Testimony of Dr. Robert Zubrin to the Senate Commerce Committee, Oct 29, 2003

Senator McCain, members of the Commerce Committee, I would like to thank you for inviting me to testify here today on the future of the US space program. Since many of you may be unfamiliar with me, I hope you will forgive me if I take a few seconds to establish my credentials. I am an engineer with a Masters degree in Aeronautics and Astronautics, a doctorate in Nuclear Engineering, and fifteen years aerospace industry experience. I currently lead my own company, Pioneer Astronautics, which has five NASA and military R&D contracts at this time. I am the author or co-author of over 100 papers, three patents, and five books related to the field, and am the head of an international non-profit organization known as the Mars Society which has built and run a human Mars exploration operations research station on Devon Island, 900 miles from the North Pole.

My remarks today will address four areas. First, I will discuss why NASA is failing, and what fundamental change in method of operation needs to be undertaken if the space agency is to be made effective again, and in particular, explain why an overarching goal must be adopted if that is to occur. Second, I will explain what that goal should be. Third, I will present a plan for a pioneering space program that would allow NASA fulfill its promise and achieve that goal within ten years. Finally, I will make specific recommendations as to what Congress and the Executive branch need to do this year in order to put the space program on the right track.

1. Why is NASA Failing?

In the recent *Columbia* hearings, numerous members of congress continually decried the fact that the US space program is "stuck in Low Earth Orbit." This is certainly a serious problem. If it is to be addressed adequately, however, America's political leadership needs to reexamine NASA's fundamental mode of operation.

Over the course of its history, NASA has employed two distinct modes of operation. The first, prevailed during the period from 1961-1973, and may therefore be called the Apollo Mode. The second, prevailing since 1974, may usefully be called the Shuttle Era Mode, or Shuttle Mode, for short.

In the Apollo Mode, business is conducted as follows. First, a destination for human spaceflight is chosen. Then a plan is developed to achieve this objective. Following this, technologies and designs are developed to implement <u>that</u> plan. These designs are then built, after which the mission is flown.

The Shuttle Mode operates entirely differently. In this mode, technologies and hardware elements are developed in accord with the wishes of various technical communities. These projects are then justified by arguments that they might prove useful at some time in the future when grand flight projects are initiated.

Contrasting these two approaches, we see that the Apollo Mode is *destination driven*, while the Shuttle Mode pretends to be technology driven, but is actually *constituency driven*. In the Apollo Mode, technology development is done for mission directed *reasons*. In the Shuttle

Mode, projects are undertaken on behalf of various internal and external technical community pressure groups and then defended using *rationales*. In the Apollo Mode, the space agency's efforts are *focused and directed*. In the Shuttle Mode, NASA's efforts are *random and entropic*.

Imagine two couples, each planning to build their own house. The first couple decides what kind of house they want, hires an architect to design it in detail, then acquires the appropriative materials to build it. That is the Apollo Mode. The second couple polls their neighbors each month for different spare house-parts they would like to sell, and buys them all, hoping to eventually accumulate enough stuff to build a house. When their relatives inquire as to why they are accumulating so much junk, they hire an architect to compose a house design that employs all the knick-knacks they have purchased. The house is never built, but an adequate excuse is generated to justify each purchase, thereby avoiding embarrassment. That is the Shuttle Mode.

In today's dollars, NASA average budget from 1961-1973 was about $17 billion per year. This is only 10% more than NASA's current budget. To assess the comparative productivity of the Apollo Mode with the Shuttle Mode, it is therefore useful to compare NASA's accomplishments between 1961-1973 and 1990-2003, as the space agency's total expenditures over these two periods were equal.

Between 1961 and 1973, NASA flew the Mercury, Gemini, Apollo, Skylab, Ranger, Surveyor, and Mariner missions, and did all the development for the Pioneer, Viking, and Voyager missions as well. In addition, the space agency developed hydrogen oxygen rocket engines, multi-staged heavy-lift launch vehicles, nuclear rocket engines, space nuclear reactors, radioisotope power generators, spacesuits, in-space life support systems, orbital rendezvous techniques, soft landing rocket technologies, interplanetary navigation technology, deep space data transmission techniques, reentry technology, and more. In addition, such valuable institutional infrastructure as the Cape Canaveral launch complex, the Deep Space tracking network, Johnson Space Center, and JPL were all created in more or less their current form.

