Spacefaring Institute LLC

Solving the Commercial Passenger Spaceflight Puzzle

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Abstract

Twenty years into the 21st century, commercial passenger spaceflight to Earth orbit has yet to begin. The limiting factor has been a lack of acceptable safety. Achieving acceptable safety is an engineering responsibility. For aircraft, this is addressed in the engineering principles and practices that deploy aircraft that are airworthy.

This paper discusses how to develop a commercial passenger spaceflight industry with acceptable safety. In Part 1, current federal law governing the safety of "spaceflight participants" is discussed along with NASA's "human-rated" approach to their astronaut safety. A proposal by the International Association for the Advancement of Space Safety for certifying safety, based on NASA's "human-rated" system, is critiqued. In Part 2, the need for commercial passenger spaceflight systems to be airworthiness certified is explained and why this is not a hindrance to advancing human spaceflight. In Part 3, the Air Force Transatmospheric Vehicle (TAV) concept of a Boeing two-stage-to-orbit system is used to highlight how a commercial passenger spaceflight industry can now be started. The author proposes the creation of a federal port authority to undertake the development of the initial commercial spaceliners and spacelifters.

Released for public distribution.
20190919

Contents

Part 1

In 1968, a year prior to the Apollo 11 landing on the Moon, as a teenager I traveled to New York City for the first time. Growing up in a middle-class suburb in middle America, this was a remarkable experience—almost an alien encounter given the tremendous lifestyle differences between NYC and my quiet suburban city.

By coincidence, the now classic science fiction movie *2001: A Space Odyssey* was opening that week. Billboards harking the opening were everywhere. Along with a group of other teenagers on this trip, I made a point of seeing the movie. Stanley Kubrick, with the help of many aerospace engineers, had created a detailed, technically accurate depiction of what humanity's spacefaring near-future could be. The realism of Kubrick's vision of this future was visually staggering, especially with the Super Panavision 70 Cinerama version projected on the large screen of a major NYC movie theater—an immersive experience missed on the home screen.

Figure 1: Illustration of the Orion III spaceliner from the movie 2001: A Space Odessey. (Model credit: B. J. West. Illustration credit: J. M. Snead.)

Dr. Heywood Floyd's trip to space aboard the *Orion III* spaceliner—the orbiter part of a two-stage-to-orbit, fully-reusable commercial passenger spaceflight system—caught everyone by surprise. Compared to the three-person Apollo capsule atop the massive Saturn V, an ability to travel to space in comfort as a typical flight passenger, while wearing a business suit, set the standard for what the future of commercial passenger spaceflight "should be." It is a goal that, 50 years later, we are still struggling to achieve, puzzled why this has not yet happened.

The focus of this three-part article is on commercial passenger spaceflight safety—what this ethically means and how to achieve it now. Without acceptable safety, a real version of Floyd's travels to and within space will simply not happen. Despite what some would have us believe, outer space will not be permanently opened to commercial development and settlement without first establishing acceptably safe commercial passenger spaceflight.

The key question, of course, is what constitutes "acceptably safe" passenger spaceflight. Developing acceptably safe human systems is fundamental to the ethical practice of engineering. For some—the extraordinary risk takers—a real threat of death is part of the allure of the activity, such as climbing Mount Everest. In the civilized world—which many like myself hope to extend into space—risk is intentionally reduced through the implementation of the best-available engineering principles and practices. For air travel, these are embodied in airworthiness regulations. To truly open space to civilization, we must now carefully select the ethical path to achieve acceptable passenger spaceflight safety. Otherwise, more time and—especially—hard-to-replace funding will be wasted.

I am addressing this question in three parts. In this Part 1, I critique a proposal to establish a "regulated self-policing" approach to commercial human spaceflight safety certification. Finding the proposed approach, largely based on NASA's "human-rated" safety process, to be unethical for commercial passenger use, I explain in Part 2 why the airworthiness approach yielding acceptably safe passenger air travel should be extended to all commercial passenger spaceflight. In the concluding Part 3, I describe how to proceed with creating an initial commercial passenger spaceflight industry, including a technical approach for developing a "DC-3" passenger spaceliner, as the initial step in building a broader American astrologistics infrastructure.

Making spaceflight safety a national priority

On the recent 50th anniversary of the Apollo 11 landing, one evening national news broadcast featured a 58-year-old woman. She was excited about the possibility that the long-awaited commercial suborbital spaceflight participant rides—legally not commercial spaceflight passenger rides—were "about" to commence.

Mesmerized by the billionaire boys of space, the "objective" news media has turned a blind eye to the safety of their version of human spaceflight. It is reminiscent of the lead-up to the fatal 1986 flight of the Space Shuttle Challenger, which was to fly the first civilian, a teacher, into space. The inherent risk the teacher was taking was part of the mission hype rather than a serious discussion of whether the teacher was intellectually capable of understanding and assessing the risk of losing her life—of making a true informed consent. Flying on the Space Shuttle was, we were then told, almost as safe as flying on an airliner. On that early shuttle mission, the probability of loss of crew is now estimated to have been 1 in 10; not the 1-in-1000 the public was led to believe. Yes, 1 in 10! Do you think that she—a schoolteacher and mother—would have signed on had she known this? Would the public have accepted this? Of course not!

NASA had turned the process of selecting the teacher into a giant publicity stunt. The selected teacher became a national media star. After disregarding known safety hazards with the seals in the giant solid rocket boosters, problems exacerbated on the exceptionally cold launch day in Florida, as the teacher boarded the shuttle, looking every bit an astronaut in her flight suit, her safety was not NASA's foremost priority. The shocked world watched her and the rest of the crew die live on NASA TV. NASA's public image of flight safety integrity evaporated.

Figure 2: Loss of the crew of the Space Shuttle Challenger in 1986. (Credit: NASA)

We are repeatedly told that human spaceflight is inherently more dangerous. In its "human-rated" requirements document, NASA says "that a certain level of risk needs to be accepted to conduct human spaceflight." This thinking will only open space to the foolishly bold and brave—such as those who free-climb mountains or wingsuit glide down mountainsides—or those who are wealthy but particularly naive. I believe this mindset will lead to more Challenger-like failures in the future, such as the loss of the crew of the Columbia in 2003 due to poor safety decisions.

America must change course regarding human spaceflight safety. Achieving acceptable commercial passenger spaceflight safety must be made a national space policy priority if we are to open space to development and settlement. To understand why changes are needed, the two current federal approaches to human spaceflight safety must be explained.

The current federal law regarding suborbital human spaceflight is simply bizarre and immoral

Returning to the woman wishing to experience suborbital spaceflight, per federal law, assuring her safety is unimportant to the government. Should she undertake a commercial suborbital spaceflight, she will be required to sign a comprehensive waiver absolving everyone, especially including the government, of any liability should harm or death occur. Federal law presumes the average person has the wherewithal to ascertain the level of risk involved and the integrity of the spaceflight operations. This is nonsense!

To further confuse the topic of safety, federal law forbids the use of the standard commercial term “passenger,” instead substituting “spaceflight participant.” Only lawyers understand the legal significance of this change with respect to the owner/operator’s common law “duty to care” obligation regarding the safety of their passengers. The change to spaceflight participant generally abrogates this obligation.

One the same day as the 50th anniversary national news broadcast, the local news reported that several rides at the state fair were shut down due to not being assuredly safe. One was permanently shut down because of visible corrosion. Several years ago, a person died when a ride at that state fair failed. Now, per state law and common sense, the safety of the ride participants is paramount to the extent that the state government took on the final responsibility to inspect the rides to ascertain their safety and close rides where the safety could not be assured by operational inspection.

In our litigious world, public safety is increasing in importance—except in the area of human spaceflight. Per federal law, there is no current requirement for the federal government to inspect and ascertain the safety of a commercial suborbital human spaceflight system except to protect the safety of the public on the ground or flying in the shared airspace. Isn't this bizarre! A state government will inspect a fair ride called "Travel to Space" to protect the public's safety, but the federal government will not inspect and certify the acceptable safety of a commercial suborbital human spaceflight system to protect an American *spaceflight participant* engaged in this legal commerce. The current 2004 federal law addressing suborbital human spaceflight is immoral and must be changed.

NASA is currently responsible for orbital American spaceflight safety

For human orbital spaceflight originating in the United States, there is no current operational capability. NASA ended Space Shuttle operations in 2011 without, for the first time in US history, replacing an important national infrastructure with a better, safer capability. With NASA able to purchase rides to the International Space Station (ISS) from Russia, NASA did not have a true operational deficiency driving the development of an immediate replacement system. Instead, NASA focused on developing the Apollo-like Orion capsule spacecraft to be launched on the expendable Space Launch System and paying for the development of two smaller, less capable space capsules to transport astronauts to the ISS. This is the Commercial Crew Program.

My understanding is that, per federal law, the NASA administrator is the authorizing authority for approving human spaceflight on NASA systems. To implement this authority, NASA developed its "human-rated" approach to human spaceflight safety. The "human-rated" approach has evolved over the years. NASA NPR 8705.2C, Human-Rating Requirements for Space Systems, is the current statement of NASA's certification process and requirements. The following two quotations outline the purpose and responsibilities:

> *The purpose of this NASA Procedural Requirements (NPR) document is to define and implement the additional processes, procedures, and requirements necessary to produce human-rated space systems that protect the safety of the crew and passengers on NASA space missions.*
>
> *The Program Manager is expected to evaluate the intent of these technical requirements and use the talents of the development and operation team to design the* ***safest practical system that accomplishes the mission within constraints****. By doing so, the program is expected to arrive at an optimal solution that represents the best overall value*

> *considering cost, schedule, performance, **and** safety. [emphasis added]*

Note that safety is the “and” requirement, establishing its apparent importance in the hierarchy of program manager responsibilities; perhaps reflecting NASA’s acceptance of “a certain level of risk” and designing the “safest practical system that accomplishes the mission within constraints.” I think it is fair to say that these are inferior to the public’s expectations of the importance of safety for commercial systems providing public transportation services.

Space Shuttle probability of loss of crew

The Space Shuttle system was developed and operated under previous versions of NASA’s human-rated requirements. After the conclusion of shuttle operations, NASA was directed by its independent Aerospace Safety Advisory Panel to conduct a retrospective assessment of the probability of loss of crew (LOC) throughout the 30-year operational life of the system. The figure below shows the results. In this chart, an LOC probability of 1 in 10 missions plots as a value of 0.1 or 10 percent. Notations indicate what changes were made to the shuttle system that affected the estimated LOC. The Challenger mission was #25 while the Columbia mission was #113.

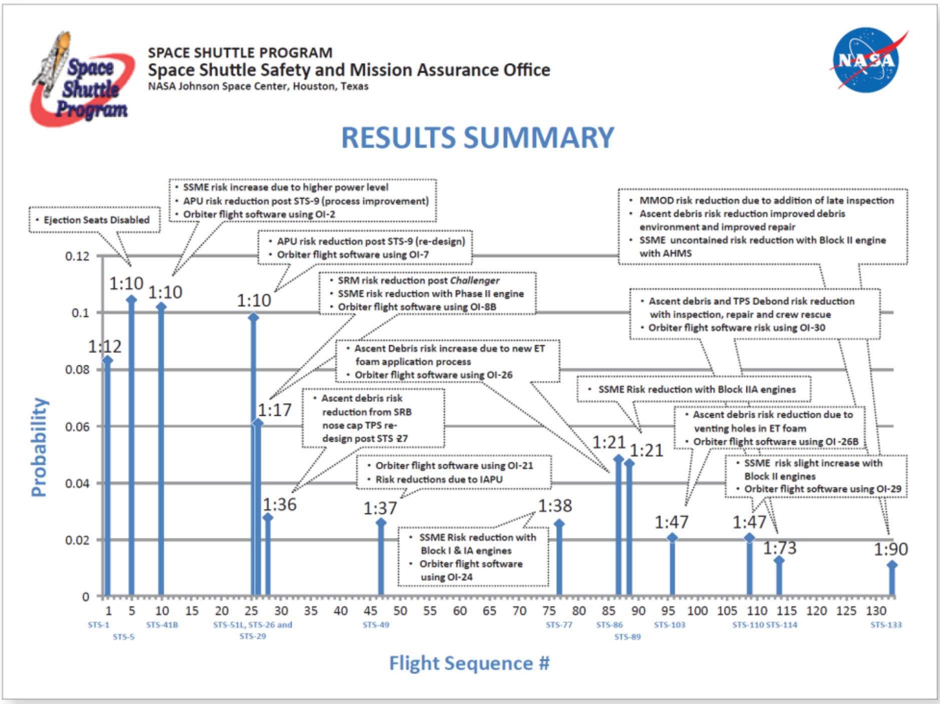


Figure 3: Summary of the retrospective analytical assessment of the probability of loss of crew over the 30-year operational life of the Space Shuttle system. (Credit: NASA.)

