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Getting Over 'Apolloism'

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Since the last footprints were left on the Moon in 1972, the U.S. government has spent hundreds of billions of dollars on human spaceflight—with precious little at the moment to show for it, other than a lightly crewed space station that we share with Europe, Japan, and Russia, and for which we currently depend on the Russians to access.

Today, as the United States contemplates new human missions in space, the space-policy establishment is in the grips of an ideology—a belief that the best, or even the only, way for America to have meaningful successes in space is to follow the model used to put human beings on the Moon the first time. The general policy approach is an attempt to replicate what was done with the U.S. space program a half century ago, except this time with the more distant target of Mars, and taking much longer than President Kennedy's promise of "before this decade is out." But while Project Apollo was arguably the greatest technical achievement in human history, it was, in terms of opening up the solar system to humanity, a magnificent disaster. Before we can judge the merits of other models of sending human beings to space, we must understand why the ideology of "Apolloism" is technically, financially, and politically unwise. And in order to do that, we must first understand some of the unintended consequences of the peculiar way the United States first ventured into space.

"Waste Anything But Time"

The story of the Mercury, Gemini, and Apollo space projects has been told and retold, but it is worth revisiting the obvious fact that gave the early U.S. space program its shape: it was hurried. Even though scientists, engineers, and science-fiction writers had for decades been imagining what man's future in space might look like, America's early space program did not arise from an attempt to map out a long-term strategic vision for humanity in space. Rather, it was a Cold War tactic. Time was at a premium.

On April 12, 1961, not even three months into John F. Kennedy's presidency, the Soviet Union sent Yuri Gagarin into space—the first human being to orbit the Earth, and a victory for the Russians in the

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space race then underway. One month later, the United States was able to put the first of its Mercury astronauts, Alan Shepard, into space, but not for a full orbit. President Kennedy realized that in the eyes of the world the Soviet Union appeared to be more technologically advanced than the United States, and he looked for a way to show the world that America was not falling behind.

President Kennedy and Vice President Lyndon B. Johnson consulted with Wernher von Braun, the German-born rocket scientist who had been employed by the U.S. military ever since he was captured by American troops in 1945. They asked von Braun which of the space options then under consideration would give the United States the best chance of beating the Soviets: "Do we have a chance of beating the Soviets by putting a laboratory in space, or by a trip around the moon, or by a rocket to land on the moon, or by a rocket to go to the moon and back with a man?" Note that the question was not about how best to conquer space but instead about which goal would provide a near-term battlefield for an American victory. Von Braun replied that the Russians were capable of building a space station in the near term, and that the Americans had a "sporting chance" of sending a rocket to or around the Moon before the Russians, but that "we have an excellent chance of beating the Soviets to the first landing of a crew on the moon (including return capability, of course)." So the answer was the Moon.

At a time when the greatest war in history was still a recent memory, President Kennedy's May 25, 1961 declaration that the country would put a man on the Moon by the end of the decade was reminiscent of the Manhattan Project to develop the nuclear bomb. The effort to realize Kennedy's goal became the biggest peacetime technology project in history, absorbing at one point 4 percent of the federal budget. (To put that into perspective, if NASA's annual budget today were 4 percent of the federal budget, it would reach $160 billion; in fact, it is under $20 billion, or 0.5 percent of the total.) Beating the Soviets to the Moon would be a Cold War victory of enormous magnitude and so the price tag was a secondary concern—hence the informal motto supposedly heard around NASA in those days: "waste anything but time."

Readiness and Reliability

At this critical point in America's early space planning, three crucial decisions were made that would affect the course of human spaceflight for most of the next half-century.

The first was technical: the notion of space planes was abandoned. Since mid-1959, the U.S. Air Force and the National Advisory Committee on Aeronautics (NACA, the predecessor of NASA) had been testing the X-15, a rocket-powered plane. They were planning on flying it into space. The X-15 would be carried by a Boeing B-52 bomber to a high altitude and then dropped; the X-15 pilot would then ignite its liquid-fuel-burning engines and leave the atmosphere. The X-15 could reach (and soon did reach) the edge of space. While these test flights lacked the capability to achieve orbital velocity, it had been expected that the X-15 would be just the first of a series of plane designs that would eventually get all the way to orbit—if not on their own, then as part of a two-stage system.

