-based procurement. We have reduced the lead-time for spacecraft procurement by a factor of four, from ten to twelve months for previous flight system procurements to ten weeks for Mars Surveyor 98 and twelve weeks for MGS. New procurement strategies have been introduced for one-day turnaround for small commercial items, and for drastically reducing the procurement time. for electronic parts, etc.

Concurrent engineering. Pathfinder pioneered concurrent engineering of the ground and flight systems. The new Mars Surveyor Operations Project is supporting all aspects of the project development cycle so that this concurrent engineering can continue throughout the program.

Use of commercial products. A commercial computer, the IBM (now Loral) 1< S6000 has been flight qualified for Pathfinder. This computer is now the basis for not only future Mars programs, but for Discovery missions, New Millennium missions, and other projects being planned well into the next century. A commercial operating system is being used by Pathfinder, and the Pathfinder flight software developed at JPL is being

transferred to Lockheed Martin for use by Mars Surveyor 98. Commercial products used in the Pathfinder rover (Sojourner) include motors, radio modems, and power converters. Use of commercial electronics has required new processes for determining how to flight qualify them.

Standard business practices and techniques. The formation of the Business Operations Office has allowed us to standardize financial and reporting formats and scheduling tools and techniques, and to integrate an electronic library for the program.

Partnering. As described above, the program is providing JPL "workers" to LMA. The possibility for long-term partnering with LMA also allows an evolutionary approach to—and is key to—keeping the costs down for future missions. This reduces procurement costs, enables the project to be done on 26-month centers, and increases efficiency of long-term planning.

New technology infusion. Mars Global Surveyor will be the first planetary spacecraft to utilize a composite structure. Pathfinder is using the RS6000 computer and has developed a new approach to entry, descent, and landing. Sojourner, the rover, is a technology demonstration to prove that small rovers can operate on the surface of Mars. Mars Surveyor 1998 is improving the RS6000 -based computer system and is introducing a robotic arm as part of the lander payload. For 2001 and beyond, technology infusion is absolutely required to reduce the mass of the spacecraft (because the launch energy requirements are higher in 2001 than in 1998) and to allow more payload percentage. LMA and JPL have developed a joint plan for utilizing technology developed with LMA IRAD funds, for infusing New Millennium technologies such as advanced electronic packaging, and for developing technologies such as the Small Deep Space Transponder (SDST) currently being built by Motorola. The SDST is being funded by a consortium of future flight projects, including Mars, New Millennium, Discovery, and Pluto Express.

Partnering with universities for outreach. The outreach Program has a series of small contracts with universities to develop and apply educational products in their states. They utilize graduate and undergraduate students for outreach to schools and communities, and they train teachers in understanding Mars information, how to use the Internet, and other skills. All this is done at a fraction of the cost of other methods of providing these services.

## SUMMARY AND CONCLUSIONS

The Mars Exploration Program is pioneering the use of "better, faster, cheaper" techniques within a program structure to achieve a steady advance in knowledge within an extremely limited budget. We have made great strides in streamlining, partnering, improving our processes, empowering our colleagues. However, much remains to be done. in particular, things still needed to protect the viability of the program include:

- Adherence to a steady, incremental, evolutionary set of missions within a stable program structure, including a long-term industry partnership.
- Access to low-cost launch services.
- A stable base of support for evolutionary technology development and infusion.
- Establishment of a minimal set of requirements for the program, i.e., "achieve the maximum knowledge within the cost constraints."
- Clear and stable programmatic priorities between knowledge acquisition, foreign policy, commercialization, science, education, small business objectives, etc.
- continuous improvement in JPL and contractor support services for the projects ; e.g., financial services, technical infrastructure, streamlined management processes.
- A process for information synthesis and translation into lay person's language and educational products.

With the two initial launches of the Mars Exploration Program (his fall and winter, a