Chapter 7

National Security Implications of Inexpensive Space Access

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The nation which controls space can control the Earth.

—John F. Kennedy
24 October 1960

There has been a great deal of discussion in the space policy community about the technical challenges of gaining economical and routine access to space. Despite this, there has been little written about the opportunities which exist for the development of new missions for US military space forces. Neither has there been much discussion of the security challenges that any proliferation of access to space may present to the United States and to the established international order. Even the most forward-looking space advocates in the Department of Defense (DOD) assume that access to space will continue to be prohibitively expensive and difficult for the foreseeable future, that a US decision not to take advantage of the military potential of space is deterministic for the rest of the world, and that "navigation, communications, and surveillance activities will likely remain the limits of space-based capabilities" for all countries.[1]

Part of this failure to consider the possibilities of a world radically changed by inexpensive access to space is a reaction to the "expectations gap" set up by the gulf between mankind's collective dreams about its future in space and the realities of its achievements so far. The collective public and political mind has been shaped by powerful and convincing fictional images of

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space activities that we are not likely to see for a hundred years. Real world, but slow moving and silent, pictures of earth from space taken from small spacecraft with cramped cabins and short mission duration suffer greatly in comparison to images of robust and operable spacecraft spanning the galaxy at faster than light speeds. A century after the Russian Konstantin Tsiolkovsky conceptually solved most of the problems involved in human space flight, over a third of a century since the Soviet sputnik ushered in the space age, and over a quarter century since the United States left humanity's first footsteps on another celestial body, many thoughtful and technically literate people are conditioned by historical experience to think of access to space as an expensive enterprise that is technically difficult, dangerous, and the exclusive province of huge government and corporate bureaucracies.[2]

This stands in stark contrast with the almost giddy optimism that characterized thinking about humanity's future in space at the beginning of the so-called space age. In a 1959 issue of *Air University Quarterly Review*, for example, a serving Air Force officer submitted an article from Command and Staff College that proposed using lunar craters as ballistic missile silos.[3] Even without the Outer Space Treaty of 1967, it is hard to imagine anyone in today's US Air Force making a similar proposal.[4] This change in outlook, conditioned in part by the "expectations gap" and by changes in the fiscal and political landscape, has shaped thinking on this subject over the past 35 years.

As a result of these diminished expectations, as well as competition with other pressing political and economic issues whose solutions don't seem related to space, the American body politic has concluded that routine civil, commercial, and military access to space is not a national priority; not because it is not technically possible, rather, because the experience of the past 38 years argues against it. This is true even at the end of a century of unprecedented technological change. This lack of practical application for access to space and the relatively small size of today's commercial space industry combine to create uncertainty about where the United States should be headed in space, and because of the bureaucratic and technical complexity of traditional space operations, makes it difficult to set a single long-range direction for the nation's efforts in space. In fact, the uncertainty with which the United States views the new medium is reflected in the fact that there was a national commission chartered to determine what should be done in space every year between the *Challenger* accident in 1986 and 1993. (This streak is still unbroken, the National Aeronautics and Space Administration's [NASA] *Access to Space Study* was again released in 1994 and 1995.)[5]

Political, economic, and technological forces may be converging at this point in history, however, to provide the United States with a way to realistically pursue its national purposes in space. With respect to political forces, there seems to be a growing awareness in the US government that something has to be done to lower the cost of space access. Most of the national reports on space over the past decade either say something like "a coherent national effort to improve launch capabilities is desperately needed," or, "above all, it is imperative that the United States maintain a continuous capability to put both humans and cargo in orbit."[6]

Part of the reason for this new awareness is the high operating costs of the current space launch fleet. As overall space budgets fall, operating costs for old-technology space launchers grow as a percentage of total costs. In fact, space shuttle operations presently consume about one-third of the total NASA budget.[7] This is one of the economic forces that is providing incentives to lower the barriers to space access. The other is the growing commercial space business ($5 billion in 1992 sales and growing at a double digit annual rate) and the possibility that new technology will make space access for profit-making enterprises economical for the first time.[8]

Underpinning these new political and fiscal realities is the maturation of technologies that, together, can solve some of the engineering problems that have traditionally forced spacefaring nations to throw away the largest part of their space vehicles. These new technologies: Lightweight materials from the National Aero-Space Plane (NASP) and National Launch System (NLS) programs, advanced propulsion from the shuttle program and from Russia (in fact, the NASA *Access to Space*

Study bases the propulsion system for its reference reusable launch vehicle on the Russian tripropellant RD-704 engine) as well as new computing techniques from the commercial sector have combined to offer the potential for an order of magnitude reduction in the cost of getting into orbit.[9]

If indeed this important part of President John F. Kennedy's New Frontier becomes more accessible, however, there will not only be new opportunities for the United States; there will also be new challenges and obligations that have not been thoughtfully considered. These issues are considered in the pages that follow.

Forces Reducing the Cost of Space Access

An examination of recent technical literature on space launch, foreign and domestic writings on space policy, and the recent activities of the US government seem to indicate that a confluence of bureaucratic, political, and technological forces may be about to lower the barriers to space access; not just for the United States, but for other nations as well. This expanded space access could have implications for US military doctrine, and more importantly, for US national security.

Since the beginning of the space age with the launch of sputnik in 1957, people who have written and thought about using space for national security purposes have proposed crewed space vessels which did not cost significant fractions of the gross national product (GNP), nor did they require an advanced education in computing and astrophysics to operate. Significantly, official Air Force publications of the late 1950s are full of speculation about the implications of such ideas. They proposed using such manned space vehicles for bombing terrestrial targets (a proposal from a general officer on the Air Staff) or for establishing intercontinental ballistic missile (ICBM) bases on the moon.[10] Even Gen Henry "Hap" Arnold, in his prespace age "Report to the Secretary of War" at the end of World War II predicts manned "space ships" as the weapons with which war would be waged "within the foreseeable future."[11] There is not a lot of this sort of thinking about space in today's military writing. In fact, there is no mention of manned military space flight in joint space doctrine, and the astronaut who returns to Space Command to write doctrine informed by experience in the medium is the exception, rather than the rule.[12]

Because of gradually declining faith in the United States's ability to repeatedly and affordably gain access to space, current thinking has become limited to automated systems with throwaway ballistic-missile-derived launch vehicles that do little more than support traditional terrestrial operations.[13] This declining faith in the potential of space power in warfare is partially traceable to perceived treaty and national policy limitations and partially to the expectations gap described earlier, but it is more fundamentally related to the immaturity of existing technology.[14] It simply has not been physically possible to conduct affordable routine operations in the Mach 18 (suborbital) to Mach 25 (orbital) regime with existing propulsion, materials, or flight control technologies. In addition, the early promise of the space shuttle (dashed with high space shuttle maintenance and launch costs and the loss of *Challenger),* the realization that air-breathing space planes (such as the late NASP program) are not affordable or technically unachievable in the near term, and large expendable launch costs that stretch far into the future, have combined to make the institutions charged with the responsibility of maintaining US access to space averse to changing the status quo and resistant to proposals that change this calculus because earlier proposals for change have come to naught.[15] Doubting that change is possible, they are loathe to accept new ideas or solutions, even if the technologies required to create General Arnold's ideal "space ship" were to become available. In fact, strong institutional forces have grown up around the established methods of doing business, even if they are demonstrably more expensive in the long run and less operable in the short run. Despite this institutional inertia, however, a conjunction of political, economic, and technological forces in the last few years of the twentieth century may finally bring down the cost and technical sophistication required to get into space, turning this period into General Arnold's "foreseeable future."

Confluence of Political Forces

Now, a quarter century after the first human beings set foot on the moon, there is an understanding at the highest levels of the US government that without repeatable and affordable access to space, it will be difficult, if not impossible, to accomplish national purposes in and from space. This understanding is driven by the poor cost performance of current space access methods (this includes low launch rates, high costs, and lack of reliability) and by the resulting lack of hands-on experience with space which, along with the expectations gap discussed earlier, cripples thinking about what can be done in space.

There are as many proposed solutions to the space access problem as there are players in the space policy debate. Nine national-level studies on the issue in eight years, plus innumerable internal studies in agencies across the government, each with its own solution, are indicative of the lack of a coherent vision for what is possible or desirable to do in space. This incoherence is due in part to the immaturity of space technology, and due in part to the fact that few "experts" have actually been in space (because access is still restricted to the select few by the expense of getting there). It has been due in largest part, however, to the struggle for organizational survival in a world of limited resources.

In the past two years, Congress has attempted to break through the roadblock of diminished expectations and lack of policy direction. There now seems to be congressional understanding that lack of assured access to space prevents the United States from pursuing its national purposes there, but at the same time, Congress has shown itself to be dissatisfied with the solutions proposed by the various agencies of the Executive Branch.[16] Congressional dissatisfaction with Executive Branch space policies has traditionally caused it to do two things: first, to cancel every new expendable launch vehicle (ELV) proposed by NASA and the DOD in recent years (the Advanced Launch System [ALS], NLS, and Spacelifter), and second, to direct a series of studies to address the problem.[17] Immediately after the cancellation of Spacelifter and the effective cancellation of NASP, Congress directed NASA and the

DOD to study space access in the FY93 NASA Appropriations Act and in the FY94 Defense Authorization Act.[18] These studies, released within three months of each other in early 1994, used the same technology base and, in some cases, the same study participants; but came up with diametrically opposed conclusions about the best way to solve the nation's space access problem (perhaps for some of the bureaucratic and organizational reasons outlined above).

The Case for and against Standing Down. With large and continuing requirements for access to space, both the DOD and NASA have little choice but to continue their costly present launch operations as they try to solve this problem. The US government mission model for the next 15 years averages about 30 launches per year, while industry will account for roughly 15 more.[19] These continuing requirements include obligations to our International Space Station (ISS) partners for space station assembly missions, DOD launches of national security payloads, and the replacement of aging communication and sensor satellites to address shortfalls highlighted in Operations Desert Shield and Desert Storm. Although the DOD could use foreign launch services to get its "must carry" payloads into orbit, former US representative Dave McCurdy and his coauthors call such a possibility "truly disturbing" in an article for *Strategic Review* in 1994. Dependence on foreign launch vehicles in time of war or crisis could turn out to be even more costly than the status quo. The private sector, on the other hand, does not mind going offshore for launch services, but with an already negative balance of payments, this poses questions of US economic competitiveness that are also ultimately questions of national security. As recently as 1979, the United States launched 100 percent of worldwide nongovernment satellites. Today, that figure is closer to 40 percent.[20] This situation has deteriorated to the point that Charles Bigot, the chairman of the European launch consortium Arianespace, no longer considers the United States to be a major competitor in the $1 billion commercial launch business because "to develop a really new transportation system you need probably between six and ten years [and] I don't believe that America will do it."[21]

With foreign officials dismissing the United States as unable to compete, with a fiscal vise closing on both NASA's and DOD's launch budgets, and with a continuing national need for sovereign space access, there seems to be a consensus growing in Washington and elsewhere that something has to be done about fixing space launch.[22] The space policy community also recognizes that the United States must simultaneously fly the missions that are necessary to the fulfillment of national policy goals. This is the context within which the following discussion takes place.

The Case for and against the Status Quo. There is always the option of doing nothing to build on the technology developed for the programs that have already been canceled. It would save on the cost of a new space launch vehicle in a time of declining budgets and would decrease the technical risk of developing new spacelift technology when the time finally comes to field a new launch vehicle. However, there are three arguments against this approach.

The first is that the US's foreign competitors are taking more and more of the launch market away. As the Vice President's Space Advisory Board on the Future of the US Space Launch Capability Task Group (the "Aldridge Commission") report put it,

> A decision by the Administration or the Congress not to fund a new, reliable, low-cost operational space launch capability is a de facto policy decision to forgo US competition in the international space launch marketplace, a mandate that the US government will continue to pay higher prices than necessary to meet future government launch requirements, and acceptance of less reliability, less safety, and higher risks for space flight than our technology is capable of providing.[23]

The second argument against the status-quo approach is that the United States has essentially pursued this policy by default after the series of program cancellations discussed earlier. This policy has gotten the nation no closer to solving the problem, but has cost several billion dollars ($2.4 billion for NASP and $600 million for advanced logistics system [ALS] and NLS).[24] If the nation does nothing with the technology from these programs, then this money will have been spent for naught. The third reason, as outlined above, is that the cost of space launch is a large part of both NASA's and DOD's continuing costs. Although the shuttle program is under continuing pressure to cut operating costs, its share of the NASA budget increases as the overall NASA budget decreases. The same can be said for the DOD space budget. As overall budgets decline and launch costs do not, there are not enough resources left over for either organization to carry out its other tasks. This is where much of the political incentive to "do something about space launch" comes from. Both the DOD Space Lift Modernization Plan (SLMP) and the NASA Access to Space Study considered the option of remaining with the status quo. Both concluded that the continuing high cost of their present space launch operations were not supportable. In addition, both concluded that waiting would not, in the end, save money. As the NASA Access to Space Study states, "delaying the decision of which space architecture to select by four or five years but not funding a focused technology phase will achieve nothing, since the lack of a focused technology program during that period will not reduce the risks of developing an advanced technology vehicle. Therefore, the choices available in four to five years would be exactly the same as those we face today."[25] NASA and the DOD both seem to agree that there is nothing to be gained by waiting.