But the X-15 program would not be able to satisfy the essential criterion for the space race: readiness. It would take too long to develop the X-15's successors to serve the purpose of putting men on the Moon. So instead, intercontinental ballistic missiles (ICBMs) were pressed into service as space launchers. These big rockets had the advantage of already existing. At the same time, NASA, under the direction of von Braun, was working on designing from scratch the largest operational rockets ever built (still down to the present day), the Saturn series.

The decision to launch manned space missions using huge missiles instead of space planes had two major long-term effects on U.S. space operations. One arose from the fact that, because they were missiles, these transportation systems were not reusable. They were used once. This locked the American space program into a paradigm of "expendable and expensive" launches.

The other long-term effect of the decision to use ICBMs arose from the fact that they were not reliable. They were designed to carry nuclear warheads around the globe; it would have cost too much, given how many were built, to make ICBMs reliable. And it wasn't really necessary anyway for their military application: In order to ensure that at least one ICBM would get through any enemy defenses, multiple missiles targeted many of the same strategic locations, so the military planners got reliable *results* from the redundancy of missiles, allowing for the reliability of any individual missile to be lower, and thus more affordable. But this theoretical level of individual reliability—probably somewhere between 90 and 99 percent (no one really knows for sure, or ever will)—was not acceptable for a vehicle that would launch human beings into space, even test and fighter pilots who had probably done riskier things in their careers.

The need to switch the ICBMs' payload from nuclear warheads to human beings led to the creation of a confusing and vexing concept:

"human rating" (formerly "man rating"). The idea was to raise the reliability of ICBMs for increased mission assurance. This entailed increasing the traceability of parts (in some cases all the way back to the mines from which the ore for the metal was obtained) and making the parts more redundant. It also required monitoring of systems that would warn if the crew had to abort their mission, and trajectories that would allow safe aborts at every stage of the ascent from the launch pad to orbit. Several early missiles were intensely human-rated, including the Redstone, the Atlas, the Thor-Delta, and the Titan II. Later rockets were designed to be highly reliable, and so the need for the human-rating concept diminished with time; indeed, no NASA vehicle, including the space shuttle, has met the agency's own standards for human rating since the 1960s. But the concept has stuck, and in recent years it has often been wielded capriciously and politically by NASA to fend off potential competition from the private sector for its own expensive systems, and to imply that, as many NASA officials and members of Congress have said, "safety is the highest priority" (which in turn implies that actually accomplishing anything in space is a lower one). The human-rating requirement has delayed the timetable for the commercial crew vehicles now under development, SpaceX's Dragon and Boeing's Starliner, extending NASA's dependence on Russia for reaching the International Space Station.

Contingencies and Their Consequences

A second critical early NASA decision that would have long-lasting consequences grew out of the agency's structure. NASA's predecessor, the NACA, was not an operational agency. It conducted basic research on airfoils, propulsion, and other aeronautical technologies, in response to the suggested needs of the aviation industry. The only airplanes it developed and flew (in conjunction with contractors such as Bell and North American Aviation) were experimental aircraft like the X-15, which were meant to prove new technologies.

When NASA was launched in 1958, nothing in the legislation that created the new agency specified that it need do more than the NACA had, except to extend the process to space technology development. In fact, the legislation creating NASA makes for interesting reading today, since it bears little resemblance to the agency that, in the wake of the decision to race the Soviets to the Moon, morphed into the human-spaceflight behemoth we know today. The key clause describing what NASA might do in space gives this objective: "The development and operation of vehicles capable of carrying instruments, equipment, supplies, and living organisms through space." Notice that it only specifies *through* space, it says nothing about how they get *to* space. Take away that clause, and there is little difference between NASA's charter and what the NACA did. The new agency could have continued on in the NACA model, with private industry developing space vehicles to provide services for government or commercial markets, and NASA providing the key basic technologies to make it successful.

