



The Space Congress® Proceedings

1989 (26th) Space - The New Generation

Apr 26th, 3:00 PM

Paper Session II-B - A Reusable Commercial Space Transport in a World of Expendables: Development, Certification and Operation

Gary C. Hudson

Pacific American Launch Systems, Inc. 115 Constitution Drive, Menlo Park CA 94025 Telephone: 415-323-3500

Maxwell W. Hunter

Pacific American Launch Systems, Inc. 115 Constitution Drive, Menlo Park CA 94025 Telephone: 415-323-3500

Follow this and additional works at: <https://commons.erau.edu/space-congress-proceedings>

Scholarly Commons Citation

Hudson, Gary C. and Hunter, Maxwell W., "Paper Session II-B - A Reusable Commercial Space Transport in a World of Expendables: Development, Certification and Operation" (1989). *The Space Congress® Proceedings*. 12.

<https://commons.erau.edu/space-congress-proceedings/proceedings-1989-26th/april-26-1989/12>

This Event is brought to you for free and open access by the Conferences at Scholarly Commons. It has been accepted for inclusion in The Space Congress® Proceedings by an authorized administrator of Scholarly Commons. For more information, please contact commons@erau.edu.

EMBRY-RIDDLE
Aeronautical University™
SCHOLARLY COMMONS

A Reusable Commercial Space Transport in a World of Expendables: Development, Certification and Operation

Gary C. Hudson & Maxwell W. Hunter, II

Pacific American Launch Systems, Inc.
115 Constitution Drive, Menlo Park CA 94025
Telephone: 415-323-3500

Abstract

Full reusability, combined with intact abort capability during all phases of flight, will have a profound effect upon the development, certification and operation of space launch vehicles. The effect will be to dramatically lessen third-party safety and liability concerns, while at the same time eliminating the need for individual flight licensing which are unnecessarily cumbersome and counterproductive. Because these future vehicles will have attributes of full reuse, intact abort and routine operations, their development, certification and operation will have much more in common with aircraft than expendable launch vehicles (ELVs). This paper argues for a clear distinction between the regulations imposed by governmental authorities upon ELVs and those for commercial reusable space transports (RSTs). This distinction must be based on a clear understanding of the engineering principles which underlie the RST.

Several types of RSTs will be discussed initially, including vertical take-off and vertical landing vehicles (VTOVL), vertical take-off and horizontal landing vehicles (VTOHL) and horizontal take-off and horizontal landing vehicles of both ground (HTOHL) and air-launched (HATOHL) varieties. The VTOVL has been selected as a case in point for further discussion.

Introduction

Several different types of fully reusable space transports are technically feasible, depending on the level of sophistication of technology one is willing to postulate. In general, we will confine our consideration of technology to that which might be brought into commercial service in the next ten to fifteen years. In our view this will exclude National Aero-Space Plane Technology, and require us to concentrate upon chemical rocket propulsion and only somewhat advanced material selections for engines and airframes.

Three general classes of vehicles can be considered. First, and the type which we believe holds great promise for widespread near-term use, is the VTOVL. Second, the VTOHL has certain potential for intermediate service as an earth-to-orbit transport. Finally, and generally more difficult to build, are HTOHL vehicles. All of these classes are considered only in their single-stage-to-orbit (SSTO) versions.

VTOVL

VTOVL space transports have much to recommend themselves as a nearly universal form of launch system. Most observers will agree that of all the classes of reusable SSTOs, the VTOVL is certainly the simplest and easiest to build. The basic concept requires a chemical bipropellant liquid propulsion system which is integrated into the vehicle base, and which would employ cryogenic liquid oxygen and hydrogen propellants. The vehicle ascends vertically and flies a throttling trajectory to low earth orbit (LEO). Once a mission is completed, the VTOVL conducts a re-entry and lands using rocket thrust to cancel residual terminal velocity. Landing of the VTOVL, as with all the concepts considered in this paper, is at the launch site.

One important attribute possessed by the VTOVL which is not shared by either the VTOHL or HTOHL is a much better ability to ascend to higher earth orbits following refueling. The blunt base of the VTOVL permits re-entry from much higher velocities than either the VTOHL or the HTOHL, both of which require wings with leading edges which are more difficult to cool when faced by the high stagnation temperatures such reentries would induce. Finally, the VTOVL can also operate off of bodies which do not have a sensible atmosphere, such as the moon or Mars. This particular attribute will be important during the early decades of space resources exploitation.