The DOD Space Lift Modernization Plan: the Case for and against Expendables. The DOD study, the SLMP, concluded that pursuing new reusable launch vehicle technology was "controversial" due in part to the risk.[26] DOD recommended, therefore, that it remain committed to the evolutionary development of its present stable of aged Atlas, Delta, and Titan launchers, while investing in incremental technology improvements. The SLMP itself admits that this would deliver little or no per launch or per pound to orbit cost savings.[27]

Despite the DOD's enthusiasm for this new evolved expendable launch vehicle (EELV), however, there is no new money in the president's budget for either new or evolved expendables. Congress has appropriated $40 million in the FY95 Defense Appropriations Bill for an evolved expendable, but that is far from the $2 billion estimated total program cost, so the Air Force plans to take $400 million out of its own budget over the FYDP to fund it.[28] As in the cases of ALS, NLS, and

Spacelifter before it, EELV is a conservative approach based on what is essentially 1950s ballistic missile technology, delivering small savings in per launch costs. It is, in fact, intended to be even more technologically conservative than earlier expendable programs to cap the development cost at $2 billion.[29] Even with such a cap, however, these development costs are still of the same order of magnitude as those for a major weapon system. With this multibillion dollar development cost, the EELV will narrow, not reduce, the range of medium lift costs from $35–$90 million to a projected $50–$80 million.[30] Although standardization of the launch fleet to a single vehicle/contractor combination from the separate and costly Atlas, Delta, and Titan programs will bring some savings, it is impossible to get away from the fact that "staged expendable" means, in effect, building two vehicles every time you fly, mating them meticulously, and sinking both craft in the ocean when the mission is complete. As W. Paul Blase says in the March 1993 edition of *Spaceflight* magazine,

> All current rocket launchers are derived from 1960s era ICBM designs, and man-rating procedures are merely ways of producing man-rated ammunition. Rocket designers are conservative by their nature and the high cost of both the vehicles and their payloads causes them to refine the same basic concepts continuously to finer and finer degrees, taking few risks with radically new ways of doing things. This has resulted in a situation very much like trying to pull a semi-trailer with a racecar. Like a racecar, ICBM-based rockets are designed to get maximum performance from minimum equipment. Technology is pushed to the very brink to wring out that last ounce of thrust. However, it is an engineering truism that when one gets near the theoretical limits of a system, every additional 10 percent increase in performance doubles the systems cost and halves its reliability.[31]

The NASA Access to Space Study—the Case for and against Reusables. The civilians at NASA, using essentially the same data, came to a different conclusion. They believe that neither ELVs nor the shuttle are suitable launch vehicles for the twenty-first century. They believe that the time has come for the nation to move to the next technological level. Accordingly, NASA's Access to Space Study recommended that the United States "adopt the development of an advanced technology, fully reusable single-stage-to-orbit rocket vehicle as an Agency goal."[32] In addition, NASA concluded, "leapfrogging" the United

States into a next-generation launch capability would place the nation in an extremely advantageous position with respect to international competition.[33]

As a result of the separate positions taken by the agencies primarily responsible for the nation's access to space, the Executive Branch has decided not to focus on a single strategy for space access in the twenty-first century. Instead, the new national space policy accepts the NASA position on sprinting ahead to reusable launch vehicle technology while also maintaining a core expendable capability in the interim (managed by the more risk-averse DOD).[34] The language of the new NASA *Implementation Plan for the National Space Transportation Policy* makes this clear. Administration policy, NASA says, "calls for a balanced two-track effort; first, to ensure continued access to space by supporting and improving our existing space launch capabilities, consisting of the Space Shuttle and current ELVs; second, to pursue the goal of reliable and affordable access to space through focused investments in, and orderly decisions on, technology development and demonstration for next-generation reusable transportation systems."[35]

This two-track approach, while it satisfies the competing bureaucracies of NASA and the DOD, and appears to manage risk prudently, does not seem to be fiscally or politically realistic. As outlined above, every expendable launch vehicle that DOD and NASA have proposed in recent years has been terminated by Congress.[36] These cancellations had less to do with the merits of the respective programs than with the limited launch savings over existing launch vehicles and high program costs (relative to those same limited savings) that are characteristic of expendables.[37] With this in mind, a space policy that calls for two new program starts, one of which is an expendable much like those canceled in the recent past, has little likelihood of continued funding from Congress. It seems more prudent, and politically realistic, for the Executive Branch to decide early which track it wishes to pursue, and then to focus its efforts there.

What explains the significant difference between the two recommendations? It is important to answer this question because the political viability of the president's two-track approach depends on the ability of NASA and DOD to convince Congress of the soundness of the reasons underlying their respective recommendations over the lifetimes of the two programs. In an era of limited resources, the recommendation that fails to stand up to the scrutiny of lawmakers will not survive, no matter how strongly its bureaucratic constituency believes in its merits. The rest of this section will attempt to determine the reasoning underlying the two recommendations, and to assess their respective political viability in the Washington of the late 1990s.

The Political Viability of the RLV and ELF. The first question in determining the viability of the respective approaches is whether technology advanced so far between the two reports that reusable launch vehicle development suddenly became more possible and less "controversial." This is not likely. In fact, the NASA report was released first and DOD used the NASA study for purposes of comparison.[38] The NASA report's assessment of the technology's potential to solve the nation's launch problem seems, therefore, to have been driven by some other factor. If the level of technology is acknowledged by both reports as being within striking distance of an operational reusable vehicle, then, to observers in Congress, NASA's choice would appear bold and the DOD's choice suffers by comparison. It would be difficult for DOD to make the "immature and risky" technology argument and maintain the funding level for the old technology EELV when NASA's flying advanced technology demonstrators are competing for the same dollars. (This calculus would change, of course, if either program ran into major technical trouble.)

The second question is whether the two conclusions were driven by differences in the risk tolerances of the two institutions. Perhaps so. The DOD argues, correctly, that the stakes are higher in the national security arena, and that the nation can ill afford another launch hiatus caused by exclusive reliance on high-risk technology (as it suffered after the *Challenger* explosion). NASA argues, also correctly, that risk has been reduced by recent advances in lightweight materials, thermal protection, high speed computing, the attendant flight control and systems integration software, and other technologies. Even though these advances do not reduce the risk of the reusable launch vehicle to zero, NASA, it seems, is willing to take some programmatic risk to protect US competitiveness in the international launch vehicle technology race. Congress is likely to be more sensitive to this concern than to DOD's national security concerns in the wake of the cold war.

Along the same lines, risk tolerance is one thing, but did the two institutions have differing perceptions of the same technical and fiscal risks? On the subject of the same prospective (RLV) technology that NASA considered, the DOD study says, "A fully reusable, single stage to orbit space plane is an exciting concept to all the space sectors and industry alike. It offers benefits of responsiveness, reliability, operability, and very low cost per flight which are universally agreed to be desirable. However, the practicality of achieving those benefits is controversial."[39] NASA, on the other hand, concluded that, "single-stage-to-orbit vehicles appear to be feasible because of reduced sensitivity to engine performance and weight growth resulting from use of near-term advanced technologies (e.g., tripropellant main propulsion, Al-Li [Aluminum-Lithium] and graphite-composite cryogenic tanks, graphite-composite primary structure, etc.). An incremental approach has been laid out to reduce both technical and programmatic risk."[40] Again, with the same information, NASA reaches the more forward-looking conclusion.

NASA may be looking further forward, but did this cause it to manipulate the numbers so that the bold RLV solution was made to look unrealistically inexpensive? The similarity with the DOD figures makes this doubtful. DOD estimated the cost for a reusable launch vehicle program (technology and engineering development) at between $6.6 and $20.9 billion, while NASA estimated the same costs at $17.6 billion.[41] Though the upper end of the DOD range is higher, there does not seem to be a significant enough difference in the estimates alone to cause the wide discrepancy between the two recommendations. If DOD was concerned that it did not have enough money to go it alone (which, given the office of Secretary of Defense (OSD) Bottom-up Review funding levels that were the SLMP's starting point, seems a reasonable assumption), it could have proposed a joint national launch strategy with NASA (as with Spacelifter and NASP), unless of course there were unstated reasons for not doing so.[42] These unstated reasons might include the perception that because cooperation with NASA on ALS, NLS, Spacelifter, and NASP was difficult, and each program ended badly, a DOD-only program might have a better chance of success (although the DOD has managed to get quite a few programs canceled on its own). Unfortunately for the DOD, Congress has a long record of preferring cooperative programs with joint program offices over competing and redundant programs.[43] Unpleasant experiences with previously canceled programs are not a politically palatable justification for the DOD going it alone.

Was there a stronger bureaucratic constituency for expendables than for reusables in the DOD? The answer to this question may lie in the strong institutional tie between the expendable ballistic missile acquisition community at the Air Force's Space and Missile Center in Los Angeles and the Air Force Space Command at Colorado Springs, Colorado. The Space and Missile Center (formerly the Ballistic Missile Office) managed all Air Force ballistic missile acquisition during the cold war. It also managed NLS and is the home of the program office for EELV. Space Command, which was recently assigned responsibility for the peacetime organization, training, and equipage of the ICBM force, has launched the majority of the payloads it now controls on expendables (and the rest on the partially expendable space shuttle), and now is staffed with officers who spent years preparing to carry out the strategic missile mission with expendable rockets. If there is an institutional tie between flying officers and the program offices at Wright-Patterson Air Force Base (AFB) where airplanes are acquired, then there may be a similar tie between the missile officers at Space Command and the Space and Missile Center at Los Angeles, California.

There was a small constituency for RLVs inside DOD who helped in the preparation of the SLMP, but it was confined to the narrow group within Strategic Defense Initiative Organization (SDIO) who had developed the DC-X subscale RLV demonstrators.[44] If there were a single difference between the two studies, this may be the most significant. In contrast with the situation within DOD, there was a strong constituency for RLVs within NASA. In fact, a group of engineers at NASA around 1991 began publishing a number of papers on the feasibility of rocket-powered-single-stage-to-orbit vehicles.[45]

This project is not intended as a study in bureaucratic decision making, it is simply intended to serve as a tool for understanding how bureaucratic forces inside NASA and DOD drove the president to a "two-track" policy, when there were strong political trends favoring one "track" over the other. In fact, a senior administration official has noted strong congressional interest in the RLV.[46] Congress was also willing to back this preference up by voting more money for the RLV subscale demonstrator in the FY95 Defense Appropriations Bill than for initial work on the EELV.[47] The EELV's chances for survival, given the unfortunate precedent of ALS, NLS, and Spacelifter, would not be very good in the best of circumstances, but given the real or perceived competition between an old-technology ELV and a flying RLV advanced technology demonstrator four years hence, Congress is even more likely to cancel the EELV. NASA has scheduled the advanced technology demonstrator RLV to fly no later than July 1999 (the 30th anniversary of the first moon landing, a coincidence to be sure).[48] DOD's EELV, on the other hand, is projected to fly for the first time in 2000.[49] In today's resource-constrained environment, an expendable launch system on the drawing board will find it very difficult to compete for dollars with a flying prototype RLV. The EELV's first flight may very well be a year late and a couple of billion dollars short. As Luis Zea says in the December 1993 issue of *Final Frontier*, "Recycling ideas like the National Launch System and the more recently proposed Spacelifter family of expendable boosters appears to be politically dead."[50] EELV program managers are working hard to prove him wrong, but the weight of history is against them.

Convergence of Economic Forces

Even if RLVs, arguably the precursors of Hap Arnold's space ships, are more politically viable and fiscally realistic than EELVs, they still may not be affordable enough to avoid cancellation themselves. If Congress won't vote $2 billion for an

EELV, why should it vote $20.6 billion, $17.6 billion, $6.6 billion, or even the $5.5 to $6.5 billion figure quoted by former astronaut Pete Conrad for a reusable launch vehicle?[51] Perhaps it would be cheaper to stay with current ELVs or the shuttle. Unfortunately, as discussed earlier, the cost of operating today's launch fleet will not permit that. The DOD's current expendable fleet costs $2.5 billion a year (about 20 percent of the DOD space budget), while NASA launches about eight shuttles a year for $4.3 billion (approximately 31 percent of NASA's budget). This is the source of urgency behind new launch vehicle development. While EELV makes a marginal improvement in per mission and operations and support costs, the RLV promises to bring launch costs down by a factor of five to 50 (to between $1 and $10 million per flight).[52] The cost savings over the life cycle of the single stage to orbit (SSTO) reusable "space ship" would be significant. The DOD estimates the annual operational cost of a fleet of four such vehicles at $0.5 to $1.5 billion (as opposed to the $6 billion plus for today's expendables and the shuttle).[53] In other words, even if the DOD is right about the high up-front investment required, the nation would save at least $4.5 billion per year. NASA conservatively estimates that payback on the initial investment will occur approximately nine years from RLV initial operating capability.[54] If this is accurate, it becomes difficult to make an economic case for remaining with the status quo. The rest of this section tries to determine whether there is a positive economic case for reducing the cost of access to space (in addition to the weaker negative motivation of dissatisfaction with the status quo). The analysis will also attempt to deal with some of the fiscal issues raised by RLV opponents.

The Economic Case for and against RLV. Even people who are skeptical about rocket-powered SSTO understand that the only reason to make the large up-front investment in RLVs is the savings in life-cycle costs. Some opponents of the technology believe that the projected savings in life-cycle costs are too good to be true. There have to be, they believe, some "hidden costs" to SSTO such as; upper stages required to reach geostationary orbit, the inability to carry heavy payloads that will force the DOD to retain the heavy Titan IV expendable for national security payloads, or the expense of building a huge liquid hydrogen storage infrastructure.[55] These criticisms, however, back a conception of new ways of doing business in a world where spacecraft have some of the operability of aircraft. (As will be discussed shortly, this conceptual limitation is even more dangerous in the national security area.)

Analysis of these three charges based on an understanding of how air transport works may be useful in determining whether there are legitimate economic reasons not to proceed with SSTO.[56] The parallel between air transport and reusable space transport operations may not be complete, but it is probably closer than the ballistic missile model in use today.