But while that approach would have been more in keeping with our nation's successful history of affordable technology development, it could not have been relied upon to achieve President Kennedy's stated objective by his deadline. The 1961 decision to reach the Moon before the end of the decade had the effect of profoundly distorting the original intent of the founding of NASA almost three years earlier. With the need to kick up lunar dust before the Russians did, it seemed appropriate to set up a Manhattan Project-like centralized command structure. But this had the unfortunate effect of giving us a space program with values that clashed with traditional American notions of private enterprise.

Even today it remains difficult for some people involved in space policy to think of American space missions in any other way, but it is worth pointing out that the controversial policy change implemented by the Obama administration in early 2010—to have astronauts delivered to low Earth orbit on commercial launchers while NASA focuses its resources on creating the vehicles meant for actual travel through space—amounts to a return to NASA's original mission, prior to the wrong turn taken with Apollo.

The third early decision that echoes down to the current day can be attributed to Vice President Johnson. A Texan, Johnson was determined to use the space program to help industrialize the South, much of which had been mired in poverty since the Civil War. The establishment of a manned space center in Houston, Texas, the new Marshall Space Flight Center collocated with the Redstone Arsenal in Huntsville, Alabama, an engine-testing facility in southern Mississippi, and the selection of Cape Canaveral on the central east coast of Florida as the launch site all went a long way toward achieving this goal.

A vast infrastructure of test, assembly, and launch facilities was constructed in Texas, Alabama, Florida, and other places. Giant rocket parts rolled off assembly lines and were shipped from California to Florida, which increased costs due to (among other things) required travel for both people and hardware, and extensive documentation to ensure that people who did not work in the same place could still adequately meet interface requirements, but it was viewed as worth it, given the Cold War stakes of the space race. But once the urgency of Apollo was gone, Johnson's decisions had the effect of turning what should have been a vibrant space program into a white-collar jobs program, with many political decisions hinging on continuing employment rather than further progress into space. For example, the Marshall Space Flight Center has from its inception designed rockets, and it has always been important to Alabama politicians to provide it with funding to do so, even though the center has not successfully designed a rocket since the 1970s. Despite the fact that commercial industry is now providing affordable launch services, this is the primary source of the congressional desire to build first the Ares series of rockets in the canceled Constellation program of the past decade, and now the Space Launch System.

One other long-lasting effect of the decisions made during the 1960s is worth mentioning. Between the Project Mercury flights (America's earliest manned missions into space) and the Project Apollo missions (culminating in the Moon landings), there was an intermediate step: Project Gemini. It was during these dozen flights that the United States learned and demonstrated many of the key techniques and technologies that would be necessary to carry out a lunar mission, such as the ability to conduct extravehicular activities (spacewalks) and the ability to rendezvous and dock with other vehicles. But one great opportunity was missed: no attempt was made to demonstrate the ability to reach the Moon without a heavy-lift vehicle. By assembling *in orbit* pieces of the system necessary to go to the Moon instead of lifting everything at once, the United States could have used relatively cheap rockets that already existed. There were many proposals, both from within NASA as well as from the aerospace contractors Martin Marietta and McDonnell, to continue to use Gemini as the basis for space stations, lunar orbit rendezvous, rescue vehicles and other applications. In addition, there was some interest from the Pentagon to use Gemini as the basis for its Manned Orbiting Laboratory program (canceled in the late 1960s). But once again, because the Cold War imperative was to get to the Moon before the Soviets and by the end of the decade—rather than to build a sustainable foundation for human spaceflight—Gemini, with all its potential and modularity, came to an end. We made it to the Moon using the expensive Apollo mission profile: a huge rocket built to carry all at once into space the crew and everything needed to reach the Moon and return.

Overcoming the Apollo Attitude

After the last Moon landing in 1972, the Apollo hardware was used a few more times: there was an orbital docking mission with the Russians in 1975, and there were three crewed flights to Skylab, America's first space station. The Apollo era finally petered out when Skylab, abandoned, was allowed to burn up in the atmosphere in 1979 because America's new space program—the space shuttle—was not ready in time to save it. (Realistically, Skylab was probably no longer usable, and it might have been more expensive to refurbish it than to launch a replacement.)

