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The Path Not Taken

Rand Simberg

On June 21, 2004, with thousands in attendance in the small southern California desert town of Mojave, a sexagenarian test pilot performed the first trip to space in a privately-built spacecraft. SpaceShipOne, as it is called, cost less than $30 million and was funded by Microsoft co-founder Paul Allen.

Occurring seventeen months after the loss of the shuttle *Columbia* put America's manned space program on hiatus, the SpaceShipOne flight received a surprising amount of publicity. The achievement, while impressive, was also limited: SpaceShipOne's flight was only a suborbital test, roughly the equivalent of Alan Shepard's historic suborbital flight in 1961. Surely, the technical achievement did not rival the achievements of NASA in its prime.

But NASA, clearly, is not in its prime, at least when it comes to manned space travel. Aside from a single American astronaut on the International Space Station, who only got there because he went up in a Russian capsule, NASA's manned space program is currently on hold. It remains unclear when the shuttle will fly again, if ever. And so one of the reasons the flight of SpaceShipOne was so compelling was its contrast with NASA's wounded, grounded shuttle fleet, and the fact that the entrepreneurs achieved this feat for far less money than NASA could.

And the contrast is telling. Unlike SpaceShipOne, a private venture born of competition and risk, NASA's present space activities remain mired in institutions and thought patterns that are decades-old artifacts of the Cold War. The way NASA works is a historical contingency that could easily have manifested itself differently had we not been locked in a global confrontation with totalitarian communism. It is distinctly at odds with traditional American values of individualism and free enterprise.

Myths of the Old Space Age

Because there are almost no other examples of human space exploration than the activities of the U.S. and Russian governments, a number of

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myths have become entrenched in our minds since the dawn of the space age, inhibiting us from fully considering more viable and entrepreneurial ways to open up our new frontier.

Myth #1: *Spaceflight, and particularly human spaceflight, is necessarily expensive and dangerous, and only major governments have the resources to engage in it.*

We are all familiar with news stories about the exorbitant cost of NASA's space shuttles and the International Space Station, and the billions of dollars of budget overruns. The shuttle cost several billion dollars to develop, and continues to cost billions of dollars per year to operate—even when, as now, it isn't flying at all. The space station was originally projected to cost eight billion dollars, but more recent estimates put the price between $30 and $60 billion.

Given these examples, it's not surprising that we have come to expect human spaceflight, at least as performed by NASA, to be expensive. Until recently, the notion that any entity lacking the resources of a major world power could send men into space was met with almost universal incredulity. For those attempting to raise investment capital to do such a thing, this widespread skepticism becomes a self-fulfilling prophecy, since no investor is likely to put forth the funds for something that is perceived to be impossible.

Myth #2: *Spaceflight is intrinsically expensive because of the basic physics—it requires so much energy and power and fuel that we will never get the costs down with conventional rockets.*

Conventional explanations of the high cost of space tend to be framed in terms of the laws of physics. In order to get into orbit, a spacecraft must achieve a velocity of 17,000 miles per hour. Rockets are the only way to propel vehicles to this velocity, because air-breathing propulsion systems, such as jet engines, don't work in the vacuum of space. The amount of propellant required for a rocket is an exponential function of the velocity required (i.e., twice the velocity requires much more than twice the propellant, and it only goes up from there). Thus, to get a significant payload into space requires a rocket many times as large as the payload.

If the launch vehicle is expendable (as almost all have been, including the Saturn V rockets used to send men to the Moon thirty-five years ago), then the cost of getting a few thousand pounds into space becomes astronomical, so to speak, because so much expensive hardware is used only once and then thrown away after each flight.

If the vehicle is reused, like the shuttle, then it has to return to Earth. Now a different kind of physics comes into play: the energy that was invested into the vehicle to get it into orbit must be shed to allow it to slow down and land. The heat generated by this process requires systems that can absorb and reflect it, and protect the vehicle from it. The failure of such a system destroyed *Columbia* during reentry on February 1, 2003.

In both cases—ascending and descending—the physical problem is not simply the *amount* of energy involved but the *rate* at which that energy must be managed. The energy must be added very quickly for launch, and removed just as quickly for entry, so it's really a matter of *power*—the rate of energy change.

All of these factors, so the argument goes, require complex systems with many components, each of which must be reliable to make the overall system reliable, and all of this costs money. Compound this with the additional requirements for "human rating" such a system: Humans are priceless, and as important as multi-million-dollar satellites and launches are, putting human lives at risk requires even more reliability and safety. Humans also require life support—pressurized volume, breathable air, food, and water—all of which adds even more weight to the needed payload. This further increases costs.