VTOHL

The VTOHL is an intermediate form of launch vehicle which has only two attributes which recommend it over either the VTOVL or HTOHL. Compared with the VTOVL, the VTOHL lands more conventionally, using lift from wings. However, these wings are "excess baggage" during all of the flight except for re-entry and landing. While they increase crossrange, moderate g loads and permit runway recovery, they cost the vehicle payload by complicating the structure and thermal protection systems, while at the same time requiring all of the infrastructure necessary for vertical launch. In addition, they are a penalty beyond LEO for the reasons noted above.

Compared with the HTOHL, the VTOHL is more technically feasible. The HTOHL requires quite large wing planforms to provide adequate lift to become airborne. This makes the HTOHL a difficult airframe to build, unless an HATOHL version is considered. The HATOHL will require wings about the same size as a VTOHL, since the vehicle is under climbing flight at relatively high speed at the moment of carrier aircraft release.

The VTOHL does not require the engines to be highly integrated with the vehicle base as is the case with the VTOVL. In general this means the engines for the VTOHL are more conventional, but also that they are much higher pressure to provide altitude-compensation during the early flight phase.

HTOHL

A chemical-rocket version of the HTOHL (as distinct from proposed airbreathing vehicles such as NASP) requires a large wing to provide take-off performance at reasonable V_r (velocity at rotation). This usually requires carriage of cryogenic propellants in conformal wing tanks at low pressure, which strains the ingenuity of structures engineers, who have to develop flat pressure vessels, and propulsion engineers, who have to produce engines with very low pump inlet pressures to ease the task of the former.

A perhaps easier development would be an air-launched HTOHL. Two types have been proposed: a vehicle carried to altitude by a 747 or similar aircraft and one that flies from the ground and then refuels at altitude from a heavy tanker. Either of these concepts would have the same level of difficulty to develop as a VTOHL, and could enter service in about the same time frame.

A Case In Point: Designing a VTOVL

To simplify this paper, we will concentrate the remainder of our remarks on the VTOVL for two reasons. First, it is the most likely to be built early for the reasons stated above. Second, the operation of winged vehicles is already accepted as being different somehow from vertically launched ELVs; consequently if we can establish that the VTOVL is a safe and reliable space transport which should be treated as a commercial aircraft for regulatory and insurance reasons, we will have made our case.

Flight Safety & Engine Redundancy. These VTOVL spaceships will be the first transport rockets to have a flight safety system which is the high-performance rocket equivalent of the system which works so well in commercial air transports. The vehicles will be able to be recovered intact at any time during flight in the event of any equipment failure *including* an engine failure. This capability will be available on the first flight of the first test vehicle — indeed the vehicles will practice many aborts before proceeding to orbit. This is not to say that there will never be a lost vehicle. It is irrational to assume that all of space will be explored by humans with no casualties. Murphy will get a few spaceships. He doesn't get many commercial aircraft today, however, and he'll have an even tougher time with VTOVL rockets.

Engine failures have always preoccupied aircraft designers, mostly because with single engined aircraft, when the engine quit, you came down. Furthermore, engines march to a different drummer than the rest of the vehicle. It is in the engines, nowhere else, that the energy to drive the vehicle is released. The engines are the part of the vehicle which routinely live with hellfire. It is easy to understand why they have always been treated as a different discipline. In living with them, however, one cannot ignore the rest of the vehicle. Expendable rockets (from the world of ammunition) cannot have the principal option - intact abort - which has made transport aircraft so spectacularly safe. *No rocket with this capability has ever been tested on this planet by anyone.*

The development cost of reusable, intact abort vehicles would rationally be expected to be much lower than any throwaway device. After all, every time you make a flight of an "expendable" vehicle, you have to get a new one. This does not seem too bad when you're testing ammunition, but it's a frightening expense for a reusable device. This is the basic reason that aircraft routinely make hundreds of test flights while rockets make do with a few. These are different worlds! One of the strangest pronouncements in most discussions of recoverable space vehicles is the assertion that they will certainly cost more to develop because, after all, they are more complicated. The huge expense of the wasted expendable hardware is never mentioned.