Charge I. Opponents claim that SSTO RLVs could not carry the significant number of DOD, NASA, and commercial payloads bound for geostationary orbit (22,300 miles equatorial orbit) since the NASA SSTO reference configuration is designed to carry a 25,000 pound payload to the planned international space station orbit at just 220 nautical miles altitude. The critics claim that the SSTO would have to carry an expendable upper stage (adding $16 million to its per launch costs for a total around $26 million, wiping out enough of SSTO's per launch cost advantage, making it uneconomical), or that the government would have to fund a multibillion dollar reusable upper stage to get the per launch costs down to $14–$16 million (with Congress in no mood to fund additional program starts.)[57] Further analysis, however, reveals an answer that is entirely different for three reasons not considered by the critics.

1. On-Orbit Refueling. During the Persian Gulf War, when planners chose targets in Baghdad for aircraft stationed in southern Arabia, a refueling tanker rendezvous was scheduled as a matter of routine. This is what reusable launch vehicles will enable the United States to do in space. Work has already been done on cryogenic fuel transfer in a microgravity vacuum environment, and even the US Air Force has considered increasing the operational availability of space assets by refueling them with ELVs.[58] (Although these ideas never flew because the high cost and long delays of ELV launches made such operations impractical, RLVs could bring them back to life because of their lower cost and greater responsiveness.)

Developing and using these techniques for on-orbit refueling, reusable launch vehicles can themselves become “reusable upper stages” at far less cost than a new program start. The cost for the “tanker” would not be analogous to that of specialized air-breathing tankers for aircraft refueling in the illustration above, and would not require the development of a new vehicle. Instead, it would mean changing out a standard RLV payload for fuel and refueling connections. Developing these new techniques will be difficult, similar to the work involved in making aerial refueling a routine and safe operation. Although ground-based experiments using possible methods of refueling in a microgravity vacuum environment have been conducted, no such experiments have been conducted in space. There are the obvious problems of gaseous venting in vacuum, frozen connections, and unknown propellant flow characteristics in microgravity. Mission needs will drive the development of this capability, not engineering curiosity. If the RLV is as operable as NASA believes it will be (seven-day turnaround with a 0.95 probability of on-time launches), then there will be a strong incentive for civil, commercial, and military operators to exploit the potential offered by that operability.[59] Refueling in space is one way to do this, allowing operators to accomplish missions that are not otherwise possible without developing entirely new vehicles.

Space ship operators would, however, have to ask themselves several essential questions before they proceeded with any refueling modification. Can we do without the ability to get heavy payloads to geostationary orbit (GEO)? Probably not, since the majority of the $5 billion space industry is presently in medium-weight geostationary communications satellites.[60] Can we afford to operate ELVs or partial reusables far into the future? Both the NASA and DOD space access studies say no. Can we afford the billions of dollars that it will take to develop a new orbital transfer vehicle?[61] Probably not, and especially if operators have just spent billions of dollars to buy an RLV. Is there a possibility of extending the range of the RLV to capture medium-weight geosynchronous satellites without the expense of a new program start? There may be, given the encouraging preliminary results of the refueling studies cited above. If so, then a relatively small investment in designing a new payload for an existing RLV seems eminently more sensible than developing an entirely new vehicle for a single purpose. Given these answers, it seems likely that the refueling option will be attractive to RLV operators after their ability to get to low Earth orbit (LEO) routinely has been proven. Again, this modification is not trivial, but engineering studies suggest that it is well within the realm of possibility.

2. Lower Insurance Costs. The ELV is a lot like an artillery shell. Once launched it cannot be recalled. That is why, at every US ELV launch, there is an official at a console monitoring the status of the mission and the ascent trajectory. If the mission deviates a given amount from predetermined parameters, the range safety officer detonates the vehicle's destruct package (if the vehicle hasn't already destroyed itself). RLVs, on the other hand, are intended to land safely after every mission and have built-in mission abort capabilities. The fact that there is no destruct package on the first flying subscale RLV model is a matter of some importance to its program managers.[62] If an engine fails after takeoff, the vehicle executes an emergency landing as the subscale RLV did after an explosion during a test flight in June 1994.[63]

Beyond the obvious material savings, this has enormous insurance implications. At present, payload insurance rates for expendable rockets are a significant part of launch costs for commercial concerns. With insurance rates around 18 percent of the total of satellite cost plus launch cost, any reduction in risk could make for significant savings.[64] Assuming a still relatively new reusable launch vehicle that has demonstrated its intact abort capability at least once, we might guess that satellite insurance companies would give commercial space ship operators an insurance discount, perhaps charging 10 percent of launch value rather than 18 percent.[65] For a $75 million medium-weight geostationary communications satellite on a $60 million expendable mission with the same payload capacity as an RLV to LEO, it turns out to be over $66 million in savings for a single mission which more than covers the cost of up to five RLV "tanker" missions insured for their launch costs at a 10 percent rate.[66] In fact, a $60 million expendable mission launching a $75 million commercial communications satellite to geostationary orbit with $25 million in insurance will cost more than six $10 million reusable missions with one payload carrier and five refueling missions. There would be a total of $13.5 million in insurance costs at 10 percent of satellite plus launch cost for the RLV ($148.5 million total launch, payload, and insurance costs). Of course, to make money, the launch operator would fly as few tanker missions as possible. The amount of fuel brought up by an RLV designed to meet NASA's X-33 requirements on five missions would be far in excess of what was needed to get to GEO. In fact, it would be enough to get to the moon.

In addition, the refueled RLV would be able to take the entire 20,000 pounds to GEO, while the ELV would have to use up some if its payload weight to LEO to get the satellite into a geosynchronous transfer orbit. The numbers outlined above suggest strongly that the enterprises with RLVs would enjoy a significant competitive advantage over those still flying ELVs simply due to insurance savings. This would not directly affect DOD launch costs, but if a significant number of commercial payloads migrate to RLVs, then ELV production rates will slow down and prices will go up. A similar slowdown in Titan IV production has been the principal cause of a 60 percent increase in launch costs.[67]

3. Follow-On Missions. This brings us to the third reason that the "additional cost for upper stages" argument is fallacious. If each of the five-tanker missions in the exaggerated example above brings up 25,000 pounds of fuel, the RLV carrying the payload would not only have enough fuel to deploy the communications satellite, it would also have enough fuel to perform a follow-on mission such as retrieval of the older satellite it is replacing (or even to go to the moon with one more tanker mission).[68]

Using a derivation of the rocket equation, $\Delta v = g\ I_{sp}\ 1n\ (M_0/\ M_E)$, a gross lift-off weight of 1,000,000 pounds; a PMF of 0.90; a resulting vehicle empty weight of 100,000 pounds; space shuttle main engine vacuum I_{sp} of 453 seconds, and an approximate Δv of 12,000 fps required for translunar injection from earth orbit; an RLV could take on six 25,000 pound-fuel loads and reach the moon for a lunar survey mission similar to the Ballistic Missile Defense Office's recent *Clementine* mission.[69] Getting 18,000 more fps (two times lunar escape velocity) for an orbit circularization burn, landing, and takeoff would require 21 more missions (which is less than NASA's projected space station construction mission model using a far less operable spacecraft).[70] This mission also requires a vertical takeoff, vertical landing (VTVL) RLV.

This may seem a massive undertaking for a mission that does not seem to have much national priority, but the operability of the RLV may make such a trip useful for economic reasons to be discussed shortly. That said, when the nation is ready to return to the moon, a $28- to $280-million mission (28 RLV missions at $1 to $10 million each) modifying a vehicle whose cost is recouped in earth-to-LEO operations would be far more cost-effective than paying the development cost for purpose built orbital transfer vehicles, lunar landers, or other specialized vehicles. It is cost competitive with a single Titan IV launch and less expensive than a space shuttle mission. There is no cost comparison with expendables for the retrieval or lunar missions, because no matter how much money is spent on a single ELV mission with present or evolved vehicles, these multiple missions are not possible without developing other specialized expendable vehicles.

This extreme example makes the point: thinking about reusable launch vehicles in the same way as expendables can prevent the analyst from seeing opportunities that will be apparent soon after RLVs become available. As this example also illustrates, it is likely that many more opportunities will arise once the space operability revolution takes place, but these opportunities are so difficult to foresee that they cannot reasonably be used as justification, economic or otherwise, for RLV development. There are, on the other hand, enough possibilities that earthbound analysts at NASA and elsewhere are able to justify the economics of proceeding along this development path if only to reduce today's high operating costs.

Charge II. Opponents also charge that first-generation RLVs will be unable to loft heavy payloads. Where the first charge was that the RLV compared unfavorably with medium-lift ELVs, the second charge is that the RLV cannot compete at all with heavy lifters. On the face of it, this claim is accurate as long as the launch operator limits the mission to a single launch. Today's space community has been conditioned to think of getting satellites into orbit as unitary events, with each launcher custom-tailored to each payload. If a payload weighs 40,000 pounds and its mission is in geostationary orbit, conventional wisdom suggests the need for a heavy-lift vehicle plus a transfer stage to take the whole package there at the same time. Again, this sort of thinking will be inadequate for the age of the reusable launch vehicle. In the RLV world, as in the rest of the transportation world, if the cargo is too heavy to take in one trip, the solution is to put it in two boxes and make two trips. As David C. Webb, president of the International Hypersonic Research Institute and former member of President Ronald S. Reagan's National Commission on Space, suggests in his Aerospace Industries Association of America (AIAA) paper, "Spaceflight in the Aero-Space Plane Era,"

Potentially, the way around this problem is to break the platform up into smaller chunks and launch them on smaller launchers. It would be even less expensive to do this with aero-space planes. [Something he defines as: "aero" because such vehicles utilize the atmosphere, "space" because they go into space, and "plane" because they are operated like airplanes. The SSTO vehicle, therefore, is considered an aero-space plane even though it may not look like an airplane.] It might seem that the large military reconnaissance satellites could not be launched on aero-space planes. However, one possibility could involve splitting the satellite into two modules that are launched separately and assembled in orbit.[71]

If a Titan IV launch costs from $250 to $320 million per launch, then one could theoretically take the payload up as separate components, launching it in 25 to 32 missions at $10 million per trip and still break even. In fact, work-on-line replaceable units for satellites (similar to those in the aircraft world) is presently under way at the US Air Force's Phillips Laboratory. Even though the laboratory is working on modular satellite construction for standardization and cost-savings purposes, some of this work could be directly transferable to the on-orbit assembly idea. Again, the extreme example makes the point. It is poor analysis to make the blanket assumption that a medium-lift RLV will be unable to carry heavy payloads. The operability revolution inherent in RLV technology will enable new solutions to old problems, and create economic and military advantages for the United States in space that are difficult to foresee. This will be addressed in further detail in the discussion of the national security implications of the RLV.

Charge III. Finally, opponents charge that because SSTO requires high I_{sp} fuels, which today means cryogens such as liquid hydrogen, the high cost of the terrestrial hydrogen infrastructure necessary to support robust operations will be prohibitive. This is more an argument against launch sites at every airport than it is against the cost effectiveness of RLVs in replacing the current fleet of expendables and semi-expendables. Many of today’s launch vehicles use cryogens, the space shuttle among them. In fact, the shuttle uses the same cryogens that NASA plans to use for its planned RLV demonstrator, the X-33. There will not be large fuel infrastructure costs associated with the transition from the shuttle to RLVs. In fact, as part of the X-33 Cooperative Agreement Notice (CAN), NASA sets out as a program goal that,

> the flight vehicle shall be capable of unplanned landing at alternate landing sites with minimal support equipment/facilities, e.g.,
> – No existing cryogenic facilities, launch stands/equipment, etc.
> – Self-ferry of flight vehicle between landing and launch sites. . . . Equipment required to repair, process, and return vehicle to launch site shall be transportable.[72]

If indeed the infrastructure requirements for ferry missions are minimal and NASA finds it useful to launch some missions from White Sands Missile Range, New Mexico, for extra energy (because of its elevation), some missions from Florida for eastward equatorial orbits, some missions from Vandenberg AFB, California, for polar orbits, and some from higher latitudes for higher inclination orbits, then the government is likely to build the skeleton of an infrastructure that private interests can use to begin commercializing the vehicles. Among past examples of infrastructure investment for national purposes that turned out to have enormous commercial implications was the worldwide network of coaling stations for steamships in the late nineteenth century. This network, built by the industry and governments of the great naval powers, became an essential element of national security and a significant factor in the worldwide trade that built the United States's national wealth.

Another example was the infrastructure required to support the automobile. In the early twentieth century, when Henry Ford decided to mass produce the automobile, the infrastructure argument would have gone something like this, "Henry, how do you expect to make any money? There are no roads to run those things on and everyone lives right next door to the store where they work. Even your factory workers are within streetcar distance of your plant. No one will spend the millions and millions of dollars to build the roads or the petroleum-based fuel distribution infrastructure for these things to run on." The critic would have been absolutely right, if Model Ts provided the same amount of productivity per mile as horse carriages.

Similarly, the infrastructure cost critiques would be right if RLVs are only as productive and operable as ELVs. However, if there is money to be made or saved by operating RLVs, then the cost of infrastructure will be amortized through savings and profit, and as the DOD estimate of annual cost savings over expendables shows, those savings are in the billions of dollars per year. If one adds the profit taken from foreign expendable launch operators, one could buy a lot of liquid hydrogen and the infrastructure required to handle it.[73]

The principal economic force acting to drive interest in and funding for the RLV is the desire to reap the benefits of the cost savings inherent in its operability. Launch costs are devouring the NASA and DOD budgets, and both institutions know they have to do something to cut costs in the face of continuing budgetary pressures. So far, this is the principal economic force acting as a stimulus to RLV development, but there are indications that it may not be the only one.