The panel's 2011 report noted, "In the Shuttle's case, the first flight risk as now retrospectively calculated was in actuality 1 in 12 for LOC, yet at least one analysis that existed at the time of the initial launch estimated the risk to be 1 in 1,000 or better." If the earlier analysis had predicted a 1 in 12 LOC probability on the first flight and this was known to the public, would the shuttle ever have flown? (Note that the retrospective LOC probability through Challenger mission #25 was 1 in 10.)

NASA made improvements to the Space Shuttle system throughout its operational life. Many of these, especially with the main engines, were noteworthy technological advances. However, even at the end of its 30-year history, the LOC probability had only improved to 1 in 90. By then, there had been two mission losses with the second mission—Columbia in 2003—being lost due to known but unresolved hazards related to the expendable External Tank's external insulation.

It is reasonable to suspect that NASA had an idea of the actual low shuttle LOC probability throughout most of the 30 years. This helps us to understand what NASA really means when saying, in NPR 8705.2C, "that a certain level of risk needs to be accepted to conduct human spaceflight" and designing the "safest practical system that accomplishes the mission within constraints."

It took the actions of NASA's quasi-independent safety panel—after decades of operations—to publicly identify this substantial discrepancy between the implied safety of NASA's "human-rated" safety regime and what was going on. This indicates that safety is apparently not the priority within NASA as the public has been led to believe as it is hard to believe that the true state of the Shuttle's safety was unknown within NASA. Essentially, "human-rated" safety was whatever the NASA astronauts were willing to sign on to do.

It is best to think of NASA astronauts as being comparable to test pilots from the early days of aeronautics. Test pilots were the final judge of the airworthiness of a new aircraft based on the technical information gained from close observation of the aircraft's development and the "feedback" from close program associates. Like test pilots, astronauts are employees voluntarily engaged in providing a service to their employer. Many employees volunteer for dangerous jobs—first responders, for example. Even then, however, normal life experience in the United States today does not provide an appreciation of what a 1-in-10 chance of death really means. Americans haven't experienced this level of risk since World War II-era combat such as bombing missions over Germany.

The SpaceX Crew Dragon commercial crew system

As previously mentioned, NASA's Commercial Crew Program is developing several additional means of transporting NASA astronauts to the ISS. Two of these, as seen below, involve the use of capsules that will be launched on rockets. Both are nearing their first human flights. Somewhat of a surprise, NASA astronauts will be the first to fly rather than company astronauts—a reverse of the normal flight test approach for government-acquired aircraft.

Figure 4: SpaceX's Crew Dragon capsule (left) and Boeing's CST-100 capsule (right) being developed in NASA's Commercial Crew System program. (Source: NASA.)

A SpaceX Crew Dragon test capsule, Demo 1, was the first to fly—uncrewed—to the ISS. On its return to the Earth, it was recovered and processed for further testing. The company's plan was to fly it a second time, also uncrewed, to activate and test the ascent escape system during an actual ascent.

Figure 5: Return of the Crew Dragon Demo 1 capsule flown unmanned to the International Space Station. This was the capsule subsequently destroyed during a static ground abort system test firing. (Source: NASA)

The Crew Dragon capsule integrates the rockets needed for ascent escape into the base of the capsule. My understanding is that this design approach was selected by SpaceX to enable the capsule to be used for other missions where a powered landing, rather than parachutes, would be used. The ascent escape rocket engines are called SuperDraco.

Figure 6: Earlier free flight test of the Dragon Crew abort system. This was a test capsule, not the flown capsule that failed. (Source: NASA.)

Prior to launching this vehicle on its second flight test, the capsule's SuperDraco engines were to be test fired in a ground static test. Less than a second before ignition of the SuperDracos during this ground test, a fire erupted destroying the capsule. As of this writing, investigation into the cause of the apparent failure is ongoing, although SpaceX says the most likely cause appears to involve valves that allowed fuel to leak through prior to pressurization of the system just before ignition. NASA has not yet released images of the capsule after that test, although some images and video are available online.

SpaceX's test program to that point appears to have been competently undertaken. After the failure, NASA commented that, "Over the course of development, SpaceX has tested the SuperDraco thrusters hundreds of times." In previous tests, the entire SuperDraco abort system had been test flown, but in a test capsule. My impression is that the ground static test was the first for a flight capsule during which a previously undiscovered design, manufacturing, or assembly error resulted in the fire. For this discussion of commercial passenger spaceflight safety, the reason why the Crew Dragon needed an ascent abort system is important to understand.

How "human-rated" safety drove the Crew Dragon design

At the end of its operational life, the Space Shuttle's estimated LOC probability was still only 1 in 90. For the follow-on human spaceflight systems, my understanding is that NASA initially aimed to achieve a 1-in-1000 LOC probability—comparable to what the public was led to believe at the start of shuttle operations. This LOC estimate was not just for ascent but covered everything from the time the astronauts arrived at the launch pad to their return to land. Some of the hazards were human created, such as incorrect manufacturing or assembly, while some were natural, such as solar flares and space debris impact.

Early full-mission LOC probability estimates apparently found that achieving 1 in 1000 would be difficult, especially with unknown natural hazards acting on skimpy capsules. Consequently, per my understanding, NASA set the LOC target at three times the last shuttle value, which is 1 in 270. For the Commercial Crew Program, SpaceX and Boeing elected to propose developing—and NASA accepted—transport systems using conventional rockets and space capsules. It was up to these companies to provide an integrated system with their LOC probability no worse than 1 in 270. (Note that preparing probability estimates are actually quite complex. Saying the probability should be no worse than 1 in 270 is a simplification.)

Had the proposed systems been "aircraft-like" by being fully-reusable, each production system could have been flight tested to establish its proper functioning and actual operational safety prior to delivery to NASA for use in transporting astronauts to the ISS. Under such conditions there would be no statistical justification for needing an emergency ascent escape system just as commercial airliners don't have such systems. (As I will discuss in Part 3, NASA had the opportunity to develop such a system.) Historically, space launch rockets have a launch failure rate around two to three percent. For example, the October 2018 launch of the crewed Soyuz experienced an ascent rocket failure, initiating an emergency separation and recovery of the capsule. By accepting proposals for systems that were not fully reusable, the need for an ascent escape system was imposed by NASA's "human-rated" requirements. NASA's decision to accept such proposals was, apparently, an implementation of their core willingness to accept "a certain level of risk" substantially worse than that of an airworthiness certified system.

Using the historical rocket launch failure rate, the probability of a rocket failure would be around 1 in 50. Without an ascent escape system, the crew would, of course, be lost. Hence, the purpose of the ascent escape system is to boost the LOC probability to a minimum acceptable risk. As NASA said after the Crew Dragon test incident, individual SuperDraco modules had been tested hundreds of time. (New jet engines are similarly tested, often for thousands of hours simulating a wide variety of flight and engine conditions, including bird ingestion.) What the accident showed was that spacecraft incorporated elements not previously tested in the flight configuration, contained parts that had critical but undetected flaws in the as-manufactured condition, were damaged during installation or handling, and/or suffered from a previously unknown failure mode. Hopefully, the accident investigation will identify the cause.

With the destruction of the Crew Dragon spacecraft in the April test, my understanding is that the capsule being built for the Demo 2 mission, which was to fly the first humans to the ISS, will now be used for the uncrewed ascent escape system test. It is possible that, after any needed changes or added inspections are identified, the SuperDraco engines will also be ground static test fired before the flight test. If these two tests are successful, then the Crew Dragon “type design” will have been shown by ground and flight testing to meet this part of NASA’s human-rated requirements—provided the minimum analytical probability LOC remains better than 1 in 270.

As will be discussed in Part 2, once an aircraft’s type design is approved and production begins, flight acceptance testing of each production aircraft is independently conducted to ensure it is airworthy before being operationally used. Only then is an airworthiness certificate issued for each aircraft. At that point, the probability of a serious accident is very low—which is why airliners, or the Orion III spaceliner, do not have emergency in-flight escape systems. Contrast this with the clear need of the commercial crew vehicles to have an ascent escape system due to the rocket having a likelihood of 1-in-50 or so of failure. Also, unlike each production aircraft, the flightworthiness of each rocket and capsule system will not be tested prior to its operational use.

In 2017, commuter aircraft in the United States—operationally equivalent to commercial crew spacecraft—suffered a serious accident in one in around 80,000 flights, with one fatality in roughly 600,000 flights. (At this commuter fatality rate, the Crew Dragon could transport more than two million people to space without a fatality.) The major airlines suffered no fatalities that year despite flying more than nine million flights. This is an indication of the statistical difference between NASA’s “human-rated” approach to achieving the “safest practical system that accomplishes the mission within constraints” and airworthiness that achieves true acceptable safety.

Space Safety Institute proposal

Several months ago, the International Association for the Advancement of Space Safety and, primarily, the International Space Safety Foundation proposed to the federal government the formation of a Space Safety Institute (SSI) to certify commercial human spaceflight safety. (Note that the proposal also uses the term “passenger” when discussing future commercial spaceflight.) I was surprised when a copy of the proposal was not made available to the public. Following my Freedom of Information Act request, the federal government provided the version they had been given. (The version of the proposal I received appears to be a draft dated March 2019, which is just prior to the Crew Dragon test accident.)

The foundation proposes to approach commercial human spaceflight safety certification as is now done for many commercial products involving human safety, with some form of safety certification provided through a non-government body.

> *The purpose of this report is to provide the rationale for the establishment of a (commercial) Space Safety Institute in the U.S. as “regulated self-policing” entity. It would be an open consortium of industry, space agencies and regulators to efficiently perform standardization and certifications activities, conduct joint research, and provide educational and professional training opportunities, within a broad framework of mandated policies and rules…*
>
> *The proposed Space Safety Institute builds on concepts, experience and practices of various programs and sectors and may be archetypal of future direction in other fields (e.g. aviation)…*
>
> *In conclusion, the Space Safety Institute would support a regulatory model that can react quickly and efficiently to technological advancements while exercising effective controls on commercial space systems developments. The Space Safety Institute would perform standardization and system certification activities, as well as educational and research activities. The regulator would establish broad policies and keep a general oversight role of institute’s processes and activities, while concentrating on other issues, which lie outside the Space Safety Institute scope, as space traffic management and international coordination.*

The Space Safety Institute proposal would make NASA’s approach to assuring astronaut spaceflight safety the basis for their certification processes.

> *Safety policy and technical standards used by NASA Crew Commercial Program represent an* ***excellent*** *reference from which U.S. commercial human spaceflight industry can develop policies and standards to be used on non-NASA suborbital and orbital commercial spaceflight programs. Furthermore, industry can use the NASA CCP certification program as model for developing their own independent third-party certification process. [Emphasis added]*

The proposal's inference that NASA's safety standards are "excellent" prompted my previous lengthy discussion of how I see the adequacy of NASA's "human-rated" safety requirements. Obviously, I do not agree that NASA's approach is excellent. Especially, I do not believe that it is a suitable model for commercial passenger spaceflight systems.

What the proposed Space Safety Institute would do

The proposal states:

> *The SSI main mission would be to establish and manage a safety certification process for commercial human rated systems which is lean, effective, and does not stifle innovation. A process that allows maximum design freedom and quick and efficient reaction to technological advancement.*

A careful reading of the SSI's mission shows that certifying only systems with demonstrated acceptable safety is neither mentioned nor implied in this brief mission statement. Instead, the foundation argues to adopt the NASA human-rated approach as the logical basis for "A process that allows maximum design freedom and quick and efficient reaction to technological advancement." I interpret this as the foundation arguing that safety must play second fiddle to technological advancement. Is this really needed?