The conclusion: Space access is exorbitantly expensive because the fundamentals of physics make it so. Short of some radically new technology, like the space elevator, access to space will remain costly. This is a seductive and plausible argument, and one that leads directly to the next myth.

Myth #3: *There is little or no use for humans in space that can justify their expense.*

The argument here is not that there is no use at all for humans in space, but no use that is worth the price tag. Yes, the Apollo astronauts did good science, and astronauts have repaired satellites on orbit—but the benefits didn't justify the costs, when such work could have been done with robots, which are lighter and don't require life support. This is particularly the case if the money being spent on expensive manned space systems had instead been used to develop smarter, more advanced robots.

Myth #4: *Space travel by members of the public will only occur (if at all) after needed technological breakthroughs dramatically reduce costs and improve reliability and safety. And this will only become possible (if at all) through continued government investment in space programs.*

While a couple of people have each paid $20 million for trips to the International Space Station on Russian hardware, the market for future space tourists at that price is not very big. The present market is too small, the argument goes, and the future market is too uncertain, for any private investor to make the enormous investment required to develop the new launch technologies that will bring prices down. Only governments can afford that investment, and until they do (perhaps in order to reduce the cost of civil and military space activity), we will be stuck with high launch costs. Once costs have been reduced with appropriate government investment—if that ever occurs—there's a possibility that those government systems can be converted into private ones that carry paying passengers. But this is off in the distant future.

Myth #5: *Reusable launch vehicles are technologically beyond us, and they wouldn't bring low launch costs, anyway.*

We thought in the 1970s that reusability was the key to cost reduction. We invested billions of dollars in the space shuttle, but it has turned out to cost *more* per pound of payload than the Saturn V rocket it replaced, while killing fourteen astronauts.

In the 1990s, we instituted a reusable experimental program called X-33, but after spending a billion dollars on it, it never even flew, and it now sits up in a hangar in the Mojave Desert along with an unused launch pad. The head of NASA's Marshall Space Flight Center declared a few years ago that X-33 proved we just don't have the technology to build a reusable vehicle. The conclusion that follows is that we should give up this dream until the technology has advanced, and return for now to the capsules on expendable launch systems that successfully got us to the Moon in the 1960s.

There are other myths of the old space age—for example, that space is for science only or that we can't afford large space programs without international cooperation. But the five I've listed are the ones primarily responsible for holding back progress. My intent was to state them fairly, as I believe those who hold them would. But I believe they are refutable, rooted as they are in misguided assumptions and analysis.

Myths Debunked

Let's begin with the notion that space is intrinsically expensive because the physics demands it—specifically, the idea that rocket technology is fully mature and has reduced costs about as far as possible. This *argumentum ab* *physics*, the linchpin of all the myths, sounds plausible. So what's wrong with it? What are the true reasons for the high cost of spaceflight (especially manned spaceflight), and are there untapped ways to lower launch costs?

Back in the 1980s and early 1990s, as an employee of a major government aerospace contractor, I participated in and managed several studies relating to future launch systems. These so-called "space transportation architecture" studies evaluated and compared alternative conceptual launch systems, with a view to guiding decision-makers at the Air Force and NASA about what future investments to make in launch vehicles and technology.

These studies considered a wide variety of vehicle types—reusable, expendable, single- and multiple-stage, various propellant combinations, air-breathing, rocket, horizontal takeoff and landing, vertical takeoff and landing, and more—the entire range of conceivable ways of getting crew and cargo into Earth orbit and (when necessary) back using semi-conventional aerospace vehicles. These studies also considered a range of potential "mission models," with different types, mass, and volumes of payloads, over the next few decades. The models ranged from the minimal (with no commercial activity and little or no growth in NASA or military space budgets) to the expansive (with major new civil space initiatives, including crewed lunar and Mars missions, and large-scale commercial activity).

As we looked at all the combinations of architectures and models, we discovered something interesting. While some vehicle design concepts were clearly better than others, they were all extremely expensive per-flight for the *low-activity* scenarios, and they were all much less expensive for the *high-activity* scenarios. Using the space shuttle as a reference, we developed a notional architecture that had sufficient facilities and vehicles for a hundred shuttle flights per year. (That sounds ridiculous today, since there have never been more than nine shuttle flights in a single year, but in fact the shuttle was originally intended to fly once a week.) Surprisingly, the per-flight costs that we estimated were much lower than the actual shuttle costs at the time. The same was true of other launch concepts we studied. The cost per-flight or cost per-pound varied dramatically—in some cases by a factor of ten—depending on the level of activity for a given vehicle in each mission model.