Despite the sad end of Apollo, enthusiasts believed that the space shuttle, which first flew in 1981, would usher in a period of space exploration and development, including space stations, returns to the Moon, and even space colonies. After all, the system was designed to be mostly reusable—only its large liquid-fuel tanks were destroyed with each use—which, in theory, would reduce costs and minimize waits between missions.

It did not work out that way. Even setting aside the question of whether the shuttle design was inherently unwise—for it was safety problems that ultimately led to the termination of the program in 2011—there was a more fundamental problem. The shuttle program was hampered by precedents from Apollo, with its adherence to the false paradigm of the need for giant rockets operated by a government space agency for human space operations, and its foundation of a system of pork for Congress. For all its technical achievements, Apollo had laid the groundwork for failure.

Even now, in the post-shuttle era, many in the space-policy establishment still ignore the historical contingencies that shaped Apollo, and they hope to recapture its glory by recreating it—by setting a goal, picking a date, and building a ridiculously expensive large rocket. Apolloism has its hold on them, and they cannot conceive of any other way of opening the solar system. Their current objects of fascination are the Orion Crew Capsule, a capsule modeled on the Apollo capsule, and the Space Launch System (SLS), a huge heavy-lift launch vehicle. Proponents of these programs claim that it will not be possible to send humans to Mars, or beyond low Earth orbit at all, without them. But most independent analyses (and at least one internal NASA study) indicate that not only are Orion and the SLS unnecessary for that purpose, but they are chewing up all the budget that could be going to things that *are* necessary but are not being funded at all, and that SLS is the most expensive way to do it. Here again, budgetary pork is a factor, which is why detractors sometimes refer to SLS as the *Senate* Launch System.

If we are serious about opening the high frontier, and maintaining public support, we need to provide much more value than can be had with a rehash of the expensive, government-led, politically motivated, centralized mission design and architecture hastily developed in the urgency of the Cold War.

Ridding ourselves of the ideology of Apolloism, we might seek out new techniques and technologies that could offer not just another brief moment of glory but rather a much more vibrant future of humanity in space. Among the alternative technologies and techniques we might consider:

Orbital Assembly. For humanity to have a true spacefaring future, we will need large-volume items in space—equipment, big habitats, the fluids needed for fuel and for supporting life, and the tanks to hold those fluids. Rather than planning missions dependent on sending a crew and all their supplies into space at once, so that the entire mission plan is limited by one launch vehicle's payload capacity, we should seriously examine the possibility of sending into orbit on multiple smaller rockets the various components needed for the missions we actually want to accomplish. Some of the basic techniques that would be necessary for orbital assembly have been considered and tested since the 1970s, and of course the construction of the International Space Station created a valuable base of relevant experience. And new assembly techniques being developed by companies like Tethers Unlimited and Made In Space will obviate the need for the kind of wide and heavy launch vehicles that SLS proponents insist are required.

In-Space Propellant Storage. The ability to deliver, transfer, and store propellant in space is likely to be a crucial technology for Mars missions, but NASA is not funding it in any significant way. Fortunately, private companies are developing upper stages that will contain the necessary technologies for transferring, using, and storing many metric tons of liquid hydrogen and liquid oxygen. Such systems could eventually be reusable over multiple missions, opening up the possibility of creating propellant depots in space. Depots would be a powerful enabling technology, permitting the execution of missions that would otherwise be difficult or impossible, and making full reusability of space vehicles possible.

In-Situ Resource Utilization. Obviously, one source of propellant needed for deep spaceflight would be the source we have been tapping since the beginning of the space age—our own planet. But if we are to open the solar system, we will have to learn to "live off the land," just as our forebears did when settling the American West. Just as on Earth, fuel for our machines will come in the form of various combinations of carbon and hydrogen, and we will have to synthesize it from raw materials. Much the same goes for the oxygen that we need to breathe and that we use to oxidize our fuel. Fortunately, we know that on the Moon there is plenty of hydrogen and oxygen to be found (in frozen water, much of it concentrated at the poles), on Mars there is plenty of hydrogen and oxygen (in water) and carbon (in the atmosphere), and various moons and asteroids in the solar system are likely to offer useful constituent elements. If we were serious about progressing into space, we would be investing in the technology development needed to take advantage of these resources—but every year, the NASA technology budget is slashed to fund a giant rocket created in the image of Apollo.