The British and French developed the ground-breaking Concorde supersonic airliner in the 1960s within the commercial airworthiness regime. This was less than 20 years after the first supersonic flight. (We are now nearly 40 years after the first Space Shuttle flight.) Boeing developed their substantially all-composite 787 airliners within the same airworthiness certification regime. Today, many companies are developing piloted and unpiloted commercial passenger flying taxis within the FAA certification regime.

Experience in the real world of aeronautics shows that making safety a priority fits well within a disciplined and well-structured system engineering development program. Airworthiness certification does not stand in the way of progress, but actually lubricates the gears driving progress forward by minimizing operational risk and encouraging future investment, just as is now happening with flying taxis.

The Space Safety Institute's role, sitting between the regulatory entity—the FAA—and private industry will need to be defined, probably through legislation.

The Space Safety Institute would be somehow a "middle-man" between the regulatory body and the commercial space companies for the benefit of both parties. The SSI would provide standardization and safety certification services as a "recognized organization" approved by and operating under oversight of the regulatory entity.

A part of the institute's organization would be a Safety Review Panel. Here is how the proposal identifies the panel's role:

> *The SSI Safety Review Panel (SRP) will be responsible for conducting flight safety reviews. The SSI SRP will assist the developer/operator in assuring that safety critical systems, subsystems and operations are appropriately designed* ***and verified****. Specifically, the SSI Safety Review Panel will perform the following functions:*
>
> a. *Assisting the developer/operator in interpreting safety requirements in a manner consistent with applicable requirements, and providing recommendations for implementation.*
>
> b. *Conducting safety reviews as appropriate during various phases of system development and operation.*
>
> c. *Evaluating changes to system that either affect a safety critical subsystem or create a potential hazard to interfacing systems, or crew.*
>
> d. *Evaluating safety analyses and safety reports, and processes Non-Compliance Reports.*
>
> e. *Ensuring the resolution of system safety issues.*
>
> *At the successful conclusion of safety reviews cycle, the SSI Safety Review Panel Chair would submit a Certificate of Flight Readiness (CoFR) to the regulatory organization (FAA). [Emphasis added]*

A key element of the panel's proposed responsibility is "assuring that safety critical systems, subsystems and operations are appropriately designed and verified." If the intent is to verify that each production system is demonstrated to be flight-worthy by independent operational testing, as is done with aircraft, then the panel is just undertaking the FAA's governmental role in verifying airworthiness. In such a case, what is the value added of the SSI? Shouldn't the FAA be organically capable of doing this?

If, instead, the Institute's intent is to adopt NASA's "human-rated" approach where independent operational testing of each production system is not needed in order to obtain a Certificate of Flight Readiness, then what real value would such a certificate have? The SRP's certification appears to just become a checklist, not an independent flight-worthiness verification that would establish public confidence in the use of each operational system used for commercial passenger spaceflight services.

I conclude that the Space Safety Institute proposal is not an effective substitute for the federal government's organic responsibility to ensure the acceptable safety of commercial passenger spaceflight, just as the government does for commercial air travel. Further, I believe the term "human-rated" should be banned from use when discussing commercial human spaceflight safety. It is totally misunderstood by the public and is, especially, misleading to those being asked to make an "informed decision" about their personal safety.

Segregate the commercial passenger spaceflight regulatory path going forward from NASA

NASA was created in 1958 to separate human spaceflight from military space activities at a time when Cold War tensions were very high. President Eisenhower, for several reasons, did not want any public focus on highly secret military space programs, primarily being undertaken by the Air Force, to enable satellite observation of the Soviet Union and to build an effective nuclear missile deterrent capability. The threat of a nuclear "Pearl Harbor"—first with bombers and, later, with ballistic missiles—drove Eisenhower's national security priorities throughout most of his administration.

President Kennedy, also for various reasons, gave NASA a political shot of financial adrenaline with his human lunar landing challenge. Only months into office, and after both the Cuban Bay of Pigs fiasco and the Soviets putting a human into orbit, he needed a political win. He decided to literally shoot for the Moon. Billions flowed to NASA and its contractors to make this happen.

Not disparaging the substantial technological and scientific accomplishments made by NASA, it has become a political juggernaut. Despite plainly stupid decisions costing lives and limiting commercial space development, it is sustained by Congress persistently funneling non-military aerospace money to favored Congressional districts and states. That Congress has consistently acquiesced to NASA's misleading "human-rated" approach to safety establishes the true unimportance of astronaut safety to Congress. That, in 2004, after the loss of Columbia, Congress legally made commercial human spaceflight participant safety also unimportant reinforces this conclusion.

What is OK for NASA is not necessarily good for everyone else when it comes to safety. Despite the clearly apparent dangers of NASA human spaceflight, it has no shortage of the bold and brave seeking the glory and rewards of becoming a NASA astronaut. More than 18,000 people applied to become NASA astronauts in the most recent application cycle. What has made this approach politically work for NASA has been the extremely low flight rate of NASA's human missions, combined with the hero worship of astronauts, especially by children. When only a handful of missions are undertaken a year, as the Space Shuttle experience demonstrated, failures are sufficiently infrequent that Congress, after appropriate public handwringing, forgives and forgets so that the money can keep flowing to key Congressional districts and states. Meanwhile, the clear lack of safety makes meaningful conventional commercial investment unwise.

Given these circumstances, setting NASA apart and letting NASA handle its astronaut safety as Congress permits is appropriate. Congress holds NASA's purse strings and, thus, controls NASA's safety morality. However, proposing to use NASA's commercial crew approach to safety as their "model for developing their own independent third-party certification process" for commercial passenger spaceflight is fundamentally unethical and the fatal flaw in the foundation's Space Safety Institute proposal. True commercial passenger spaceflight will involve much higher flight rates requiring much, much lower analytical probabilities of loss of life. Acceptable commercial passenger spaceflight safety will not arise from NASA's inherently broken safety system. Instead, we must turn to what has worked for air travel and extend this to all commercial passenger spaceflight: the hands-on federal government regulation of commercial passenger spaceflight systems to establish their airworthiness.

In Part 2: For decades, space advocates have argued that the federal government should stand aside and let private industry take the lead. This wishful thinking has led to the decades-long stagnation of America's human space enterprise. Fifty years after our first landing on the Moon, Americans remain planet-bound. Contrast this stagnation with the rapid progress in commercial air travel that began with Congress enacting legislation regulating commercial air travel. Within 30 years of the Wright Brothers' first flights, airworthiness-certified airlines were operating, offering routine and acceptably safe (for that time) commercial passenger air travel. This industry has now extended worldwide. On July 24, 225,000 commercial passenger flights occurred worldwide, all within government-regulated airworthiness regimes. In Part 2, I explain why airworthiness should be extended to all commercial passenger spaceflight.

Part 2

In 1968, the movie *2001: A Space Odyssey* forecast routine and frequent commercial passenger spaceflight to, from, and within space within three decades. Most in the aerospace community likely saw this as a reasonable forecast given the rapid advancement of human spaceflight capabilities in only a decade. Yet, five decades later, such commercial passenger spaceflight remains a puzzling, elusive goal.

Now with the American public and Congress awakening to China's growing challenge to America's free world leadership, as happened in the 1960s with the Soviet Union, space has again become an arena of technological competition as an element of national ideological cold warfare. As was recognized many decades ago at the end of World War II, space is the new "high ground." Military experience clearly shows that national technological and operational domination of the high ground is essential for our freedom and prosperity. President Trump is calling for broad changes to, in part, answer China's growing technological challenge, but also to support the broad expansion of American private enterprise into space as space industrialization and settlement begin. In the White House's August 30 statement of fiscal year 2021 research and development budget priorities, "American space exploration and commercialization" will be a priority. We must now organize and effectively utilize our industrial base to boldly accelerate America spaceward, just as we did in the 1950s and 1960s.

Many recognize that acceptably safe passenger spaceflight is essential for the human opening of space to permanently take hold. Recently, the International Space Safety Foundation proposed one approach for undertaking the safety certification of commercial passenger spaceflight systems. In part 1 of this article, I discussed the faults of this proposal, focusing on the proposal's reliance on NASA's dysfunctional "human-rated" approach to safety embodied in their Commercial Crew Program. Further, I do not believe the proposed Space Safety Institute is needed given that it would duplicate what the federal government must do.

If commercial passenger spaceflight is to be legal commerce in the United States, I believe the Federal Government has a constitutional and moral obligation to regulate the safety of this new industry—precedence established by the federal safety regulation of railroads, foods, drugs, and, especially, airlines, for example. This section examines the application of airworthiness certification to commercial passenger spaceflight in more detail. This sets the stage for, in the next installment, my proposal on how to jumpstart commercial passenger space travel by developing the first airworthiness certified spaceliners.

Lessons from aviation history

A century ago, coming out of World War I, aviation was starting to blossom. Private industry rapidly advanced aeronautical technologies, developed new aircraft types, and expanded commercial aviation to transport passengers. The number of accidents, often with fatalities, started to increase. With an industry aimed at the rich and famous, Congress acted beginning with the Air Commerce Act of 1926 focusing on improving the safety of airline flight operations. This included the issuing of airworthiness certificates. On December 7, 1926, the Aeronautics Branch issued the first airworthiness certificate after a government inspector flew the aircraft, establishing that that particular aircraft was airworthy prior to its delivery to the customer. On March 29, 1927, the first airworthiness "type certificate" was issued. This established the expected airworthiness of a particular aircraft's design. However, each production aircraft still required an individual airworthiness certificate to independently validate that it was built per the approved type design and that, through independent ground and flight inspection, it was airworthy. On May 15, 1930, airlines engaged in interstate passenger commerce were required to obtain a separate certificate to legally operate. On May 21, 1936, the famed DC-3 airliner was airworthiness certified with the first airline use on June 25, 1936.

Figure 7: A Buhl Airster CA-3, a three-place open biplane was the first aircraft to receive an airworthiness certificate. (Source: NARA)

It is noteworthy that from the start of federal airworthiness regulation in 1926, modern commercial airline operations began within a decade using what many believe to be the first profitable airliner, the DC-3. Federal regulation focusing on safety did not hamper the rapid development of air commerce but, in fact, promoted rapid progress by giving investors and the public increasing confidence in the safety and practicality of commercial passenger air travel. This was especially true during the late 1950s when jet travel became the preferred mode of air travel. The argument by some that human space travel inherently requires a different, less ethical approach to safety is without merit.

Addressing the common law "duty to care" obligation

British common law, widely adopted within the United States, defines obligations of those engaged in legal commerce. Those engaged in legal commerce are not free to operate however they wish but are constrained by the liabilities imposed by law.

Not being an attorney, my understanding is that common law states that those engaged in commercial passenger transport have a legal "duty to care" to protect the safety of their passengers. It is my understanding that the use of "passenger" in describing the services offered, such as operating a "passenger ship" or commercially offering to transport people to a destination, implies to the public that the duty to care obligation holds. A failure to faithfully meet this duty can subject the owners and operators to civil and, possibly, criminal consequences. Common law liability, in various forms, dates back thousands of years.

From a design and engineering perspective, the duty-to-care obligation means that the best available engineering and operating safety principles and practices are to be used, not just what can be afforded by the available funds or as directed by the owners. For commercial air travel, federal legislation makes the government an independent judge of whether the best available safety principles and practices, defined by government airworthiness regulations, are properly used.

The Federal Aviation Administration (FAA), with more than 1,300 engineers, scientists, inspectors, test pilots, and other safety professionals, defines its aircraft airworthiness certification process in this manner:

> *The FAA's aircraft certification processes are well established and have consistently assured safe aircraft designs. As part of any certification project, we conduct the following:*

- *A review of any proposed designs and the methods that will be used to show that these designs and the overall airplane complies with FAA regulations;*
- *Ground tests and flight tests to demonstrate that the airplane operates safely;*
- *An evaluation of the airplane's required maintenance and operational suitability for introduction of the airplane into service; and*
- *Collaboration with other civil aviation authorities on their approval of the aircraft for import.*

Essentially, my understanding is that airworthiness regulation shifts the common law “duty to care” burden from the aircraft builder/owner to the government to ensure that the best practice airworthiness regulations are faithfully being followed. This approach segregates safety from the commercial pressures of profits, public relations, and employee job security. I believe that only government civil servants can properly carry the ethical burden of making airworthiness oversight function acceptably well.