This means that even the theoretically best vehicle concept, if flown rarely, will be unaffordable to fly. A mediocre design, flown often, will beat it in cost per flight. How frequently we used the hypothetical launch system was much more important than what kind of propellant it used, or how many stages it had, or whether it took off or landed horizontally or vertically, or any other design choice. This, to me, was the key insight from all of those studies, and it's one that remains true to this day. For example, the costs associated with the space shuttle largely go to pay the army of personnel and associated infrastructure needed to keep the shuttle fleet operational at all, even when the shuttles don't fly. This doesn't mean, of course, that we should ignore vehicle design, but it does mean that we need to pay much more attention to the dynamics of the market.

The reason for this is obvious, in retrospect. Consider the following example, for which I'll use some simplified but reasonable figures. Imagine that Boeing spent $10 billion to develop the 747—but instead of building hundreds and flying each of them daily (as is the case), they only built five and flew each one only once per year. Let's say that Boeing didn't make any profit, but sold the five airplanes to American Airlines for $2 billion apiece. Assuming that American Airlines can borrow money at less than ten percent interest, it has annual costs in aircraft payments of roughly $200 million per year for each airplane. Even if they had absolutely no other expenses (fuel, pilots, flight attendants, marketing, ticket agents, etc.), and if each aircraft had 400 seats, the airline would have to charge half a million dollars per ticket just to cover the loan for the aircraft purchase.

The design and the physics haven't changed—the only difference is the number of vehicles built and the flight rate. In the real world, the ticket price is a few hundred or at most a few thousand dollars. In the hypothetical case, the ticket cost is five hundred times greater, without even paying for the necessary fuel and support personnel. In other words, if we ran the aviation industry in the same manner that we run the space shuttle program, it would be almost as costly.

Here's another real-life example. The Air Force and its launch contractors invested billions of dollars in the Evolved Expendable Launch Vehicle (EELV) program in the 1990s, with the goals of improving reliability and reducing costs for the existing Delta and Atlas rockets, built by Boeing and Lockheed Martin, respectively. The specific goal was to reduce their operating costs by 25 percent. In other words, they determined that by coming up with a new vehicle design, the best they could do was reduce costs by a quarter. Some might interpret this as vindication for the *argumentum ab physics*—a sign that very little marginal improvement can be expected from conventional rockets in the future.

The calculations that led to the hoped-for 25 percent figure assumed there would be a high flight rate from both Air Force and commercial payloads, including many launches to put communications satellites into orbit. But after the "dot-com bubble" popped, one of the many casualties was the communications satellite market. Boeing has dropped out of the commercial launch market as a result, and the total expected flight rate for the Delta and Atlas EELVs has plunged, resulting in a per-flight cost rise of up to 50 percent. The lesson: A simple change in the market had a much larger effect on launch costs than the billions of dollars spent on redesigning the launchers.

While the absence of economies of scale is perhaps the dominant reason that launch costs are so high, it isn't the only reason. Because our space activities have been dominated by government contracts from the beginning, with goals for which cost was no object (i.e., defending the nation with ballistic missiles and beating the Soviets to the Moon), we have developed an industry culture in which high costs are expected and accepted. And despite all the lofty rhetoric about science and exploration, the civil space program is supported in Congress largely because it provides jobs in key congressional districts, whose representatives get assigned to committees overseeing its budget. When contractors have contracts that reimburse them for all costs, plus a percentage as profit, and when creation of constituent jobs rather than conservation of taxpayers' funds is the congressional priority, it is not surprising that government space programs are so expensive.

Of course, these are not the only reasons that launch costs are so high. Physics *is* a problem, and getting things into space *is* a technical challenge. But these realities alone can't explain the high cost of getting to orbit. Again, compare the airline industry to the space-launch industry. For airlines, fuel is the second-largest expense; airlines spend an enormous amount of money on the energy required to solve the physical problem of getting from one place to another. A naïve observer might also assume, upon seeing the size of the propellant tanks on a rocket, that the cost of fuel makes up a large part of the total cost of a space launch, yet propellant costs are actually an insignificant proportion of the total cost. The new Boeing Delta IV launch vehicle, for example, requires over half a million pounds of liquid oxygen and liquid hydrogen to get its payload to orbit. The cost of these propellants is far less than a dollar per pound (the price of liquid oxygen is actually comparable to the price of milk). But even if we grossly overstate these costs, putting them at a dollar per pound, this is still only half a million dollars for the propellants—and this for a launcher priced at roughly $100 million per flight. So for a space-launch, as opposed to an airline flight, the fuel needed to meet the challenge of physics is currently less than one percent of the total cost per launch.

The analogy to airline flights is admittedly imperfect, but it does suggest that rocket technology is perhaps still far from maturity. If we could get to the point where propellant costs are a significant proportion of the overall cost, launches would be much cheaper.