Private Sector Argument for RLVs. Private sector interest in a reusable space launch vehicle and in a possible reusable hypersonic point-to-point (as opposed to earth-to-orbit) cargo carrier is another economic trend working to stimulate RLV development. The US government has attempted to take advantage of this interest by pursuing a unique acquisition approach in the development of the RLV, offering "Cooperative Agreement Notices" rather than traditional requirements statements to begin the acquisition process. NASA, to maximize the private sector's intellectual, entrepreneurial, and financial contribution to the RLV program, has issued a CAN for an experimental flying vehicle, the "X-33," that allows the private sector, for the first time, to propose and include independent research and development as part of their corporate contribution.[74] This new approach is designed to keep NASA engineers from driving RLV design toward a predetermined solution that meets only NASA's needs, and not industry's. In fact, some NASA centers have had difficulty adjusting to the new reality, publishing reports that seemed to favor one RLV solution over another, and earning a written reprimand from NASA headquarters for their trouble.[75] The objective of the CAN, NASA says, is to

> stimulate the joint industry/Government funded concept definition/design of a technology demonstrator vehicle, X-33, followed by the design/demonstration of competitively selected concept(s). The X-33 must adequately demonstrate the key design and operational aspects of a reusable space launch system. As a minimum, the scaleability and traceability of the X-33 airframe, cryogenic tanks, and thermal protection system (TPS) to the corresponding proposed SSTO rocket must be identified.[76]

As of this writing, three prime contractors, Lockheed Martin, Rockwell International, and McDonnell Douglas have entered competitive SSTO concepts. One of their designs is scheduled to be selected by July 1996 for construction and flight as early as possible but not later than July 1999. NASA will make every effort to accelerate this schedule and will assist the selected contractor(s) in any feasible manner to fly the advanced technology demonstrator before July 1999.[77] At least one other private company sees the economic potential of reduced cost access to space and is pursuing RLV technology outside of the CAN process. Kistler Aerospace is using the profit its founders made from their Spacelab venture (a private/NASA cooperative project that has flown on the shuttle) to finance their own reusable launch vehicle. They plan to raise $400 million from private investors and to put up $100 million of their own money to fund the estimated half-billion-dollar program cost. Though industry and government officials give Kistler little chance of success, given estimates of RLV development costs in the billions, the fact that investors are willing to risk $100 million of their own money to pursue the possibility of reusable space ships is another strong indicator that economic forces are in place that are providing a push to the technology.[78]

There are other potential commercial uses for an RLV that have spurred some interest from the private sector. Science and science fiction writers have described intercontinental ballistic passenger and cargo spaceships for years. In Philip Bono and Kenneth Gatland's seminal 1969 book, *Frontiers of Space*, the authors propose a 200-foot-tall intercontinental passenger/cargo carrier for suborbital missions which could haul 1,200 passengers 7,500 miles in slightly over one-half hour. A second idea, *Hyperion*, was a conical VTVL SSTO (much like McDonnell-Douglas's current ideas) that could carry 8,100 pounds to orbit.[79] In the December 1993 issue of *Analog* magazine, science writer G. Harry Stine calls suborbital hops the "hidden market" for SSTO services. As Stine points out, "any SSTO spaceship that can take a payload to orbit can also deliver passengers and cargo to any place in the world in less than an hour."[80]

This could all be dismissed as idle speculation but for the fact that Federal Express (FedEx), one of the leading on-time freight express companies in the world, is giving its support to the design review processes of all three teams competing to develop the X-33.[81] The FedEx interest on its own will not build the space ship, but it does seem to indicate that there are uses beyond access to orbit for reusable hypersonic technology. This could provide an even stronger economic stimulus for the near-term development of single-stage rocket technology in light of the fact that the $200 billion size of the commercial air transport market dwarfs the total worldwide space-market figure of $5 billion.

There are also other missions for RLVs outside of conventional earth-to-orbit NASA/DOD mission models that could drive the market for them. Orbit-to-earth return missions may also turn out to be nearly as lucrative (e.g., space debris cleanup, on-orbit satellite repair and salvage, and what might be called single-stage-to-earth [SSTE] operations). The economics of these missions, however, are difficult to foresee and were already proposed as missions for the space shuttle in the early 1980s (and then turned out poorly). It may, in fact, be so difficult to foresee the cost implications of SSTE missions that they are not useful as economic justification for SSTO. The ability to routinely rendezvous with and retrieve material from space may, however, be an interesting capability that space ships give their operators which has enormous national security implications.

Other possible missions are even more speculative (such as space tourism, deep space exploration, military presence missions); using them as economic justification for RLV development quickly degenerates into an argument over causality. In addition, these missions are not relevant to the debate in the near term. RLV space ships are justifiable on the economic grounds of cost savings to be gained by eliminating ELV and shuttle operating costs, by reducing the need for orbital transfer vehicles and Upper Stage Development programs, and (if FedEx’s interest in X-33 is an indication) on the grounds that there are air transport missions they can perform at hypersonic speeds.

Technological Forces

Finally, recent technical advances provide the underpinning for some of the economic and political trends discussed above. Although space ships have been foreseen at least since the advent of the German A-4 rocket (known to the Allies as the V-2) at Peenemünde on the Baltic coast during the Second World War, they have not been technically possible because the weight of the materials and the specific impulse of the rocket engines available did not permit single-stage vehicles to achieve orbit.

As early as 1946, US rocket designers believed that it was possible to build SSTO vehicles with lightweight materials (usually allowing pressurized propellant tanks to double as vehicle structure to save weight as the early Atlas ICBM did) and high specific impulse oxygen/hydrogen engines.[82] Unfortunately, neither lightweight materials nor LOX/LH_2 engines were available in the late 1940s. A LOX/LH_2 engine had to wait until Centaur in the 1960s and the shuttle became the first vehicle to use LH_2 at liftoff in 1981.[83] Early drawings of these prospective single stage vehicles bore an uncanny resemblance to the V-2. Although some successor to the V-2 was arguably what Hap Arnold had in mind when he wrote about "space ships," the V-2, in fact, turned out to be the technological predecessor of the costly expendable rocket approach. The same German rocket engineers who designed the V-2 also developed the Redstone missile for the United States. Alan B. Shepard rode this missile on a 15-minute suborbital hop in 1961 to become both the first American in space and the first American to ride a suborbital hypersonic transport.

The German engineers from Peenemünde then went on to form the nucleus of the design teams that built the Jupiter missile, which led to the Saturn I and, in turn, the Saturn V moon rocket. Offshoots of the Huntsville team include the Titan ICBM, which has become the Titan IV, today's largest and most expensive US ELV.[84] As Stine says in *Confrontation in Space*, "nearly all of the USA space launch vehicle stable stands on the foundation of Peenemünde."[85]

Interestingly, the design heritage of the modern RLV goes back, not to Peenemünde, but to work done by Douglas Aircraft for a nuclear-powered bomber for the US Air Force in the early 1950s. In the late 1950s, a young Douglas engineer named Maxwell Hunter took the engine design for the canceled Air Force nuclear airplane and began to investigate a single-stage-to-orbit nuclear rocket called the Reusable Interplanetary Transport Approach (RITA). After the RITA program ran its course, aerospace engineer Bono came to work for Max Hunter at Douglas and began his long work on the series of VTVL SSTO concepts which he describes in *Frontiers of Space*. Through the 1960s and 1970s, SSTO ideas languished because of materials and propulsion limitations. Serendipitously, US government intervention in the form of the lightweight materials that came out of the NASP and NLS programs revived these discussions in the late 1980s and early 1990s.

At this point, political forces converged with SSTO technology. At the beginning of the President George S. Bush administration, a group of conservative space advocates including Max Hunter and retired Army Maj Gen Daniel Graham, met with the vice president and the National Space Council to advocate a reusable VTVL SSTO rocket vehicle. Given the administration's commitment to former President Ronald Reagan's scramjet-powered SSTO, the National Aerospace Plane, however, it would have been politically difficult to start another NASA/Air Force Joint Program Office to investigate rocket SSTO, so the administration decided that the well-funded SDIO should foot the initial bill. Significantly, General Graham's High Frontier Foundation had been part of the initial impetus for SDI and he remained one of its staunchest supporters. It is not surprising, therefore, that SDIO obligingly funded four aerospace industry study teams to research and design SSTOs capable of launching 10,000 pounds to polar low earth orbit. In 1991, however, Ambassador Henry Cooper, director of SDIO, under funding pressure from Congress and interagency pressure growing out of the perception that SSTO had become a very popular rival to other launch system improvement programs, elected not to assume management of the program beyond suborbital testing of a one-third scale model, the DC-X. The program title was changed to Single Stage Rocket Technology (SSRT), with any additional SDIO funding beyond DC-X contingent upon a derivative of DC-X meeting SDIO's suborbital launch requirements. As a result, and with the 1993 dismemberment of SDIO, SSRT became an institutional orphan.

Not content with cutting Air Force follow-on funding for the technology, agencies with competing agendas actively worked to dismiss the possibility of rocket SSTO. In 1991, Martin Marietta (makers of the Titan IV ELV) cast doubt on the economics of rocket-powered SSTO and the Air Force space acquisition community dismissed the technology in a 1992 NLS decision brief to the secretary of the Air Force.[86] A primary back-up chart from the briefing reflects this position in a quote from the Aldridge Report, "NASP, SSRT, and High Speed Civil Transport (HSCT) are not in competition with or a substitute for NLS since these technologies are not sufficiently mature to risk 'leap-frog' development."[87]

Despite this Air Force and contractor nay-saying Dan Goldin, the NASA administrator, became interested in the idea of a reusable single stage-to-orbit launch vehicle after seeing the DC-X fly.[88] He saw the possibility of an advanced technology program building on the knowledge gained from DC-X that would restore US leadership in space and perhaps solve the nation's access to space problem. This was the genesis of NASA's sponsorship of the subscale advanced technology demonstrators that are now flying, and arguably, the beginning of NASA's interest in the X-33 idea.[89]

This idea did not spring up overnight. It has a long technological and engineering history and significant backing inside and outside of the space technology community (there are even three Internet home pages dedicated to RLVs and to political activism on the technology's behalf).[90] With private sector interest inside and outside of the NASA CAN process, with public advocacy groups developing briefings for members of the public to show to their members of Congress, and with a real national need to solve the access to space problem, there now seems to be a significant impetus for the RLV to change how the United States operates in space.

This moment in history is unique in American development of the space frontier. The combination of the political, fiscal, and technological forces that are driving the RLV idea seem to add up to the possibility, and perhaps even the probability, of significant near-term change in our ability to access space. What will that mean for US national security? That is the topic of discussion in the remainder of this work.

Military Implications of Inexpensive Space Access

As already outlined, the lack of routine civil and commercial access to space militates against the development of robust methods for using the medium for commercial purposes. For similar reasons, it may also work against the development of robust methods for using the medium for national security purposes. In fact, the current difficulty in accessing space is a fundamental reason for the limited perceptions of what it is possible to do there.

The state of present joint US military space doctrine as the United States lowers the barriers to space access is a case in point. Joint doctrine assumes that one of the "operational characteristics" of space cited in "Joint Doctrine, Tactics, Techniques, and Procedures" (JDTTP) 3-14, *Space Operations*, is "difficult access."[91] Any doctrine that assumes that access to the medium it addresses is going to be difficult and infrequent is also likely to assume that operations which require robust and continuous access (such as protracted combat or logistic resupply) will not take place there. If the conditions underlying the doctrinal assumptions change, however, then the doctrine derived from those assumptions is not likely to be prepared for the changed conditions. This happened on the Western Front when Great Power assumptions about the density of fire on the World War I battlefield proved incorrect, it happened to the French during the Battle of France in 1940 when assumptions about the speed of armored maneuver coordinated with airpower changed, and it happened to the Iraqis during the Persian Gulf War in 1991 when assumptions about the effectiveness of airpower changed. This section attempts to determine whether this sort of doctrinal discontinuity is likely in the next few years if the RLV programs called for by the president's new National Space Transportation Policy are developed and access to space is made much less "difficult."

Despite the limiting assumption of "difficult access," there are nevertheless ideas in present joint space doctrine and objectives in the president's National Security Strategy (NSS) that will be useful in the RLV era. The 1994 NSS, for example, says that two of the United States's main policy objectives in space are, "continued freedom of access to and use of space" and "maintaining the US position as the major economic, political, military and technological power in space."[92] The draft joint armed forces space doctrine, although written two years earlier in support of Bush-era space policy, supports the objectives of the 1994 NSS in this regard with the recognition that there are certain strategic locales in space that have to be controlled in order to maintain access, what Joint Pub 3-14 calls "decisive orbits."[93] It also posits that space forces should consider capabilities to "control" these orbits by force, but then, in a "Tactics, Techniques, and Procedures" manual, it provides no tactics, techniques or procedures for doing so.[94]

To be fair, access to space has heretofore been difficult and, in part because of that difficulty, few people on the Joint Staff have had to think about how realistically to control "decisive orbits." Nevertheless, as General Arnold said of Air Forces in 1945, "National safety would be endangered by an Air Force whose doctrines and techniques are tied solely to the equipment and processes of the moment. Present equipment is but a step in progress, and any Air Force which does not keep its doctrines ahead of its equipment, and its vision far into the future, can only delude the nation into a false sense of security.[95]

The same might be said today for "any space force" or for any service that claims as its mission the defense of the United States through the control and exploitation of their respective realms. If, in fact, access to space is about to become much less difficult, then it behooves military thinkers and doctrine writers to determine what the deficiencies in their doctrines are before the fundamental assumptions underpinning them are invalidated (or at least to think far enough ahead not to be blindsided when it does happen).