In contrast, during the period from 1990-2003, NASA flew about three score Shuttle missions allowing it to launch and repair the Hubble Space Telescope and partially build a space station. About half a dozen interplanetary probes were launched (compared to over 30 lunar and planetary probes between 1961-73). Despite innumerable "technology development" programs, no new technologies of any significance were actually developed, and no major space program operational infrastructure was created.

Comparing these two records, it is difficult to avoid the conclusion that that NASA's productivity in *both* missions accomplished *and* technology development during its Apollo Mode was at least ten times greater than under the current Shuttle Mode.

The Shuttle Mode is the expenditure of large sums of money without direction by strategic purpose. That is why it is hopelessly inefficient. But the blame for this waste cannot be placed on NASA leaders alone, some of whom have attempted to rectify the situation. Rather, the political class must also accept major responsibility.

Consider the following. During the same week in September that House members were roasting Administrator O'Keefe for his unfortunate advocacy of a destination-free NASA, a Senate committee issued a report saying that a top priority for the space agency was to develop a replacement Space Shuttle system. Did any of the Senators who supported this report explain why? Why do we need another Shuttle system? To keep doing what we are doing now? But is that what we actually want to do?

Congress and the Executive branch need to get together and open a discussion as to what the nation actually wants to accomplish in space. Hearings should be held, and the options for a strategic objective examined in public. Is our primary aim to keep sending astronauts on joyrides in low Earth orbit? In that case, a second generation Shuttle might be worth building. But if we want to send humans to the Moon or Mars, we need make that decision, and then design and build a hardware set that is appropriate to actually accomplish *those* goals.

Advocates of the Shuttle Mode claim that by avoiding the selection of a destination they are developing the technologies that will allow us to go anywhere, anytime. That just isn't true. The Shuttle Mode will never get us anywhere at all. The Apollo Mode got us to the Moon, and it can get us back, or take us to Mars. But leadership is required.

In the beginning, there was the Word.

2. What Should our Goal Be?

In order to accomplish anything in space we need to set a goal. What should that goal be? In my view, the answer is straightforward: Humans to Mars within a decade.

Why Mars? Because of all the planetary destinations currently within reach, Mars offers the most, both scientifically, socially, and in terms of what it portends for the human future.

In scientific terms, Mars is critical, because it is the Rosetta Stone for letting us understand the position of life in the universe. Images of Mars taken from orbit show that the planet had liquid water flowing on its surface for a period of a billion years during its early history, a duration five times as long as it took life to appear on Earth after there was liquid water here. So if the theory is correct that life is a naturally phenomenon, emergent from chemical complexification wherever there is liquid water, a temperate climate, sufficient minerals, and time, then life should have appeared on Mars. If we can go to Mars, and find fossils of past life on its surface, we will have good reason to believe that we are not alone in the universe. If we send human explorers, who can erect drilling rigs which can reach ground water where Martian life may yet persist, we will be able to examine it, and by so doing determine whether life as we know it on Earth is the pattern for all life everywhere, or alternatively, whether we are simply one esoteric example of a far vaster and more interesting tapestry. These things are worth finding out.

In terms of its social value, Mars is the bracing positive challenge that our society needs. Nations, like people, thrive on challenge and decay without it. The challenge of a humans-to Mars program would also be an invitation to adventure to every youth in the country, sending out the powerful clarion call: "Learn your science and you can become part of pioneering a new world." There will be over 100 million kids in our nation's schools over the next ten years. If a Mars program were to inspire just an extra one percent of them to scientific educations, the net result would be 1 million more scientists, engineers, inventors, medical researchers and doctors, making technological innovations that create new industries, finding new medical cures, strengthening national defense, and generally increasing national income to an extent that utterly dwarfs the expenditures of the Mars program.