Cutting Costs by Cutting Waste

The most significant reason that rocket launches are so expensive is that we throw away a very expensive vehicle each time we use it. This brings us to Myth #5—the idea that reusable vehicles are not the key to reducing launch costs, and that they can't even be built. By the late 1960s, it was common wisdom and common sense that we couldn't afford to continue, in Arthur C. Clarke's words, to carpet the bottom of the Atlantic with spent hardware; it was clear to almost everyone that we needed a reusable launch system.

This thinking led to the development of the space shuttle, which is a partially reusable launch system. The large external fuel tank, which costs tens of millions of dollars, is thrown away during every shuttle launch to burn up in the atmosphere. The two solid rocket boosters used for each shuttle launch fall into the ocean and are retrieved—but only the casings are reused, after being reassembled into essentially new boosters. Only the orbiter itself is truly reusable, and even that requires a great deal of maintenance between flights.

The shuttle actually demonstrates that a reusable vehicle can be built, and can be quite reliable, *if we consider only the orbiter.* In the case of neither the *Challenger* nor the *Columbia* accident was the orbiter the cause of the disaster. *Challenger* was destroyed due to the failure of an expendable O-ring (they're replaced each flight) in one of the rebuilt boosters. While *Columbia's* thermal protection system failed to protect her from the heat of reentry, this was the result of an external event—a foam strike from the expendable external tank. It makes no more sense to blame the orbiter for this accident than it would to blame an airplane if it were hit by a piece of debris for which it wasn't designed.

A more recent attempt at designing a reusable space vehicle came with the X-33 program based at NASA's Marshall Space Flight Center in the 1990s. The goal of the X-33 program was to build a test vehicle that could demonstrate the technologies needed for a single-stage-to-orbit launch vehicle—that is, the entire vehicle would go all the way into space and return, without dropping any stages on its way up. The X-33 itself wasn't designed to go into orbit; it was a subscale version intended to show that a larger orbital vehicle (called "VentureStar" by the winning contractor, Lockheed Martin) could be built commercially. Because it incorporated several cutting-edge technologies in a single vehicle, it was a very risky program, and in fact was chosen for that reason—NASA wanted to "push the technological envelope." A key element of the program was that the proposal evaluation would be based in part on a "business plan" purporting to show how the winning contractor would proceed with its own (or private) money instead of relying solely on the federal government.

Unfortunately, Lockheed Martin had nearly no commercial experience since the 1970s; the company was (and still is) almost exclusively a government contractor. Its proposed business plan for VentureStar relied on taking over the existing communications satellite market and the space shuttle missions (primarily to provide support to the International Space Station). But since the business plan didn't propose to open up any significant new markets, which would increase the flight rate to a level that justified the development of a reusable vehicle, it appeared from the start to be unrealistic.

One cynical view is that Lockheed Martin achieved its strategic business objective simply by winning the contract. If the X-33 project was a success, Lockheed would take away business from its competitors. And if it was a failure, Lockheed would prevent the development of a new vehicle to compete against its own existing Atlas and Titan rockets and its stake in the space shuttle. NASA apparently didn't notice—or didn't care—that by selecting an incumbent launch vehicle provider, there were intrinsic incentives for program failure. Nor did it occur to them, more generally, that one shouldn't seek innovation from an entity with a massive stake in the status quo. In the end, the X-33 never flew and the project was cancelled in early 2001 after spending more than a billion dollars.

So what were the lessons of the X-33 (and the X-34, another failed Marshall program)? According to a March 2001 statement from Art Stephenson, director of NASA's Marshall Space Flight Center, "We have gained a tremendous amount of knowledge from these X-programs, but one of the things we have learned is that our technology has not yet advanced to the point that we can successfully develop a new reusable launch vehicle that substantially improves safety, reliability and affordability." But this conclusion is absurd. In reality, all that the X-33 and X-34 failures proved was that we did not have the technologies in place to build an X-33 and an X-34. But few, if any, of these technologies are essential to building a generic reusable launch system. Since there hasn't been any evidence to the contrary, the common-sense view from the 1960s—reusability will save money—is still a very reasonable proposition.

Failed Paradigms

By now it should be clear that space launches are so expensive not because of the amount of energy required or the laws of physics in general, but because of the way we've chosen to undertake them, and the fact that we do so few of them. In the case of the *expendables*, it's because we throw away expensive hardware with every flight; in the case of *reusables*, it's because we don't reuse them very much. This suggests that the key to low-cost and reliable launch is the following: (a) to stop throwing the launch vehicles away, in whole or in part, and (b) to fly them a lot. If this is true, what are the implications for our national space policy, and in particular for the vision of space exploration articulated by President Bush?