That said, the next section builds on the technological possibilities previously discussed to determine what doctrinal deficiencies a possible "space operability revolution" will reveal in US joint space doctrine, and what new doctrines might be required in a proliferated space access world. Before proceeding, however, it is necessary to challenge some shibboleths about the military uses of space.

Political Sensitivity of the "Militarization" of Space

The Outer Space Treaty of 1967 prohibits several specific activities in space. It prevents signatories from stationing weapons of mass destruction anywhere in space and forbids the construction of military bases on the moon. Article II says that "Outer space is not subject to national appropriation by claim of sovereignty" and Article V says that the Moon and other celestial bodies shall be used exclusively for peaceful purposes. There are no prohibitions, however, against reconnaissance, surveillance, military communication, navigation, or other uses that support terrestrial military operations. These uses, whose value to the United States and its Coalition partners was demonstrated in the Persian Gulf War, create tension between the "no national appropriation" rule and reality. The war demonstrated that there are orbits and force structure in space that the United States must be able to control and protect in time of war to fight successfully. This is the origin of the "decisive orbits" idea in the 1992 draft joint space doctrine as well as the statement that force may have to be used in order to secure them. On the face of it, this statement is a violation of the spirit, if not the letter of the Outer Space Treaty, but the president's National Security Strategy echoes this sentiment when it speaks of "freedom of access" (similar language with respect to freedom of the sea has been the basis for a good part of the development of the US Navy).

The very existence of the "space control" mission, in joint as well as Air Force doctrine, is an acknowledgment that the United States has equities in space that it cannot afford to lose in time of conflict, the Outer Space Treaty notwithstanding. As a result of the new higher stakes in space, it has been suggested that military space operations could see the same progression from observation and signaling to pursuit and bombardment that aviation made during the course of World War I.[96] Since early airplanes were relatively inexpensive, the armed forces could afford to experiment with various types and to determine their capabilities under combat conditions. A few aircraft losses while trying to work out the details did not threaten the air program as the loss of *Challenger* threatened the space program. Another analogy may also be useful, that of the development of submarine warfare before World War II. Submarine warfare, after the political and moral opprobrium aimed at the Germans for sinking troop ships and merchant men in World War I, could not be politically justified based on the Corbettian idea of the commerce raider.[97] Nevertheless, the Navy was able to buy submarines and field them in a world where new technology and doctrine had to be developed in a hostile political climate to set the stage for American success in World War II. In fact, the submarine's threat to the battleship Navy led to its misapplication in war games and to the promotion of conservative skippers who had to be replaced by a more aggressive breed in 1941. One submarine captain put it this way, "The minds of the men in control were not attuned to the changes being wrought by advancing technology. Mahan's nearly mystical pronouncements had taken the place of reality for men who truly did not understand but were comfortable in not understanding."[98]

This example shows that it is possible for the US armed forces to field new technologies that give them the edge in future wars without clear positive national policy goals (and even in the face of some political and senior military resistance). As we have seen, the NSS already reflects American national interests more than it does the spirit of the Outer Space Treaty. If and when RLVs begin to fly, policy makers can reasonably be expected to use them to further the national interests of the United States, as they did with the submarine in the 1940s, and as any nation will if and when it builds its own space ships.

Traditional Military Missions in Space

Some of the possibilities for reaping the economic rewards of increased operability in space have already been discussed. Using some of these economically useful capabilities, this section will explore some possibilities that space operability offers for national security.

Current joint and air doctrine divides military operations in space along the same lines as current US armed forces doctrine. These four broad functions are force enhancement, force application, space control, and space support.[99] Today's doctrine lists activities such as communications, navigation, intelligence and surveillance, environmental monitoring, mapping, charting, and warning processing and dissemination as part of force enhancement. Within force application are ballistic missile defense, aerospace defense, and power projection. In space control, protection, negation, and surveillance of space are listed. Space support consists of launch, satellite control, and logistics.

As with much of terrestrial US armed forces doctrine, this speaks very much to the nuts and bolts of how military power is used in warfare, but does not say a great deal about what it is used for. It also is deficient in describing uses for military power outside of the context of a shooting war. There is usually a diagram at the beginning of US doctrine manuals that outlines the tie between the National Security Strategy of the United States, the national military strategy (NMS), and the doctrine in question, but the logic flow between the boxes or circles in the diagram is not clearly spelled out.[100] For example, when the same four pillars of the National Military Strategy of the United States (deterrence, forward presence, crisis response, and reconstitution) can support both former President George Bush's NSS and President William "Bill" Clinton's new National Security Strategy of Engagement and Enlargement without significant change, it is reasonable to suspect that there is little real deterministic relationship between the NMS and the grand strategy it is supposed to support. The military has simply divided warfare into four parts and tied it to the NSS at only the most superficial level. What is the logical tie, for example, between President Clinton's new national objective of "promoting democracy" and the combat-oriented strategy of "deterrence, forward presence, crisis response, and reconstitution?"[101] As a result, when the president wants to use military forces to achieve precise political effects that don't involve combat, the armed forces are often reluctant, pressing instead for either overwhelming force or non-involvement. Unfortunately for the Department of Defense, achieving precise political effects (not involving combat) is what the armed forces are called upon to do much of the time. In the first 45 years of the US Air Force's existence, for example, it was called upon for "air movements of national influence" hundreds of times, as opposed to only a few combat operations.[102] American military forces are often used in situations where "force" and "control" (as in force enhancement, force application, and space control) are not acceptable. Humanitarian operations and operations other than war are good examples of this language's failure to describe the full range of possible military operations in support of national policy objectives.

Joint doctrine's inadequate treatment of these subtleties in terrestrial operations is a handicap, but not a fatal one, because policy makers can conceive of and implement uses of the terrestrial military for noncombat policy purposes without the help of military doctrine. The blockade of Cuba during the 1962 missile crisis is a good example. Even though traditional US Navy blockade procedures were not followed (sometimes over the vociferous objections of flag officers), the blockade was conducted as the president wanted it, not in accordance with traditional naval practice. Similarly, in 1993, President Clinton directed a reluctant US Air Force to begin night food-pallet drops to Bosnian civilians to directly achieve specific national policy objectives. If this sort of operation, which often characterizes the exercise of US power in both the cold war and post-cold-war periods, continues to be prevalent, then space doctrine as well as terrestrial doctrine should reflect this reality.

However, doctrine's inadequate treatment of this type of operation in space may be a more serious handicap in the coming RLV era. This is because decision makers will find it much more difficult to conceive of the possibilities for using newly operable space power to implement their policies. Missions such as enforcement of today's ongoing terrestrial sanction regimes or air exclusion zones, blockade of other groups' access to space, repositioning space forces over a target state or group's territory as a demonstration or to provide presence over a given region or in a specific "decisive orbit," or providing rapid humanitarian relief using the suborbital lift technique discussed previously could be extraordinarily useful politically, but they are likely to be outside of the cognitive schema of most military leaders, let alone civilian policy makers.[103]

New Space Missions in the RLV Era

The RLV space ship's characteristics would make it not only possible, but affordable and politically feasible to use military space forces to “move national influence” in the same way that air and sea power do today. In other words, operable space forces could participate in military missions that directly support the achievement of national policy goals not necessarily in direct support of a combatant commander on earth in ways that today’s few and fragile space forces cannot.[104] Some of the contributions of the space operability revolution that would enable such participation would be timely logistic resupply, rapid maneuverability, and on-scene human judgment. All three are to be discussed here, with no particular significance to the order in which they are presented. Relationships between the three will become evident in the discussion. As each is discussed, trade-offs with current terrestrial methods, some possible strategic circumstances under which these capabilities might be useful, and some tactics, techniques, and procedures for using them are also addressed.

Logistics. There have been a number of US Air Force and NASA studies of refueling and refurbishment of on-orbit force structure.[105] Many of these studies were predicated, however, on expensive and unresponsive expendable launch vehicles to bring refueling and servicing payloads up to target satellites from earth. As a result, these studies never progressed past the paper stage. With reusable space ships, however, the calculus changes. As previously discussed, RLVs make it economical to replace and retrieve the current generation of satellites. It also becomes possible to refurbish satellites that are designed for on-orbit servicing, thus avoiding the cost of new satellite design and construction. Reconnaissance and warning satellites could have their sensor packages upgraded with the latest technology using line replaceable units (like those the Air Force’s Phillips Laboratory is developing today), rather than becoming obsolete. In today’s context, with RLVs and modular satellite design, the debate over the Defense Support Program (DSP) follow-on would have a simpler answer. Rather than asking Congress for a new program start (such as the canceled Follow-on Early Warning Satellite or the controversial DSP II proposal), the United States could replenish station-keeping fuel, replace sensors, and upgrade the communications and data-processing equipment aboard existing spacecraft.[106] No longer, for instance, would this nation's reconnaissance and surveillance architecture require tens of billions of dollars invested in lump sums to wholly replace on-orbit capability. Rather, individual spacecraft could be updated or replaced without entire constellation replacement. The mean mission duration (lifetime) of these national assets would be significantly extended at a great savings.

Such logistic resupply (especially of oxidizers for propellant) could actually be easiest using a base on the moon. The 9,000 feet per second (fps) change in velocity (_*v*) required to escape the moon's gravity is a lot cheaper than the 31,000 fps required to get to LEO from earth, even assuming a 12,000 fps _*v* to get back to the moon. For GEO and high earth orbit (HEO), the advantages are even greater. In fact, the energy required to bring materials from the moon to HEO is less than a twentieth of that needed to lift an equal mass from earth to such an orbit.[107] Since oxygen is about 40 percent by weight in lunar soil, it would be fairly simple to extract. In fact, some have called the moon a "tank farm" in space.[108] Although hydrogen is in low concentration at the Apollo landing sites, its relatively higher concentration in fine-grained lunar soils may allow for its extraction as well.[109] Just as building RLVs would save billions of dollars every year in continuing launch costs, building an automated lunar extraction facility and geostationary satellite resupply base would save a significant amount in propellant costs over time. Since it takes 1/20th as much fuel to get to HEO from the moon than it does to get to HEO from earth, we would burn 6,429 pounds of hydrogen and 38,571 pounds of oxygen ($18,000 in fuel at current prices of $0.05/pound for oxygen and $2.50/pound for hydrogen) to get to HEO from the moon (with the notional 100,000-pound dry weight, 0.90 PMF vehicle).[110] This saves 122,142 pounds of hydrogen and 732,858 pounds of oxygen compared to launch from earth (with 900,000 pounds of fuel at a 6:1 oxygen/hydrogen ratio, which would cost $360,000). That is a total fuel cost savings of $342,000 per mission (which becomes significant if per mission cost is as low as $1 million), with the added benefit that such a logistic base would be even more useful to the numerous commercial and civil satellite operators than to the military.[111] The downside is, of course, the infrastructure investment in building such a facility. In addition, there is the cost of semipermanent stationing of RLVs on the moon that would not be available for earth-to-orbit launch services. The savings and profits from such an enterprise would have to be tremendous to justify such an investment.

If, however, there are hundreds of US flights per year leaving earth to refuel and refurbish high-altitude satellites, then the United States, as the only space power capable of such a project in the near term, could improve its balance of payments by selling propellant resupply and on- orbit repair services to the rest of the world at premium prices. The continuing high cost of lifting fuel out of earth's deep gravity field (sometimes described as a "gravity well") could convince RLV operators to make the investment in a lunar base to lower their operating costs, just as NASA is investing in the RLV itself to lower large and continuing operating costs. Such a base, essentially civilian in nature, would also provide enormous treaty-compliant strategic advantages.[112]

Rapid Maneuverability. Although spacecraft governed by the laws of orbital mechanics move at five miles per second with respect to the surface of the earth, they are not very maneuverable from orbit to orbit. ELV-era space operability does not allow the United States to position its space forces where it wants them when it wants them there. At present, with a limited and unreplenishable amount of maneuvering fuel in orbiting satellites, it is not a trivial matter to reposition them to influence or even monitor events on earth. Although the details of defense satellite fuel-states are not releasable, the laws of physics suggest that the unexpected movement of today's unrefuelable DSP missile warning satellites to cover the Arabian Gulf during the 1991 war undoubtedly reduced their on-orbit lifetime and reduced the US's flexibility in responding to future emergencies. If RLVs gave us the ability to refuel sensors such as DSP and other satellites (as discussed in the preceding section), they could be repositioned to cover any area of interest without posing the danger of future station keeping fuel shortfalls. Later, smaller, less capable, but less expensive and more numerous sensors could be deployed in orbit in response to a crisis. With the RLV and a supply of such sensors ready to be launched on short notice, this could be done in a matter of hours rather than the months that are currently required for a launch campaign.

