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The Paradigm Shift to Effects-Based Space:
Near-Space as a Combat Space Effects Enabler

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FOREWORD

Near-Space

Space effects have revolutionized the modern battlefield. However, we still have a long way to go to truly operationalize space and bring it to the combatant commander. I've been intrigued by near-space's potential for persistent space-like effects on the battlefield ever since I first heard about it. Near-space has been a cultural blind spot – too high up for aircraft, but too low for satellites. Once we step back from platform-based thinking and look at effects, near-space becomes intriguing – opening doors for completely new air and space opportunities.

As we push to make space more accessible to warfighters, we need to ensure that near-space capabilities are considered in the mix. The Space Battlelab and Air Force TENCAP are doing great work experimenting with early near-space capabilities. We need to push the envelope to determine what effects we can produce from near-space. More importantly, we need to find the right synergistic mix of air, space, and near-space capabilities to produce the battlefield effects our combatant commanders need.

Lt Col Tomme's research offers us an opportunity to get these issues on the table, spur discussion, and perhaps develop completely new capabilities. It's our duty as air and space professionals, as warriors, to find better ways of defending our nation and its interests.

Doing something new is not easy. We must educate our planners, programmers, and operators while simultaneously doing the research and development necessary to bring near-space from concept to fielded system. Exploring the potential of near-space will take significant work on many fronts, but I'm convinced the effort will be worth it. This is an excellent opening salvo in a debate we need to have.

JOHN P. JUMPER
General, USAF
Chief of Staff

Executive Summary

This paper is an outgrowth of comments I heard and attitudes I experienced at the JFCOM Joint Space Concept Development and Experimentation Workshop in Norfolk at the end of March 2004. I presented a briefing on near-space at the conference along with colleagues from JFCOM, the Army Space and Missile Defense Battlelab, the Naval Research Laboratory, and the Navy Warfare Development Command. It discussed how many functions that are currently done with satellites could be performed for tactical and operational commanders using near-space assets much more cheaply and with much greater operational utility. The briefing was very well received with nothing but positive comments all around. However, once we broke into focus groups trying to develop exercise inputs for such subjects as operationally responsive space, the near-space concept was almost forgotten. It didn't fit into the normal mindset of what space meant, so it was difficult to convince other group members that it should be discussed in the same breath as, say, a TacSat-type program.

After much thought, it was my perception that the problem was one of mindset as to what the word “space” meant to the warfighter. After reading space doctrine (Army, Navy, Air Force, and Joint), I discovered that the mindset I sensed at the workshop had actually been codified to define space as a place where we operate satellites. That mindset is counterproductive.

The thesis of this paper is that space is currently a medium through which warfighters get effects—typically those effects are strongly related to Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR)—not just a place and not based on a specific platform type. Until recently, most C4ISR effects have been delivered from satellite platforms (apologies to our manned and unmanned air-breathing ISR assets). The reason for operating in such a manner was that, in general, no other way existed to obtain similar effects. The extreme costs of space were justified due to their monopoly on the ability to provide those needed effects. However, with the advent of near-space concepts, those same effects can be obtained in a different way, especially for operational and tactical users.

The paper discusses strengths and weakness of near-space, doing a top-level comparison with satellites, manned ISR, and UAVs. Satellites are shown to have great strengths for strategic missions where freedom of overflight is required. However, for operational and tactical missions—primarily after or just before commencement of hostilities—near-space holds strong advantages, especially over so-called tactical satellites. It is important to note that I do not advocate *replacing* satellite assets with near-space assets. On the contrary, near-space allows our high-dollar strategic assets to do their jobs even better by relieving national assets of the tactical and operational burdens commanders place on them during times of crisis.

Broad concepts of operations for near-space assets are discussed next. Near-space assets will soon be available that can provide stay-and-stare persistence of days, months and perhaps years. These mission durations far exceed those of unmanned aerial vehicles (UAVs) and begin to approach those of satellites. The logical organizational structure for these near-space units thus would appear to resemble our current space operations squadron model. In such a notional near-space operations squadron there would be care and feeding transmissions and occasional navigation inputs. The remainder of the problem would be data stream management—exactly how satellite fliers currently do business.

Right now, Air Force Space Command's contribution to the joint force structure includes providing the bulk of space expertise (read: space effects, primarily C4ISR) to the joint forces commander. This is not to say that other services do not also contribute space expertise, but the primary contribution does come from the Air Force, the DoD Executive Agent for Space. This situation is similar to, say, how the Army is the primary contributor of long-term ground troops, while the other services also contribute smaller but meaningful numbers. Near-space provides a similar function, in fact an almost identical function, to what the Air Force provides with its space expertise. By operationally grouping near-space with space, the functional expertise synergies would allow much more efficient delivery of space effects to the joint commander. What better way of ensuring that the disparate space effect delivery systems work together in a machine-to-machine interface to produce a single space effect picture than to have their procurement, training, and operational employment be coordinated by a single commander?

While many of these ideas may seem heretical to some, they are thoroughly supported in the paper. In fact, after several months of briefing this concept to Department of Defense (DoD) senior leadership, the only opposition seems to come from a few low-level individuals within organizations with vested interests in the space status quo. Gen John Jumper, Chief of Staff of the Air Force, clearly recognized the opposition from managers of existing programs when he said "Try and sell a concept that makes very good sense like the one I think I just outlined [near-space] and you find antibodies all over the place."[1] Senior Air Force leadership appears to have wholeheartedly accepted near-space as a concept worth serious investigation, based upon numerous recent speeches and its inclusion in the 2005 Defense Authorization Act.[2] Much of the discussion of ideas in the paper is also contained in the endnotes, as more lengthy argument frequently digressed and detracted from the flow of the paper. Thus, I recommend a thorough reading of the notes, as they are not simply source citations. If you have comments or suggestions on the paper I would be happy to hear them and will possibly incorporate them in future versions. There is a list of acronyms at the end of the paper for quick reference. Hope you enjoy the read.

Ed "Mel" Tomme

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Section 1

Introduction

Space. Depending on one's background, that evocative word can conjure up a multitude of images, perhaps ranging from *Star Wars* and spaceships to NASA, telescopes, and satellites. The average warfighter is not yet routinely schooled in the nuances of our nation's complete space capabilities. Ask a warfighter what the word space means to him and you will likely get a discourse on the overhead imagery provided by strategic national assets. A well-educated warfighter might even mention the command and control (C2), communications, and navigation support he gets from space. An exceptionally well-educated warfighter might also consider possible missile warning and counterspace missions. In almost all cases, though, the intelligence, surveillance, and reconnaissance (ISR) and weather products they are used to seeing will get top billing.

The reason warfighters develop these somewhat constrained mental images of space is they are interested in the *effects* space can provide for them. Effects are "the tactical, operational, and strategic level outcomes that a military action produces."[3] If it has no effect on the battlefield, a warfighter has little use for it, especially in a time of crisis. For this reason it is currently in vogue to place the phrase "effects-based" in front of a wide variety of legacy concepts to emphasize the new thought processes that must be used to employ them with more success. Space, primarily through its ISR, C2, communications, and navigation missions, provides easily understandable effects for the warfighter—those effects that give him the ability to more efficiently prosecute his battle.

As it is now understood by the warfighter, the term "space" generally means satellites traveling above the atmosphere subject to the laws of orbital mechanics. Communications are provided by some satellites, navigation by others, while imagery and other forms of intelligence come from yet another distinctive set. One purpose of this article is to demonstrate that for the warfighter, such a mental image of space is counterproductive. Thinking about space as just a location or a set of platforms is an *artificial* constraint that distracts from the whole point of launching satellites into orbit—getting the desired *effects* for the warfighter. We do not launch satellites just to launch them—space launch is a very expensive proposition, requiring the dedication of vast amounts of resources and personnel that subsequently cannot be used elsewhere. We launch satellites only when we determine that they are the best way to get the desired effects related to their missions in spite of their costs. It is the *effect* that is paramount for the warfighter, not the platform or the environment where the platform resides. The *primacy* of the concept of space as a set of related effects rather than a location or a set of platforms is a true paradigm shift. [4,5]

Once the mindset of space as a place is overcome, once the doctrinal limitations are recognized and removed, once *effects* become paramount in planning, a multitude of possibilities for operational concepts begin to open up. Take for example the Chief of Staff of the Air Force's recently unveiled strategy for a deployable, operationally responsive space force. In his original vision, called Joint Warfighting Space (JWS),[6, 7, 8] space squadrons would deploy to a theater of operations where they would control cheap "tactical" satellites,[9] kept in storage as a sort of space war reserve material and launched on demand from CONUS locations, to provide the theater commander with tactical space effects. The vision, tactical space effects, is exactly what is needed to solve recent vexing lapses in battlespace awareness at the operational level. However, the method was one bound up in the current space mindset: to get "space" effects one had to use satellites in space.[10]

Another purpose of this paper, in addition to demonstrating the need for doctrinal change to emphasize the primacy of effects, is to introduce the concept of *near-space*, the region between the traditional realms of satellites and air-breathers. Combining the doctrinal change recognizing the primacy of effects with the possibilities offered by near-space, the solution to one layer of tactical and operational "space" is clear. Near-space is the "obvious, correct solution" to the JWS vision,[11] forming an additional layer of effects producers between satellites and air-breathers and enhancing the survivability and redundancy of such a system of battlespace awareness systems. This bold statement is presented here with little support, but arguments will be presented below to convince the reader of its validity.

Air Force leadership gave tacit acknowledgment of the inherent linkage between space and space effects when they tellingly named the *Space and C4ISR CONOPS*, one of six basic mission concepts promulgated from the highest levels of the service. In that document, responsibility for not only space but also space *effects*, the C4ISR part of the title, was delegated to Air Force Space Command (AFSPC).[12]

Looking at effects instead of medium or platform also facilitates the transformational concept of a "Space and C4ISR Command." Since C4ISR is really a space effect, the name could conveniently simply be "Space Command." AFSPC should be the single Department of Defense (DoD) repository of overhead C4ISR assets. Such a structure would streamline many of the unwieldy, stove-piped processes that currently plague rapid dissemination of information throughout a joint command structure. The Holy Grail of C4ISR is the seamless, horizontal, real-time integration of all intelligence assets into a Single Integrated Space Picture (SISP)[13] and a Common Operational Picture (COP).[14] There would appear to be no better way to achieve such a seamless integration of information than consolidating the acquisition, training, and operation of all overhead C4ISR assets, from air-breathers to near-space to satellites.