It seems clear that the Bush administration doesn't believe that truly reusable launch vehicles are technically feasible. Not only were the X-33 and X-34 programs cancelled, but NASA also terminated the Space Launch Initiative last year, a program whose goal was to demonstrate the technologies needed for reusable launch vehicles.

Instead, the administration has called for a return to the Apollo-era model of sending humans to and from orbit in capsules on expendable launchers. This is the essence of NASA's new "Crew Exploration Vehicle" program. Unfortunately, this model runs counter to a key element in the president's new vision—that human exploration of space be "affordable and sustainable." The Apollo model was demonstrably neither affordable nor sustainable; we didn't sustain it the first time around, largely because of the perception that we couldn't afford it.

The Bush decision highlights a longstanding debate between two fundamentally different approaches to space operations. The first approach is to launch everything required for a mission all at once. The second is to deliver things in pieces and assemble them in orbit. In terms of physics, there is no inherent reason that either can't work—but there are big differences in terms of sustainability and affordability.

This debate first reared its head during the early planning of Apollo, and those who advocated the single-launch approach won out—which allowed the United States to meet President Kennedy's goal of landing Americans on the Moon "before this decade is out." The single-launch approach won for good reasons, but it's important to understand those reasons, so we can understand why, forty years later, they no longer apply.

The initial plan for reaching the Moon, developed by rocket pioneer Wernher von Braun, called for multiple launches whose payloads would be mated in orbit before heading off to the Moon. But at the time, we had very little experience with rendezvous and docking, and it was judged to be too risky. So NASA instead went with a plan that allowed the mission to be performed with a single launch of a huge launcher. The single-launch approach wasn't chosen because it was the cheapest, or because it was the best way of building a sustained capability or infrastructure. In those days, everything—including the science, the price, and the sustainability—was subordinate to the only real goal: beating the Soviets to the Moon.

That was then, this is now. As President Bush said in his speech on January 14, 2004, in which he laid out his new "Vision for Space Exploration," it's not a race, but a journey. Our goal this time is to build capability, and to do so in a way that builds momentum, both politically and economically, so our space program doesn't falter as happened after Apollo.

The question is: How do we accomplish this?

First, we have to unburden ourselves of the confining myths of the old space age. Mark Twain wrote that a cat that sat once on a hot stove would never do that again—"but also she will never sit down on a cold one any more." We seem to be taking the same approach with space. We have been convinced by the shuttle experience that we cannot build affordable reusable launch vehicles, and we are convinced by the space station experience that we must avoid assembly in orbit. This is what space historian Henry Spencer has memorably called the "Wile E. Coyote" approach to engineering, after the hapless hunter of the Roadrunner in the Warner Brothers cartoons. We try a particular technical approach, and when it fails spectacularly, we simply drop it and try something completely different, rather than examining what went wrong and incrementally improving the concept.

The shuttle didn't fail because it was reusable. It failed because it wasn't reusable enough, and because it had too many conflicting requirements, and because it wasn't funded properly during development, and because the true goal of the program was not to reduce launch costs, but rather to give NASA something to do after Apollo wound down that could maintain jobs in politically important congressional districts.

Similarly, the International Space Station didn't fail because it required too much orbital assembly. It failed because we've never developed the necessary orbital assembly tools and capabilities, and because it had too many conflicting and ever-changing political requirements (like the promotion of "international cooperation"), and because we didn't have routine and affordable access to orbit, and because the goal of the program was not to build a station but to give NASA something to do after shuttle development wound down.

More fundamentally, the failure of both the shuttle and the International Space Station can be attributed to a failed paradigm: the belief in beneficent and competent government agencies as the trailblazer in space exploration, complete with five- and ten-year plans. Of necessity, in response to the Soviet space agency, we created a government agency of our own, except it was in the service of a democratic political system, not a totalitarian one. It worked fine for a short Moon-race, but we made the mistake of thinking, in utter defiance of our nation's tradition of individualism and free enterprise, that this could be a successful model for opening a new frontier.

Lots of Eggs, Too Few Baskets

President Bush's new vision for space shows some burgeoning signs of recognizing this reality, but it fails to reckon adequately with its implications. It is encouraging that both the president and his advisory commission, led by former Air Force Secretary Pete Aldridge, urged NASA to work with space entrepreneurs and private enterprise and to integrate them into the vision. But the Bush plan still gives NASA the lead in developing a new vehicle for carrying humans to and from space, and it doesn't require them to purchase such services from the private sector.