But the most important reason to go to Mars is the doorway it opens for the future. Uniquely among the extraterrestrial bodies of the inner solar system, Mars is endowed with all the resources needed to support not only life but the development of a technological civilization. In contrast to the comparative desert of the Earth's Moon, Mars possesses oceans of water frozen into its soil as permafrost, as well as vast quantities of carbon, nitrogen, hydrogen, and oxygen, all in forms readily accessible to those clever enough to use them. These four elements are the basic stuff not only of food and water, but of plastics, wood, paper, clothing, and most importantly, rocket fuel.

In addition, Mars has experienced the same sorts of volcanic and hydrologic processes that produced a multitude of mineral ores on Earth. Virtually every element of significant interest to industry is known to exist on the Red Planet. While no liquid water exists on the surface, below ground is a different matter, and there is every reason to believe that geothermal heat sources could be maintaining hot liquid reservoirs beneath the Martian surface today. Such hydrothermal reservoirs may be refuges in which survivors of ancient Martian life continue to persist; they would also represent oases providing abundant water supplies and geothermal power to future human settlers. With its 24-hour day-night cycle and an atmosphere thick enough to shield its surface against solar flares, Mars is the only extraterrestrial planet that will readily allow large scale greenhouses lit by natural sunlight. Mars can be settled. For our generation and many that will follow, Mars is the New World. In establishing our first foothold on Mars, we will begin humanity's career as a multi-planet species.

Mars is where the science is, Mars is where the challenge is, and Mars is where the future is. That's why Mars must be our goal.

3. How Do We Get There?

Humans to Mars may seem like a wildly bold goal to proclaim in the wake of disaster, yet such a program is entirely achievable. From the technological point of view, we're ready. Despite the greater distance to Mars, we are much better prepared today to send humans to Mars than we were to launch humans to the Moon in 1961 when John F. Kennedy challenged the nation to achieve that goal – and we were there eight years later. Given the will, we could have our first teams on Mars within a decade.

The key to success come from rejecting the policy of continued stagnation represented by senile Shuttle Mode thinking, and returning to the destination-driven Apollo Mode method of planned operation that allowed the space agency to perform so brilliantly during its youth. In addition, we must take a lesson from our own pioneer past and from adopt a "travel light and live off the land" mission strategy similar to that which has well-served terrestrial explorers for centuries.

The plan to explore the Red Planet in this way is known as Mars Direct . Here's how it could be accomplished

At an early launch opportunity, for example 2009, a single heavy lift booster with a capability equal to that of the Saturn V used during the Apollo program is launched off Cape Canaveral and uses its upper stage to throw a 40-tonne unmanned payload onto a trajectory to Mars. (Such a booster could be readily created by converting the Shuttle launch stack, deleting the Orbiter and replacing it with a payload fairing containing a hydrogen/oxygen rocket stage.) Arriving at Mars eight months later, the spacecraft uses friction between its aeroshield and Mars' atmosphere to brake itself into orbit around the planet, and then lands with the help of a parachute. This payload is the Earth Return Vehicle (ERV). It flies out to Mars with its two methane/oxygen driven rocket propulsion stages unfueled. It also carries six tonnes of liquid hydrogen cargo, a 100 kilowatt nuclear reactor mounted in the back of a methane/oxygen driven light truck, a small set of compressors and automated chemical processing unit, and a few small scientific rovers.

As soon as the craft lands successfully, the truck is telerobotically driven a few hundred meters away from the site, and the reactor deployed to provide power to the compressors and chemical processing unit. The hydrogen brought from Earth can be quickly reacted with the Martian atmosphere, which is 95 percent carbon dioxide gas (CO_2), to produce methane and water, thus eliminating the need for long-term storage of cryogenic hydrogen on the planet's surface. The methane so produced is liquefied and stored, while the water is electrolyzed to produce oxygen, which is stored, and hydrogen, which is recycled through the methanator. Ultimately, these two reactions (methanation and water electrolysis) produce 24 tonnes of methane and 48 tonnes of oxygen. Since this is not enough oxygen to burn the methane at its optimal mixture ratio, an additional 36 tonnes of oxygen is produced via direct dissociation of Martian CO_2. The entire process takes ten months, at the conclusion of which a total of 108 tonnes of methane/oxygen bipropellant will have been generated. This represents a leverage of 18:1 of Martian propellant produced compared to the hydrogen brought from Earth needed to create it. Ninety-six tonnes of the bipropellant will be used to fuel the ERV, while 12 tonnes are available to support the use of high powered, chemically fueled long range ground vehicles. Large additional stockpiles of oxygen can also be produced, both for breathing and for turning into water by combination with hydrogen brought from Earth. Since water is 89 percent oxygen (by weight), and since the larger part of most foodstuffs is water, this greatly reduces the amount of life support consumables that need to be hauled from Earth.