Flight safety is achieved in transport aircraft by the rigid application of certain basic design philosophies. The principle rule is that no single point failure cause a crash. This became especially crucial with respect to engine failure. The development of multi-engined aircraft is widely viewed as having been an absolute necessity for commercial air transports. Of course, not all problems can or should be solved by redundancy. We do not carry extra wings or fuselages. Such structures, however, are usually highly internally redundant (most three-spar wings work very well on only two, for example). It is also crucial that the aircraft not be needlessly redundant or it will be too complicated, require too much maintenance, be needlessly confusing to check out and likely more difficult to handle in an emergency.

The most useful rule is that you do not design for simultaneous failures. If, for instance, an engine failed and it was necessary to raise the flaps to climb out, it was assumed that the flaps would work. Designing for double (or more) failures usually led to hopelessly complicated designs. This rule was violated when there was reason to suspect a new component needed more time to be reliable, it did not complicate the vehicle or the results of a failure of one item out of two would be ambiguous (it's better to have three inertial navigation units than two, unless, of course, a totally different navigation system can arbitrate).

There is important engineering drudgery in making safe flight vehicles. This is the Failure Modes and Effects Analysis. FMEA takes every component in turn, assumes it has failed, and traces the effects of the failure including what can be done about it. Sometimes redundancy is added, and always the "work-around" procedures which will be used during any emergency are identified. In addition, and equally important, the location of equipment is often changed so that one failure does not needlessly induce another.

This drudgery pays off handsomely when the vehicle is recoverable. Take-off and landing are

especially crucial. Aircraft depend on aerodynamic forces to stay up in the air and handle take-off problems by utilizing wings and long runways to generate flying speed. Up to a certain velocity (V_0), if an engine fails the plane stops on the runway. If the failure is after V_0 , it climbs out with a dead engine. Extensive flight tests determine the parameters of this situation (rates of climb with a dead engine and gear down, for example) and the take-off weight is limited to values which permit the successful execution of this emergency. If configuration changes (flaps or gear) are required, the crew is given adequate time to react. Once the plane is up to flying speed, it usually has time to decide what to do and especially dump fuel before landing since landing with a full fuel load is decidedly chancy.

Rocket engines have very high thrust/weight ratios, and prefer to climb vertically to get out of the atmosphere as quickly as possible. The engines, not aerodynamic forces, supply lift and control. Rockets can fly at zero airspeed. They do not need runways and are much less efficient if constrained to use them. A vertical climbing rocket can, moreover, attain the same ability to survive an engine failure as an aircraft. It must simply have enough engines that if one fails, it still has enough total thrust to hover, dispose of its propellants, and land. Aircraft dump fuel before landing since it can be dumped faster than it can be run through the engines. In the rocket case, it is likely that the fastest dumping will occur when the fuel is processed out through the engine pumps and although burning it in the chambers produces a hot exhaust, it also inertes the exhaust products. If the rocket were to lose thrust from all engines shortly after take-off it is, of course, in deep trouble. Likewise, if the aircraft were to lose thrust from all engines shortly after reaching V_0 and committing to take-off, there's going to be quite a mess somewhere beyond the end of the runway. The simultaneous failure of all engines is a fuel-feed system rather than an engine problem. Thus, redundant valving in feed systems is the norm. Aircraft fuel-feed systems are very complex compared to a single stage VTOVL because many tanks are spread throughout the wings and it is usually necessary to program the use of fuel to keep the aircraft center of gravity within aerodynamic stability limits. Rockets also have stability limits, of course, but the problem is not further complicated by the tank/wing geometry.

There is a sometimes subtle point here. Most people feel that since rockets attain much higher speeds and have only become prominent in the last few decades, they are in all respects far more complicated and exotic than aircraft. This is simply not true, and such thinking is a poor substitute for engineering analysis.

VTOVL space transports will always have the option of aborting to orbit or returning to the launch site. In the former case, the assumption is that after the RST has passed the point where it has started to throttle its engines, any failure can then be compensated for by increasing the thrust of the remaining engines. The flight can continue as if no failure had occurred. Returning to the launch site is a matter of burning-off propellant and changing the vehicle velocity vector.