The chief problem with the Bush vision for NASA is not its technical approach, but its programmatic approach—or, at an even deeper level, its fundamental philosophy. This is not simply a Bush problem, but a NASA problem: When government takes an approach, it is *an* approach, not a variety of approaches. Proposals are invited, the potential contractors study and compete, the government evaluates, but ultimately, a single solution is chosen with a contractor to build it. There has been some talk of a "fly-off" for the Crew Exploration Vehicle, in which two competing designs will actually fly to determine which is the best. But in the end, there will still be only one. Likewise, if we decide to build a powerful new rocket, there will almost certainly be only one, since it will be enough of a challenge to get the funds for that one, let alone two.

Biologists teach us that monocultures are fragile. They are subject to catastrophic failure (think of the Irish potato famine). This is just as true with technological monocultures, and we've seen it twice now in the last two decades: after each shuttle accident, the U.S. manned spaceflight program was stalled for years. Without Russian assistance, we cannot presently reach our (one and only) space station, because our (one and only) way of getting to it has been shut down since the *Columbia* accident.

The lesson—not to put your eggs in one basket—hasn't been learned. The Air Force is now talking about eliminating one of the two major rocket systems (either Boeing's Delta or Lockheed Martin's Atlas), because there's not enough business to maintain both. The president's new vision for space proposes *a* "Crew Exploration Vehicle" and *a* new heavy-lift vehicle. The same flawed thinking went into many discussions in the last decade about what *the* "shuttle replacement" should be.

In *The Future and Its Enemies*, Virginia Postrel writes of "stasists" versus "dynamists." To stasists, the highest values are planning and order and avoidance of change—especially unplanned change. Dynamists are more interested in organic and emergent market-based solutions to problems—not as predictable, but ultimately more resilient and more satisfactory to individuals.

Historically, the United States has been a dynamist nation. But our national space policy, largely because of the nature of its birth in the fear and urgency of the Cold War, has been one of stasism. And for all of its vision, the president's new initiative remains at its heart a stasist one, though in its call for more participation from free enterprise, it contains the seeds for dynamism.

What would a truly dynamist space exploration culture look like?

Imagine, instead of launching a few government employees once every few months, daily trips into space by hundreds or thousands of private citizens by multiple vehicle types, just as our airline industry today uses Boeings and Airbuses. Some conduct research at private orbital laboratories, some head to orbital resorts, others board cruise liners for trips around the Moon. There are hotels in high inclination orbits for spectacular views of Earth, and vehicle assembly hangars in low inclination for departure to points beyond Earth orbit. There are huge radio telescopes on the far side of the Moon, protected from the incessant radio noise of our industrial planet, and at the poles are research facilities and tourist spots, using the water ice hidden in the craters there. The vast majority of the funding comes from private expenditures made by people seeking their own adventures off-planet, and NASA has little involvement, other than to take advantage of the dramatic reductions in cost and dramatic improvements in technology to do those things that only it can do, such as expeditions to the outer planets.

Is this a science-fiction fantasy, or is it economically and technologically realistic? How could we get there from where we are now?

A New Path

As Tom Wolfe chronicled in *The Right Stuff*, while Lyndon Johnson was declaring that our nation wouldn't go to bed by the light of a communist Moon, and while the German refugees from Hitler's rocket program were in Alabama developing the vehicles that would eventually take us to the Moon, there were rocket planes flying in the Mojave Desert, released from B-52 bombers. They sundered the skies, probing the upper reaches of the atmosphere and even temporarily leaving it. These were the first, tentative space vehicles, and had they not been interrupted by the urgency of beating the Soviets to the Moon, their successors might have continued. They might have flown higher, and faster, and faster yet, until at last they flew fast enough to defy the gravity of the Earth and reach orbit.

That might have been another road to space, a path not taken—one that might have provided a more incremental, affordable, and reliable approach, instead of one in which we put small capsules on unreliable and expensive munitions, and hoped for the best.

We'll never know, of course. But perhaps we saw the germ of a new, dynamist space age—one that was bypassed decades ago by the demands of the Cold War—in the clear blue skies over the Mojave in June. SpaceShipOne was built in response to the Ansari X-Prize, a private purse put up to urge private activities to seek the heavens, just as a private purse drew Charles Lindbergh across the Atlantic in 1927. Although SpaceShipOne is the most promising of the contenders, it's by no means the only one, and the $10 million purse has generated many times that amount in efforts to win the prize. In fact, SpaceShipOne itself has reportedly cost more than double the prize value, but no one complains. Contrast this to the cost-plus-fixed-fee contracts of the traditional aerospace industry.