The propellant production having been successfully completed, in 2011 two more boosters lift off the Cape and throw their 40-tonne payloads towards Mars. One of the payloads is an unmanned fuel-factory/ERV just like the one launched in 2009, the other is a habitation module carrying a crew of four, a mixture of whole food and dehydrated provisions sufficient for three years, and a pressurized methane/oxygen powered ground rover. On the way out to Mars, artificial gravity can be provided to the crew by extending a tether between the habitat and the burnt out booster upper stage, and spinning the assembly.

Upon arrival, the manned craft drops the tether, aerobrakes, and lands at the 2009 landing site where a fully fueled ERV and fully characterized and beaconed landing site await it. With the help of such navigational aids, the crew should be able to land right on the spot; but if the landing is off course by tens or even hundreds of kilometers, the crew can still achieve the surface rendezvous by driving over in their rover. If they are off by thousands of kilometers, the second ERV provides a backup.

However, assuming the crew lands and rendezvous as planned at site number one, the second ERV will land several hundred kilometers away to start making propellant for the 2013 mission, which in turn will fly out with an additional ERV to open up Mars landing site number three. Thus, every other year two heavy lift boosters are launched, one to land a crew, and the other to prepare a site for the next mission, for an average launch rate of just one booster per year to pursue a continuing program of Mars exploration. Since in a normal year we can launch about six Shuttle stacks, this would only represent about 16 percent of the U.S. launch capability, and would clearly be affordable. In effect, this “live off the land” approach removes the manned Mars mission from the realm of mega-spacecraft fantasy and reduces it in practice as a task of comparable difficulty to that faced in launching the Apollo missions to the Moon.

Fig. 1 The Mars Direct plan. First an unfueled Earth Return Vehicle (ERV, right) is delivered to Mars where it manufactures its propellant from the Martian atmosphere. The crew then flies to Mars in the tuna-can-shaped hab module, which also provides living quarters, lab, and workshop for a 1.5 year Mars stay. (Artwork courtesy of Robert Murray, Pioneer Astronautics.)

The crew will stay on the surface for 1.5 years, taking advantage of the mobility afforded by the high powered chemically driven ground vehicles to accomplish a great deal of surface exploration. With a 12 tonne surface fuel stockpile, they have the capability for over 24,000 kilometers worth of traverse before they leave, giving them the kind of mobility necessary to conduct a serious search for evidence of past or present life on Mars—an investigation key to revealing whether life is a phenomenon unique to Earth or general throughout the universe. Since no-one has been left in orbit, the entire crew will have available to them the natural gravity and protection against cosmic rays and solar radiation afforded by the Martian environment, and thus there will not be the strong driver for a quick return to Earth that plagues alternative Mars mission plans based upon orbiting mother-ships with small landing parties. At the conclusion of their stay, the crew returns to Earth in a direct flight from the Martian surface in the ERV. As the series of missions progresses, a string of small bases is left behind on the Martian surface, opening up broad stretches of territory to human cognizance.

In essence, by taking advantage of the most obvious local resource available on Mars—its atmosphere—the plan allows us to accomplish a manned Mars mission with what amounts to a lunar-class transportation system. By eliminating any requirement to introduce a new order of technology and complexity of operations beyond those needed for lunar transportation to accomplish piloted Mars missions, the plan can reduce costs by an order of magnitude and advance the schedule for the human exploration of Mars by a generation. Indeed, since a lunar-class transportation system is adequate to reach Mars using this plan, it is rational to consider a milestone mission, perhaps five years into the program, where a subset of the Mars flight hardware is exercised to send astronauts to the Moon.