This paper first discusses what near-space is, why it has only recently become feasible to use near-space, and how the properties of near-space can provide an advantage in delivering "space" effects to the warfighter. It then examines several near-space platforms: the hardware that enables the use of near-space. After technical discussions of the *whys*, *wheres*, and *whats*, it then turns to the *whos* and *hows* for an operations-based look at how near-space provides effects to the warfighter. Finally, it suggests possible concepts of employment that include organizational management structures to most effectively achieve these space effects. Once these sections are read, the answer to *when* is inescapably obvious: the time for near-space is now.

Section 2

Synergistic Technology as the Near-Space Enabler

Until very recently, the distinction of space as a set of effects instead of a medium was irrelevant because the only platforms that could deliver space effects were satellites. However, a convergence of several technologies has changed the capabilities landscape, now making this distinction an important one. Evolutionary advances in several disparate disciplines have led to a revolutionary advance in capability. Some technologies contributing to this revolution in capability are (a) power supplies including thin, lightweight solar cells, small, efficient fuel cells, and high-energy-density batteries; (b) the extreme miniaturization of electronics and exponential increase in computing power, enabling extremely capable, semi-intelligent sensors in very small, lightweight packages; and (c) very lightweight, strong, flexible materials that can resist degradation under strong ultraviolet illumination and are relatively impermeable to low-atomic-mass gases.

Taken alone, the above technologies, in general, are progressing at normal, evolutionary rates. There have been few, if any, large, unusually rapid increases in capability in any of the fields. However, when those technologies are combined into a system called a *near-space platform*, the convergence of the technological advances allows a revolutionary, transformational increase in capability. Small, capable electronics powered by long-lasting and efficiently renewable power supplies lifted to extremely high altitudes by durable, long-lasting helium-filled balloons can perform many of the missions currently performed by satellites, in many cases just as effectively and more timely than their more traditional brethren. It is the advent of these near-space platforms that requires a reevaluation of the concept of space as it applies to the warfighter from a platform/medium point of view to a mindset of effects. Synergistic technological advances are what allow us to field near-space platforms today, but technology is only a partial answer to the *when* question for near-space posed earlier. Technology drives the *could* portion of when the time for near-space is right.

Section 3

Space Effects from Near-Space

The preceding paragraph foreshadowed the direction this paper will take: a discussion of how near-space assets can deliver space effects. However, before looking at those platforms it may be useful to examine some of the limitations of our current methods of delivering space effects.

The Current Way of Doing Business

Based on numerous published accounts of lessons learned from recent conflicts,[15, 16] two space effects that the warfighter desperately wanted—and in many cases did not always receive—are persistent, organic ISR and 24/7 over-the-horizon communications.[17, 18] There are surprisingly few national ISR assets actually orbiting the earth.[19] These assets are frequently needed for higher-priority missions and are so heavily tasked with strategic missions that they may not be readily available to operational or tactical commanders.[20] The various service TENCAP (tactical exploitation of national capabilities) programs were originally set up to address these issues.[21] Even the national agencies are looking for some way to augment their satellite-based ISR.[22] Similarly, communications resources, regardless of where the nodes are located, never seem to be available in sufficient quantity.[23] Satellite-based communications are very expensive to field and generally have limited bandwidth and availability. Those assets with continuous availability are extremely expensive to build and the costs of boosting them to their distant geosynchronous earth orbits (GEO) put them well beyond the price range of operational and tactical commanders. The current alternative, terrestrial communications systems such as cell-phone networks, are difficult and time consuming to set up and are non-responsive on a moving battlefield.

The currently fielded constellation of communications, navigation, and ISR satellites does an exceptionally good job of providing strategic space effects. However, even as good as they are, as currently envisioned and employed it is not possible for our limited non-GEO ISR and communications assets to provide a constant, staring presence on a timescale of days, weeks, or months over a selected target or area of interest without fielding a larger constellation of assets. Satellites traditionally operate in orbits above 200 km where the effects of the tenuous atmospheric drag on orbital lifetime begin to markedly decrease.[24] Orbiting much lower than 200 km significantly reduces the time before drag causes a satellite to spiral back toward its eventual fiery demise.[25]

Being subject to the laws of gravity and orbital mechanics, satellites cannot stay in place over a single spot on the ground except when they are more than 35,000 km above the earth orbiting over the equator in a geostationary orbit.[26] Traveling at a minimum of about seven km/second, non-geostationary satellites measure their persistence in pass times instead of hours. For example, most low earth orbit (LEO) satellites have a specific target in view for less than 15 minutes at a time and revisit the same sites only infrequently.[27] This kind of persistence is stroboscopic at best. Costing billions or at least millions each, countering the strobe-like view with multiple satellites to provide staring persistence is almost prohibitively expensive. Additionally, satellites can only carry very limited amounts of maneuvering fuel so their orbits and times overhead are very easily predicted,[28] a fact many of our enemies exploit.[29] The current openness surrounding the nation's spying activities has made it a nearly trivial exercise to defeat our ISR efforts.[30]

Although the discussion to this point has been about space in the traditional sense of the word, thinking about ISR as a space *effect* naturally leads to consideration of other means of achieving this effect, such as airborne platforms. Just as orbital platforms have a lower boundary for operation based upon the extent of the atmosphere, airborne platforms are similarly limited. In their case, however, the limit is an upper bound. Attempt to fly too high and there is insufficient oxygen to allow conventional fuels to burn, to allow engines to operate. At high altitudes, aerodynamic effects also become much harder to achieve, causing wings to be very inefficient. Generally, air-breathing aerodynamically lifted platforms do not routinely operate much above about 60,000 ft (18.3 km).[31]

While much more responsive than orbital assets and capable of returning much higher resolution imagery, due to their limited numbers airborne assets still cannot always provide the persistent look needed by battlefield commanders. Fuel consumption rates for unmanned aerial vehicles require frequent returns to base. In addition to fuel restrictions, crew duty restrictions on manned ISR assets such as the U-2 and RC-135 do not allow more than a handful of consecutive hours over a target. Physical limitations due to orbital mechanics and fuel consumption thus prevent long-term persistence for both orbital and airborne platforms. In short, as a result of being tied to expensive, limited quantity platforms operating in the traditional media of space and air that do not have the capability to stay on station for extended periods of time, a battlefield commander has only a limited chance for tasking a national or airborne asset that provides him with all the information or communications capability he needs where and when he needs it.[32]

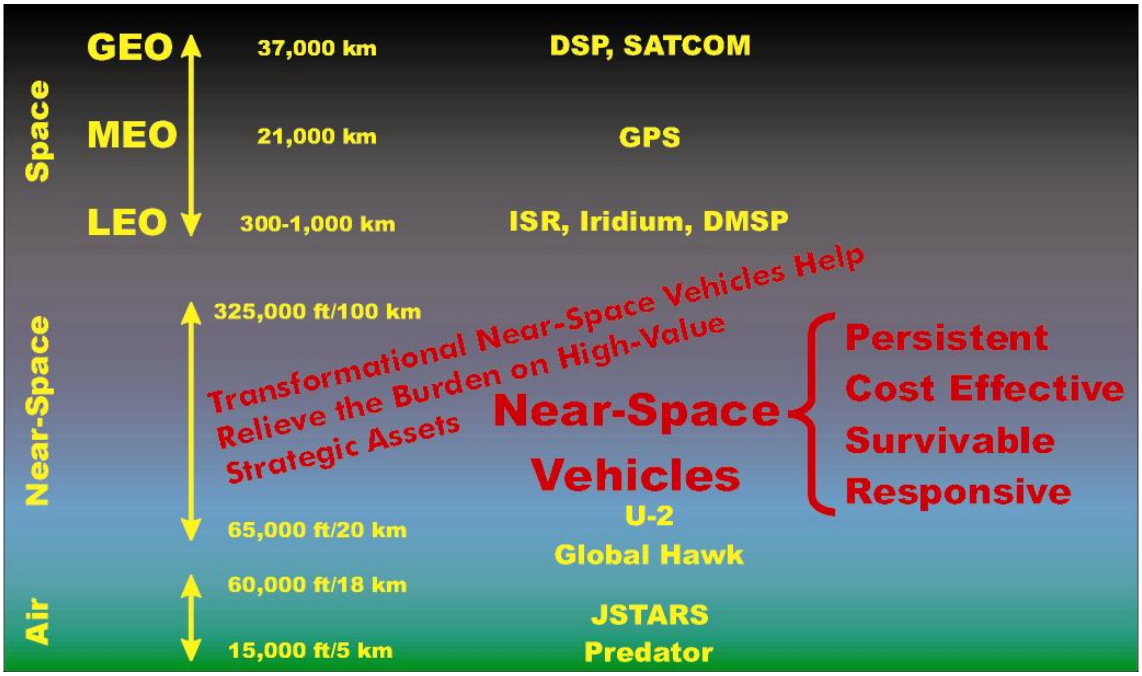

Figure 1. Graphical Depiction of the Gaps Filled by Near-Space.[33]

We thus have two gaps. The first is a gap in capability, a gap where the need for the effects of persistent communications and ISR goes unfilled. The second is a gap in the altitudes covered by military assets. These two gaps can be simultaneously filled through the use of near-space platforms. Near-space platforms operating in the altitude gap can provide the missing persistent communications and ISR effects desired by warfighters.

At a recent conference designed to assess the state of the art in near-space,[34] a panel of experts agreed to loosely define near-space as that region between about 65,000 ft (20 km) and 100 km, a definition with admittedly mixed units. Sixty-five thousand feet was chosen as the lower boundary in order to be above the current International Civil Aviation Organization (ICAO) controlled airspace limit of 60,000 ft. As will be discussed shortly, being above 65,000 ft also has significant meteorological implications. One hundred kilometers was chosen to be at the Karman line[35] loosely defining the boundary of space. Although our definition of near-space reaches up to the boundary of space, we cannot currently sustain operations throughout all of near-space. We can, however, comfortably achieve long-term presence in near-space below about 120,000 ft (36.6 km).

Capabilities Near-Space Brings to the Fight

Many of the near-space platforms in use by industry today as well as most envisioned systems are essentially variations on the lighter-than-air balloon theme. However, the majority of them are much more high-tech than the simple balloons people imagine. While some simply drift with the wind, others are able to maneuver and station-keep, providing a level of control unthinkable to the ballooning community only a few years ago. Not constrained by the orbital mechanics of satellite platforms or the high fuel consumption rates of airborne platforms, many envisioned near-space systems could stay on station above a specified site almost indefinitely, providing persistent coverage of up to an 850-mile-diameter field of view on the ground. In the following sections we will discuss some of the ways near-space can enhance the delivery of space effects. A few of these factors include footprint size, persistence, sensor resolution, space weather mitigation, and survivability.