As these words are written, SpaceShipOne's backers have given notice of their intent to go for the prize, with the first of the two required spaceflights to be attempted on September 29. If all goes well, in early October of this year, the prize will have been won, and private astronauts will have flown into space on a privately-built reusable spacecraft twice within two weeks. But the important thing is not that there will be a winner, but that there will also be runners-up and other competitors with their own plans. The vehicle that wins the X-Prize may not be the vehicle that taps the potential new space markets. The Wright brothers, after all, were the first to master controlled flight, but they weren't the ones to benefit the most financially from it.

Competition of this sort will be critical to affordably opening up the cosmos to humanity. The government approach to low-cost spaceflight has been to figure out first how to achieve a high performance level, and *then* figure out how to make it cheap. NASA's approach has been to start by getting each advanced system fully working. This approach worked well in the Apollo era, because it allowed us to meet President Kennedy's end-of-decade goal, but it was never cheap. In the shuttle era, the approach failed utterly, in terms of delivering affordable and routine access to space.

The new private approach is radically different—but it's one with which aviation enthusiasts will be familiar. It's how aircraft technology advanced rapidly between the two world wars. And it's the same incremental approach used on the old experimental rocket planes out in the Mojave in the late 1950s and early 1960s, before the Moon-race mentality took over. In this approach, vehicles are tested incrementally, slowly expanding the envelope of performance. The emphasis is on low cost from the outset. As Jeff Greason, president and co-founder of the private company XCOR Aerospace, has explained, it's easier to figure out how to do something reliably and affordably and then get more performance out of it, than to focus on the ultimate performance first and try to reduce its costs and increase its reliability later.

Thus the suborbital spacecraft in private development today can be scaled up to reach greater altitudes, extending the performance envelope further with new vehicle designs, while still maintaining low costs per flight. And if there are multiple companies building such vehicles, they'll be able to learn from each other's mistakes and innovations as well. Mach 5 can become Mach 7, Mach 7 can become Mach 12, Mach 12 can eventually become Mach 25 and orbit, as experience is gained and designs evolve.

The fundamental question, of course, is what will be the economic driver for it? Are there adequate private markets?

The conventional wisdom of the old space age is that a private market for space travel can only develop after crucial technological breakthroughs (remember Myth #4). But exactly the converse is true: Technology won't enable public space travel; public space travel and new markets will financially enable the development of the new vehicles necessary to satisfy the demand.

If one accepts the premise that low costs come from high flight rates, then absent any other large markets, large-scale public participation in space flight is essential to lowering the costs of access to space. Indeed, we know from numerous public opinion polls that at least half the U.S. population (and a higher percentage in Japan) wants to visit space, assuming adequate safety and low enough prices. The best thing about the space tourism market is that, unlike other postulated space market drivers—such as solar-power satellites, or space manufacturing, or lunar mining—it requires no technological developments other than the space vehicles themselves: the payloads are in fact already built, they are self-loading, and they have a simple interface to the vehicle (keister meets seat).

There remains somewhat of a chicken-and-egg problem here. Low costs are necessary to satisfy demand; new vehicles are necessary to provide low costs; demand from a promising but still-unproven market is necessary to build the new vehicles. Fortunately, thanks to the increasing interest from the public and investors, a small hummingbird egg is slowly starting to hatch. It may provide the beginning of a virtuous cycle of development that eventually results in hummingbirds, then sparrows, then chickens and chicken eggs, and eventually eagles.

In fact, there have been many deposits already taken for suborbital flights, and with the success of SpaceShipOne, it's becoming clear that they can be offered at a price acceptable to the market. Yes, people will pay more for trips into orbit, but that doesn't mean they'll pay nothing for suborbital flights. Based on hints about a SpaceShipTwo, with larger passenger capacity, and in light of Amazon.com founder Jeff Bezos's investment into his own suborbital venture, it is clear that some serious people believe that there's a business case to be made. Research from the Futron Corporation indicates that there's a market for at least several thousand tickets, even at a price level of a hundred thousand dollars.

In addition, as the vehicles become more capable, they may open up new markets for rapid delivery of people or cargo from one continent to another. They may find applications for potential military and remote sensing missions, and high-altitude or weightless research. They might even deliver components for orbital tourist hotels—like the ones Budget Suites owner Bob Bigelow is spending his own hundreds of millions to develop in North Las Vegas.

What are the implications of all this for President Bush's vision for space? NASA's Crew Exploration Vehicle is not planned to fly with a crew aboard until well into the next decade. Even ignoring its billions in development costs and the fixed costs of supporting it, it will likely cost at least $100 million per flight just for the expendable launcher to deliver it to orbit with its tiny crew complement.

If progress in the private sector can occur sufficiently rapidly—and based on the progress of companies vying for the X-Prize, it could be rapid indeed—it's quite possible that by the time NASA's *one* Crew Exploration Vehicle is ready to fly with its first crew of government astronauts, it may already be superfluous, superseded by multiple vehicles capable of delivering humans to and from orbit for a fraction of its costs. Indeed, it's not inconceivable that the first NASA astronauts back to the Moon since 1972—sometime around 2020—could be greeted by the concierge at the Luna Hilton.