Exploring Mars requires no miraculous new technologies, no orbiting spaceports, and no gigantic interplanetary space cruisers We don't need to spend the next thirty years with a space program mired in impotence, spending large sums of money and taking occasional casualties while the same missions to nowhere are flown over and over again and professional technologists dawdle endlessly in their sand boxes without producing any new flight hardware. We simply need to choose our destination, and with the same combination of vision, practical thinking, and passionate resolve that served us so well during Apollo, do what is required to get there.
We can establish our first small outpost on Mars within a decade. We and not some future generation can have the eternal honor of being the first pioneers of this new world for humanity. All that's needed is present day technology, some 19th century industrial chemistry, a solid dose of common sense, and a little bit of moxie.

4. What Congress Needs to Do Now

The US civilian space program is presently in a crisis. It is now apparent that the Shuttle Orbiter cannot be used much longer as a system for transporting crews to Earth orbit. The *Columbia* disaster has made it clear that the antiquated Orbiters are becoming increasingly unsafe. Moreover, even if the Orbiter could be flown safely, it is clear that using a launch vehicle with a takeoff thrust matching that of a Saturn V to transport half a dozen people to the Space Station makes about as much sense as using an aircraft carrier to tow water skiers. The Shuttle was designed as a self-launching space station. Absent a permanent space station on-orbit, such a vehicle had some justification. But with the establishment of the ISS, the rationale for using a flying Winnebago as a space taxi is no longer sustainable.

NASA has already begun to respond to this reality by starting the Orbital Space Plane (OSP) program, which will move the human taxi-to-orbit function from the Shuttle to a small capsule or mini-orbiter that can be launched on top of an Atlas or Delta. If constrained to the objective of producing a simple reliable capsule instead of a complex mini shuttle, such a program could make a great deal of sense. A simple capsule will be much safer than a more complex system, will have a much lower development cost, and can be made available for flight much sooner, thereby cutting short the risks and costs associated with prolonged Shuttle operations. Launched aloft a medium lift expendable launch vehicle, it could assume the Shuttle's crew transfer function at less than 1/5th the cost.

As rational as such an approach might be, however, it poses a direct threat to the jobs of hundreds of thousands of people associated with the existing Shuttle program, and to the bottom line of several major and many minor aerospace companies. For this reason, some people have been lobbying for making the OSP a complex mini shuttle program that would take many years to complete, and cost, at most recent estimate, some $17 billion.

This is the wrong approach, and is emblematic of the pathology associated with what we have termed NASA's Shuttle Mode of operation. The raid upon the treasury it involves would sap funding for any other space initiatives, and the delay it would entail in Shuttle replacement would expose our astronauts to serious unnecessary risk. Furthermore, despite patently false claims to the contrary, the wing-and-landing gear ballasted mini-Shuttle is wildly suboptimal for use in any missions beyond low Earth orbit.

As presently constituted, Congress should not fund this program. Making a gold-plated mini-shuttle the centerpiece of NASA's development efforts for the next ten years would prevent any human exploration operations for a generation, at the end of which we would be no better prepared to commence piloted planetary exploration than we are today. In fact, we would be worse off, since by simply downsizing from the Orbiter to the OSP mini-Shuttle as a means of transporting humans to orbit at lower recurring cost, we would end up discarding the ten-billion dollar asset represented by the STS launch stack. This would be a disaster, since in the context of a well-planned human exploration initiative, the STS stack would almost certainly be converted into a heavy lift vehicle, rather than scrapped. Such would be the consequences of adopting the piecemeal, reactive approach to dealing with the Shuttle/OSP problem.

Rather than appropriate $17 billion for an OSP program that will not take us anywhere, Congress should appropriate $60 million to fund *two* six-month $30 million studies to develop end-to-end plans for human exploration of Mars. One of these $30 million studies should be conducted at NASA Johnson Space Center. The other $30 million should go to fund a competing interagency team led by someone from one of the non-NASA government space agencies. Each of these teams should be charged with the task of developing a complete space architecture and mission plan that enables humans to Mars within ten years of program start, with lunar missions enabled by a modified subset of the Mars mission hardware. Constraints should be placed on the plans such as a total development cost limit of $30 billion or less, with a recurring Mars mission cost no greater than $3 billion.