Engines. Aircraft engines must function during the entire flight while rocket engines only run for about 10 minutes regardless of the time on orbit. Should all engines fail on an aircraft in the middle of the ocean, the aircraft will be lost. The orbital vehicle, however, will not fall out of orbit. Interestingly enough, an aircraft on an 8-hour flight puts as much time on its main propulsion as an orbital rocket does in 50 orbital flights. A jet engine which has run 10,000 hours between overhauls has run for the equivalent propulsion time of 60,000 orbital flights. Of course it's not this simple, but you can make a case that we should quit treating rocket engines as if they are mysterious, exotic devices not controllable by good hard-headed engineering design. Aircraft (and VTOHL or HTOHL rockets) do have the ability to land with all engines dead (if they can reach a suitable landing site) and that is not possible with the VTOVL design. But less than 10 percent of take-off thrust is required for landing the VTOVL and consequently the vehicle can land safely with 90 percent of its engines dead. Considering the reliability of modern turbine engines, this is felt to be a very minor risk. Nonetheless, you must design for a crash. (This thought is abhorrent to the current American space program administrators, who insist that they will prevent all crashes. *We all know where this has led.*)

Propulsion redundancy can be achieved in two ways. First, one can have many engines arranged around a central plug nozzle. Alternatively, a few pump and turbine sets may be used to feed multiple combustors. In the latter case dual propellant feed manifolds are desirable.

Engines must also be designed for "tractable" failures. This means that an engine failure and shutdown is not accompanied by destruction of the engine, at least not in a fashion which creates risk to other components in the vehicle. (A good example of this type of engine is the Pratt & Whitney RL10, which by its very nature is strongly resistant to catastrophic failure.) Turbine confinement rings (used in jet engines), jacketed feed lines, and condition-monitoring sensors contribute to this goal. In addition, there should always be a "fleet leader" engine set which has significantly more ground test time on it than any flying engine component. This is especially true of engine parts such as thrust chamber (which suffer many fatiguing thermal cycles) and turbine/pump bearings.

Crash Safety. The terminal velocity of the current VTOVL design at sea level is about 200 fps. If the crash were cushioned by a 40 foot uniform collapse (constant g) of the propellant tanks and lower structure, 15 g's would be felt by the payload at the top of the tank. Most people would survive this if in a reclining position, but it's not really good, especially considering that uniform collapse depends somewhat on good fortune. Should the vehicle base diameter be doubled for the same landing weight, the terminal velocity would be cut in half and the g's felt in a crash would decrease by a factor of four which is a very benign crash, as such things go! Since rockets land with very little fuel on board, most of which might be dumped prior to a hard landing, the chances of fire or explosion compared to airplanes are minimal. At this point, the chance of surviving a landing with no engines seems somewhat dicey, but the subject, surprisingly enough, is very worthy of analysis.

One could consider supplying a parachute as an emergency landing system. They weigh in at about 1 percent of the weight landed and consequently are by no means an unacceptable penalty. Parachutes might be used to recover the entire vehicle, or in some instances, only the crew compartment or payload.

The subject of crash safety is also of interest to people under the path of the vehicle. While ELVs are directed to fly over water, and are automatically destroyed if they so much as turn in the direction of land, this is not rational in the case of an RST. RSTs will be essentially as safe as commercial aircraft and thus must be allowed the same overflight privileges. When there is an accident, however, the risk presented by a VTOVL may well be lower to people on the ground for two reasons. First, the vehicle is likely to have a velocity vector which is straight down or nearly so; therefore a relatively small area will be affected by the impact, compared with a jet aircraft flying horizontally. Second, if the fuel of the VTOVL is hydrogen (as is widely believed to be likely) the amount of fuel is quite low (less than the equivalent fuel load of a DC-9, for an orbital payload of 20,000 pounds) and it is rapidly volatilized. Unlike misting aviation kerosene, the fireball produced by a hydrogen-fueled VTOVL is transitory and rises away from the crash site.

In general, the VTOVL has a much better chance of bringing crew and/or cargo home safely, even when compared to highly reliable commercial aircraft.

All-Weather Operations. Transport airplane designers fought for decades to achieve their current ability to operate aircraft almost independently of the weather. We must try for the same in space, especially so since atmospheric operations are such a minor portion of the total operational time of a space mission. Being able to use reliable, predictable rocket thrust which is not affected even by micro-bursts seems likely to make this possible.

The VTOVL blunt-cone design is aerodynamically uncomplicated and relatively inefficient at generating lift compared to a wing. Thus, it will be inefficient at generating lateral loads, and the

wide-beam structure will easily handle such loads. There will be almost no aerodynamic interference loads on the vehicle. It will be, consequently, almost impervious to the loads from winds aloft. Current launch vehicles are relatively long, slim vehicles. Furthermore, some configurations have large parallel staging configurations which create aerodynamic interference loads between the bodies (Titan and Shuttle, for example). The Shuttle orbiter wings enhance these loads. Consequently, the most modern of the launch vehicles have actually retrogressed in the matter of all-weather operations and often can't be launched on a clear day! The VTOVL design should be one fundamental solution to this problem.