Improving the Bush Vision

If the private sector does make rapid progress, with or without government nurturing, it will become clear long before the Crew Exploration Vehicle flies to orbit with a crew, let alone to the Moon, that the NASA policy has to be adjusted to the new reality. In the meantime, there are a number of specific steps the federal government can take to ensure that the new space vision doesn't get stuck in the deep ruts of the last two decades.

First, NASA should seed and encourage follow-on purses for the Ansari X-Prize, with new prizes for more altitude and higher velocities.

Second, NASA should fund other technology prizes, at a higher level than the new Centennial Challenges proposed in the president's new vision, for breakthrough technologies in such areas as orbital assembly, extra-vehicular activity equipment, and the exploitation of extra-terrestrial resources.

Third, the Bush administration should explicitly reverse the disastrous Clinton-era policy of assigning reusable launch systems to NASA as a monopoly. The Pentagon needs cheap routine access to space as well, in order to defend vital assets in orbit. Innovative agencies like DARPA could make a serious contribution to the problems of designing reusable spacecraft, beyond the two small reusable programs that it currently supports.

Fourth, Congress should remove impediments to passenger spaceflight by insisting on sensible regulatory regimes to relieve potential liability, remove regulatory uncertainty, and perhaps mitigate the high costs imposed on new companies and spaceports by the National Environmental Protection Act. There is currently legislation pending in Congress—the Commercial Space Launch Amendments Act of 2004—to do just that. It would codify into law the new FAA regulations on suborbital spaceflight, institute a "fly at your own risk" liability regime for passengers (while still maintaining the high degree of safety for uninvolved third parties on the ground), establish as part of the launch licensing process training standards for passengers and crew, and provide at least the potential for environmental relief, an issue that is currently daunting for potential licensees of both vehicles and spaceports. Passing this bill would also reduce the uncertainty of the licensing process, thereby removing one of the major barriers to investment.

Fifth, lawmakers should think creatively about modern analogs to the old airmail subsidy that helped create the modern airline industry in the 1930s. For instance, the government could offer to purchase thousands of tickets to orbit at unimaginably low prices. If the market responds to the demand, the government can use however many of them it needs for a more vigorous human space program (for both defense and civil space needs), then auction off the rest in the market, for citizens to do with as they wish. Or the government could offer to purchase thousands of tons of water in low Earth orbit at fifty bucks a pound—far cheaper than it costs today to get a pound of water into orbit—that could be used for rocket propellant and life support.

Sixth, the United States should renegotiate or withdraw from the 1967 Outer Space Treaty, which bans declarations of national sovereignty off-planet, and makes the defense of private property rights in space problematic. It was passed in the 1960s, in the full flower of the mood of decolonialization and socialism, to prevent a true space race and save funds for "terrestrial" needs. It has worked all too well, and it, like the old space age itself, is another relic of the Cold War. The time has come to update space law for the twenty-first century.

Finally, NASA should back off from the specifics of the president's vision—like the Crew Exploration Vehicle and the heavy-lift for putting it into orbit—and open up to ideas and services from non-traditional players. (NASA may be moving in this direction; we'll know for sure if they provide contracts for the new exploration architecture studies to other than the usual suspects.)

The loss of *Columbia* last year made it very clear that our space policy cannot continue on the inertia of the failed past, so it is to President

Bush's great credit that he established the goal of moving out into the cosmos. But it's not unreasonable to step back now and accept a little more delay as we try to determine how best to implement a policy to make that happen. Not just to make it happen, but to make it happen for *all* of us—not only NASA astronauts, and not only according to the five- and ten-year plans of government bureaucrats.

We no longer face a choice between old government space programs—shuttle and station—and new ones with the "right technical approach." The choice is more fundamental. We can remain constrained by the old familiar myths, or we can cast them off and take a fresh look at space policy. We can return to the path we might have taken, had we not been diverted by the need to defeat communism so long ago—or we can remain in the current state of NASA paralysis.

If we think in new ways, we can build a new space age on the ashes of the old—a space age not based on central planning and command but on organic growth; not one for a few public employees but for many private citizens; not just for the sake of science and national security and federal pork but in service to the growing wealth and education and entertainment of the planet. It can be a space age built on the traditional values that opened up earlier frontiers—individualism, free enterprise, daring, and liberty. And perhaps, decades from now, our descendants will look back on Earth from somewhere in space, and wonder why, for so many decades, we fooled ourselves into believing that it could have been done any other way.