Today, for commercial passenger spaceflight, the “duty to care” obligation is not discussed, at least not in public. I find this disconcerting as it implies a lack of senior government and corporate attention to implementing the ethical engineering processes necessary to meet this common law safety obligation. Just as the aeronautical industry pushed for Congressional engagement to improve commercial air safety in the 1920s, it’s time for the human spacefaring industry—if it truly embraces protecting the public’s safety—to push for Congress to make comparable changes in federal legislation to protect and advance commercial passenger spaceflight safety. Every day that the duty-to-care safety obligation is not faithfully met is a day wasted in terms of advancing America’s ascent to becoming a true human spacefaring nation.

Change “spaceflight participants” to “passengers” in the law

In 2004, Congress was told that ensuring safety needed to be ignored if rapid commercial advancements in human spaceflight were to be achieved. Congress implemented this “strategy” by legally defining a human engaged in spaceflight commerce as not a “passenger” but instead as a “spaceflight participant” where the common law duty-to-care obligation is generally not applicable. Thus, while traveling to the launch site by commercial air, the spaceflight participant would be protected by airworthiness regulation. However, while traveling to space, the spaceflight participant is left to figure out for themselves if they are safe. Further, they are mandated by law to waive any liability that the federal government would normally have to ensure their safety. This is immoral foolishness!

Congress needs to reverse its flawed 2004 approach to human spaceflight participant safety and extend the mandate for airworthiness to commercial passenger spaceflight. Whether a commercial passenger takes an airliner to distant lands, uses a suborbital spaceplane, or travels to, from, and within space, they should be afforded the same ethical protection of their safety by the federal government through mandated airworthiness certification. The human spaceflight industry should welcome this change.

NASA is not the leader to make this needed change

Even though NASA labeled their new astronaut transport capability the Commercial Crew Program, substantial federal investment was required to develop these systems. Unfortunately, from the perspective of creating a technological path to future commercial passenger transport, this approach has failed, as discussed in Part 1. For the two capsule systems under development, NASA is struggling to achieve an analytical probability of loss of crew no worse than 1 in 270.

Figure 8: Illustrations of commercial crew capsules to transport NASA astronauts to/from the International Space Station. (Source: NASA.)

The fundamental failure was NASA's decision to regress technologically back to expendable systems rather than advance to fully reusable systems. Going this route was a top-level government policy decision that, I expect, NASA had a substantial role influencing. It was another of a series of poor decisions by or for NASA that has brought us to this point of struggling to be able to fly Americans to space safely and routinely.

Fifty years ago, as the Apollo program was reaching its goal, interest in the post-Apollo human space enterprise emerged. Around 1970, a senior government panel, led by the then vice president, evaluated the options and recommended developing a fully-reusable, two-stage-to-orbit, vertically-launched, horizontal-landing system: a

TSTO VTHL system. The stated goal was routine and frequent human and payload transport to and from low Earth orbit with airline-like operations. This would have been the first part of an expanding national astrologistics infrastructure—a vital spacefaring capability discussed since the early 1950s.

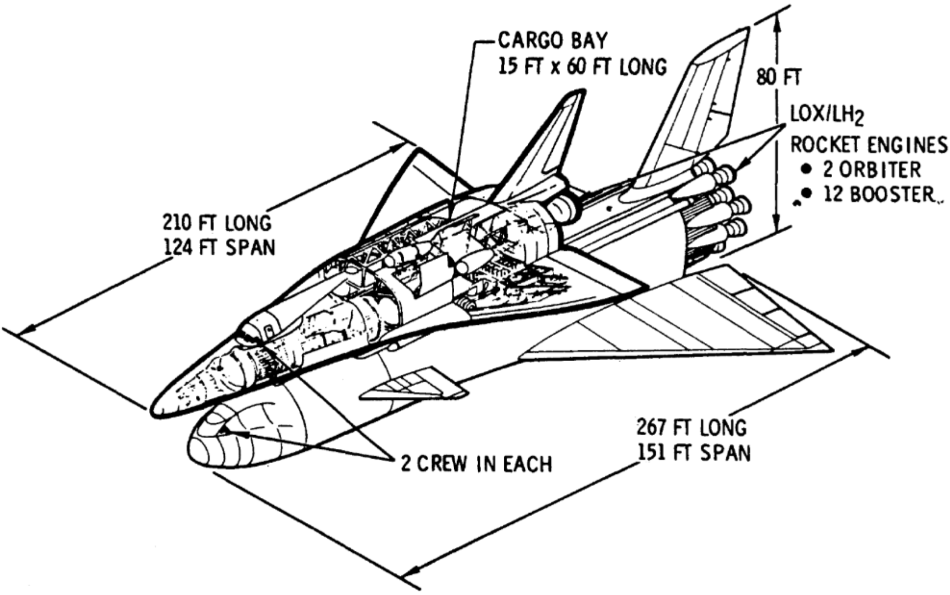


Figure 9: TSTO HTHL concept Rockwell 1971 TSTO HTHL concept. (Source: US Air Force.)

Subsequent budget-driven decisions transformed this fully-reusable system into the substantially-expendable/refurbishable Space Shuttle system, with all of its inherent safety and operational limitations. Acknowledging that, in the early 1970s, developing a fully-reusable TSTO system would have been challenging, it could have received a measure of airworthiness certification, something the revised design as the partially-reusable shuttle could not achieve.

Airworthiness requires full reusability so that prototype systems can be thoroughly flight tested to ascertain the overall airworthiness of the type design and, subsequently, each production flight system can be in-flight inspected to establish that it is airworthy prior to being placed into service. Each mission of the Space Shuttle was a substantially new system with potentially embedded manufacturing flaws and assembly/refurbishment mistakes or damage. Hence, its airworthiness was unknown when it was placed into service.

Whether the loss of the inherent operational safety of a fully reusable original design was a consideration in the decision to go with the partially expendable Space Shuttle system is unknown. Summaries of the decision process indicate it was driven by politics and development budget considerations. However, most believed the assertion that human spaceflight was unavoidably a high risk.

(Apollo 13 had happened in 1970 just three years after the Apollo 1 on-pad fire that killed the crew.) Thus, a reduction in operational safety was likely not a significant consideration.

Fast forward three decades to 2002. The need to replace the shuttle with a better, safer system was apparent to government officials. The Air Force and NASA were tasked to jointly propose a program to prototype such a capability. After the failures of the NASP/X-30 and X-33 single-stage approaches, a TSTO VTHL system, similar to that envisioned in 1970, was selected. For many months, NASA and Air Force designers and engineers met at the NASA Marshall Space Flight Center to develop a technical baseline and broad development proposal. Many of the Air Force engineering contingent were, including myself, from Wright-Patterson Air Force Base (WPAFB) where Air Force crewed aircraft development is managed and aerospace plane research had been underway since the late 1950s.

As the TSTO design space narrowed to a mutually acceptable prototype solution, NASA made a key management decision to go it alone. Rather than jointly developing a prototype that would then lead to likely separate NASA and Air Force operational systems, NASA decided to skip the joint prototype and immediately develop its own small fleet of operational systems. At that point, this opportunity to transform human spaceflight collapsed. The Air Force would likely not invest in an operational system without first undertaking a prototype program or do a separate prototype at the same time NASA developed an operational system.

In early 2003, the shuttle Columbia, with its crew, was lost during reentry due to damage to its wing's thermal protection system by an uncorrected known hazard. As with the political circumstances after the loss of the Challenger in 1986, NASA and its political supporters went into NASA/shuttle preservation mode. After the loss of the Challenger, the International Space Station (ISS) emerged as the justification to continue the shuttle program. After the loss of the Columbia, finishing the construction of the ISS justified restarting shuttle operations. However, in 2004, with the end of the shuttle program in sight, then President George W. Bush announced an ambitious lunar and Mars human exploration program. Rather than seeking a reusable system to replace the shuttle, NASA turned back to expendable rockets and capsules with "human-rated" safety. This effort eventually became the Orion spacecraft for deep space missions and the separate Commercial Crew Program.

To those from the aircraft side of the Air Force engaged in the TSTO planning, we were dumfounded by NASA's decision to skip to operational systems. I believe the decision was a pure space politics power play by NASA to keep American human spaceflight to themselves. This decision was likely supported by the space side of the Air Force that did not see—and still does not see—any need for crewed military space missions.

Had this TSTO system prototype been undertaken, Air Force airworthiness requirements would have been implemented using the systems engineering expertise at WPAFB. All military aircraft are airworthiness certified before they are placed into operational use. All experimental/prototype military aircraft receive a limited airworthiness certification before Air Force test pilots/personnel fly in the aircraft. Generally, this airworthiness certification is not issued through the FAA but by the responsible Air Force system development commander following an independent airworthiness assessment. The prototype TSTO would have achieved the equivalent of a preliminary airworthiness certification, followed by the equivalent of a type certification and individual airworthiness certificates for the operational military systems. Once the initial small Air Force fleet was built, private industry could have built and operated commercial versions, whose airworthiness would have been certified by the FAA, to undertake commercial passenger transport. This is the opportunity that vanished with NASA's intransigence and the tragic loss of the Columbia, also due to NASA's intransigence. These poor decisions have cost America a generation of lost time and clear leadership in human space operations.

Courtesy of the Spacefaring Institute LLC

Figure 10: YF-23 Northrop-McDonnell Douglas YF-23 prototype Advanced Tactical Fighter in the National Museum of the United States Air Force. Two YF-22s and two YF-23s were built and test flown many times. The author was on the independent first-flight review team that reviewed the design and fabrication of these aircraft to provide an independent airworthiness release before Air Force test pilots flew these prototype aircraft. The YF-22 won the competition. Prior to acceptance by the Air Force, each production F-22 received the military equivalent of an airworthiness certificate after being inspected, to demonstrate compliance with the approved design and proper fabrication and assembly, and test flown to show its airworthiness. Airworthiness is maintained through prescribed inspections and modifications. (Credit: J. M. Snead.)

We now need to embrace airworthiness to achieve commercial passenger spaceflight

To meet the "duty to care" obligation, airworthiness certification of all commercial passenger spaceflight systems is ethically mandatory—something all engineers working on such systems should acknowledge. Thus, in pursuing its Commercial Crew Program, NASA is now on a separate path from where the rest of America's commercial human space enterprise needs to go. The rest of the nation's spacefaring enterprise now needs the capability to develop, manufacture, and operate fully-reusable, airworthiness certified human spaceflight systems.

Focusing on the immediate need for commercial Earth-to-orbit-and-return passenger service—illustrated by the Orion III spaceliner from 2001—technology maturity indicates that a TSTO solution will be needed. While future technology advancements may enable a single-stage solution, the current national requirement is to develop an operational commercial service. We must be careful not to fall, once again, into the trap of putting all of our efforts into achieving a single-stage capability as was attempted with the failed National Aerospace Plane/X-30 and NASA's X-33 programs. Some, especially in the research community, will strongly urge that this be done. Such recommendations must be rejected!

There will be two primary initial markets for commercial TSTO systems. One will be commercial passenger transport to and from space. Initially, this would provide NASA with the ability to transport its astronauts to the ISS—to do what the Commercial Crew Program is intended to do but with an airworthiness certified system. This would provide NASA with the ability to much more frequently rotate personnel through the ISS to perform experiments and, when needed, undertake specialized repairs and upgrades. As this commercial capability serving NASA comes online, it may be expected that other commercial Earth orbit destinations will emerge, perhaps using various private space station capabilities under development. While the operators of the Commercial Crew Program cannot legally sell "passenger" services, the operators of the commercial spaceliners would. The spaceliner developers and operators would have this emerging market all to themselves.

The second primary market will be an operational military capability to transport military personnel and materiel to Earth orbit to support US Space Force, US Space Command, and US Space Guard operations. It is quite possible that this will not, at least initially, be a unique military system. Rather, as is done with commercial airliners, some of the commercial spaceliners would be under contract to operate with “military” crews to fly military spacelift missions. Some commercial flight crews would be reserve Space Force officers temporarily placed on active duty to perform these missions with mission control handled through the US Space Command. Should a future president wish to travel to space, one of these flight systems would temporarily become Space Force One.