Artificial gravity. Enduring low gravity for a long time has numerous deleterious effects on the human body, a fact understood at least since the 1970s when the United States and the Soviet Union put their first space stations into orbit. Recently, NASA astronaut Scott Kelly completed almost a year in orbit aboard the International Space Station—a duration comparable to the length of a trip to Mars—returning with bone loss, kidney stones, skin soreness, and vision problems. Such ill effects of weightlessness could be mitigated or even eliminated with artificial gravity, which could be implemented relatively simply by spinning habitats. But because NASA is not yet truly serious about either exploring or developing space, no experiments have been done to investigate the feasibility of such a system. Nor for that matter has NASA attempted to investigate the effects of *partial* gravity on fundamental aspects of human biology; this must be a priority if we are going to settle other planets.

Magnetoshell Aerobraking. The atmosphere of Mars is much thinner than Earth's, which can make the aerodynamics of landing difficult. While robotic landers have been parachuted to the Martian surface, parachutes don't scale well, and some other technology will be needed to safely land humans and their habitats and supplies. This is why SpaceX, the private company whose founder Elon Musk is fixated on reaching the Red Planet, announced in April 2016 that it would be testing the use of retrorockets on Mars as soon as 2018. However, another technique called magnetoshell aerobraking, proposed by the Seattle-based company MSNW, may make it possible to use the planet's atmosphere to slow down an approaching spacecraft with much lower mass than traditional aeroshells, while allowing real-time adjustment to unknown atmospheric conditions. This could dramatically improve the safety and the weight limits of Mars mission profiles. NASA has recently awarded MSNW funding to study the concept—although only about 0.05 percent of what the agency spends each year on the Space Launch System.

Nuclear and Electric Propulsion and Power. Nuclear reactors would present a major breakthrough in propulsion. The heat from a reactor could be used to increase the temperature of a working fluid (such as hydrogen) to accelerate it out a nozzle at much higher exhaust velocities than those provided by the energy from chemical reactions. This would enable high-thrust efficient systems, and much faster trip times. Electricity generated by a space nuclear reactor could make up for the power limitation of solar panels, which are less useful farther away from the sun. And beyond propulsion, nuclear power in space will be necessary for survival itself—providing the reliable energy needed for life support, for powering the chemical reactions needed to make rocket propellant, and other needs. The fact that there is no significant government funding for this vitally important technology, nor even plans for overcoming the public fears associated with nuclear energy, is a testament to how unseriously the space-policy establishment is approaching humanity's future in space.

Celebrating Apollo, Abandoning Apolloism

There is one more component of Apolloism worth mentioning. Those in the grip of the ideology believe that if we are to reach Mars we will need a "national commitment." They do not understand the difficulty—if not impossibility—of getting such a thing in a democratic republic, in which policy directions change with the political winds. Because they view Apollo as the model for how large space programs should operate, and because they believe that Apollo represented a moment of national unity, they seem to think that we ought to recreate it.

In a sense, however, a critical reason that we cannot do what they want is because we never really did it the first time. Yes, we landed men on the Moon, but the national commitment was actually brief. In private, Kennedy admitted "I don't care that much about space," and before his death he considered canceling the Moon program, or doing it in cooperation with the Soviets. There was never widespread public support for the program; it only briefly had majority support, around the time of the first Moon landing. It was likely only the public's respect for the assassinated leader who started the program that allowed it to go on as long as it did.

Apollo was a glorious achievement of technology, ingenuity, and courage. It was also a historical anomaly, a fiscal extravagance, a political pork barrel, and finally a dead end. We should remember it with pride, and should heed its lessons—using it not as a model of what to do going forward, but as a model of what to avoid.