Balloons can operate at altitudes well below near-space. In fact, low altitude tethered balloons have been used by the US military since the War Between the States.[36] One of the biggest benefits of going to near-space with balloons is that they are above the troposphere, the region of our atmosphere where most weather occurs. Tethered balloons currently in use by the military are severely constrained by weather, being pulled out of the sky whenever the forecast includes storms or high winds. They are typically available less than 60% of the time because of these weather limitations.[37] Balloons in near-space are above all storms and above the jet stream in a region where the prevailing winds are relatively benign. In fact, the winds in the region between about 65,000 and 80,000 ft average less than 20 miles per hour, increasing to an average of about 40 mph at 100,000 ft. There are only limited wind data above 100,000 ft, but models seem to show that even at 120,000 ft the wind is not likely to average greater than 50 mph. These relatively low winds are a large part of what allow near-space platforms to deliver their unmatched persistence to the warfighter.

Large Available Footprint

The footprint, the area in which the platforms can provide their space effects, covered by near-space assets is very large. The accompanying figure shows the extent of the footprints covered by platforms at two representative near-space altitudes, one at the bottom of the regime shown over Washington, DC, and the other at an altitude easily within reach of current technology depicted over Colorado Springs. Three footprint rings are shown for each platform showing the footprint to the set of points where the platform would appear to be 5 degrees above the horizon (solid circles), to the horizon (dash-double dot circles), and to the set of points where a second platform at the same altitude would just be visible above the horizon (dashed circles). The different footprints show the possible coverage of a payload used for different missions. For example, a communications link on a near-space platform requires a line of sight view of the other node. If this node is on a second co-altitude near-space platform, the second node must be above the horizon. If it is further away than the dashed circles, it will be below the horizon and useless as a communications link. The ground-based node of a ground-to-space (or ground-to-near-space) communications link generally requires the space-based link to be a specified angle above the horizon to ensure connectivity; the solid circles

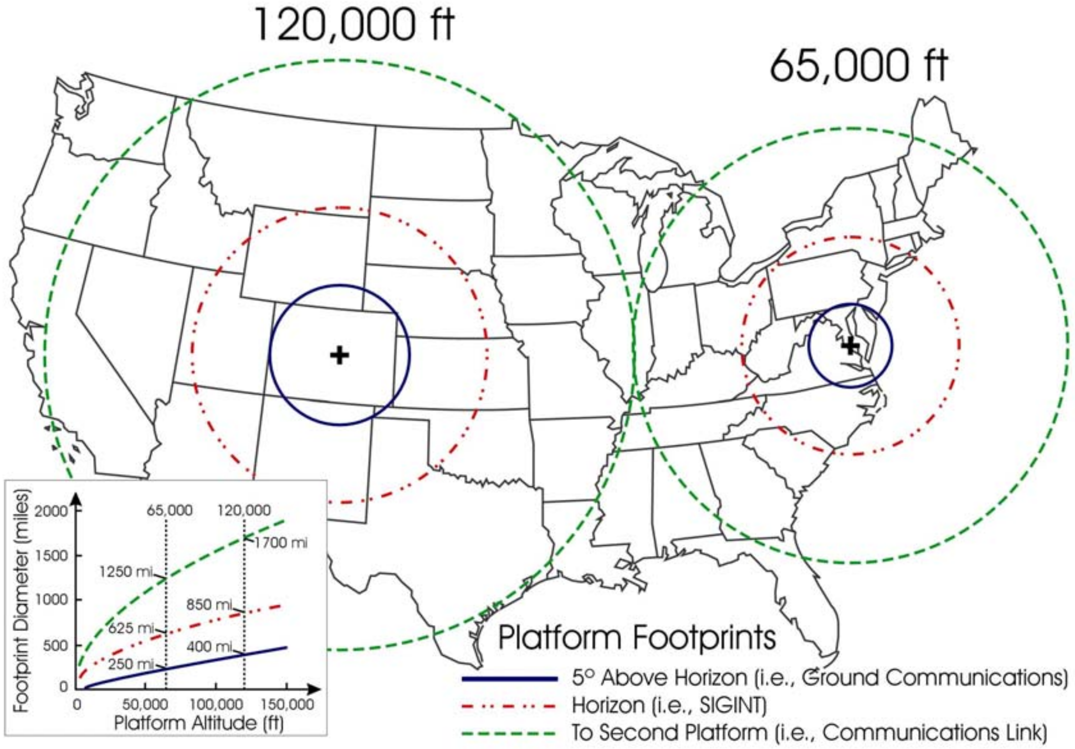

Figure 2. Footprint Sizes for Platforms at 65,000 and 120,000 Feet for Three Look-Angle Restrictions.

show the footprint in which this criterion is met. The dash-double dot rings show the region where an ISR sensor has line-of-sight to the ground. It is important to note that most ISR sensors would not be able to image the entire footprint at any one time; those fields of view are sensor, not platform, dependent and are typically much smaller than the possible regions for imaging shown by the footprints.

High Resolution, Better Sensitivity

While near-space platforms are high enough to provide space effects across theater-sized regions, they are much closer to their targets than their orbital cousins. Distance is critical to resolving features in images and receiving low-power signals. Resolution at long ranges and small fields of view scales almost exactly with the distance between the sensor and the target.[38] The power received by a passive antenna drops off as the square of the free-space distance to the transmitter, while that of an active transmitter/antenna system drops off as the fourth power of the transmitter/target distance.[39] Considering a point at nadir, near-space platforms are 10-20 times closer to their targets than a typical 400-km LEO satellite. This distance differential implies that optics on near-space platforms can be 10-20 times smaller for similar performance, or the same size optics can get 10-20 times better resolution. A passive antenna on a satellite that received 1 watt of power from a transmitter in its footprint would receive between 100 and 400 watts on a near-space platform, implying that it could detect much weaker signals (10 to 13 dB weaker). The signal strength improvement for active systems such as radar or ladar would be factors of 10,000 to 160,000 (40 to 52 dB) for near-space platforms. These examples at nadir are *best* cases for the satellites, too. Any off-nadir angle only increases the distance differential, increasing the near-space signal strength and resolution advantages markedly. When you realize that most communications satellites orbit not at 400 km but 35,000 km above the earth, one to two *thousand* times further than near-space, it is apparent that the received power difference between the two sites is almost unimaginably large.[40]

Being lower than satellites also brings about another decided advantage to near-space platforms: they fly below the ionosphere. Short-wave fade (HF fade) is a reasonably common occurrence tied to solar flares. It enhances electron densities in the lower ionosphere and can completely black out long-range HF and VHF communications over large regions for hours at a time.[41] Ionospheric scintillation can also have significant effects on radio communication[42] and GPS navigation accuracy.[43, 44] This scintillation is essentially the same effect that causes stars to twinkle but is caused by rapid spatial changes in electron density across portions of the ionosphere instead of by high altitude wind. Ionospheric scintillation is very difficult to predict, but is primarily a problem in polar regions and near the equatorial day/night terminator. It can disrupt satellite signals for several hours.[45] Satellites that might attempt to geo-locate terrestrial radio transmissions encounter the problem of signal refraction as they pass through the ionosphere, the same effect that causes a straight rod sticking out of water to appear to bend. In many cases, refraction causes large errors in the reported coordinates of the signal, errors that are difficult to reduce due to uncertainty in the localized electron density of the ionosphere through which the signals are passing. There are many environmental effects that have large impacts on a comparison of space, near-space, and air-breathing platforms, but perhaps the most important environmental effect is that many of the space weather effects that unpredictably plague satellite communication and navigation capabilities are automatically mitigated in near-space where the signals never traverse the ionosphere. Other relevant aspects of the near-space environment are discussed at length in Appendix A.

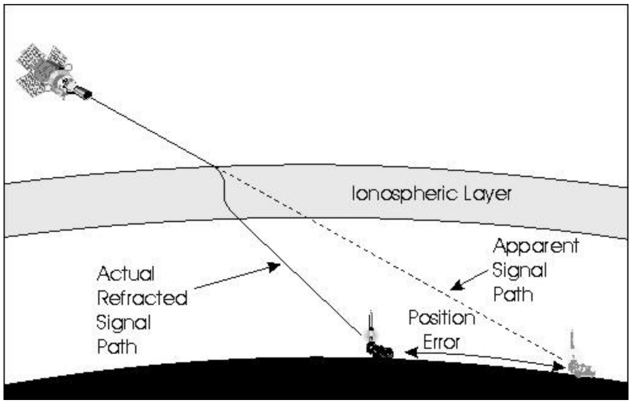

Figure 3. Ionospheric Distortion of Electromagnetic Signals Can Cause Geolocation Errors.

Survivability

Near-space platforms are inherently survivable. They have extremely small radar and thermal cross sections,[46] making them relatively invulnerable to most traditional tracking and targeting methods. Estimates of their radar cross sections are on the order of hundredths of a square meter,[47] about the same as a small bird.[48] They also tend to move very slowly compared to traditional airborne targets, almost drifting on the wind similar to the chaff that modern Doppler radars are designed to ignore. Documented examples exist of sophisticated military airborne radar platforms being unable to find high-altitude balloons.[49] At these altitudes, they are very small optical targets as well, only showing up well when the background is much darker than they are—dawn and dusk. Thus, the acquisition and tracking problem is very difficult even without considering what sort of weapon could possibly reach them at their operating altitudes. Manned aircraft and surface-to-air missiles (SAMs) could be a threat at the lower end of near-space, but even if they were able to acquire, track, and guide on a near-space platform, their probability of kill would likely be low, as will be discussed below. As platform altitudes get higher, the difficulty in delivering a weapon to the target only increases. Very few SAMs are designed to reach above about 80,000 ft, and those that do are most likely not designed to engage a very low cross section, slow, non-maneuvering target at those altitudes.[50] Economics also discourages such an exchange, as the trade between an inexpensive, quickly replaceable near-space platform and even a relatively cheap SA-2 would rapidly become cost-prohibitive.

