Accepting the Challenge Before Us

Testimony of Dr. Robert Zubrin to the Committee for Review of U.S. Human Space Flight (Norm Augustine, Chairman)

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Mr. Augustine, members of the Committee, I would like to thank you for inviting me to testify here today on the future of the U.S. human spaceflight 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 over two decades of aerospace industry experience. I currently lead my own company, Pioneer Astronautics, which has successfully completed some forty NASA contracts over the past thirteen years. I am the author or co-author of over two hundred papers, nine patents granted or pending, and five books related to the field, and am the head of an international non-profit organization known as the Mars Society which has, among other projects, built and run a human Mars exploration operations research station on Devon Island, nine hundred miles from the North Pole.

My remarks today will address four areas. First, I will discuss why NASA's human spaceflight program has been floundering, 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, 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 a specific recommendation as to what needs to be done now in order to put the space program on the right track.

1. Why is NASA Failing?

In the recent years, members of Congress have repeatedly decried the fact that the U.S. 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 that 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*.

As a metaphor, 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 appropriate 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's average budget from 1961-1973 was about $18 billion per year. That is the same as 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 1997-2009, as the space agency's total expenditures over these two periods were roughly 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 1997-2009, NASA flew forty-seven Shuttle missions allowing it to repair and upgrade the Hubble Space Telescope and partially build the International Space Station. About a dozen interplanetary probes were launched (compared to over thirty 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 NASA's productivity in *both* missions accomplished *and* technology development during its Apollo Mode was at least ten times as great as 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 for allowing matters to drift without decisive and resolute direction.

The administration needs to take stock and consider what the nation actually wants to accomplish in space. Is our primary aim to keep sending astronauts on rides to low Earth orbit? In that case, extending the Shuttle program might be justified. 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 real 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 and the ground 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 for life to appear on Earth after there was liquid water here. So if the theory is correct that life is a naturally occurring 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.

This point is so critical that it is worthy of further emphasis. The wealth and the strength of a nation are based first and foremost on its intellectual capital. In this respect, the Apollo program produced a terrific return, as it doubled the number of our science graduates, at every level—high school, college, Ph.D. This paid off massively when those twelve-year-old little boy scientists of the 1960s became the forty-year-old technological entrepreneurs of the 1990s and launched the computer revolution. A humans-to-Mars program today would repay even greater dividends, because in this day and age the science and engineering professions are also open to women in a way that was simply not the case during the 1960s. Thus an Apollo-like challenge today would not only inspire into being legions of little boy scientists, but little girl scientists as well, whose ensuing research and inventions would benefit the nation, and humanity at large, for decades to come.

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 propellant.

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 twenty-four-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.

For the coming age of space exploration, Mars compares to the Moon as North America compared to Greenland in the previous age of maritime exploration. Greenland was closer to Europe, Europeans reached it first—but it ultimately proved too barren an environment for the establishment of a new branch of human civilization. Similarly, in contrast to the Moon, 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 within a compressed time frame, 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 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 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 2016, 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. (NASA's Ares V could serve in such a capacity, as could some of the designs derived from the Direct 3.0 concepts.) Arriving at Mars eight months later, the spacecraft uses friction between its aeroshield and the Martian 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 2018 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 2016, 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 2016 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 2020 mission, which in turn will fly out

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.)*

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. Compared to a normal year of STS operations during which we were able to launch about six Shuttle stacks, this would only represent about 16 percent of the U.S. heavy-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.

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 direct-launch-style 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, or more likely to a near-Earth asteroid, as a NEO mission requires no extraneous equipment that is not available in the basic Mars mission hardware set.

Exploring Mars requires no miraculous new technologies, no orbiting spaceports or propellant depots, 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 sandboxes 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 nineteenth-century industrial chemistry, a solid dose of common sense, and a little bit of moxie.

4. What Needs to Be Done Now

The U.S. human spaceflight 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. 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 Orion program, which will move the human taxi-to-orbit function from the Shuttle to a capsule that can be launched on top of a medium-lift launch vehicle, such as an Ares 1, or conceivably an Atlas or a Delta. Launched aloft a medium-lift expendable launch vehicle, such a capsule could assume the Shuttle's crew transfer function at less than one-fifth the cost.

The Orion program thus makes a great deal of sense on its own terms, but again, we must ask ourselves: What are our real objectives? Do we simply want to ferry crews up and down to the space station? If so, why? The primary value of activity at the space station is to learn about the effects of long-duration spaceflight on humans. But without intent to sail to deep space destinations beyond LEO, such research is essentially pointless. Indeed, if conducted as NASA's primary human spaceflight activity, such a program would be comparable to a decision by Henry the Navigator to shun voyages of exploration, in favor of sending his ships on a multi-decade program of long-duration excursions 100 miles offshore, so as to gain data on the effects of stale rations, seasickness, floggings, and scurvy on sailors. The absurdity of such a program speaks for itself. Similarly, we should not go to space in order to endure the hazards and hardships of space. Rather we should endure the hazards and hardships of space in order to sail across space to explore new worlds on the other side of space. If we are to accept the costs and risks of human spaceflight, we must embrace the goal that makes it worthy of such costs and risks.

Mr. Augustine, members of the Committee, we meet here today at a great moment. It is a great moment, because it is a moment in which great things are possible. We have a new administration, which is committed to audacity, and hope, and the fierce urgency of now, and which has the congressional backing to implement great plans should it elect to adopt them. And this administration has appointed you to provide it with advice as to what course it should take with respect to setting its agenda in space. Many options have been placed before you, but really only one fundamental choice: and that is to shun challenge or to embrace it, to choose to do things because they are easy, or because they are hard. Humans to Mars is the challenge that has been staring NASA in the face for the past forty years. It is the challenge that says to us: "Are you still a nation of pioneers? Do you still have the guts, and fortitude, and vision that your predecessors had—those brave men and women who took the risks to get you to where you are today? Are you still a nation whose great deeds will be celebrated in newspapers, or just in museums?"

In point of fact, we have the technology to take on this challenge. And while we could undertake a variety of activities first to nominally better prepare for such a program, there are an infinite number of such precursors that could be inserted into the queue on the basis of such a rationale. Thus, if we choose to adopt such an approach, we will *never* get to the Red Planet. If we want to go to Mars, we need to go to Mars. Furthermore, if we want to go to Mars, we need to do it within a limited time horizon. You cannot get to Mars in thirty years. You cannot get to Mars in twenty years. If you want to get to Mars you have to do it within a decade or so of program start, or you are more are less guaranteeing that the political conditions that allowed you to launch the program in the first place will not remain in place long enough to carry it out. If God parts the waters, you can't take thirty years to cross the Red Sea. In 1961, John F. Kennedy called on the nation to reach the Moon by the end of the decade, and we did. If instead he had set the goal for the year 2000, the wild ride of subsequent history would have insured that the program was cancelled long before the goal was ever reached. If we want the program to actually achieve its goal, we need to be serious, commit to do it in a finite span, appropriate the required funds, and get to work. Any other approach guarantees failure.

5. Conclusion

Mr. Augustine, distinguished members of the 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 would 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 room 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 Committee, I ask that you embrace the challenge of Mars, and act forcefully to recommend to the administration that it 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 to produce a plan, and from that plan, action. It is within your reach to make this happen. It is within your reach to cause a program of exploration to be initiated that will lead in time to the greatest flowering of human potential, knowledge, progress, and freedom that history has ever known.

It is a grand moment. I ask that you stand forth and make it produce a grand result.

Thank you for your attention.