Contributing to the ability to operate in all-weather environments is the proposed thermal protection system of the VTOVL. We suggest active cooling with a transpiration flow of water. This technique will permit the VTOVL to be manufactured from conventional materials such as aluminum and composites. Further, simply by increasing the flow of water much higher heat loads can be accommodated, such as those encountered by vehicles returning from the moon or GEO. Any other type of "soft goods" thermal protection system will probably be unable to operate in rainy weather. This option gives rise to the prospect that these spaceships will sit out-of-doors and not in a protected hangar, and in other ways will be treated much like a modern jet transport.

Materials Choices and Fatigue Life. Because the RST requires long life coupled with very low empty weights, the matter of materials for the vehicle is a very difficult one. Generally, if one accepts the use of water (or other fluids such as hydrogen) cooling of the airframe, then the choice of materials is much easier.

Present vehicle baseline calls for the use of aluminum-lithium as the outer aeroshell skin and fuselage structure. ALi has the advantage of high modulus and high tensile strength and a mass some 10% lower than conventional aircraft aluminum. By the time an RST flies, ALi will have seen relatively widespread civil and military aviation use.

Propellant tanks are another matter. These tanks will see many thermal cycles (about 1000 in our baseline case), going from room temperature to cryogenic temperature and back. We suggest that cryoformed stainless steel (perhaps the 301 alloy) or certain aluminum alloys will be suitable for these pressure vessels. A development program of thermal cycling needs to be initiated to make the final material choice.

Finally, the designers of the engine combustion chambers will face the most severe material challenge. They will have to find a material which can undergo approximately 700-1000° F thermal cycling for three or four times per flight. This material might be oxygen-free copper, copper-zirconium or copper-silver alloys. All have demonstrated a few hundred thermal cycles at the temperatures and pressure of interest to the VTOVL RST designer. It may be necessary, however, to adopt a policy of chamber changeout for the RSTs every hundred flight or so, until evidence accumulates that the chambers can undergo more numerous cycling.

Avionics. Vehicle avionics for an RST is virtually a non-issue. Almost without question the principal means of flight control will be through fly-by-wire or fly-by-light technology. Because there is little probability of mechanical backup, the electronic control system must be highly reliable. Fortunately, this problem has been solved many times in recent aviation history: most new military aircraft use such control systems, and some (such as the X-29) rely upon them for *all* flight stability. Adoption of existing rules for flight safety which dictate the design of commercial aircraft should be sufficient for RST development to proceed.

Fire and Explosion Prevention and Mitigation. The RST will possess several advantages over commercial aircraft when it comes to fire and explosion threats. The most important of these is that the vehicle uses up the vast bulk of hazardous propellants quickly, and for the rest of the mission is largely inert, except for a small quantity of landing propellants. Another advantage is that the cryogenic propellants are rapidly dispersed in the event of an accident, and do not pool or

coat vehicle components or payloads.

Examination of the *Challenger* loss demonstrates this fact. Post-accident investigation showed virtually no blast or fire damage from destruction of the external tank. All of the damage to the Orbiter came from aerodynamic forces and the exhaust plume of the right Solid Rocket Booster. By one calculation, the explosive yield of the entire External Tank's remaining propellants (about 60% full) was a few tons of TNT equivalent.

Operational Issues. It would be very desirable, of course, to be able to launch from normal large airports. Although the VTOVL will not interfere with normal horizontal traffic around airport approaches, there are other problems. VTOVL rocket jets, either on landing or take-off, are hot and tend to chew up normal concrete. It may be possible in both cases to run the engines very oxygen-rich and thus lower the temperatures to more easily handled values. The increased propellant load may not be much since it would only be required for a few seconds. This has not yet been investigated. There is also the question of whether it is necessary to hold the vehicle down for some seconds while the engines are checked out running at full thrust. Although some believe this is necessary, it was never done on many liquid propellant rocket programs, and certainly isn't done with solid engines. Furthermore, the VTOVL can lose an engine immediately and still save the vehicle. It is likely that large, water-deluged flame defectors will *not* be needed, but the degree of special pad protection must be worked out. We expect, however, that the integration of the VTOVL vehicle (and by extension, the VTOHL or HTOHL) into a routine airport flow can be managed.