Even if the acquisition, tracking, targeting, and munitions delivery problems are overcome, near-space assets are notoriously difficult to destroy. The way they are manufactured and inflated has a lot to do with their relative invulnerability. Unlike the Hindenburg, which was filled with extremely flammable hydrogen gas, modern balloons are filled with inert helium that does not burn.[51] Balloons are normally manufactured in two basic types: zero-pressure and super-pressure. Zero-pressure balloons are similar to familiar hot air balloons, having a venting system that ensures the pressure inside the balloon is the same as the surrounding atmosphere. The zero in their name refers to the amount of overpressure inside of them—being at the same pressure implies no overpressure. Super-pressure balloons are inflated and sealed, much like a child's toy helium balloon. However, most are generally constructed of strong, rip-stop material and do not catastrophically deflate after puncture as rubber balloons do.

Most super-pressure balloons have overpressures of less than a pound per square inch, making them relatively insensitive to puncture damage.[52,53] Zero-pressure balloons are less vulnerable to puncture, as significant amounts of the lifting gas must diffuse out through the holes before lift is lost. Imagine an inflated, lightweight plastic garment bag used by dry-cleaners floating on the wind. Put even a large number of small holes in such a bag and the bag would most likely continue to float.

A recent flight mishap delivered a powerful example of how invulnerable to puncture these balloons are. Canadian scientists lost control of a 100-meter-diameter weather balloon in August 1998. Fighter jets from three nations were scrambled to shoot it down as it first flew across Canada, then the North Atlantic, Norway, Russia, and into the Arctic Ocean. Canadian F-18 fighters put an estimated 1000 20-mm cannon shells into the balloon, which obstinately continued flying for another six days.[54]

It is evident that to destroy a near-space asset requires targeting something other than the platform itself. In fact, the relatively small payload of a near-space asset is really the most vulnerable portion. Unless using lasers to carry their information, communications platforms are vulnerable to some radar-guided missiles, acting as a radar beacon at their communications link frequencies. ISR payloads designed to be passively stealthy in both the infrared and radar frequency bands are beacons at the frequencies at which they transmit their data, although this vulnerability can be managed to a very low level by employing low probability of interception techniques. Both types of payload are vulnerable to directed energy threats (e.g., lasers and microwaves), as are similar payloads on satellites and UAVs, but their UAV-like unpredictability and the difficulty in acquiring and tracking them diminishes this threat.

Responsive Persistence

Although the near-space advantages in footprint size, resolution, received and radiated power, cost, and survivability are significant, perhaps the most useful and unique aspect of near-space platforms is their ability to provide responsive persistence, the ability to deliver their space effects to battlefield commander-specified locations around the clock with no gaps in coverage. The greatest persistence that a commander can currently expect from an air-breathing asset is about a day or so for a Global Hawk.[55, 56] Air-breathing assets provide responsive, close-up, staring persistence for the duration of their limited loiter times. In contrast, one near-space platform currently receiving technology demonstration funding will be able to stay on station for *six months*, and planned follow-ons are projected to stay aloft for *years*.

Satellites complement UAVs well, with persistences measured in years. Unfortunately, their responsiveness is also measured in years, the years one has to wait to get a spacequalified system built and the years it takes to arrange for space lift. While this wait can be a reasonable trade for the superb strategic space effects we now expect, it is not the responsiveness a battlefield commander requires.[57] Additionally, satellite persistence[58] is stroboscopic, dictated by orbital mechanics, which can cause important developments to be missed should they occur during times that the satellite is not overhead. Fielding constellations of satellites to mitigate the gaps in the strobe effect can be prohibitively expensive for short-duration events, even for proposed lower-cost "tactical microsats."[59] When presented with the concepts side-by-side, the combatant commanders unanimously preferred near-space to tactical satellites.[60]

Weaknesses of Near-Space

In all fairness, near-space platforms have some weaknesses. The two most prominent weaknesses are launch constraints and legal constraints. Large helium-filled balloons present large cross sections subject to the effects of wind and turbulence during inflation; launch; ascent and descent through the troposphere; recovery; and deflation. Inflation times on the order of hours will probably require the construction of hangars to protect against the wind. These constraints are not showstoppers. Very large balloons (up to 300 times the volume of the Goodyear blimps) have routinely launched for years with similar constraints,[61] and lightweight, inflatable hangars suitable for deployment already exist.[62] The susceptibility of near-space vehicles to low-altitude wind means design constraints and employment concepts need to allow for missions of sufficient duration to allow for launch and recovery when the weather meets system requirements and may require construction of hangars for some types of platforms. Such considerations are required to ensure seamless coverage of the area of responsibility. Existing data on tropospheric weather conditions allow statistically based requirements for mission durations to be constructed. Note that satellites face similar launch constraints, but that those constraints only have to be met once—during launch. UAVs and manned aircraft are also subject to similar launch and recovery constraints, although their limitations are less stringent than those for near-space platforms. Additionally, construction of hangars for near-space platforms is a relatively minor project when compared with construction of the launch infrastructure for other types of platforms.

Freedom of overflight is another weak area for near-space. ICAO treaties cover the airspace up to 60,000 ft. Satellites enjoy free overflight via other treaties and US national policy.[63] However, the legal status of the near-space regime is a grey area that to our knowledge is not directly addressed by treaty or policy.[64] Near-space is not a new legal regime; the question is only whether it falls under air law, where nations claim sovereignty over their airspace, or space law, where overflight rights exist. Due to lack of clear legal precedent governing the near-space regime, there is considerable disagreement among legal analysts over whether overflight rights exist,[65] although a recent memo from the Air Force General Counsel addressing the matter can be paraphrased to say "although we have not defined the boundary between air and space, it will be higher than near-space."[66] In other words, the Air Force position is that near-space over a country will be treated as sovereign territory and air law will prevail. It is problematic whether the United States should even push for such overflight rights for our systems. Such rights may open up the near-space environment over our own country to reciprocal overflights by foreign powers. Space is an expensive game to get into, so only a few nations can afford to place assets over us now. The low costs of near-space could greatly expand this list of countries. The legal quandary surrounding overflight is not a fatal flaw for the concept, however, as properly designed methods of employment can avoid the problem for most proposed systems, especially those designed for tactical and operational use.

At the present time, aside from several low-end platforms that are currently used commercially and a few small-scale demonstration models, complete systems required to maneuver in near-space exist almost exclusively on paper.[67] There appear to be no scientific or engineering obstacles that cannot be overcome in short order, provided that sources of funding can be found. The reason that near-space platforms do not already exist can likely be traced, not to technical reasons, but to the fact that in many people's minds balloons are historically tied to the specter of the Hindenburg disaster, as well as to some amount of "giggle factor" whenever balloons are discussed as a military option. People tend to form mental images of the very simple balloon systems of the past instead of imagining the possibilities offered by more complex and capable systems now proposed by industry. The fact that near-space platforms do not act like the usual suspects—air-breathers or satellites—does not seem to help, either. Military planners historically tend to go with what they know, and many times it takes a great deal of push from a vocal minority within their ranks to get them to adopt new ways of doing business.[68]

Even considering these weaknesses, near-space assets can form an additional layer of persistence between satellites and air-breathers, complementing both and making the combination of systems more survivable and redundant by their presence. With on-station times proposed to be on the order of months or years, they can stay and stare for much longer than any envisioned airborne asset could ever hope. They get their lift from buoyancy, not from fuel. They move slowly enough and at such high altitudes that overcoming drag requires a minimal draw on their power supplies. Their large footprints are not offset by the extremely fast orbital speeds and short pass times of satellites. They improve upon the long-term persistence traditionally provided by satellites while providing the on-call responsiveness of airborne assets. They can be on-station when and where a battlefield commander needs them. They provide the answer to the needs for organic persistence so poignantly stated by the coalition commanders of recent conflicts.

At the risk of beating a dead horse, warfighters primarily care about effects, not about what platforms or locations the effects come from.[69] Platforms operating in the near-space regime can provide the "space" effects warfighters need, and those effects come with significant advantages over the current ways of doing business. The cost of near-space platforms is low enough and the logistics tail so small that a battlefield commander can afford to own *and personally exercise control over* a number of them.[70] Space is no longer just a strategic asset; tactical and operational commanders can now produce their own space effects.

Section 4

Filling the Gap between Air and Space

Now that we have seen how near-space can deliver many of the effects historically associated with space and with orbital platforms, we will take a look at the point where the rubber meets the road: platforms. Without physically achievable hardware to realize the transformational theories presented above, all of this near-space discussion would be nothing more than a thought experiment. Fortunately for the theorists, some of the platforms already exist and are just awaiting payloads, concepts of employment, and appropriate funding before they can be fielded. A great deal of additional hardware is currently in prototype development. This section will give a brief overview of the basic types of hardware that can be used in near-space. A more detailed look at specific systems under consideration by various government agencies is given in Appendix B.

A near-space platform is designed to be a sort of "truck." Just as an eighteen-wheeler does not care what cargo is in the trailer as long as it meets specified weight and volume requirements, a near-space platform does not care what its payload is as long as the payload mass and power requirements are within specified ranges. The platforms are designed with plug-and-play type connectors, providing great flexibility in what the payloads can be. Payloads currently envisioned provide the obvious communications, C2, and ISR effects, but other effects such as force application and counterspace could also conceivably be provided. Due to the inherent payload flexibility, the following discussion of near-space platforms will not generally include specific payloads. Doing so would be akin to describing an Atlas or a Titan as the better way to deliver a specific communications capability. Near-space platforms are enablers for a new layer in the system of space effect systems; obtain them and whatever sensors one could previously only place on UAVs or satellites now have a new place to operate.

Instead of concentrating on payloads, the technology discussion below will describe the three basic types of near-space platforms currently in use, in active development, or envisioned: free-floaters, steered free-floaters, and maneuvering vehicles.[71] To understand just how different the types of near-space platforms are from each other, it is useful to use an analogy with the classification of ships. Free-floaters are like rudimentary rafts where the speed and direction of travel is completely determined by the direction of the current. Steered free-floaters are akin to sailboats: the current still has a large effect on their motion but they can steer within that current with various degrees of effectiveness by using the additional motion of the wind. Maneuvering vehicles, on the other hand, are like steamships. Strong currents can at times overwhelm them, but in general they can go where they want and stay there for as long as they like, fuel permitting.