Today's maneuverability shortfall also limits thinking about nondestructive inspection of unknown satellites. Instead, we inspect satellites that we want to know more about by taking pictures of them from the ground, which is hundreds of kilometers away and blanketed by the distorting interference of the earth's atmosphere. After the space operability revolution, reusable space ships or satellites resupplied by them could close the minimum distance permitted by international treaty in peacetime and inspect unidentified satellites and their payloads (by optical, radar, and other means) up close without the distortion of the atmosphere. In a period of escalation short of a shooting war, RLV space ships would intercept unidentified traffic and inspect it for hostile capabilities or intent. If no such capabilities are found, the satellite could be released to go on its way. If hostility is suspected or confirmed, or in accordance with policy-driven rules of engagement, the RLV would have a wide range of options. It could capture the offending satellite, jam it, or disable it (preferably using nondestructive means that would enable the use of the disabled satellite for leverage in negotiations, which would have the added advantage of not worsening the space debris problem). Contrast this with today's space doctrine. The neutralization of hostile space forces by nonlethal technical methods is currently the only method of space control short of destruction. The United States is limited to these techniques (such as eclipsing adversary solar panels or jamming uplinks), however, because rendezvous with, and capture of, hostile satellites is considered a rare, expensive, and risky operation. This will not be the case after the operability revolution, when rendezvous and capture are practiced on a routine basis in the course of repairing and retrieving friendly satellites. There are also fewer simple countermeasures to physical capture. Jamming originating from the earth can be overridden and satellites can maneuver on battery power to escape an artificial "eclipse." It will, on the other hand, be much more difficult for an adversary to avoid capture by a grappling arm guided by human intelligence in real time. In addition, a captured asset can be used to coerce or deter some space-faring adversary from a hostile course of action. Leaving the satellite on-orbit, as done with today's disabling schemes, however, gives the adversary time to devise a technical countermeasure to the disabling technique. Capture puts an end to such hopes.

The maneuverability of RLV space ships would also make them useful for missions that are more accurately described as denial than destruction. They could mine decisive orbits (as could ELVs), but they could also conduct mine-clearing operations, soft landing the cleared mines for storage back on earth, something an ELV could not. These mine fields could be laid in a crisis and cleared afterward, giving new flexibility to national policy makers. RLVs would also be able to respond to crisis situations with all of these capabilities more quickly than the ELV due to launch preparation times that are forecast to be months shorter.[113]

The increased mobility provided by the RLV would enable the United States to move its forces to decisive orbits in space or over any trouble spot on earth more quickly (typically 31,000 feet per second with reference to the earth's surface) than any form of terrestrial military power.[114] Threatened uses of force or nonlethal inspection of enemy forces (space or terrestrial) could work to achieve policy objectives without firing a shot.

As the president's *National Security Strategy of Engagement and Enlargement* puts it, "all nations are immediately accessible from space."[115] It follows that when space itself becomes immediately accessible to the United States, then the United States will have immediate access to all other nations. This access can mean the ability to observe, or it can mean the ability to influence. The movement of space forces to threaten on-orbit force structure have been discussed, but RLV space ships would also allow the United States to deliver destructive or nonlethal power to any point on earth less than an hour after launch.

Although many of the missions made possible by the RLV's maneuverability discussed to this point are not captured in present space doctrine, the idea of force application from space is. Although the perception exists that force application from space is prevented by international treaty or US policy, it is not. Joint Pub 3-14 puts it this way, "international law . . . allows the development, testing, and deployment of force application capabilities that involve nonnuclear, nonantiballistic (ABM) weapon systems (i.e., space-to-ground kinetic energy weapons)."[116] Because it has been difficult to access space, however, it has been difficult to develop any such concept beyond the idea stage. Concepts such as Sandia National Laboratory's Winged Reentry Vehicle Experiment, a ballistically delivered, nonnuclear, long range, precision-guided kinetic energy penetrator flew three times on the front end of ICBMs before it ran out of funds.[117] Many other studies never got past the paper stage. Studies with acronyms such as data analysis control (DAC), program management plan (PMP), independent cost estimate (ICE), BRIM, and GPRC spent hundreds of thousands of dollars and produced stacks of reports without really demonstrating any technology.[118] With reusable space ships and routine access to space, however, research payloads can be flown on operational missions without waiting for rare ICBM test launch opportunities. Separation tests would be scheduled similar to current scheduling for US Air Force Seek Eagle weapons carriage and separation tests for air breathers.

The RLV could also deliver nonlethal payloads such as ground-based sensors, radio and television transmissions, and humanitarian relief supplies (via suborbital lift into secure areas or via shielded reentry containers in denied areas) to places that may not be accessible even to airpower (due to threat, distance, or overflight restrictions). If fuel costs for an orbital mission are $360,000 and overall launch costs can fall to $1 million, then suborbital missions requiring less _*v* and therefore less fuel should cost even less. These missions could be cost competitive with military aircraft. A 1991 Air Force regulation says that in FY92, the DOD would have had to charge NASA $403,132 for a 28-hour, 450-knot average speed, 12,500 nautical miles, nonstop C-5 mission.[119] In the RLV era, if NASA has priority cargo to transport to its few remaining overseas tracking stations, it might be smarter to pay the same or similar costs and cut the trip time by 27 1/2 hours.

Such a capability would allow the United States to protect its interests, on earth or in orbit, at times and places of its choosing, without having to consider the risk of loss to enemy action. States or other groups with nascent ballistic missile or space programs will soon have primitive ASAT capability in the form of sounding rockets carrying kinetic energy submunitions (as simple as sixpenny iron nails) launched in the path of an oncoming satellite in a predictable orbit.[120] These ASATs, a threat to any satellite in a predictable LEO, are of limited utility against an RLV space ship launched on a suborbital or fractional orbital trajectory. There is very little possibility that nonspace-faring nations or groups could detect launches from US sovereign territory. At present, only the United States has a publicly disclosed missile warning satellite, although the Russians have reconnaissance satellites and are likely to have missile warning satellites left over from the cold war as well. If these nations detect launchers, they do not have the data-processing infrastructure to predict and disseminate suborbital trajectories and impact points to space weapon defense forces. While making a case for an independent European satellite reconnaissance capability in the wake of the Gulf War, former French foreign minister Pierre Joxe acknowledged the "supremacy of the US space surveillance machine with its range of missile early warning, ocean surveillance, photographic and radar reconnaissance, electronics eavesdropping and weather satellites . . . with its massive supporting processing and communications chain."[121] France's and Britain's $1 billion investment in military spacecraft could not match the $200 billion US military space machine during the war, and it is not likely that many other nations on earth could do so in the foreseeable future.[122]

That said, it does not take a lot of money to buy sixpenny nails. Low technology ASATs would, however, be difficult to use against an RLV changing its orbit from revolution to revolution. Even the United States would have a great deal of difficulty engaging hypersonic maneuvering reentry vehicles (which would be very similar to the strategic defense problem).

On-Scene Human Judgment. The "difficult access" paradigm has also worked to keep space doctrine notably free from references to the idea of military personnel in space. Even White House policy makers recognize the Department of Defense's aversion to the idea of manned space flight. Richard Dalbello, assistant for aeronautics and space in President Clinton's Office of Science and Technology Policy says, "policy recognizes that DOD has little current interest in human spaceflight."[123] This could be related to the fact that there is a "manned military space expectations gap" that goes along with the overall launch expectations gap. This part of the expectations gap is also a result of dashed hopes and unsatisfactory reality. The dashed hopes can be traced to events such as President Richard Nixon's cancellation of the Air Force Manned Orbiting Laboratory, the shutdown of the Air Force's space shuttle launch facility at Vandenberg AFB, in 1986 after the *Challenger* accident, and, in both cases, the subsequent disbanding of military astronaut groups who had been screened and selected through an arduous board process.[124] The disillusionment (or, at least, the skepticism) concerning the role of military man in space is evident from the deafening silence on the subject in Air Force doctrine, in joint doctrine, and in even the most forward-leaning research papers and projects such as the US Air Force's recently completed *Spacecast 2020* study. This has led to an almost universal assumption in the US space community that most DOD space missions can be performed by robots; some contend that any requirement for human judgment in space can be fulfilled today by unmanned systems and tomorrow by telepresence or virtual reality.

There may nevertheless be a case for military personnel in space. The experience of land, sea, and air warfare seems to indicate that the judgment and initiative of the human being on the scene is critical to success in battle against a reacting enemy. It is not obvious that this pattern will be repeated in the new space medium, but history suggests that the presence of military personnel could help with the continuous tactical improvement and adaptation that has traditionally made for victory in war. As John Collins of the Congressional Research Service says in *Military Space Forces: The Next 50 Years,* "sizable manned contingents probably should deploy in space, because commanders and staff far removed from crises seldom can assess the situation and take appropriate actions as well as on-the-spot counterparts."[125] Commanders and staff on the ground may also have their links with RLV ships disrupted or jammed, while it is much more costly for the enemy to break the man-machine link in a piloted vehicle. There are also complexities in military operations that may not lend themselves well to remote control. As with the submarine, a complex vehicle with multiple missions in a challenging and dynamic physical environment with a reacting enemy, it is very difficult to imagine a remote crew of operators coordinating rendezvous, grappling, defensive countermeasures, damage reporting and control, and all of the subtasks implicit in those operations simultaneously, whether under the sea or in space.

To adapt to such rapidly changing situations, military man on earth has had to have repeatable and regular familiarity with the medium in which combat operations take place. This repeatable and regular familiarity with the medium is what the RLV operability revolution will provide that is now missing from current space doctrine. Without personal experience with the medium, it is arguable whether sound doctrine can be devised for operating there. It is difficult to imagine that the Navy could have gained enough experience in subsurface warfare before World War II to enable it to sink over five million tons of enemy shipping in the Pacific if all subsurface operations before the war had been conducted by remotely controlled undersea robots.[126]

It can be argued that the same results would have been obtained with submarines controlled from shore via twenty-first century telepresence or virtual reality. The complexity of submarine combat suggests otherwise. Damage control and loading torpedoes in combat situations would have to be done by onboard robots. Torpedo misfires would also have to be cleared by such robots. Software would have to be written to fuse sonar inputs and onboard ambient noise so that the teleoperator could monitor both for damage cues and situation awareness. It seems that the added level of complexity required for a teleoperated combat submarine would be significant and might outweigh the advantages of removing man from the scene. In any case, the pre-World War II US Navy overcame the inherent hostility of the undersea environment and a clear lack of political enthusiasm for undersea warfare and put men to sea on submarines.[127] A similar case may be made for the manned combat RLV in space.

Policy makers, too, may also be reluctant to trust unmanned or teleoperated warships even though the teleoperated RLV would be like any weapon on earth, a machine executing a decision made by man just as a firearm does when a soldier pulls the trigger. There should, therefore, be the same amount of trust in the teleoperated RLV as in the soldier's rifle. The difference is, however, that when the soldier's rifle misfires, he is on the scene to unjam it or fix the bayonet. In the event of onboard failure, link jamming, or battle damage, the unmanned or teleoperated RLV would have no trained soldier on the scene to make sure that high-stakes political missions are carried out successfully.

In addition to the arguments outlined above, there is also a simple physical argument against remote or virtual reality (VR) piloting of space vehicles in wartime or crisis situations: the speed-of-light delay inherent in the long slant ranges that would be involved. It would take an earth-based operator at a console or in a VR environment, 0.25 seconds to send a command to a refueled RLV intercepting a maneuvering adversary satellite in geostationary orbit and perceive that the vehicle was responding (22,300-mile orbit, 186,000 miles-per-second speed of signal, two-way trip). This assumes that the vehicle is directly overhead the operator. If the space ship is inspecting a satellite in geostationary orbit on the other side of the planet, the signal is likely to be relayed via two or more geostationary satellites. The round trip in this case is over 1.00 light seconds and begins to be problematic even for cooperative targets. Speed-of-light delay is acceptable when sending instructions to unmanned deep-space probes, but, just as in air-to-air refueling at 0.70 Mach, rendezvous would be much more difficult and dangerous with a one-second flight control delay as would maneuvers in close proximity to another spacecraft at Mach 25. This would be especially true if the target spacecraft were itself maneuvering.

Automation, VR, and telepresence would reduce vehicle cost and complexity since there would be no need for life support and a reduced need for vehicle reliability. There would, therefore, be military missions that machines or telepresence can perform perfectly well (e.g., routine reconnaissance, space station resupply, satellite deployment). The Russians have been resupplying their manned and politically valuable *Mir* space station for years via automated docking with the unmanned *Progress* resupply rocket.[128] But in general, high-stakes missions in which failure would be politically disastrous, especially in an international crisis, argue for man's presence, even if this increases the risk to RLV crews.

Although the weight and complexity of the generic RLV might be reduced through teleoperation, the necessity for combat vehicles to operate in degraded modes, the onboard maintenance often required in dynamic situations, and the coordination required for multiple missions would seem to argue for the restriction of teleoperation and automation to relatively benign environments. Man should not be excluded from space simply because he requires added vehicle complexity in the form of life support. What he brings to the game in terms of degraded operations, jam resistance, and damage control may be worth the extra weight. This, however, is not the approach of today's US space policy and doctrine. People sitting at consoles on earth sending inputs to robots in space are the US armed forces' space officers, who are the experts qualified to write space doctrine. It may be useful to remember how unsophisticated early air doctrine, created by people without much flying experience, seems today.[129] Space doctrine developed in institutions that assume away routine manned operations in space may not stand the test of time much better.

The preceding discussion of potential missions and arguments for and against manned RLVs highlights interesting parallels with undersea warfare. Given long duration inspection and/or presence missions in an extremely hostile environment, multiperson crews performing specialized tasks, and the ability to maneuver in three dimensions, the best model for the fighting RLV may be the submarine. Missions requiring presence over adversary territory or near adversary space facilities through the course of a terrestrial political crisis, long inspection patrols to survey other nations' satellites, confinement in small pressurized spaces for long periods, and specialized crew functions appear to fit the submarine paradigm more than any other.[130] This is not to say that there are not significant analogies to air operations as well, but there are many things about military operations in space, especially those that have to do with control of the medium, that seem to be closely analogous to submarine operations.

It is when space power acts to affect political outcomes on earth that the tie to airpower roles and functions is strongest. If airlift (as suggested by the "suborbital hop" idea), strategic attack, interdiction, and perhaps even close air support are possible from space, then these missions, more than space control or presence, are where military power from space might have real leverage on political outcomes on earth.[131] That said, space operations will require an infusion of naval as well as air "culture" and doctrine. This will be discussed further in the next few sections.