In Part 3: In Part 1, I explained why the International Space Safety Foundation’s proposed approach to certifying human spaceflight safety, based on NASA’s “human rated” safety system, is substantially inadequate to meet ethical commercial passenger spaceflight needs. Here, I explained why airworthiness regulation should be extended to commercial human spaceflight by revising federal law. In Part 3, I propose my approach to jumpstart the commercial passenger spaceflight industry under an airworthiness regime.

Part 3

Recently, I casually discussed the topic of space with a millennial professional working outside the aerospace community. I related watching the Apollo 11 mission when I had just graduated from high school. After I answered the surprising question of what year that happened, this very nice person wondered out loud about why so little had happened since then. This observation is valid. Fifty years after landing on the Moon, we are still taking “expeditions” to low Earth orbit—the uniqueness of which has long since faded away.

I thought I could best answer the question of why so little had happened by starting with a common point of reference. I asked if they had ever seen the movie 2001 as I was going to mention the famous scene of the Orion III spaceliner and talk about the lack of commercial passenger spaceflight a generation after it “should” have existed. Responding to my question about seeing the movie, I was asked if this was another Apollo movie. This millennial had never even heard of *2001: A Space Odyssey*. Others I have spoken with assert that Dr. Floyd’s peaceful ride into orbit aboard the Orion III spaceliner is decades in the future—with an implied “if ever.”

In Part 2, I related how around 2002 NASA had the opportunity to replace the Space Shuttle with a better system. The Air Force—primarily the Wright-Patterson Air Force Base (Wright-Patt) contingent where I worked—and the NASA Marshall Space Flight Center were tasked to evaluate jointly developing a fully-reusable, two-stage-to-orbit (TSTO), vertical-takeoff, horizontal-landing (VTHL) spaceplane system. This was essentially what the Space Shuttle was originally meant to be back in 1970. Eventually, after months of meetings, using its well-developed bureaucratic finesse, NASA turned this opportunity down. In early 2003, Columbia and its crew were lost during reentry due to NASA’s intransigence, across decades, to fix a known flight safety hazard. The post-incident politics threw the fully-reusable opportunity into the trash can of history as NASA fought to keep the shuttle flying.

The situation with the Air Force has not been much better. Air Force support for human military spaceflight has waxed and waned since the late 1940s. In 1948, just one year after separating into a separate service, space and satellites emerged as an area of focus by the Vice Chief of Staff. This was viewed as a manned effort. “Rocketing into space without men on board was as unthinkable to the Air Force as conquering the sea without sailors was to the Navy, or the conquest of the continents without soldiers might have been to the Army.” [1] Just seven years later, a young major working on the first Air Force ICBM program quite vocally expressed his view of the Air Force’s fledgling first spaceplane project, Dyna-Soar: "We wouldn't give you a wooden nickel for your damned winged, boost-glide bomber concept. The Intercontinental Ballistic Missile is the ultimate weapon!" [1] And so it has gone ever since, with echoes of these sentiments embedded in the Air Force's resistance to the formation of a true US Space Force.

Beginning in the late 1970s, senior Air Force interest in human military spaceflight again surfaced. A political battle began within the Air Force acquisition community for "ownership." The political battleground was the Wright-Patt Transatmospheric Vehicle (TAV) concept studies. Out of Wright-Patt's effort came the most achievable, fully-reusable, two-stage-to-orbit spaceplane system that I know. Long buried in the dustbin of history, in Part 3, I resurrect this concept to illustrate how America can promptly begin to build a robust commercial passenger spaceflight industry.

The Orion III spaceliner

Figure 11: Mock-up of the Air Force Dyna-Soar spaceplane introduced in Las Vegas. (Source: USAF.)

Spaceplanes had been presented to the public going back to, at least, Wernher von Braun's ideas of the early 1950s. During the heady times after Sputnik in 1957, Wright-Patt began the development of the Dyna-Soar rocket-boosted spaceplane. After six years of development and just as flight hardware was starting to be built, in 1963 the program was abruptly cancelled. The goal of this "experimental prototype" had been suborbital flight testing in 1965 with an orbital capability by 1970. Boeing was the prime contractor and roughly $5 billion, in today's dollars, of effort was made before the program was cancelled. A four-minute video shows the 1962 unveiling of the mockup in Las Vegas, while a longer Air Force film explains Dyna-Soar.

With the nation's intense interest in space due to the growing arms race with ballistic missiles, the first satellites, and plans for the first human space missions, getting to space with something resembling normal aircraft-like commercial flight operations was a hot topic within the aerospace community. Starting in 1957, the Air Force sponsored conceptual design studies of single-stage and two-stage aerospace planes capable of achieving orbit after taking off from a runway. This effort spawned a large number of spaceplane concepts throughout industry and the government. The aerospace plane studies identified that substantial technology development was still needed. These became the focus of government and industry R&D, such as the development of scramjet propulsion.

A couple of years after Dyna-Soar was cancelled, film director Stanley Kubrick began to develop the classic science fiction movie 2001: A Space Odyssey. Based on a short story by Arthur C. Clarke, it was a bold, technology-focused look intending to convey what our spacefaring future could be by 2001. Kubrick enlisted aerospace experts to make his movie as technically correct as possible. For example, memos were written about how the hibernation of the astronauts would be done. Highly realistic sets and models were developed with a substantial focus on minute details that are barely visible in the film.

After a long sequence setting the premise for the plot, the shift to the future of 2001 opens in Earth orbit. A commercial spaceliner is approaching a large, partially constructed, rotating space station. Dr. Heywood Floyd is the lone passenger in what appears to be a fairly conventional passenger compartment. He is asleep, indicating that the travel to space, at least for Dr. Floyd is just another routine business trip.

The spaceliner is the Orion III. I use it in these articles to illustrate what commercial passenger spaceflight should look like. The movie's fictional Orion III was conceived in 1966 as a TSTO spaceflight system. Although not shown in the movie, it was ramp-launched with the 175-ft long Orion III spaceliner mounted atop a nearly identical Orion I first-stage booster. The two stages separated at Mach 14 with the spaceliner continuing to orbit, as seen in the movie. Noting that Kubrick called upon expertise from across the aerospace industry, the "design" of the Orion III appears to have benefitted from some engineering thinking. A 3-D model of the Orion III is shown below.

The Orion III would hold 30 passengers and a crew of three. Assuming an average of 250 pounds (1113 kilograms) for the crew and passengers—passenger, baggage, and incidentals—the net payload weight would be 8,250 pounds (3740 kilograms) delivered to the space station.

Figure 12: Illustration of the Orion III spaceliner from the movie 2001: A Space Odessey. (Model credit: B. J. West. Illustration credit: J. M. Snead.)

Air Force interest in human military spaceflight returns

In late 1963, the politically struggling Dyna-Soar program was abruptly cancelled by the new Johnson administration just two weeks after President Kennedy was assassinated. The stated reason was that Dyna-Soar duplicated NASA's human spaceflight efforts, satellite-based reconnaissance, and ICBMs for nuclear weapon delivery. Throughout the Eisenhower, Kennedy, and Johnson administrations, human military spaceflight was shunned. Fortunately, as spaceplane technologies advanced, new Air Force leadership reopened this closed door just a decade later. As I recall, the illustration below was on the cover of Airman magazine in the 1970s. Note the "U.S. Aerospace Force" on the S-17 military spaceplane. (Since the 1960s, the "S" designation has been listed for use for spaceplanes.)

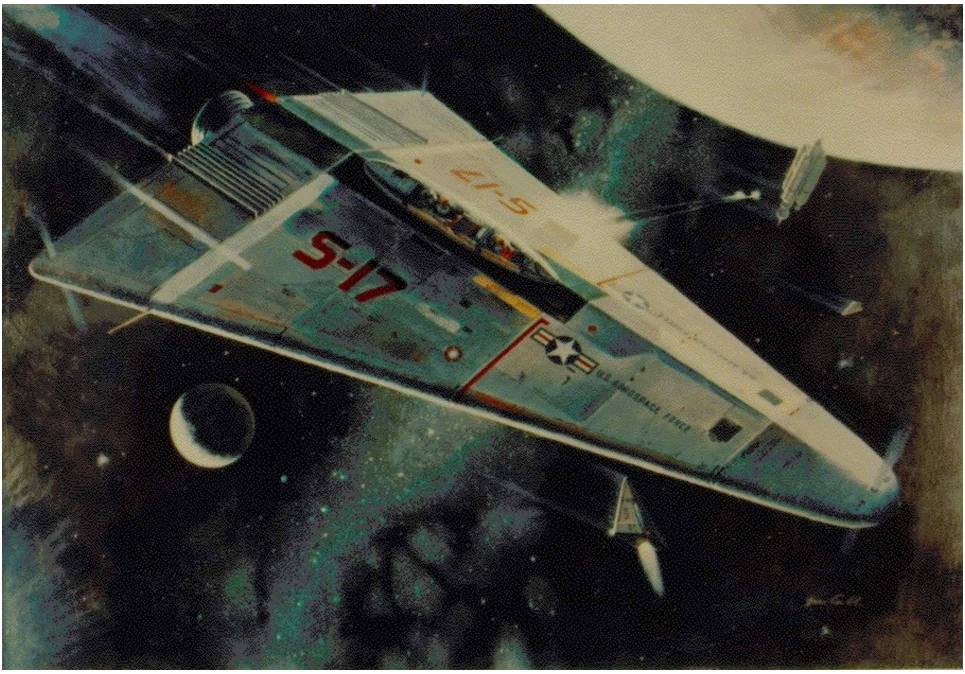


Figure 13: Air Force wall art of S-17 U.S. Aerospace Force spaceplanes. (Source: USAF.)

Boeing's Reusable Aerodynamic Space Vehicle

As mentioned in Part 2, the need to develop more aircraft-like space access was well understood in the late 1960s. Throwing expensive rockets into the sea would not open the space frontier to routine access. A Vice President-led committee proposed that a fully-reusable, TSTO VTHL system be developed by NASA. Politics and budget cutting turned this into the partially-reusable/refurbishable Space Shuttle. Its cumbersome and expensive operations prevented it from becoming the "DC-3" opening space as intended.

At the same time that NASA was beginning the development of the Space Shuttle in the early 1970s, the Air Force again began to explore the roles and missions of human military spaceflight. Surprisingly, this was initiated by the "space" side of the Air Force, who had historically opposed human military spaceflight. One of these explorations was with Boeing, looking at military aircraft-like SSTO horizontal-takeoff, horizontal-landing (HTHL) concepts. By the end of 1974, through Boeing Independent R&D, the Reusable Aerodynamic Space Vehicle (RASV) concept was defined.

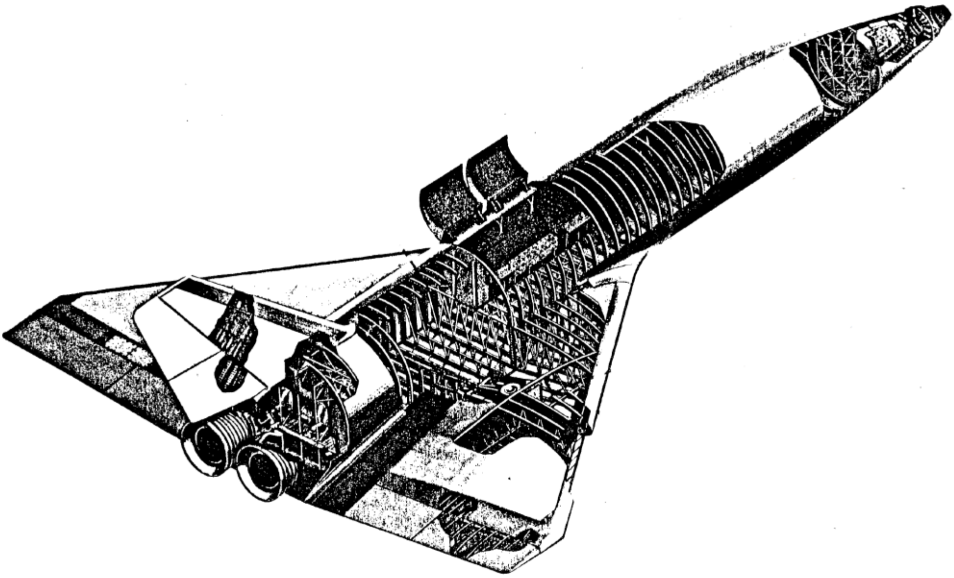


Figure 14: Structural design of the Boeing Reusable Aerodynamic Space Vehicle. (Source: USAF.)