Free Floaters

Free floaters are basically the simple weather balloons many people imagine when they think of lighter-than-air. They are very straightforward to construct and launch and very inexpensive, but lack the station-keeping capabilities of their more complex brethren. Once launched, they are at the mercy of the existing winds. Limited steering is possible by variable ballasting, causing the balloon to float at different altitudes to take advantage of different wind directions and speeds. However, no conventional active steering or propulsion systems are used on these platforms. These balloons can take tens to thousands of pounds to over 100,000 ft,[72] but more typical weather balloon payloads are on the order of tens of pounds. Free-floater systems have already demonstrated commercial viability as communications platforms and the international community has already allocated communications frequencies for use specifically by near-space assets.[73]

Other than the continual constellation replenishment necessary to ensure persistent coverage, at first look the biggest drawback to most free-floater concepts would seem to be that their payloads generally cannot be recovered. For the conventional free-floating platforms that have been used for decades, this drawback is reality. The best that could be hoped for was to use a parachute or a short-range paraglider recovery system to get a payload back. While this extremely inexpensive solution may be useful in low-threat situations where recovery crews have relative freedom to maneuver while attempting payload recovery, the obvious tactical implication to this limitation in higher-threat situations is that only expendable, lightweight payloads are likely to be launched on such platforms.

Innovative balloonists, however, have devised a way around this free-floater limitation. By encasing the payload in a high-performance autonomous glider, expensive or sensitive payloads can be recovered safely and reused. The payload is sent aloft just as it would have been on a conventional free-floating system, providing its space effect as it drifts over the theater of operation. However, instead of destroying the payload as it drifts out of theater, as the balloon approaches the maximum range of the glider, the glider is cut loose from the balloon. The payload then autonomously glides back from hundreds of kilometers away, staying aloft for several hours before landing safely on relatively small, relatively unprepared surfaces. The payload can continue to be used during the glide. The glider can either fly a preprogrammed route home or can be directed to overfly targets of opportunity until it reaches the minimum altitude for safe return based on existing wind conditions. Once safely back on the ground, the payload and glider can be quickly reattached to another balloon and floated again. Only the very cheap balloon part of the system is lost each mission. A variety of such hybrid glider/balloon systems are available off the shelf today, ranging from extremely inexpensive plastic gliders with quite limited payload capability (tens of pounds) to much more complex and capable composite gliders such as those designed to land payloads on Mars.[74]

Steered Free-Floaters

Steered free-floaters also drift on the wind, but they are able to exploit the wind much like sailing ships to maneuver almost at will. Sailing requires the vehicle to be immersed in two media moving at different speeds. For example, a sailboat simply drifts with the water currents if the wind is the same direction and speed as the current. No steering is possible. However, if the wind is in a different direction or speed than the current, then the boat can be steered, using the aerodynamic properties of the sail and the hydrodynamic properties of the rudder to control the direction of the boat. Steered free-floaters use a similar principle, but the two different media are the different air masses at widely separated altitudes. A large balloon at high altitude moves at a different speed through the air than a wing suspended below the balloon at a different altitude. The air around the wing is moving at a different speed than the air pushing the balloon. The entire platform is then steered when the differential wind between the two parts of the platform enables the wing to become aerodynamically effective.

No integrated steered free-floater has yet been flown, although most of the component parts have been tested individually.[75] Theoretically, such platforms could be navigated with a fairly high degree of precision, generally going with the flow of the prevailing latitudinal winds but being able to speed up, slow down, and move perpendicular to those winds to various degrees. Although the limited amount of possible tacking could allow a single platform to stay on station for short periods, a constellation of steered free-floater platforms would generally be necessary to maintain persistence. Having the capability for steered flight, payloads could be more complex than those flown on basic free-floaters as they could be navigated to a depot, recovered, repaired, and reflown.

Maneuvering Vehicles

An even more sophisticated option involves near-space platforms that are able to maneuver and thus fly to and station-keep over specified points. Such platforms are the functional cross between satellites and airborne platforms, providing the large footprint and long mission durations commonly associated with satellites and the responsiveness of a tactically controlled UAV.

Maneuvering vehicles will use a variety of schemes for propulsion. At the lower end of near-space, the air is thick enough for high-efficiency propellers to provide effective propulsion for these large vehicles. Higher up, propeller requirements increase significantly in the thinner air, and other propulsion methods begin to become more efficient. Some vehicles vary their buoyancy, ascending and descending within an altitude band during operations. Just as a glider moves forward as a consequence of its downward motion, such vehicles glide as they descend. When the buoyancy is changed so that they ascend, they also move forward using a similar set of forces. Thus, their motion through near-space resembles that of a porpoise, moving forward as they move up and down.[76]

As with steered free-floaters, no integrated maneuvering vehicle has yet been flown in near-space. In fact, according to the military's ballooning experts at the Air Force Research Laboratories the longest a powered airship has been aloft in the stratosphere is a measly 3 hours.[77] However, the Air Force Space Battlelab has been working on a proof-of-concept design for a few years,[78] the Navy has a lower-altitude pathfinder flying and has established a significant funding line for the near-space follow-on,[79] and the Army expects to fly a much larger-scale advanced concept technology demonstration (ACTD) maneuvering vehicle in 2006.[80] Many other maneuvering vehicle concepts are on the drawing board, being funded by numerous government agencies as well as by the civilian sector. Maneuvering vehicles do not require the continual replenishment of free-floaters or the large constellations of steered free-floaters to provide persistence. Their payloads are large enough to be militarily useful and they can be recovered for repair and reuse. It is primarily maneuvering vehicles that are the revolutionary technology behind the paradigm shift to effects-based space. Again, a much lengthier discussion of specific near-space hardware may be found in Appendix B.

Section 5

An Effects-Based Comparison of Platforms and Missions[81]

After this discussion of near-space platforms, it may seem that we have deviated from the thesis of this paper, that "space" as understood from a warfighter's perspective is a set of effects instead of a platform or a medium. This is far from the case. Near-space is the new kid on the block, and its possibilities are much less understood than the neighboring air-breathing and orbital regimes. Without the context of the possibilities of near-space and the physical realization that hardware gives to those possibilities, a rational comparison of how to best achieve "space" effects would have been impossible.

To recap earlier discussions, we do not launch satellites for the sake of launching satellites. Historically, we have launched them because the hard numbers had been crunched, the analyses had been done, and we had determined that for some missions satellites were the best ways to achieve the desired effects. With our new ability to fill the gap between air and space, the input to the analysis has changed significantly. The trade-space calculus needs to be re-accomplished to determine the best way to achieve what until now have been assumed to be "space" effects.

In effects-based planning, we need to consider what system or combination of systems will provide the greatest effect on the battlefield for the least expenditure of resources. Here we will consider effects as they enable the Secretary of Defense's Joint Operations Concepts (JOpsC) and the Air Force Chief of Staff's published CONOPS. The JOpsC and CONOPS cover much of the same broad functional areas. The JOpsC headings are Major Combat Operations, Stability Operations, Homeland Security, and Strategic Deterrence,[82] while the CONOPS titles are *Global Mobility*, *Global Response*, *Global Strike*, *Homeland Security*, *Nuclear Response*, and *Space & C4ISR*. The most relevant of these CONOPS to the present discussion is *Space & C4ISR*, which "describes how the AF will harness capabilities to achieve horizontal integration of manned, unmanned and space systems, eventually through machine-to-machine interface of ISR and C4 to provide executable decision-quality knowledge to the commander in near real-time from anywhere."[83] Near-space supports many of the other CONOPS and JOpsC as well. A complete listing of the unclassified AF CONOPS, their overarching effects, required capabilities, and an indication of the items directly supported, enabled, or enhanced by near-space are listed in the notes; however, almost all of the other CONOPS which near-space enables are supported through effects and capabilities similar to those listed in the *Space & C4ISR* CONOPS (see Appendix C).

Under that CONOPS, near-space primarily provides two distinct effects for the warfighter: ISR and communications. C2 and computers are generally *enabled* through these two effects, but are not outright effects of near-space on their own. Near-space assets offer tremendous advantages to tactical and operational commanders, providing the "space" effects of ISR and communications much more responsively, persistently, and affordably than any envisioned satellite system. On the strategic level, satellites generally do a better job of providing those effects, primarily due to the legal entitlement to free overflight they enjoy. Given that caveat, near-space assets can still perform strategic missions during peacetime much as the U-2, Global Hawk, and RC-135 do, standing off outside of sovereign airspace while collecting data.

The reason that near-space assets are the better choice for providing tactical/operational communications and ISR "space" effects becomes evident when we perform a direct comparison with satellite assets. We will now compare cost, capability to deliver space effects, and mission suitability, both for strategic and tactical taskings, of generic satellite, UAV, and near-space platforms to get a feel for the relative merits of each system.

Cost

When the cost variable is examined in isolation, near-space has no peer. Their inherent simplicity, recoverability, relative lack of requirement for complex infrastructure, and lack of space-hardening requirements all contribute to this strong advantage for near-space assets.

Requiring only helium for lift, near-space platforms do not require expensive space launch to reach altitude. Over and above the obvious cost savings when the approximately $10,000–$40,000 per payload-kilogram[84] current cost[85] of a space launch is unnecessary, near-space platforms offer other inherent cost advantages compared to satellites.[86] If the payloads they carry malfunction, they can be brought back down and repaired; should they become obsolete, they can be easily replaced. Neither of these actions are possibilities for satellite platforms, many of which had their designs frozen ten or more years before launch and are designed to last for another decade.[87] Imagine what capabilities satellites could have if we replaced their twenty-year-old electronics with modern processors. Imagine the savings when every component does not require thorough testing to ensure perfect functionality the first time in space.[88] Imagine the related insurance savings.[89] Not being exposed to the high levels of radiation common to the space environment, payloads flown in near-space do not require the costly space-hardening manufacturing steps required of orbital assets. Near-space payloads also are not exposed to high-G forces during launch, as are satellites. Operating in near-space obviously eliminates a great deal of expense involved in space sensor construction.

Additionally, the infrastructure cost savings involved with near-space are huge. Near-space assets require extremely minimal launch infrastructure. Compare the cost of a simple tie-down and an empty field or of an inflatable hangar to building a space launch complex or even to building a hard-surface runway. The elimination of space-hardening and space-launch costs enhanced by the ability to repair and upgrade payloads is a powerful incentive to obtain tactical and operational space effects from near-space platforms.