Upon completion of the study, each of the plans should be submitted to a blue-ribbon panel appointed by Congress for evaluation on merit of cost, technical feasibility, and exploration capability. Based on that assessment, the team deemed superior should be selected to lead the human exploration program, and the hardware elements required to implement its plan should be funded and built in accordance with a multi-year schedule laid down in the plan, and then flown.

Once again, Congress should not fund the construction of *things*. It should fund the implementation of a *plan*.

Directing funding in this focused way does not preclude engaging in exploratory research. What it does mean, however, is that the technologies chosen for research and development are those necessary to enable or enhance the plan, rather than those needed to maintain or enhance the funding of established research and development constituencies.

The recommendation to fund two competing program design teams may seem surprising to some. However the experience of the past several decades has made it clear that, absent the spur of competition, efficient plans will not be generated. The nation does not need a Mars program plan that is bloated with funding for a plethora of unnecessary technology and infrastructure developments. Yet the incentive of as bureaucracy is to use the Mars mission as a kind of Christmas tree upon which to hang various desired technology programs as ornaments. This is the problem that caused NASA to respond to the elder president Bush's call for a Space Exploration Initiative with a hopelessly bloated and overpriced plan in 1989, and is the root pathology that drove the generation of a hyper-complex gargantuan space program design by the NASA Headquarters NExT group during the more recent period.

Mark Twain once said that nothing so focuses the mind as the knowledge that you are going to be shot in the morning. Only the certain knowledge that the cost increases associated with insertion of unnecessary elements in the mission plan threatens the complete loss of programmatic control will force either NASA or an alternative government organization to put parochial interests aside and design the best and most streamlined program possible.

5. Conclusion

Senator McCain, distinguished members of the Commerce Committee. Humanity today stands at the brink of a liberating development which will be remembered far into future ages, when nearly all the other events of our time are long forgotten. That development is the initiation of the human career as a spacefaring species.

The Earth is not the only world. There are numerous other planetary objects in our own solar system, millions in nearby interstellar space, and hundreds of billions in the galaxy at large. The challenges involved in reaching and settling these new worlds are large, but not beyond humanity's ultimate capacity. Were we to become spacefarers, we will open up a prospect for a human future that is vast in time and space, and rich in experience and potential to an extent that exceeds the imagination of anyone alive today. When we open the space frontier, we will open the door to the creation of innumerable new branches of human civilization, replete with new languages, new cultures, new literatures, new forms of social organization, new knowledge, technological contributions, and epic histories that will add immeasurably to the human story.

We were once a small collection of tribes living in the east African rift valley. Had we stayed in our native habitat, that is all we would be today. Instead, we ventured forth, took on the challenges of the inhospitable ice age environments to the north, and then elsewhere, and in consequence, transformed ourselves into a global civilization. When we go into space, the expansion of our possibilities will be equally dramatic. As a result, the human experience a few thousand years from now will be as rich in comparison to ours, as our global society is in comparison to tribal culture of the Kenyan rift valley at the time of our species' origin.

Therefore, I believe that we here today sitting in this historic chamber are gathered not at the end of history, but at the beginning of history. That our nation shall be remembered not so much for the great deeds our predecessors have already done, but for the still greater accomplishments they have prepared us, and those who will follow us, to do. Let us therefore embrace our role as humanity's vanguard, as pioneers of the future. Let us honor the true American tradition by continuing it, and bravely take on the untamed space frontier to open new worlds for our posterity, as our courageous predecessors did for us.

Ladies and gentlemen of the Senate, I ask that you embrace the challenge of Mars, and act forcefully to put NASA on a track that will deliver real results. The American people want and deserve a space program that is actually going somewhere. For that to occur, it needs be given a goal, from that goal a produce a plan, and from that plan, action. It is within your power to make this happen. It is within your power to initiate a program of exploration that will lead in time to the greatest flowering of human potential, knowledge, progress, and freedom that history has ever known. I ask that you do so.

Thank you for your attention.