Range Safety and Environmental Issues. After the issue of vehicle safety has been settled by adopting rules for RSTs similar to those for aircraft, the biggest launch constraint is likely to be the sound level. Rockets have higher velocity exhausts than jet engines and higher jet velocity means more noise. Almost no work has been done on the problem of quieting rocket engines. Yet, once all the other safety features of the VTOVL rockets are understood, sound level is likely to be the constraining factor in the ability to use normal airports or build launch terminals convenient to cities. The same use of oxygen-rich engines mentioned above also, by lowering the exhaust velocity, would be expected to lower the sound level. Another possibility is water injection into the shear layer between the high velocity jet and the stagnant surrounding atmosphere. It is not clear how much can be accomplished, but the VTOVL development must pursue a lively program of attempted rocket noise reduction.

Market Drivers. We expect that RSTs will be used in a variety of roles and missions almost unfathomable by present-day mission planners. The launch of discrete satellites will be a microscopic part of the business of the RST fleet. With a dramatic reduction in launch costs which is likely based on an understanding of the technology in the RST, we can expect several major markets to emerge. They will be controversial here and now, but two decades in the future historians may well wonder why these markets were not pursued earlier.

Three markets which might be considered are: space power, space tourism and extraterrestrial resources. Interestingly enough, the market which is most probable to emerge first is tourism, since it requires a smaller initial investment (i.e., only in the vehicle, and not in solar-power satellites or lunar bases).

Such a market driver is important to vehicle design and certification, because the standard of safety for the RST is likely to be equivalent to commercial air transports. Further, there will be tremendous pressure to reduce the vehicle operating costs in order to expand the market, and this pressure will produce a very low cost per pound of payload delivered in orbit: a vital development if satellite solar power or extraterrestrial resources are to be next in line.

A future RST might, if it operates from conventional airfields, enter the market for high speed trans-Pacific travel in competition with hypersonic transports.

Manned vs. Unmanned. It is widely accepted that the development cost of an unmanned launch vehicle will be less than that of a manned version. We regard this as one of classic examples of conventional wisdom which is completely wrong. When you adopt the RST philosophy of development, there can be no difference between the cost of the manned or unmanned version (except for incidentals such as crew accommodations, which are a trivial part of the vehicle cost). By analogy to aircraft development we can ask the questions: when do we find it necessary to build unmanned aircraft? The answer is: only when we intend to use them in an expendable role — as ammunition.

Therefore we assume without further comment that the RST will always be flown with a crew, except when it is uneconomic to do so. *The manned versus unmanned debate will be determined by operational requirements, not by perceived risks or costs.*

Regulation: Flight Safety & Mission Review. By now it should be apparent that the operation of RSTs will be dramatically different than the present conception of ELVs. The extraordinary attention which RST designers will pay to flight safety (in order to *get the vehicle back*) will clearly have a salutary effect on range and third-party (i.e., public) safety. This in turn will have a major effect on insurance. It will be as inappropriate to require \$0.5 billion insurance policies for RSTs as it is to require them for commercial aircraft (which operate under far less burdensome federal insurance rules). Operation from conventional airfields will further affirm the inherent safety of the RSTs. With such routine operation it is obviously impractical to require launch licenses for each flight, any more than a license is required for each aircraft departure (we accept the necessity of a flight plan).

Finally, the issue of regulation of payloads must be addressed. Present federal policy is to regulate vehicle safety for public safety. In addition, a Congressionally-mandated "mission review" is conducted to determine the impact of the payload on national security and foreign policy. While this has not excited much concern to date, it will be utterly unworkable in a world with RSTs. By analogy, when a Lear jet departs San Francisco International, it does not require the approval of the Departments of State, Defense, Commerce, the White House and NASA. Neglecting troublesome issues of the Fourth Amendment, it will simply not be tolerable to burden space commerce with such bureaucratic mischief. If we are to create a climate for the commercial development of the space frontier analogous to the tremendous success of American commercial aviation, we must abandon notions of smothering federal control in favor of the common heritage of the United States: the freedom to innovate in our lives and enterprises.

Fortunately, technology has given us the means to access space at low cost and risk. It is up to us to grasp the potential and the opportunity.

Acknowledgements

The authors would like to thank Tom A. Brosz, James R. Grote, Patrick J. G. Stiennon and Jay Miller for their comments on the subject of commercial space transports.