The low price of near-space assets enables operational commanders to own and control fleets of them for the price of a single national asset. For example, at the low-cost end, free floaters cost much less than $1,000 per platform, excluding payload. The high-end near-space platforms envisioned for tactical/operational use are on the order of a million dollars each, also excluding payloads. These costs are on the order of many *individual weapons*, not on the order of competitor satellite or UAV systems. Even for a near-space system with primarily a strategic mission, HAA, the $50 million price tag for a production version is less than our current “cheap” TacSat satellites.[90] For example, compare these near-space costs with a typical commercial imaging satellite, Quickbird-1, which cost $60 million in 2000 dollars,[91] and with the military-procured GPS-2 and DSP satellites that cost $60 million and $330 million per unit, respectively, in 2000 dollars.[92, 93] The near-space platform price estimates admittedly do not include the substantial costs of their payloads. However, the quoted satellite costs do not include the substantial costs of space launch for these platforms, currently estimated to be at least $12 million each just to get 1,000 pounds to LEO.[94, 95] Even the highly optimistic[96] Air Force Research Laboratory (AFRL) TacSat goal of designing, building, and launching a satellite in the near future for under $15 million substantially exceeds the cost of obtaining comparable near-space capabilities, especially if you consider the number of satellites that would be required to obtain similar persistence and the fact that the stated mission duration goal for such systems is only one year.[97]

Even when compared with air-breathing assets, near-space platforms are a bargain. A low-cost UAV that provides reasonably long persistence, the Predator, can carry 450 pounds to 15,000-25,000 ft, can travel 400 nautical miles and then loiter for 14 hours before returning to base—all for a price of about $4.5 million each, not including infrastructure costs and the training costs required for the highly skilled rated officers the Air Force assigns to fly them.[98] More expensive but more capable, the Global Hawk can take a 900 pound sensor package[99] to over 65,000 ft, flying for more than 35 hours at up to 350 knots. The cost for this capability is projected to be about $48 million each for the production versions of the aircraft.[100] At the high end on the cost scale, the venerable RC-135 Rivet Joint (RJ) provides unmatched capability for signals intelligence. Carrying a crew of six flight officers plus up to 27 analysts in back, the RJ can travel up to 3,900 miles unrefueled at up to 40,000 ft and 400 knots.[101] The cost of refurbishing and converting an existing KC-135 tanker to the RC-135 model was $90 million in 1999,[102] a cost in addition to the $40 million for a basic KC-135.[103] Another comparison that could demonstrate a large cost advantage for near-space assets is that of operating cost. The per-hour cost of surveillance would likely yield a huge advantage for near-space, but these numbers are much more difficult to compute than acquisition cost.

Major constraints on sensor packages for satellites and UAVs include power available, weight, and size. Much of the cost of sensor platforms involves the engineering required to fit the systems inside of the platform, for example, trying to squeeze a new laser rangefinder inside of the existing space in a Predator ball. These costs are virtually eliminated for most near-space platforms, since volume is not a major design point. This factor and the aforementioned advantages of not requiring radiation hardening and space qualification mean that not only are near-space platforms less expensive than their orbital and air-breathing counterparts, but the sensors they carry will be less expensive as well. When compared to UAVs, manned ISR, and satellites, near-space assets easily win the cost competition.

Capability to Deliver Space Effects

The space effects needed at the tactical and operational levels of war are persistent and responsive communications and ISR, both of which enable C2. The desire for persistence is self-evident; the commander has a continuous requirement for ISR and communications—he cannot afford sporadic availability as it could afford the enemy sanctuary times, deny the commander the ability to act at the time of his choosing, or both. Orbital mechanics prohibit staring-type persistence by individual satellites in any orbits except in the distant (and expensive to reach) geostationary belt. Fuel considerations limit the loiter of air-breathing assets to at most a few days. Conversely, many near-space assets are specifically designed to have the ability to stay and stare for months at a time. Near-space's forte is persistence.

Responsiveness is another self-evident requirement for commanders. Unforeseen requirements for imagery or communications arise constantly as a result of friction and the fog of war. It does not seem possible to predict every possible enemy or friendly action, so continually updated information is needed to allow the commander to direct his or her forces to the appropriate points to take appropriate actions. This information needs to be responsive enough that the commander can act inside the enemy's OODA (observe, orient, decide, act) loop.[104]

Once on orbit, satellites are all but unresponsive. It takes an enormous amount of energy to change the orbit of a satellite. To change the plane of a satellite in orbit by 60 degrees takes almost as much energy as it took to get the satellite into the original orbit. If the space shuttle burned all of its onboard fuel, it could only change its inclination by 2½ degrees.[105] It is these huge energy costs that all but prohibit repositioning of satellites at the whim of a commander. Satellites are also non-responsive to launch, currently taking from an advertised eight days for the newest evolved expendable launch vehicles (EELV), the Delta IV or Atlas V, up to 200 days to process a Titan IV launch site.[106] These numbers are also predicated on having a satellite built, checked out, and available for mating to the launch vehicle. The Joint Warfighting Space concept calls for much more responsive launches of small satellites, ideally within hours of notification. However the problems involved in the co-located warehousing of the appropriate satellites and launchers required to achieve this goal seem quite formidable at the present time. The capacity of the nation's budget to sustain the heavy blow dealt by requiring a large number of "tactical" satellites and launchers to be kept in warehouses "just in case" is another serious flaw with this program that is seldom addressed by proponents. Even if these sobering troubles could be overcome, they do not obviate the on-orbit non-responsiveness of satellites.

Air-breathers, both manned and unmanned, are extremely responsive. They can be launched in minutes to hours, and once on station they can be redirected at will. During Operation IRAQI FREEDOM, UAVs were the choice for real-time information. Their video feeds were watched live by commanders, at least one of whom personally commanded a real-time weapons release on a high-sensitivity target to ensure responsibility for a potential high-visibility mistake would not fall upon his subordinates.[107] Near-space platforms are also extremely responsive compared to satellites and almost as responsive as air-breathers to launch and redirect. In general, near-space platforms require about a minute per thousand feet to ascend,[108] so it takes about two hours for them to be on-station at 120,000 ft. They also cruise more slowly than most air-breathers, so getting to their assigned stations will take longer. However, once they are there, they can stay there for a very long time. Operational risk is substantially reduced because of the single launch and recovery cycle that produces months of duration on station.

Table 1. Comparison of Mission-Useful Distances for Various Platform Types.

		Distance to:			
Asset Type	Asset Altitude	Horizon	5 deg lookup	10 deg lookup	45 deg lookdown
Predator	15,000 ft.	150 miles	30 miles	15 miles	3 miles
Near-Space	120,000 ft.	425 miles	200 miles	120 miles	25 miles
LEO	200 km.	980 miles	700 miles	500 miles	120 miles

Satellites obviously orbit much higher than near-space or the air-breathing realm, and have much larger footprints. In fact, it takes just three geostationary satellite footprints to be able to completely cover the globe with the exception of latitudes greater than about 80 degrees. These footprints are huge compared to just about anything else. On the other end of the scale, a Predator flying at 15,000 ft has a footprint such that the horizon is only 150 miles away. Remember, though, that the horizon footprint number can be deceiving. As an example, were the Predator to be used for a communications link, ground antenna-pointing limitations (5–10 degrees above the horizon) would require the UAV to be between 15 and 30 miles from the ground antenna to be useful. To have at least a 45-degree lookdown for imagery applications, the Predator would have to be within 3 miles of the target. Similar numbers for an envisioned TacSat-like LEO satellite and a near-space asset are given in the accompanying table. Note that near-space assets have footprint capabilities much better than the UAV.

Sometimes a smaller footprint can be an asset. When a satellite is launched, a frequency band or bandwidth must often be set aside to communicate with it around the globe. The alternative is to devise a complicated frequency-sharing scheme to ensure that when the operator needs to contact the satellite he is able to do so. Bandwidth is a precious commodity, with a very limited supply that is managed by international bodies.[109]

Satellites, with their global-coverage, require their associated operating frequencies to be blocked out globally to preclude interference. Near-space platforms can reuse their bandwidth. Two or more near-space platforms whose footprints do not overlap can share the same bit of the spectrum, a much more efficient system for using a scarce resource.

Large footprints also come with their own detrimental baggage. A smaller operational footprint implies a smaller footprint for encountering interference, whether unintentional or not.[110] Larger footprints also imply higher altitudes. As has been noted earlier, satellites operate above or in the ionosphere, leading to a number of detrimental effects on their signals. Near-space assets and air-breathers operate below these charged layers and thus do not have to contend with the associated signal propagation difficulties. The high altitudes associated with satellites also require large optics for imaging or large antennae to detect signals. As was previously discussed, the closer the asset is to the target, the better the possible resolution and the weaker the signals that can be detected. UAVs and other air-breathers clearly can get much closer to a target than either near-space assets or satellites, but the resolution and signal sensitivity possible from near-space is quite comparable to that achievable by UAVs. The stay-and-stare capability, wider field of view, and near-UAV-quality resolution provided by near-space assets could easily enable much more effective use of high-demand UAV assets by acting as a cuing mechanism. Near-space can act as a key link in the find, fix, assess, track, and target portions of the time-critical targeting (TCT) kill chain.[111] Near-space can effectively multiply the asset-limited UAV force by only sending them where their additional capabilities for enhanced resolution and, with some systems, force application are needed.

So, if satellites are so expensive and so non-responsive; if they are physically unable to provide persistent coverage; and if their inherently large footprints come with the commensurate problems of ionospheric penetration, global communication frequency restrictions, and severe resolution and sensitivity restrictions, why do we buy them at all? The answer today is the same answer that convinced President Eisenhower to fund the first military ISR satellite—freedom of overflight.[112] The importance of freedom of overflight cannot be overemphasized as a positive aspect of orbital operations. Satellites are the only legal means by which overhead ISR can be performed deep inside the territory of sovereign nations during peacetime. Air-breathers, both manned and unmanned, must conduct their missions outside of claimed airspace, which generally lies directly above a country's land area, extending 12 miles out to sea for countries with a coastline,[113] a significant limitation during times of peace. As discussed above, the legal waters are a bit muddy concerning overflight rights for near-space platforms, and the decision on whether to push for those rights will likely come from

Table 2. Relative Strengths of Satellites, Near-Space Platforms, and Air-Breathing Assets.

	Satellites	Near-Space	Air-Breathers
Cost		✓	
Persistence		✓	
Responsiveness		✓	✓
Footprint	✓	✓	
Resolution		✓	✓
Overflight	✓		

outside of the DoD. It is interesting to note, however, that overflight is actually the only attribute for delivering space effects where satellites hold a distinctive advantage, as can be seen in the accompanying table.