Building on the Joint Doctrine of "Decisive Orbits"

After the discussion of what the RLV revolution will allow the United States to do in space, it may be useful to explore the physical nature of the earth-moon system and why certain places in it have military advantages over others. The doctrine of decisive orbits touches on this point, but the RLV space ship could make control of these orbits even more decisive, especially if it makes them more usable.

Physical Characteristics of Decisive Orbits. Before proceeding with how decisive orbits in space should be used, however, it is necessary to define their physical characteristics. It is also necessary to understand how the physical characteristics of space fit into air, land, and sea doctrine.[132]

Some space doctrine writers focus on the physical differences between operating in space and operating in the atmosphere to emphasize the point that air and space are distinct military media.[133] The organization and doctrine of forces designed for operating in one medium are not appropriate, these writers believe, for the organization and doctrine of forces in the other. These writers focus on the physical differences of astrodynamics versus aerodynamics rather than on whether the effect of an action in or from space is the same as actions taken in or from the air. This could be called doctrine with a focus on engineering, rather than doctrine focused on what one is trying to do to the enemy. Air and space vehicles do require different sorts of engineering, but the effect of a destructive strategic attack from space (given good intelligence and similar accuracy) is likely to be the same as a destructive strategic attack from the air (allowing for the greater energy inherent in orbital energy states). The reason for the similarity of effect is the similar nature of the advantages that air and space power hold over terrestrial forces and political entities. US Air Force doctrine says that speed, range, and flexibility are among the characteristics of airpower. It seems that a case can be made for these as characteristics of space power as well.

Both air and space power have the advantage of elevation (with its corollaries, superior viewing, and energy advantage) over terrestrial forces. This difference between air and space forces on the one hand and terrestrial forces on the other unites air and space power in a very fundamental way. It means that no matter what its physics, flight is still flight, and that the "control and exploitation of air and space" should be performed for very similar political purposes. If the advantages and uses of the two media are the same or similar, it does not seem to make a lot of doctrinal sense to try to separate them.

That said, there are physical characteristics of operations in the space medium that make the methods for gaining control of the medium very different from the "air superiority" mission. First, there are certain energy-states in earth orbit that are of particular utility in conducting space operations. These energy-states are associated with certain orbits that have been proven to be militarily useful. Among these, and cited by Collins of the Congressional Research Service as “key terrain” in *Military Space Forces: the Next 50 Years*, are geostationary and other equatorial earth orbits.[134] Second, these orbits can be controlled by occupation or other forms of denial in ways that have no analogues in air operations. It is necessary to send up several multiship formations of air superiority fighters in more than one combat air patrol (CAP) “orbit” to prevent enemy aircraft from entering friendly airspace. It is only necessary to occupy an equatorial geostationary orbit with a single long-duration “fighting RLV” at a given longitude to prevent anyone else from putting a spacecraft there (just as with terrestrial power, blocking avenues of approach by occupying key terrain is possible in space where it is not possible in the air). Circumstances are somewhat different for orbits that are not fixed with respect to the earth’s surface, which describes virtually all other Earth orbits. For these orbits, multiple spacecraft are necessary to provide global coverage. Third, and related to the previous point, the laws of orbital mechanics allow spacecraft to persist in these decisive orbits with very little expenditure of energy. As a result, spacecraft on blockade or blocking missions could stay on station without refueling significantly longer than the two to three hours characteristic of fighter CAPs because one can maintain an orbit above the drag of the atmosphere with the expenditure of little or no energy. In simple terms, the air-to-air fighter’s engine is running the whole time it is on patrol, the RLV’s is not.

Geostationary orbits are obviously critical to terrestrial forces because they provide stationary “relay towers” in the sky for communication and other purposes, and may therefore qualify as “decisive.” There are other militarily useful orbits that may also qualify for this distinction. Among these are the polar orbits flown by many reconnaissance satellites. As Collins notes, “reconnaissance and surveillance missions inclined 90 degrees sooner or later loop directly over every place on Earth.”[135] That is why he counts these orbits as “key terrain” as well, which leads one to believe that they may also be “decisive” even though it would take many more spacecraft to occupy them.

The RLV will play in this military geography of earth orbital space in four ways. First and foremost, it gives the United States routine access to these orbits for peaceful purposes, for political signaling and other nonlethal propaganda purposes, as well as for military purposes. One of these purposes will be to take unimpeded advantage of one of the corollaries of space power's elevation, superior view. A space-faring power's awareness of what is going on on earth is far superior to that of nonspace-faring nations. A nation with routine access to space will multiply that advantage with the ability to access any orbit at will. Second, as noted above, the RLV will be able to occupy these orbits to prevent others from using them. Third, it will allow the United States to engage adversary space forces at times and places of its choosing from a position of energy advantage. Fourth, it will allow the United States to engage adversary ground, air, and sea forces and political entities at times and places of its choosing from a position of energy advantage. As mentioned above, one of the corollaries to the elevation of air and space power is the energy advantage of superior altitude (what fighter pilots call "God's G"). This discussion naturally leads to a concept which may be most useful in understanding the importance of this energy advantage to space doctrine in the RLV era.

The "Gravity Well." The earth, with its relatively strong gravitational field, "bends" space in its vicinity to create an attraction to nearby objects. That attraction decreases as the inverse square of the distance from the earth. What this means is that objects farther away from earth ("higher up" in the gravity well) have more gravitational potential energy than those below. This has obvious military implications. Collins points this out when he says,

> Military forces at the bottom of Earth's so-called gravity well are poorly positioned to accomplish offensive/defensive/deterrent missions, because great energy is needed to overcome gravity during launch. Forces at the top, on a space counterpart of the "high ground," could initiate action and detect, identify, track, intercept, or otherwise respond more rapidly to attacks. Put simply, it takes less energy to drop objects down a well than to cast them out. Forces at the top also enjoy more maneuvering room and greater reaction time. Gravitational pull helps, rather than hinders, space-to-Earth flights.[136]

The military implications of the physical facts have long been recognized, but again, the high cost of doing anything about them has made force application from space problematic. As mentioned earlier, this is less a problem of policy than a lack of a realistic and affordable way to take advantage of the leverage that space provides. Space-to-earth kinetic energy weapons that would achieve the same effects as air-delivered weapons do not merit multibillion dollar investments (current Air Force concepts of permanently orbiting space strike weapons are unmanned and can be launched on expendables).[137] Space strike weapons developed incidentally to highly profitable RLV operations (that will go on with or without those weapons) may, on the other hand, merit the relatively small investment required. An example is Gen William "Billy" Mitchell's development of antiship bombing techniques in the early days of aviation. The US Army did not set out to take advantage of the energy advantage of the airplane over the surface ship when it bought its first airplane for the Signal Corps. Despite this, once aircrews gained practical experience with the "reusable air vehicle," experimenting with it and finding out what it could do became part of the airman's culture. A similar course for the development of the RLV is logical and desirable.

Nature of Space Doctrine in the RLV Era. This discussion leads to at least three possible conclusions about what the RLV will mean to the broad outlines of space doctrine. First, it may mean that space doctrine should become more naval, with emphasis on the protection of US economic interests in space and protection of free access to space lines of communication. This would tend to emphasize the control of the medium. Second, it may mean that space doctrine should become more aerial, focusing on the earth as the seat of political purpose and space as a place from which to affect those purposes. In the language of the US Air Force, that would be "exploitation" of the medium. The third possibility is that there is some intermediate position between the first and second ideas, some merging of air and naval culture and doctrine that would be most useful for space. A comparison of the relative merits of all three options may shed some light on how doctrine writers should approach space doctrine in the RLV era.

1. *Space Doctrine More Naval.* As outlined earlier, there are strong arguments to support this position. The physical characteristics of orbital space, the nature of possible operations there (blockade, mining), the ability to conduct long duration patrols, and the enormous national and commercial investment on station in orbit all lend themselves to naval thinking. Satellites on orbit are much like commercially valuable islands or oil platforms in strategic locations at sea. In addition, once in space, the RLV is far closer to a ship than to an airplane in terms of the amount of effort required to stay "afloat." Aircraft must be continually "flown," ships float more or less of their own accord. Even at five miles per second, the similar characteristics of the space ship will give the crew time to devote its attention to other things, including interaction with other vessels. The RLV, unlike the airplane, can rendezvous with other spacecraft and exchange crew members or cargo other than fuel, and doesn't have to destroy or even disable adversary spacecraft to control the medium. Control of the sea or of space does not necessarily mean using lethal firepower to destroy an adversary (as it usually does for the airman). It can also mean interposing oneself between adversary forces and the objective, occupying the objective, or nondestructive inspection backed up with the threat of force (as in the Gulf War maritime intercept operation). Mastering such operations would take a tremendous amount of time, doctrine development, and training. If they were the priority missions of a "space force" as a result of maritime tradition or service culture, there might not be much time left over for other important tasks that may also be done from space.

2. *Space Doctrine More Aerial.* Although counterintuitive, it seems fair to say that space forces become more aerial as they look toward the earth. The fundamental elevation advantage of both air and space forces over terrestrial forces is the underpinning of this assertion. Because most policy objectives for the foreseeable future will be aimed at adversary terrestrial decision makers, strategic operations (nonlethal and lethal) from space aimed at the center of the enemy's decision-making apparatus (food drops and propaganda broadcasts to target national populations, high probability of strikes against leadership and national-level command and control as well as other targets) are most like air operations. At the operational level, space power will be able to conduct air interdiction and counterair missions, and with enough affordable force structure in space (provided by the advent of the RLV), terrestrial forces should be able to call in all of the close support they need to accomplish tactical objectives.

This leads us to the important advantage of space power over other forms of military power. This advantage is the previously cited corollary of air and space power's elevation: higher energy states. The energy states inherent in orbital and suborbital spacecraft can provide an enormous amount of firepower for a relatively small investment in the size of a given vehicle or weapon. As Collins notes, "Offensive kinetic energy weapons (KEW) plummeting from space to Earth at Mach 12 or more with terrific penetration power have a marked advantage over defensive Earth-to-space counterparts that accelerate slowly while they fight to overcome gravity."[138] Space forces will look very much like air forces to those who are at the receiving end of their effects on earth. They will also look very much like air forces at their terrestrial bases. They must, after all, traverse the atmosphere in order to get into space. In this respect, they are much like air forces, vulnerable and useless while on the ground. The compensating factor is their range. American military RLV bases are likely to be far from the US coastline and secured against terrorist attack. This is beyond the strategic reach of most nations on earth. They will, however, (within the limits of RLV response time and dispersability) be vulnerable to intercontinental, submarine-launched, or space-launched hypersonic strikes. If such an attack were launched, though, with or without nuclear weapons, the United States would have larger concerns than RLV survivability.

The demonstrated ability to strike any target on earth with precision and discrimination could, in fact, be a potent deterrent to or factor in conflict. This deterrent, unlike nuclear weapons, could be used against nonnuclear powers without the collateral damage and the negative moral and political fallout of nuclear weapons use.

A notional case may be useful in developing this argument. Assuming RLVs in orbit that are able to employ 30-pound kinetic energy weapons using the same techniques as ICBM bus separation, precision guidance of the type employed on the DOD's information network system (INS)/global positioning system (GPS) guided joint direct attack munition (JDAM), and a global communications system (i.e., the proposed Iridium or Teledesic cellular systems), a US ambassador anywhere in the world would have a "flying gunship" that could support him or her with precise and discriminate force when necessary.[139] Unmanned space-to-earth strike platforms similar to ICBM reentry vehicle buses could be employed quickly in times of crisis, as in the mine example discussed earlier, and cleared when not needed. Putting these platforms in orbit should be no more difficult than the civil satellite deployment for which the RLV is being designed. This would also allow the United States to upgrade the platforms on the ground in the periods between crises, and would reduce their vulnerability to ASATs, unlike permanent stations in orbit.

With such a capability before the Gulf War, the American ambassador's meeting with Saddam Hussein might have gone a little differently. With platforms launched in the preceding weeks passing overhead every few minutes (assuming little or no cross-range for their weapons, 32 space ships in 90-minute orbits would be in employment range every 45 minutes), the ambassador could have made a case for Iraqi vulnerability to US power by looking at her watch, making a phone call, and asking Hussein to step to the window to watch a demonstration. (Admittedly, this example may not ring true because of the low probability of State Department use of strategic strikes on foreign territory.) Perhaps an example of sea control from space may seem more politically plausible. Again, assuming little or no cross-range for the orbit-to-earth weapon, it would take 128 orbital weapons employed by RLVs in a crisis to revisit a maritime exclusion zone every 11 minutes. United States or allied naval vessels enforcing international sanctions could order threatening or suspicious vessels to heave-to with the knowledge that they were supported with precise firepower from space. Hypersonic projectiles could create impressive warning shots across the bows of recalcitrant ships. If such a situation escalates, sinking the ship from space is not only physically possible, but could also be much more politically palatable than the first scenario.[140]

3. *Space Doctrine as a Combination of Naval and Air Doctrine*. The preceding discussion seems to show that operations for control of the space medium are more nautical, while the leverage it provides in accomplishing the most important national policy objectives is more like airpower.