Boeing's conceptual design engineers had developed a hot structures design that would take off and land on a runway. (A "hot structures" design does not have a separate thermal protection system over most of the airfame but, instead, uses high-temperature materials. This was how the Boeing Dyna-Soar spaceplane was designed.) Two Space Shuttle Main Engines (SSME) were used on the spaceplane. Takeoff would use a large SSME-powered sled, from which the spaceplane would separate at 400 miles per hour (640 kilometers per hour) after a ground roll of a little over a mile. (The use of a takeoff-assist is what makes this a quasi-SSTO concept.) After liftoff, the spaceplane would accelerate to orbit while the sled would be decelerated on the runway in about 7,000 feet (2,160 meters); a jet pack could be used in place of the sled to ferry the spaceplane. After liftoff, the spaceplane would execute an aerodynamic turn to the desired heading before accelerating to orbit or, for many military missions, completing only a once-around flight. The net payload capability to a low orbit, without an aerodynamic turn, was around 20,000 pounds (9,070 kilograms), depending on the amount of on-orbit maneuvering required.

In today's dollars, the recurring operational cost was estimated to be about $4 million at a flight rate of 25 flights per year for the fleet. Yes, $4 million or about $200 a pound! The estimated program cost through the production of four flight units, in today's dollars, was $14 billion, taking about eight years. In 1979, the Boeing president offered to build a prototype RASV for about $4 billion in today's dollars.

In 1979, the Acting Secretary of the Air Force, in a memorandum to the Air Force Chief of Staff (the service's senior four-star general officer), wrote about the RASV:

> *I have been interested in the Reusable Aerodynamic Space Vehicle (RASV) concept for a number of years. Such a single-stage-to-orbit system has the potential of providing us with a manned platform that can be over any point on earth in less than a hour. The RASV could perform a wide variety of very important missions, including reconnaissance, rapid satellite replacement and space defense to name just a few.*
>
> *I would like to express my continuing support for the RASV efforts. As you know, both SAC [Strategic Air Command] and ADCOM [Aerospace Defense Command] have already addressed RASV requirements. In addition, I believe we have invested about $225K prior to FY 79, and plan to spend about $1M this year and $2M in FY 80 for RASV. Although the technology has a ways to go, I believe the potential benefits of such a system warrant this level of effort. I hope you will give this program your support as well.*

In short, the potential of human military spaceflight was again officially on the service's radar. The "air" side of the Air Force jumped at the opportunity to pursue human manned spaceflight.

Transatmospheric Vehicles at Wright-Patt

At the end of the 1970s, with renewed senior-level interest in human military space access, the various Air Force laboratories, system development organizations, and operating commands began to undertake needed studies and map out possible future acquisition plans. It is not possible, unlike in some privately held companies, for the Air Force Secretary to snap his or her fingers and start a major new weapon system acquisition. It takes several years of effort to reach the point where a technically defendable proposal to develop a new weapon system can be presented to Congress as part of the service's proposed future budget. This preparatory work is called development planning.

With the RASV seeking to achieve aircraft-like operations with a system that was, essentially, an advanced aircraft, the Air Force's Aeronautical Systems Division (ASD), located at Wright-Patt near Dayton, Ohio, acted on the Acting Secretary's interest to begin studies in 1979. ASD was one of the divisions of the Air Force Systems Command (AFSC) which was responsible for managing the acquisition of new Air Force weapon systems. Another AFSC division, Space Division (SD), acquired ballistic missiles, expendable launch vehicles, and satellites. (SD had initiated the RASV study.) At that time, in addition to many smaller programs, ASD was managing the acquisition of the F-22, C-17, and B-2.

In early 1983, as ASD was about to issue short-term study contracts to define useful solutions, SD's sensitivity to ASD's focus on space access became apparent and a political hot potato. Especially, they opposed any use of "space" in the title such as in "spaceplane". After the name sensitivity became apparent, the name "Transatmospheric Vehicle" or TAV was invented. It did not use space, spaceplane, or shuttle, but it correctly identified the intended operational characteristics of the system much as do the generic names "bomber" and "fighter." In late 1983, ASD's Deputy for Development Planning wrote:

> *We believe the Transatmospheric Vehicle Program is a unique potential application of atmospheric and exoatmospheric (space) capabilities. The thrust of our ongoing TAV investigation is to predict, project, and evaluate military missions for this type of system. Once established, these missions will be translated into conceptual TAV systems that use the latest in technology advancements and projections. An evaluation will be conducted into the merit of these conceptual TAV designs against alternative system applications.*

In May 1983, ASD released $1.6 million in today's dollars for Phase 1 study contracts to define TAV concepts. The dollar amount of these initial contracts is usually low, with the contractors often investing company funds in the efforts. What is important to the contractors is that the Government is expressing official interest in possibly acquiring a new weapon system that would be a major new source of income. Multiple contractors submitted concepts by the end of 1983 and the ASD development planners evaluated these during the first part of 1984.

Several quasi-single-stage-to-orbit (SSTO) concepts were submitted, including the RASV. All were found to have technical and operational issues. The Lockheed concept, for example, required a short-duration solid rocket booster capable of producing in the ballpark of two million pounds of thrust to lift the TAV off its launch stand and accelerate it to a minimum safe flight speed and altitude. This was impractical—operationally unsuitable—for routine military airfield operations.

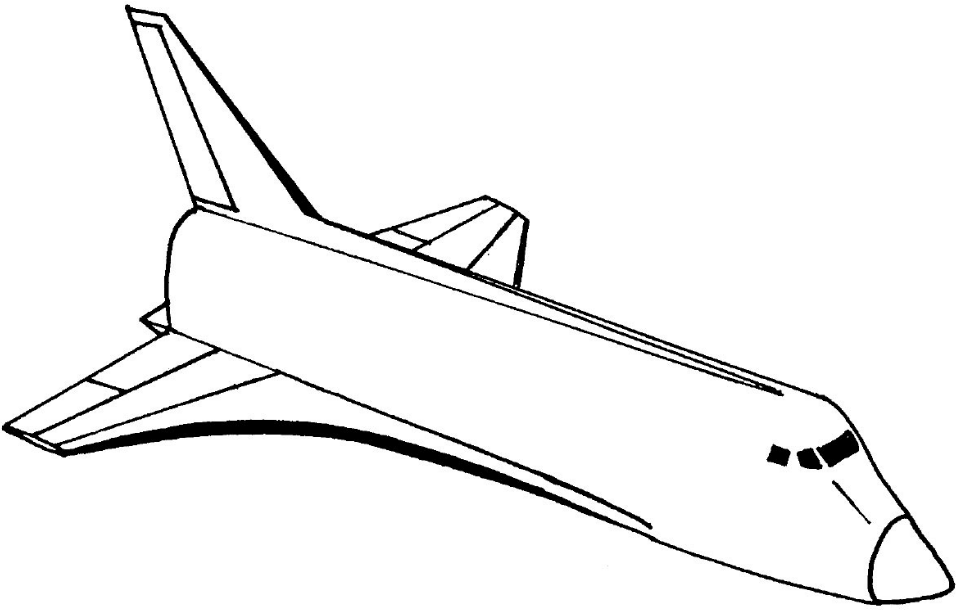


Figure 15: Lockheed quasi-SSTO TAV concept from 1983. (Source: USAF.)

The RASV also had several identified issues that removed it from consideration. Among these was the need to accelerate to 400 miles per hour for liftoff. This was substantially faster than the takeoff speed of most aircraft. The need to start four SSMEs on the ground was also a concern.

Boeing's TSTO TAV

Besides the RASV, Boeing submitted two other TAV concepts. One, very similar to the Dyna-Soar spaceplane, used an expendable external tank to carry the propellants. It would be air-launched from the top of a Boeing 747, much as NASA used a 747 to release the Space Shuttle Enterprise during unpowered landing tests. This was also not a practical operational system.

Fortunately, a two-stage-to-orbit (TSTO) TAV concept was also proposed by Boeing that was operationally suitable with good performance. From a design perspective, it was a "sweet" design. In 1984, Boeing filed for and, in 1989, received U.S. patent 4,802,639 for this concept.

As shown in the illustrations below, the Boeing TSTO TAV uses a large aircraft carrying the orbiter in its belly. Mating uses a standard aircraft ground tug to tow the orbiter under the carrier aircraft. The carrier aircraft uses eight large military turbojet engines. This enables the mated vehicles to taxi under their own jet power to complete propellant loading and undertake takeoff without the use of the rocket engines. Obviously, this approach has minimal ground support requirements compared to a traditional vertically-launched large rocket. Also, the carrier aircraft would be used to ferry the orbiter as needed and used to airdrop the orbiter during developmental testing. As shown in the patent, the carrier aircraft can also be used to launch experimental aircraft carried in place of the orbiter. (Another series of illustrations is here.)

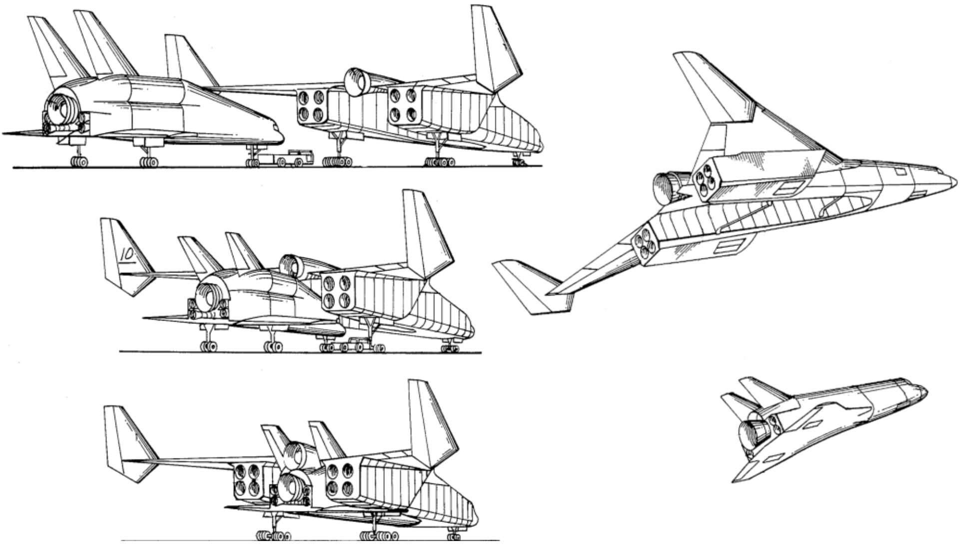
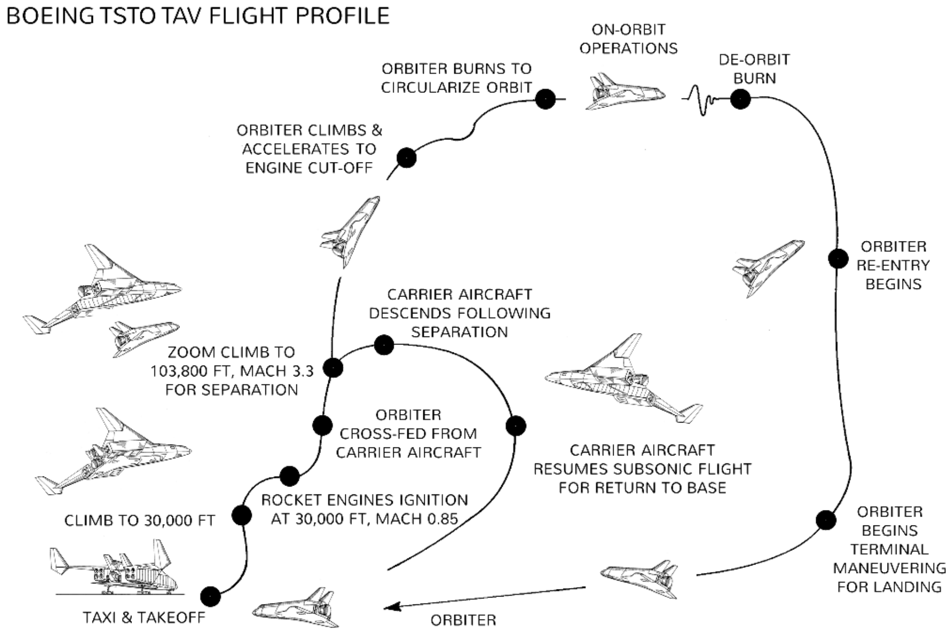


Figure 16: Cleaned up illustrations from the Boeing patent of the TSTO TAV orbiter mating (left) and separation (right). These illustrations show the -111 orbiter configuration. (Credit: J. M. Snead.)