Mission Suitability

The preceding discussion of the overflight attribute is a good segue into a comparison of how suitable the various types of platforms are to conduct C4ISR missions. In this paper, we will consider a dichotomy of missions and levels of control, strategic and operational/tactical. According to joint doctrine, the term *strategic* generally refers to activities related to developing and employing instruments of national power in a synchronized fashion to secure national or multinational objectives. These are activities that have global impact. The term *operational* links tactical employment of forces to strategic objectives, and generally represents thinking on a theater level. Finally, the term *tactical* deals with much smaller scale engagements, smaller in number and effect, and shorter in duration.[114] In this paper we will discuss operational/tactical C4ISR as a single group based on the convoluted intertwining of the desired level of control for space effects (primarily operational) and the locations where those effects can be directed (both operational and tactical). The strategic level, for the purposes of space effects, seems to be a distinct category.

Strategic and Peacetime Space Effects

Considering the peacetime strategic level first, satellites are highly suitable for this mission. In fact, based on the overflight restrictions placed on (or likely to be placed on) the other platforms, satellites may be the *only* platform suitable for some aspects of the strategic mission. Deep look into the large landmasses of some potential adversaries cannot be performed without directly overflying that territory. Even a near-space platform flying at 120,000 feet would only have a horizon footprint that could look inland for a little over 400 miles, well short of requirements for all but the smallest countries. While it is conceivable that a steered free-floater constellation similar to that described earlier could be fielded that could perform the deep look round-the-clock mission, an informal poll of international law and policy experts make that option seem less than likely.

There are strategic missions that near-space (and, in fact, air-breathers) can and do perform. Some of these missions are currently performed by the U-2 and RC-135 variants. The stand-off imagery and SIGINT missions these jets do could easily be performed by near-space assets, in some cases much more effectively due to their comparatively long loiter times. Imagine the sensor suite for the RC-135 mounted on a production version High Altitude Airship, with the collected data being analyzed in the CONUS after reach-back transfer via laser communications links above most of the atmosphere to communications payloads on other near-space platforms. The 65,000 ft planned altitude for HAA would allow it to see almost 50 percent further inland than the RC-135, and due to its years-long loiter capability the adversary would not have the luxury of simply turning off their equipment as they occasionally do when the Rivet Joint is on station. Additionally, the cost of building and maintaining the life support systems for manned air-breathing platforms is eliminated. While satellites are the obvious answer to most peacetime strategic missions, there is still a place for air-breathers, and now for near-space. As with most things, a layered approach makes the defenses harder for an adversary to construct, and makes it much more likely that we could achieve the effects we want. With near-space, the defense-in-depth approach simply adds another layer with capabilities that complement the existing space and air-breathing approaches.

There are also space effects other than C4ISR that fall into the strategic realm. For the most part, these effects are likely better accomplished by traditional space-launched assets. Among these effects are force application and some aspects of space situational awareness (SSA) and counterspace. Force application from space is currently a contentious issue,[115,116] but space has been used as a transit path for weaponry since World War II.[117] The historic instruments of this force application method are, of course, ballistic missiles. There are currently a number of non-nuclear programs under investigation for the transitory use of space for global weapons delivery, including many housed in the common aero vehicle (CAV).[118] UAVs have also demonstrated their ability to effectively deliver ordnance.[119] Near-space assets, with the exception of perhaps the High Altitude Airship, do not appear to offer many force application possibilities due to their relatively small payload-carrying abilities, and even then their use as a force application platform appears to be better suited for tactical or operational levels of war.

Other areas where traditional satellite concepts can accomplish much that near-space platforms cannot are related portions of the SSA/counterspace missions. Although the technology is currently experimental, military research labs are actively pursuing microsatellites with the ability to autonomously navigate near other satellites.[120,121] This ability could foreseeably allow these microsatellites to perform close inspection of other orbital assets, both friendly and otherwise, to determine probable missions and status much more accurately than the resolution limits of current ground-based systems could ever do. They could also potentially become potent anti-satellite weapons, taking on many subtle forms that close proximity, velocity-matched flying will enable.[122] Near-space assets and UAVs will obviously never have such abilities.

It must be noted, however, that there are strategic SSA effects that could be enhanced with near-space assets. Being above 96 to 99 percent of the atmosphere in the 65,000 to 120,000-ft altitude range, large telescopes with membranous, holographically corrected and/or adaptive-optically corrected mirrors could provide much better resolution of space assets than their earth-bound brethren that are limited to looking through the significant distortion of the atmosphere.[123] As solid-state directed energy devices grow simultaneously more powerful and smaller, they could also contribute to strategic active-illumination SSA programs aboard near-space platforms. Downward-looking lasers would also be highly effective, as the beam-distorting effects of the lower atmosphere would occur during the latter stages of beam propagation near the target, where the distance from the energy source would help to minimize distortion-induced pointing errors when compared with perturbations near the source. Several steerable platforms

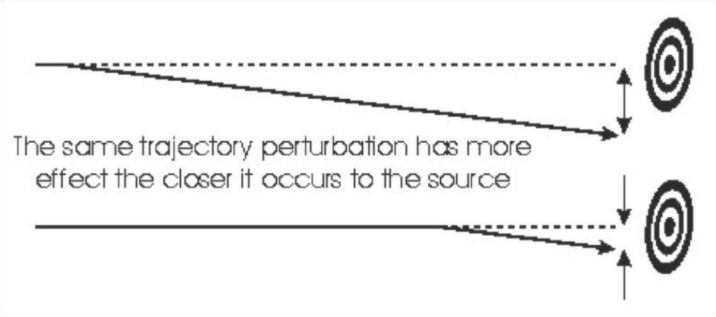

Figure 4. The Effect of the Location of a Perturbation between Source and Target.

stationed near the North Pole could also act as a third sensor for missile defense, augmenting the DSP satellites and ground-based radars currently in use. Thus, near-space assets can act as another layer in a system of systems working to deliver strategic space effects.

Near-space can also be a deterrent to opponents' counter-space efforts, a distinctly strategic defensive mission. Potential adversaries are quick to recognize the US dominance in space, and also quick to recognize our associated space-related vulnerabilities.[124, 125, 126] One relatively easy way to negate this dominance would be to explode an exoatmospheric nuclear device. In addition to the destructive electromagnetic pulse (EMP) such an explosion would immediately create, it would also supercharge the Van Allen radiation belts for a period of six months to two years. Military satellites are presumably hardened against the EMP, but the extra radiation doses a satellite operating within the belts would receive could reduce the life expectancy of such a satellite to mere months. Additionally, the enhanced orbital radiation environment would remain lethal enough to delay reconstitution launches for one to two years.[127]

Near-space can address these nuclear detonation issues by providing an alternative method for delivering space effects that would be unaffected by lingering space radiation. The availability of these assets could be a strategic deterrent to the intentional launch and high-altitude detonation of a nuclear device. For example, one of the primary space effects that threaten potential adversaries is the US dominance in navigation. Additionally, the availability of precision timing is critical to homeland security. All automated teller machine, credit card, and bank-to-bank transactions are synchronized via worldwide timing; should that timing function fail our economy would be turned off for a significant period of time.

Precision navigation and timing are currently performed by a constellation of semi-synchronous Global Positioning System (GPS) satellites orbiting at about half GEO altitude, right in the heart of the Van Allen belts. Although the GPS mission is currently accomplished with satellites to ensure efficient global coverage, that is not the only way it can be done. The Air Force Space Battlelab is currently working a preliminary investigation of GPS accuracy augmentation and GPS reconstitution using near-space platforms, and the Air Force Unmanned Aerial Vehicle Battlelab recently conducted a similar investigation that successfully demonstrated the usefulness of a UAV as an aid to GPS navigation in a jamming environment.[128] There appear to be no technical hurdles to either augmentation or reconstitution via near-space platforms, although the number of required platforms would be significantly higher than the existing constellation to provide global coverage. It would appear to be more realistic to envision near-space reconstituting theater-sized regions. The existence of a readily-available, relatively inexpensive reconstitution method for US space effects, GPS via near-space being only one example of the capability, could thus tend to dissuade an adversary from committing to such a politically-charged action as a nuclear detonation when the payoff would be so short-term and the costs so high.

Operational/Tactical Space Capabilities

For peacetime strategic missions, the overflight freedom enjoyed by satellites is of paramount importance, enabling many C4ISR effects that no other platform can perform. However, once war is declared or hostilities commence, near-space becomes the clear choice to achieve the space effects required for many operational and tactical missions; near-space platforms become even more effective once the balloon has gone up, so to speak. During hostilities, airspace sovereignty over enemy territory is no longer a consideration; near-space assets can operate above the same locations that air-breathers can, subject to similar enemy threats. Near-space assets can then provide organic C4ISR. Battlefield commanders desire organic communications and ISR primarily due to the necessity for responsiveness; they require communications and imagery when and where they need it. When a battle is raging, they do not want to have to ask to task assets controlled by other commanders, never knowing for sure if the effects they require will be delivered.[129] They want direct control of the assets so they are guaranteed access when and where they need it. UAVs provide exactly this sort of local control, but the footprint of a UAV can be much smaller than that of a higher-flying near-space asset, and the near-space platform has the persistence advantage.

Satellites are typically so expensive; are procured in such limited quantities; take significant lead times to plan, build and launch; and generally possess such highly classified capabilities that they are centrally controlled by doctrine.[130] "Tactical" control of satellites, while a proposal receiving serious Air Force attention at the present time,[131] appears to be problematic. The largest difficulty seems to be that it is difficult for a satellite to have a tactical mission. A recent RAND Corporation study supports this statement by arguing, "[A]irpower *can* be global in its reach and ability to impose effects on an opponent, whereas space power, by its very nature, can *only* be global."[132] Global effects imply strategic missions.

Due to the unavoidable consequences of orbital mechanics, a satellite at other than GEO altitudes cannot remain within view of a single commander indefinitely. Even if one were able to launch a satellite on demand for a particular mission, it would only be in view of that commander for *very* short bursts of time a few times a day. The accompanying table shows just how short these times would be for selected LEO orbits.[133] No reasonable person would suggest turning off that expensive satellite and only activating it while it is over the theater controlled by the tactical commander who authorized its launch. If it is operating even when not over the particular theater, then someone else might as well be using it. If multiple users can task the satellite, which one is responsible for overall coordination and control? Will a battlefield commander be willing to devote resources to this coordination in the midst of a war? These orbital and mission realities seem to point away from theater control of any asset delivering global effects.

Table 3. Circular LEO Useful Pass Times by Required Visibility Angle.