Between the two emphases, it seems clear that in high stakes conflict, US objectives will likely be tied to some outcome on earth rather than in space. That said, the strategic view of the airman, whose culture and doctrine is more consonant with such ideas, seems to be best suited to carry them forward into space. If, on the other hand, humanity's political centers of gravity move outward into space, then control of the medium and the lines of communication between these new political entities will become most crucial. For the foreseeable future, however, the United States is most concerned with what happens in the international system here on earth. This seems to argue fairly strongly for airmen to lead the US armed forces into space. These airmen must, however, adapt to the naval nature of the new medium. This may mean discarding many of the things that make airmen unique. The destructive offensive counterair model as the best way to gain control of the medium may have to be deemphasized, as may the role of the solitary pilot. If launch and landing are automated (which is the NASA CAN requirement) and orbital mechanics allow the vehicle to keep on station without much intervention, there is little need for a pilot who is continuously at the controls.[141] Again, the terrestrial analogue is the ship captain who is rarely in direct physical control of the helm. He or she has more important things to do. The ability to command a crew rather than hand-eye coordination may become the yardstick by which space combat officers are measured. These new ship captains must, however, remember that their mission is to directly affect adversary decision making on earth in accordance with national political objectives, not simply to fly around in orbit. In this, they will be more akin to airmen than to sailors.

This section has attempted to show the changes in US space doctrine that will be the outgrowth of reduced barriers to space access. It has outlined the assumptions in current doctrine that will be shaken and drawn parallels between what the RLV will mean for civil operators and what it will mean for military operators. It has also tried to use the physical characteristics of space and the capabilities of the RLV to outline a rudimentary space doctrine. The reasoning here is handicapped, however, by the same problem besetting the overwhelming majority of all space doctrine. It is written by someone who has not left Earth. Nevertheless, this outline, based on the assumption that space access will soon be routine and inexpensive, may more closely reflect the realities of the RLV era than doctrines which do not.

Summary and Conclusions

After determining that the United States is making steady political, economic, and technical progress toward fielding an affordable reusable launch vehicle, this study has attempted to induce the economic and military implications of such a development. From this, a few key themes and conclusions can be drawn.

1. The United States is developing an RLV that will lower the cost of access to space early in the twenty-first century.
2. RLV operations will have significant economic impact on the cost of today’s commercial space activities and foster the development of new ones.
3. The RLV will have a significant impact on joint US military space doctrine.
4. The RLV will make space operations much more analogous to present-day naval and air operations.
5. Of the two analogues, the similarity to air operations will have the greatest impact on terrestrial political structures in the immediate future.

A short discussion of each conclusion may help to provide direction for thinking about these issues as the United States and the world enter the RLV era.

The RLV is Coming

The first conclusion that this study suggests is that the RLV is coming soon. The president's new Space Transportation Policy indicates that the US government is serious about building a fully reusable launch vehicle that will reduce the cost of access to space.

The idea has growing support in Congress and in the space policy community, if not in DOD. There is a confluence of political, economic, and technological factors creating an environment conducive to the development of a reusable rocket ship.

Economic Impact of the RLV

The first order economic consequence of the advent of the RLV will be reduced cost access to space and reduced demand for expendable launch vehicles. The ultimate result of reduced ELV production would be increased prices for ELV launches, reducing demand and production even further. Eventually, prices would rise to an uneconomic level. This could presage the end of the throwaway rocket industry, both in the United States and abroad.

There would be at least two other economic consequences of low-cost access to space. The first would be improvements in the US's economic competitiveness and balance of payments. The second would be an even further reduction in the cost of access to space after the amortization of the cost of the RLV. In such a case, DOD would find resisting RLV technology more difficult, especially with the concomitant reduction on operating costs. This would allow the US armed forces to achieve the US's national objectives of assured access to space and maintenance of its military advantage there using technologies whose cost was recouped in the private sector.

Military Impact of the RLV

The high "sortie rate" of the RLV will rapidly fill orbital space with billions of dollars worth of politically and economically important manned platforms, civil and commercial remote sensors, cellular communications satellites, and other objects. Conflicts over orbital position (which have already arisen over the desire of poor equatorial nations to "own" the geostationary orbits over their territory) will become more frequent as the number of satellites increases.

Space-faring nations flying RLVs will have the ability to monitor, threaten, sabotage, disable, or destroy the space investments of other states using techniques very similar to those used in commercial operations. If the United States sees the possibility of such operations, then other powers may as well. If so, the assumptions underlying US space doctrine (difficult access to space, no role for man in space) would become dangerously out of date.

Military Space Operations More Aerial than Naval

Space operations even in the near-term RLV era will have many characteristics of naval operations. Most of these characteristics will have to do with control of the space medium. Where military space operations intersect with terrestrial forces and political structures, space power will have more of the characteristics of airpower. These operations, especially at the strategic level, will be more decisive than the missions with naval analogues.

Conclusions

The energy advantage of RLV-equipped space-forces will be their most significant military characteristic in the context of the present international system. As orbital energy-states become more accessible to larger numbers of people and groups for commercial reasons, they will also become more accessible for military reasons. That said, a world in which any state or political group can buy an RLV whose cost has been amortized by years of routine operations may be a world where there are new and larger threats to US security than terrestrial dictators and intercontinental missiles.

Notes

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3. S. E. Singer, "The Military Potential of the Moon," *Air University Quarterly Review,* Summer 1959, 35.

4. This treaty prohibits stationing weapons of mass destruction in space, or any military base on the moon.

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6. Vice President's Space Policy Advisory Board, *A Post Cold War Assessment of US Space Policy: A Task Group Report* (Washington, D.C.: Government Printing Office [GPO], 1992), 26. National Commission on Space, *Pioneering the Space Frontier* (New York: Bantam Books, 1986), 109.

7. Vice President's Space Policy Advisory Board, 7.

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9. *NASA Access to Space Study, Summary Report* (Washington, D.C.: Office of Space Systems Development NASA Headquarters, January 1994), 48.

10. Homer A. Boushey, "Blueprints for Space," *Air University Quarterly Review,* Spring 1959, 18; Singer, 35.

11. Henry H. Arnold, *The War Reports of General of the Army George* C. *Marshall, Chief of Staff, General of the Army H. H. Arnold, Commanding General, Army Air Forces, and Fleet Admiral Ernest J. King* (New York: J. B. Lipincott Co., 1947), 463.

12. Joint Doctrine, Tactics, Techniques, and Procedures (JDTTP) 3-14, *Space Operations*, final draft, 15 April 1992.

13. Szafranski, 80.

14. The Outer Space Treaty prohibits weapons of mass destruction in space and military bases on the moon, but does not prohibit the use of space for military purposes. This perception exists even though there are no US policy limitations on force application from orbit. In fact, pages 11–21 of DOD Joint Pub 3-14 says, international law "allows the development, testing, and deployment of force application capabilities that involve non-nuclear, non-ABM weapons systems (i.e., space-to-ground kinetic energy weapons)."

15. *Report of the Task Force on the National Aero-Space Plane (WASP) Program* (Washington, D.C.: Defense Science Board, November 1992), 23.

16. "DOD Space Launch Modernization Plan Executive Summary," draft, April 1994, iv.

17. Ibid.

18. *NASA Access* to *Space Study Summary Report,* 1; "DOD Space Launch Modernization Plan," 1.

19. DOD Space Launch Modernization Plan, 30.

20. Ibid., 20.

21. "Ariane Chief Says Eastern Nations, Not US, Will Be Future Competition," *Aerospace Daily,* 4 October 1993.

22. "DOD Space Launch Modernization Plan," 10-11.

23. "Air Force Position on the Future of Space Lift: An Approval Briefing," 2.

24. Memorandum for the Special Assistant to the Secretary of Defense (Patty Howe) Reference the Clinton Transition Team Tasking of 17 December 1992, Attached NASP Paper (Unclassified); and "Air Force Position on the Future of Space Lift: An Approval Briefing," 14.

25. *NASA Access to Space Study Summary Report*, 72.

26. "Air Force Position on the Future of Space Lift: An Approval Briefing," 29.

27. "DOD Space Launch Modernization Plan," 13, 18.

28. "DOD Appropriators Boost NASA Reusable Rocket Effort," *Space Business News,* 11 October 1994, 3; "Air Force Wants Less Oversight and More Insight for EELV Program," *Space Business News,* 2 March 1995, 4; and Lieutenant Colonel Smith, EELV Program Manager, telephone interview with author, May 1995.

29. Smith interview.

30. "DOD Space Launch Modernization Plan," 13, 18.

31. "The First Reusable SSTO Spacecraft," *Spaceflight*, March 1993, 91.

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35. "Revised NASA Implementation Plan for the National Space Transportation Policy," November 1994, 3.

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37. Marcia S. Smith, *Military Space Programs in a Changing Environment: Issues for the 103d Congress,* CRS Issue Brief 92879 (Washington, D.C.: GPO, 1992), 5.

38. "DOD Space Launch Modernization Plan Executive Summary," 10.

39. Ibid., 29.

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41. "DOD Space Launch Modernization Plan Executive Summary," 19; *NASA Access to Space Study Summary Report*, 62.

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43. Marcia S. Smith, 4–5.

44. This is evident from the list of participants cited on the last page of the SLMP. Only two, Maj Jess Sponable and Colonel Worden, had worked in offices where there was RLV work in progress.

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46. "Conversations," *Aerospace America,* May 1995, 12.

47. "DOD Appropriators Boost NASA Reusable Rocket Effort," *Space Business News,* 11 October 1994, 3.

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49. “Air Force Wants Less Oversight and More Insight for EELV Program,” *Space Business News,* 2 March 1995, 5.

50. “Sailing Space on the Clipper Ship,” *Final Frontier,* December 1993, 52.

51. Charles “Pete” Conrad, *Beyond the NASA Shuttle,* remarks to the Washington Roundtable on Science & Public Policy, George C. Marshall Institute, Washington, D.C., 8 November 1994, 8.

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61. Briefing, Martin Marietta Corp.

62. Strategic Defense Initiative Organization, “Single Stage Rocket Technology, Program Status and Future Systems Feasibility Assessment,” briefing, August 1992, 15.

63. “Rocket on a Round-Trip,” *Discover,* May 1995, 54.

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65. Ibid.

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69. Where *g* is the acceleration due to earth's gravity, I_{sp} is rocket engine vacuum specific impulse in seconds, M_0 is starting mass, M_E is ending mass, and PMF is propellant mass fraction or the fraction of the gross vehicle weight that is fuel as opposed to structure—the critical number for SSTO and why breakthroughs in lightweight materials have been necessary to make it a possibility; Strategic Defense Initiative Organization, briefing, 28; Robert M. Zubrin and Mitchell B. Clapp, *An Examination of the Feasibility of Winged SSTO Vehicles Utilizing Aerial Propellant Transfer,* AIAA Paper 94-2923 (New York: AIAA, June 1994), 1.

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90. The X-33 Home Page for Space Activists, http://www.contrib.andrew.cmu.edu/usr/fj04/x33.html; The NASA/Marshall Space Flight Center RLV Home Page, http://rlv.msfc.nasa.gov/rlv_htmls/rlvl.html; and Delta Clipper/SSRT Program, http://gargravarr.cc.utexas.edu/delta-clipper/title.html.

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110. Telecon with Maj Jess Sponable, DC-X Program Manager, 14 December 1992.

111. This assumes final cost of extracted lunar oxygen and hydrogen is similar to present cost (infrastructure excluded).

112. This complies with Outer Space Treaty of 1967 which the United States has signed, and does not comply with the Moon Treaty of 1979, which the United States has not signed. This is not to say there are no political issues to be considered. If the president's policy is to remain the major economic power in space, this is one way to do so.

113. "RLV Advanced Technology Demonstrator X-33"; "NASA Cooperative Agreement Notice," A-5.

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123. "Conversations," *Aerospace America,* May 1995, 12.

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126. R. J. Overy, *The Air War 1939–1945* (Chelsea, Mich.: Scarborough House, 1991), 96.

127. This was partly because of its association with the politically unpleasant memory of World War I's "unrestricted submarine warfare."

128. "Beam Me Down, Scotty," *Time Daily News Summary,* 3 February 1995. Interestingly, the Russians were reluctant to let a possibly defective US space shuttle flown by a human pilot within 30 feet of *Mir* on the first shuttle-*Mir* rendezvous mission.

129. There is very little mention of weather, for example in Giulio Douhet's *Command of the Air*. Some attribute this to the fact that Douhet was not himself a flier.

130. The RLV could perform ship-to-satellite reconnaissance, ship-to-earth reconnaissance, orbital intercept and rendezvous, satellite grappling and capture, strategic attacks, and a myriad of other tasks that seem to require some human intervention.

131. As laid out in three "Axioms of Space Combat Power" by Lt Col Michael R. Mantz in *The New Sword: A Theory of Space Combat Power*

(Maxwell AFB, Ala.: Air University Press, 1995), "Axiom 1. Space strike systems can be employed decisively by striking earth forces, both independently and jointly. . . . Axiom 2. Space-strike systems can be employed decisively in war when the enemy's essential means for waging war (industry, transportation, and communication) are vulnerable to attack from space. . . . Axiom 3. Space-strike systems can be employed decisively by striking at the decision-making structure (leadership and command and control) of the enemy." Mantz, 75–76.

132. Clausewitz was more fortunate in *von Krieg* because most of his readers understood how horses and the firearms of the day worked. The contrast with modern doctrine is stark. Today, lengthy technical explanations are necessary before even getting to subjects as important as the subject of policy.

133. For example, see Michael Wolfert, "Concept Paper on Space Organizational Options" (paper for the DOD Roles and Missions Commission, 12 December 1994), 9.

134. Collins, 23.

135. Ibid., 24.

136. Ibid., 23.

137. Mantz, 20.

138. Collins, 56.

139. Warheads of this size were tested recently in hypersonic weapons effects tests at Sandia National Labs. Orbital versions of these weapons would have to weigh more than 30 pounds when launched because each would need a small rocket motor to impart about 7,450 fps of _*v* to deorbit.

140. Mantz, 48.

141. "Reusable Launch Vehicle (RLV) Advanced Technology Demonstrator X-33"; "NASA Cooperative Agreement Notice," A-5.

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