The flight profile is shown below. The mated systems take off under airbreathing power, climbing to 30,000 feet (9,140 meters) altitude. To begin the ascent to orbit, the two SSMEs ignite and the mated systems begin a zoom climb to 103,800 feet (31,640 meters) and Mach 3.3, where the orbiter is released. (These Mach 3 flight conditions are less severe due to the higher altitude than that experienced by the SR-71 or the XB-70.) The orbiter continues to climb and accelerate to orbital conditions while the carrier aircraft returns to the airfield under airbreathing power. Once the orbital mission was completed, the orbiter would re-enter and land unpowered as the Space Shuttle orbiter did.



(Based on Boeing patent US 4,802,639. Credit: J M. Snead.)

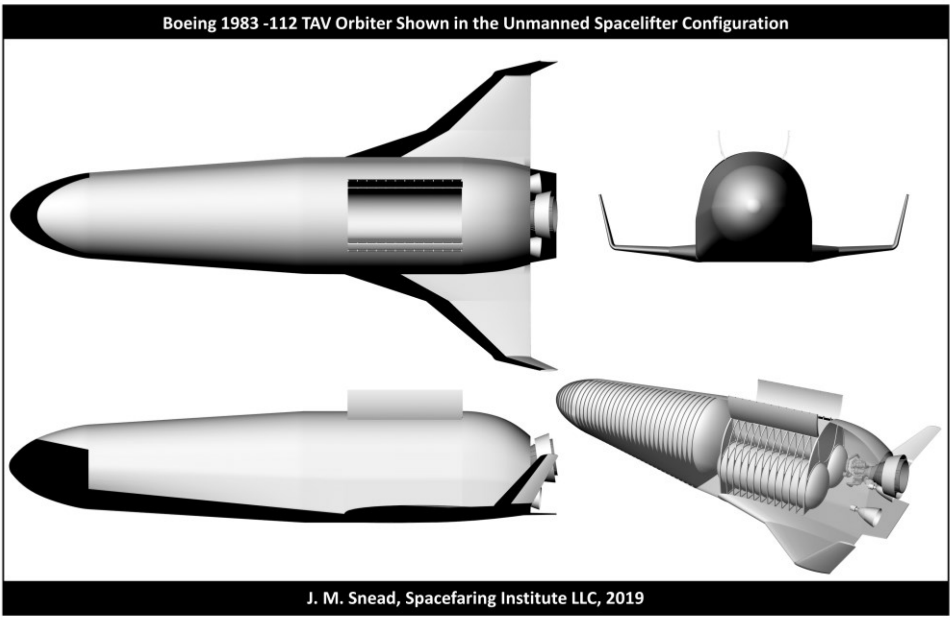
Figure 17: Boeing TSTO TAV flight profile illustration based on the Boeing patent. (Credit: J. M. Snead.)

Boeing configured two orbiters to be carried by the same carrier aircraft. The -111 orbiter used a hot structures approach similar to RASV. The -112 orbiter used a cool structures approach with an external passive thermal protection system such as was used on the Space Shuttle. Both are about the same size as the Space Shuttle orbiter. The -111 orbiter has a payload bay, 11 feet (3.35 meters) in diameter by 21 feet (6.4 meters) in length. A payload up to 30,000 pounds (13,600 kilograms) could be carried on a once-around mission due east, with minimal fuel for orbital maneuvering. For an orbital mission due east from the Kennedy Space Center to a circular orbit of 250 nautical miles (463 kilometers), the delivered payload would be around 10,000 pounds (4,530 kilograms) with a crew of two. (Of course, this system can take off from many other locations.) An orbiter configured as an uncrewed spacelifter would have a somewhat larger payload capability. Note that these performance estimates are 35 years old indicating that better performance may be achievable today with updated analyses.

In 1983, Boeing estimated an initial operational capability being achieved in 1995—before 2001! The estimated development and acquisition cost for 50 orbiters and an appropriate number of carrier aircraft was $62 billion in today's dollars. A 20-year operational and support cost for a total of 2,000 missions was $16 billion in today's dollars or $8 million per mission. The return payload would be 5,000 pounds (2,270 kilograms), or about ten passengers and three crew, with the orbiter configured as a spaceliner. A passenger ticket would then be about $2 million. Later analysis indicated that a 50-orbiter fleet could support in the ballpark of 1,000 missions per year. If the fleet has 20 spaceliners and 30 spacelifters, 4,000 passengers and 3,000 tons of cargo could be transported to LEO each year. Clearly, such a commercial spaceflight system would need to be airworthiness certified.

The illustrations below are of the -112 orbiter, which would have a Shuttle and X-37-style thermal protection system (TPS). In the 1983 trade study, with the carrier aircraft being primarily sized to the -111 orbiter, the -112 orbiter loses some useable propellant volume due to the TPS. This reduced the payload performance by about 25 percent. These were, of course, very preliminary estimates, 35 years ago.

The internal arrangement is very straightforward, with a ring-frame-supported liquid hydrogen tank forward and two liquid oxygen (LOX) tanks mounted aft under the payload bay. Structural frames transfer the payload and LOX inertia loads into the primary structure. A single SSME, with an altitude compensating moveable nozzle, and two RL10-type engines are mounted at the rear.



Boeing 1983 -112 TAV Orbiter Shown in the Unmanned Spacelifter Configuration

J. M. Snead, Spacefaring Institute LLC, 2019

Figure 18: Boeing 1983 -112 TAV orbiter in the unmanned spacelifter configuration. (Credit: J. M. Snead.)

TAV technology readiness assessment

I joined the small TAV project office 35 years ago as the “project engineer.” My primary role was to interface with the Air Force labs and the ASD engineering directorate—my home office—and to lead the formal “tech eval” to determine industry’s readiness to proceed into full-scale engineering development. This “tech eval” was done per the guidance of a General Officer Steering Group and involved about 60 Air Force engineering and scientific experts. If the tech eval and associated reviews indicated that industry was ready to proceed, that all requisite critical path technologies were sufficiently mature, and that the general class of solutions satisfactorily addressed a valid operational shortfall or identified threat, a new weapon system development effort would be recommended with requested funding. ASD used this same process prior to starting its F-22, B-2, and C-17 programs then underway.

The Boeing TSTO TAV concept was used as the baseline for this assessment. In the late summer of 1985, based on the completed tech eval and other considerations, ASD formally recommended establishing a system program office, programming needed development funds, and initiating full-scale engineering development of a TSTO crewed capability.

In 1992, as I just recently found out, Boeing engineers updated the TSTO design and performance analysis. This was published in the AIAA 93-4161 technical conference paper, “A Reusable Two Stage Launch System”. Expressing conclusions similar to those from the ASD 1985 tech eval, the Boeing 1993 paper’s summary states:

> *The TSTO approach as described herein, exhibits significant potential benefits to the space access/transportation capability by offering system features which are prerequisite to long term affordability and utility. Principal among these tangible benefits are:*
>
> - *Full reusability of flight hardware – no expendable or recurring flight hardware required.*
> - *Two-stage efficiency – designed in margins/derating for life cycle reliability/growth.*
> - *Airplane type infrastructure – efficient launch processing, increased basing flexibility.*
> - *Jet powered horizontal takeoff and landing – offset launch, mission recall.*

The decision whether to start a major weapon system development comes from a complex mix of funding, politics, and Air Force/DoD/ Congressional priorities. AFSC declined to support a new program start, ending the TAV effort in the late summer of 1985. Shortly thereafter, the National Aerospace Plane (NASP) SSTO program was started based on presidential direction. The NASP/X-30 program was to build an experimental aircraft to conduct research flights at high Mach numbers with the goal of being able to achieve orbit using a single stage. The X-30 program ended in the early 1990s when the inability to confidently predict high Mach number scramjet performance made finalizing the design impossible. By the time NASP ended, TAVs would have been nearing flight.

The takeaway is that, in 1985, industry was judged ready to begin developing a fully-reusable TSTO system, possibly becoming operational prior to 2001. The very public emergence of the National Aerospace Plane program in late 1985, followed in early 1986 by the loss of the Space Shuttle Challenger, rapidly swept aside the TAV study results. Very little about this effort was recorded in permanent Air Force historical reports. While Boeing had filed for a patent while the TAV study was underway, this would not be published until 1989. Unaware of the patent filing, for 20 years I assumed the concept was proprietary until I found the patent around 2007. Government employees are not permitted to divulge company proprietary information.

The illustration below shows the fictional Orion III spaceliner with the spacelifter configuration of the Boeing -112 TAV orbiter.

Figure 19: The 175-ft long fictional Orion III spaceliner and the 114-ft long conceptual Boeing TAV -112 orbiter are shown to the same scale. The TAV orbiter would have two versions: an unmanned cargo spacelifter and a passenger spaceliner. (Credit: J. M. Snead.)

Boeing's recent spaceplane efforts

My recent inquiries with Boeing found that they had completely forgotten about the TSTO concept and had no records of it. However, Boeing has been involved with two relevant efforts—the X-37 and X-40 spaceplanes and the DARPA Experimental Spaceplane.

In 1998, Boeing built the X-40A Space Maneuver Vehicle to perform drop tests of a small, uncrewed spaceplane. This was followed by the X-37B Orbital Test Vehicle that has now been launched five times into space performing long-duration missions. The spaceplane configuration enables an unpowered landing similar to that baselined with the Dyna-Soar spaceplane and used by the Space Shuttle orbiter. The X-37B, along with the Space Shuttle orbiter, validate that unpowered landings can be used for normal operations and that passive thermal protection systems are adequate. The X-37B is launched atop a large rocket within a protective shroud.

Figure 20: Boeing X-37B after landing. (Credit: USAF)

Boeing is also developing the DARPA Experimental Spaceplane. This is to demonstrate, by flight test, the practicality of a fully-reusable first stage capable of achieving around Mach 10 during its ascent prior to releasing an expendable rocket-boosted second stage.

Boeing's design incorporates a modified SSME as the primary propulsion system. This year, a test version of the SSME was ground fired ten times over ten days to demonstrate the readiness of this engine for the flight testing. A goal of the DARPA program is to fly the spaceplane ten times over ten consecutive days.

In developing and flight testing the DARPA spaceplane, Boeing will have measured flight loads, actual installed engine performance, aerothermal loads and the airframe's structural response, and the cryogenic liquid hydrogen/liquid oxygen propellant system performance. A validated set of avionics, guidance, communication, and telemetry systems will have been demonstrated. Most importantly, the mass property engineers will have actual versus predicted mass properties improving the accuracy of future preliminary design efforts. Similarly, the system planners will have actual versus predicted manufacturing costs and schedules.

Figure 21: Boeing Experimental Spaceplane. (Source: DARPA.)

From my perspective, this Boeing spaceplane is an engineering test bed for the TSTO TAV orbiter. When combined with the operational experience from the Space Shuttle orbiter and the X-37B spaceplane, the engineering development risk of the Boeing TSTO TAV is being substantially reduced. We now have an opportunity to shorten the development time and reduce the development risk of commercial spaceliners and spacelifters that should not be ignored!

Airworthiness, suitability, and effectiveness considerations

Little information has been released about the two spaceplane efforts. Hence, I have no understanding of what airworthiness criteria may have been imposed on their designs. My expectation is that little, if any, safety-related criteria was required other than that associated with the handling of the spaceplanes on the ground and range safety for spaceplanes during flight.

Had Wright-Patt led the development of the Boeing TSTO TAV system in the 1980s, operational safety (airworthiness), suitability, and effectiveness would have been baked into the program from the outset as is done for all Air Force aircraft. Military aircraft are required to be airworthiness certified because they usually carry crew and passengers but also because some carry weapons, including nuclear weapons. Hence, operational safety is the foundation when a new flight system is being developed. To ensure that the new system meets the using command's needs and is financially affordable to operate, suitability and effectiveness requirements are also included. These are all factored into the program from the outset to preclude sudden "gotchas" as the program transitions from the prototype to the production and operation phases.

If the TAV program had been started as ASD recommended, achieving an initial operational capability in 1995, these military TAV systems—both the carrier aircraft and the orbiter—would have been airworthiness certified by the Air Force using a modified version of the Air Force's military aircraft criteria. Subsequentially, a commercial version of the military system, with orbiters configured as both spacelifters and spaceliners, could have come into operation by 2001. These would have been airworthiness certified by the FAA, building on the Air Force's airworthiness certification experience and lessons learned. With one change, what we should have done in 1985 is what we now need to do to jumpstart an American commercial passenger spaceflight industry.

How the jet age came into being

Recognizing that some will be skeptical of the approach I outline below, it is helpful to briefly look back at how America's world-leading commercial passenger airliner industry came into being in the 1950s.

Immediately after World War II, the Air Force began a rapid transition to jet-powered aircraft. Boeing was selected to develop the jet-powered B-47 bomber. The B-47 pioneered the swept wing design for large aircraft with the jet engines mounted on pylons under the wing. This was a significant design improvement that is still standard for subsonic airliners. (Others were embedding the engines in the wing, which created safety and maintenance issues.) Jet propulsion, combined with the swept wing, enabled flight at near sonic speeds at high altitudes for long distances. Building on the B-47 success, the Air Force initiated the development of the longer-range B-52 that, after Air Force prodding, incorporated a swept wing design. Developing these two jet bombers at government expense provided Boeing with the expertise needed to transition this swept wing jet technology to commercial airliners. The Air Force programs also developed the jet engines and other related auxiliary equipment Boeing needed.

Figure 22: Development of the modern jet transport design. (Credit: J. M. Snead.)

In the early 1950s, Boeing bet the company on building what became the jet-powered, swept-wing Boeing 367-80 prototype, where the "-80" indicated the 80th design iteration. (Publicly, this was referred to as the 707 prototype.) The prototype aircraft, fitted with a refueling boom, was demonstrated to the Air Force. Having the need for a new jet tanker to keep up with the jet bombers, the Air Force quickly placed an order for what became the KC-135. Boeing used their growing jet-powered design and manufacturing expertise in building the KC-135 to quickly produce the very similar final design of the Boeing 707 jet airliner. Along with the Douglas DC-8, these two airliners ushered in the jet age at the end of 1957. The first 707 flew the New York City to London route. It did not fly with an empty seat for six months; such was the demand for the speed and comfort of jet travel.

The B-47, B-52, and KC-135 were airworthiness certified by the military per the requirements of that time. Their demonstrated airworthiness—resolving lingering concerns about the safety of jet travel—provided the basis for the FAA's development of its new jet airworthiness regulations and certification requirements. This military jet "track record" enabled the 707 and DC-8 to quickly enter commercial service.

While the B-47 and B-52 were weapon systems with true war-fighting capabilities, the KC-135 was essentially a passenger/cargo aircraft with the added ability to refuel military aircraft. It did not have warfighting capabilities beyond airlift and air refueling. Hence, just as was demonstrated with the -80 prototype, the KC-135 could have been developed as a dual-use aircraft with military versions delivered with a refueling boom and commercial airliner versions delivered without the boom. The further feasibility of this approach is seen today with the "new" Air Force KC-46 tanker that is a Boeing 767 commercial airliner with an added refueling capability. With one difference, the successful and rapid development of jet-powered large aircraft provides the model to now use to bring an American commercial passenger spaceflight industry into being. The one difference is that such a system would not be acquired by the Air Force as a military weapon system but through a new civilian port authority.

Establish a civilian astrologistics port authority

With the 1926 Air Commerce Act, besides airworthiness, the US government also undertook to license pilots, establish air traffic rules, establish airways, and operate and maintain aids to navigation. In 1936, the government took over operations of several major air traffic centers established by airline operators. In 1938, the government took over accident investigations to make sure that the airworthiness of the operating fleets was maintained and that lessons learned from accidents were integrated back into the approved engineering and operating principles and practices. Just prior to World War II, the government took over the control towers at the airports. The FAA was formed in 1958 as the jet age took hold. A retired Air Force general became the first FAA administrator. Overall, beginning in 1926, the Us government led the establishment of an integrated air-faring logistics infrastructure that continues to serve Americans very well.

For America to become a true commercial human spacefaring nation, an integrated human spacefaring logistics infrastructure—what I refer to as astrologistics—will be needed. Despite having spent nearly $1.2 trillion (FY2020 dollars) since 1958, everyone now realizes that NASA has failed to meet this need. The reality is that NASA, through its congressional funding, has other priorities such as returning Americans to the Moon. Port authorities have long been used to build government-funded and government-sponsored infrastructure. A civilian astrologistics port authority—with initial military engineering management assistance—is now needed.

The military has been involved in many major infrastructure projects as most meet important dual-use needs. In 1956, Congress passed the National Interstate and Defense Highways Act. Military logistics needs were integrated into the design of the system, including connecting the highways to the major Air Force bases. Also, some defense funds were initially redirected to help start construction. When building the Panama Canal was taken over by the United States, a US Army Corps of Engineers officer led most of the construction of the canal even though it was a civilian project. Military space needs are now being integrated into commercial space systems. And, as we all know, the military's Global Positioning System has become a vital part of world commerce—built despite the Air Force leadership's initial opposition.

An integrated astrologistics infrastructure will have many elements, including transportation, communication, navigation, energy, life support, medical care, housing, materiel storage, operations oversight, emergency response, and law enforcement. Some of these elements, such as communication and navigation, are already in place. Private industry now provides an initial medium and heavy uncrewed cargo transport capability, while the Space Launch System will provide a vital uncrewed super-heavy and oversize spacelift capability.

The immediate astrologistics need is for a non-warfighting mission capability to perform passenger transport and cargo spacelift. Hence, the logical initial responsibility of the astrologistics port authority is to undertake the acquisition of airworthiness certified passenger spaceliners and cargo spacelifters to provide commercial service to and from LEO. Drawing on the KC-135 and KC-46 examples, the first-generation spaceliners would serve the needs of civilian commerce as well as the military, NASA, and other federal agencies. When federal employees, military personnel, and even astronauts fly on routine duty, how do they travel? On commercial airliners. The same will be true when commercial passenger spaceflight service to LEO is established.

Locate the astrologistics port authority near Dayton, Ohio

Port authorities build many types of infrastructure: airports and seaports, tunnels and bridges, highways and rail systems, power generation facilities, and more. In acquiring these capabilities, operational safety is but one consideration as the new infrastructure must also be useful (suitable) and affordable (effective). Therefore, when acquiring first-generation spaceliners and spacelifters, besides airworthiness, the port authority will also need to focus on suitability and effectiveness to ensure that acceptable systems are delivered.

The port authority will need a sound systems management methodology and the requisite experience and expertise to manage the contracts. There is no reason to start with the proverbial clean sheet of paper. Following the historical example of the development of jet air travel, organizing the acquisition using the Air Force's approach to achieving operational safety, suitability, and effectiveness should be used. NASA's" human-rated" approach to safety is substantially deficient for ethical commercial use, as was previously discussed, while the FAA does not acquire capability. This means that the systems engineering and management expertise resident at Wright-Patt must be tapped as no other government organization has the requisite airworthiness and large human flight system acquisition expertise.

I propose that a new federal port authority—perhaps organized as a Federal Government Corporation—be established off base near Dayton, Ohio, to lead the development and acquisition of these new human spaceflight capabilities. Just as happened with the founding of NASA, military and civilian personnel from Wright-Patt would be initially collocated to the new organization to provide most of the initial technical and management staff. Being located close to Dayton, this will not require travel or moving expenses and family disruptions, enabling the initial functions of the organization to begin quickly. This will also enable the highly experienced retired aerospace personnel resident in the Dayton area to be enlisted in this effort.

Over time, many of the port authority's personnel will be hired separately. However, my expectation is that a continuing rotational assignment of Wright-Patt personnel will prove advantageous to expand and update the Air Force's organic experience and expertise with these new spacefaring capabilities. Eventually, the US Space Force will need its own crewed spaceliners and spaceships. Wright-Patt would be the logical source of the technical and management expertise to acquire these airworthiness-certified Space Force operational capabilities just as it does for all Air Force aircraft.

Spaceward Ho!

Thirty-five years ago, Wright-Patt believed that a HTHL TSTO TAV system was sufficiently technically mature to begin full-scale engineering development. Developing HTHL TSTO commercial spaceliners would be the first operational capability that the new astrologistics port authority would pursue with other astrologistics capabilities to follow. Wright-Patt's approach—not NASA's "human-rated" approach—to operational safety, suitability, and effectiveness would be tailored to these efforts. Wright-Patt, in conjunction with the FAA, would provide the independent airworthiness certification of the prototype flight systems with the FAA providing the final production type certificate and airworthiness certification. These initial spaceliners and spacelifters would be leased to commercial spaceflight companies with the stipulation that military missions using reserve officer flight crews could be conducted. Additional spaceliners and spacelifters of the same type design could be sold directly to these companies as demand grew.

Within perhaps a decade, America can be on a firm path to becoming a true commercial human spacefaring nation. A robust and expanding American spacefaring industrial base would be meeting our growing commercial and governmental passenger and cargo spaceflight needs. Commercial passenger spaceflight would expand into permanent LEO astrologistics operations with true spaceships navigating Earth-Moon space. America would finally be moving boldly spaceward! Our national struggle to solve the commercial passenger spaceflight puzzle would be permanently behind us with a dazzling spacefaring future ahead.

The president of the Air Force Association, Lt. Gen. Bruce "Orville" Wright, (USAF, ret.), recently released his "President's Perspective" on the Air Force-Space Force political wrestling match in Congress. He advocates for a Space Force within the Air Force.

> *Hence, there may be a time in the future to rename our long-established and proven Department of the Air Force as the Department of the US Air and Space Forces or Aerospace Force, to underscore the importance of both domains. Together, this air and space team would operate from, through and in the air and space domains.*

Recalling the earlier nearly 40-year-old illustration of an Aerospace Force S-17, Gen. Wright raises this possibility:

> *THE NEED FOR A MANNED COMBAT SPACE PLANE*
>
> *Our Space Force Airmen will also have the opportunity to fly the combat space plane force that must be a future leading-edge deterrent capability of the new Space Force. Our enemies cannot be allowed to field such capability before we do. While debates over manned or unmanned space planes will continue, one central fact remains. The human brain is not reliant on the electromagnetic spectrum to make life and death decisions and cannot be jammed. More important, neuroscientists tell us that only the human cerebrum can rapidly make the transition from ruthlessness to compassion within the demands of combat operations. With the power of space-based weapons and worldwide strategic consequences looming in our future, we must keep the reliability of manned, not just unmanned, combat space planes in our planning, research and development.*

Gen. Wright anticipates the need for future human military spaceflight capabilities. As I discussed earlier, these will necessarily be airworthiness-certified military flight systems, placing the acquisition responsibility of such systems clearly with Wright-Patt. Establishing an Astrologistics Port Authority in the Dayton area to acquire the initial commercial TSTO systems, with the close-by assistance of Wright-Patt managers, engineers, and scientists, will strengthen Wright-Patt's capabilities, when the need arises, to more effectively acquire crewed combat space planes, other human military spaceflight systems, and, of course, their necessary astrologistics support. This unique public-private partnership worked well with jet travel and will also work well for ushering in true commercial passenger spaceflight while preparing for the inevitable future human spaceflight needs of the Space Force.

Endnotes

(1) The Rise and Fall of Dyna-Soar: A History of Air Force Hypersonic R&D, 1944–1963, Roy Franklin Houchin II, Major, USAF, 1995. This is available through DTIC.

About the author

Mike Snead is a professional engineer and Associate Fellow of the American Institute of Aeronautics and Astronautics (AIAA). He is the founder and president of the Spacefaring Institute (spacefaringinstitute.net) and writes the Spacefaring America blog (spacefaringamerica.com). His technical papers are available at mikesnead.com. Mike Snead has authored the eBook Astroelectricity: Why American engineers should advocate for GEO space solar power to end America's CO2 emissions, make America energy secure, and prepare America for the 22nd century. (ISBN 9781732991408)