	Maximum Pass Time (minutes:seconds)				
Orbital Altitude (km)	Mission Required Angle Above Horizon (degrees)				
	0	5	10	30	45
200	7:49	5:37	4:08	1:40	1:00
300	9:35	7:16	5:34	2:24	1:27
400	11:10	8:44	6:54	3:08	1:54

On the other hand, near-space assets and UAVs are ideally suited for local control. They are exactly the organic, responsive, and persistent C4ISR platforms battlefield commanders have lacked. Instead of having forward-deployed satellite operating squadrons backed up by CONUS-based satellite launch squadrons, the somewhat convoluted structure envisioned with the original version of Joint Warfighting Space,[134] a theater commander would directly control all of the parts of his near-space assets, including launch, recovery, and the entire duration of flight operations. His ownership would thus extend to the entire mission of the asset. As there would be no stroboscopic pass times, no sharing would be required and no permission for control need be granted. Near-space assets are inexpensive enough for him to own numerous platforms and their associated sensor packages, flying exactly the kinds of packages he requires and giving him the flexibility to tailor his C4ISR effects to his needs at the time. The logistics of such deployments approach those of satellite-centric JWS plans. Squadrons of operators will still need to be deployed. The cost of the flexibility of organic ownership to the theater commander comes with the additional logistics tail associated with taking the near-space equipment with him and with the additional personnel required for planning, launch, exploitation, recovery, and maintenance. However, due to the low weight and small volumes of near-space assets, these costs are expected to be low compared with the additional benefits provided in the way of organically delivered, persistent space effects. Near-space *is* forward deployed space once the commander realizes that it is space effects, not platforms, which enable his victory.

When one looks at the desired tactical and operational space effects, it is evident that there are large niches where near-space assets perform much better than orbital and air-breathing assets. When one understands that it is *effects* that matter on the battlefield instead of the platform or medium from which the effects are delivered, near-space makes much more sense for many applications. There are also missions that satellites do extremely well, and for which near-space is not competitive. The point is that a layered approach whose goal is to enable space effects in the most economical, effective way will direct the acquisition of the appropriate platform using the appropriate medium, turning the current acquisitions methodology of medium-then-platform-then-effect on its head.

Section 6

Toward a Near-Space Concept of Employment

To this point we have discussed the evolutionary technological advances that make near-space viable, the advantages and hazards of the near-space environment, a variety of specific near-space hardware concepts, and most recently discussed different ways of achieving various space effects from space, air, and near-space. From that comparison, we have shown that, for many missions, near-space is the answer battlefield commanders are seeking. Now that we have demonstrated the possibilities and advantages of near-space, it is time to discuss concepts relating to the operational employment of near-space assets.

What would a near-space unit look like? The variety of near-space platforms naturally leads to a variety of answers. On the small side, free-floaters could be operated by individuals within squad-sized units, much like a contemporary radio operator, or within small groups of special operators. Their effects could easily be tactical or operational, as could be their command and control. Of course, the data they collect would be fed into the overall theater intelligence picture and the data they relay would be centrally deconflicted for frequency and bandwidth. For the most part, however, these small free-floaters would likely operate below the noise level of the theater commander and of the Joint Warfighting Space concept.

Slightly larger units of seven to ten personnel could be deployed to deliver space effects from glider-return free-floaters. A two-guys-and-a-humvee launch concept will limit payloads to several tens of pounds and about 80,000 ft, but a fleet of 20 airframes and about half as many avionics systems and payloads could be acquired for one or two million dollars. These numbers will be sufficient for a unit to provide continuous coverage of a desired footprint area for several months. Such a system with a communications relay payload is currently being developed by the Air Force Space Warfare Center for possible deployment to Southwest Asia in the spring of 2005.

Instead of small, disposable or recoverable free-floating assets, the theater commander’s interest would likely lie in the more capable maneuvering vehicles with their unique attributes of responsiveness and persistence. Near-space maneuvering vehicle squadrons, the logical backbone of Joint Warfighting Space and major contributors to other CONOPS like Homeland Defense, would likely look a lot like current space operations squadrons (SOPS). Their long-duration missions begin with a distinctly low-tech inflation and launch requiring a fair number of non-specialists and very few specialists.

The bulk of the platform's mission would be automated, requiring it to station-keep at predetermined locations or to maneuver to position its sensors for optimum data collection. The sensors could be operated independently of the platform, as is currently done with satellites. Individual units could be empowered to obtain access to real-time ISR, perhaps even commanding sensor coverage by pre-determined unit priority lists through virtual mission operations centers (VMOC)[135] or fed into Predator-like cells. Communication with the asset would likely consist of periodic health and maintenance queries and commands, along with commands for the sensors and machine-to-machine data stream download into the SISP and COP, also similar to current or planned satellite operations. These mission operators would likely work shifts and require many of the same skills as are found in present-day SOPS. Their ground equipment seems ideally suited to be containerized much as a Predator operations station is for easy deployment to theater. An existing Predator station could possibly even handle the data stream. The ability for a single ground station to control multiple near-space platforms would seem to be much easier to implement than for UAVs due to the lethargic maneuverability available to any high-altitude platform and the anticipated low rate of repositioning commands due to the inherently large available footprint. Finally, the same set of people who launched the vehicle would be required to recover it at the end of its mission.

Unlike SOPS, however, there would be an associated near-space maintenance squadron, responsible for hands-on repair and refit of platforms and payloads of assets not currently airborne. These maintenance squadrons would likely look like any aircraft maintenance back shop instead of a flightline maintenance unit, as the components would not normally be expected to return to service in a matter of hours. One reason for this expected delay would be that in order to ensure continuous coverage, a near-space wing would control more platforms and payloads than would be airborne at any one time. The extra payloads would be available as programmed spares or as extra units of various interchangeable components such as communications or ISR payloads that the commander could call up as requirements dictated. The extra platforms would also be available as programmed spares and as units required to cover the transit time to the loiter locations during platform swap-out. For example, a fleet of three maneuvering vehicles might have one platform on-station nearing the end of its planned mission duration, one on the way to replace it for seamless mission coverage, and one on the ground undergoing programmed maintenance. Using near-space for CONUS-based strategic missions, such as extremely long-term, RC-135-like surveillance of potential adversaries; aerostat-like or space-based-radar-like surveillance of the nation's borders; or AWACS-like monitoring of drug-trafficking transportation links would require a similar organizational set up.

It would be easy to classify near-space platforms, especially maneuvering vehicles, simply as extremely high-altitude UAVs. The comparison is a fair one, especially for almost completely automated systems such as Global Hawk. Near-space operations squadrons would be very different from a Predator squadron, however, as continuous, hands-on operation by a skilled pilot would not be required.

The comparison of mission and operating concept between satellites, near-space assets, and UAVs does bring up an interesting point, though. AFSPC currently controls orbital assets and Air Combat Command controls most Air Force UAVs.[136] As pointed out repeatedly in this paper, the paradigm shift to effects-based space is the change in mindset that enables the shift of many operational and tactical space effects from expensive national assets to near-space, relieving the heavy wartime burden on our strategic satellites. That same paradigm shift would appear to force the change in mindset from having control of UAVs and manned ISR assets by a command primarily devoted to force application to one devoted to the space effect of C4ISR. Senior military leaders already note the similarity between the orbital and air-breathing effects, referring to UAVs as "low altitude satellites"[137] or "atmospheric satellites."[138] As has been noted previously, responsibility for space and space effects has recently been given to AFSPC through its ownership of the *Space and C4ISR CONOPS*. What better way to give the battlefield commander a seamless, integrated picture of his theater and seamless, integrated communication with his command than to have all of the C4ISR assets become a layered, interleaved system of systems that are planned, acquired, and operated by a command tasked with that mission? Relieving Air Combat Command of its manned and unmanned ISR assets would also allow it to better concentrate on its core competency of putting iron on target.

Such a change in asset ownership, where AFSPC would control most C4ISR assets, must necessarily be accompanied by a significant change by AFSPC. The current command posture consists almost exclusively of a strategic outlook, where satellites provide long-term, global effects and a hopefully never-to-be-used missile fleet awaits an apocalyptic exchange of nuclear weapons. AFSPC is already working towards acquiring an operational/tactical mission in addition to the strategic missions it should continue to field. Joint Warfighting Space, with its associated TacSats and CAVs, is the first step into pushing Space Command toward a more operational and tactical role. Assuming responsibility for DoD C4ISR could be the next.

Section 7

Summary

The goal of this paper was to be a single-source document for a basic understanding of the technology related to, the environment of, and doctrinal possibilities enabled by near-space. While making a good deal of headway toward that goal, the paper falls short. Many related subjects that call for intense, immediate study—for example counter-near-space—cannot be dealt with in an unclassified document. Other subjects quickly become too technical for this forum. If the topics presented here stimulate further interest in near-space; lead to enhanced funding of existing programs and stimulate development of future ones; further basic research into near-space materials and technology; and if they cause serious doctrinal discussion at high levels, then it will have accomplished at least part of its goals.

Near-space does indeed seem to be the "obvious, correct solution"[139] to operationally responsive space. However, without appropriate funding it will languish and perhaps die stillborn. In times of limited funding, money for new programs must come from somewhere. It would seem that the logical source of such funding would be the programs for which near-space appears to be a much more cost-efficient, operationally effective solution. But how does one go about providing evidence that one conceptual solution is more effective than another? The military commonly uses war games for just such purposes. Head-to-head competition between alternatives, if the granularity of the war game simulation is appropriate, can provide reasonably clear answers to such questions.[140] Preliminary results from war games have already demonstrated effectiveness of near-space platforms,[141] but the simulations have yet to directly compare competing concepts. The time for such a competition has arrived.

In conclusion, operationally responsive space really means operationally responsive space *effects*, and near-space can provide many of those effects more responsively and more persistently than space itself. The shift in mindset is of such a magnitude that it will require a substantial rewrite of current military space doctrine.[142] It may also require a reorganization of Air Force and DoD force structure to most efficiently realize the benefits of centralized, seamless effects-based space. Near-space is the catalyst for these significant changes. The paradigm shift must occur. The time for near-space is definitely now.

Appendix A

The Near-Space Environment

While a complete discussion of the near-space environment is beyond the scope of this paper, it is important to understand a few of the basic conditions that near-space platforms will encounter. Contrasting them with air and space will give an understanding of relative advantages and disadvantages of operating in each of the media.

The weather most of us are familiar with occurs in the lower portion of the atmosphere known as the troposphere. Clouds, rain, and severe turbulence almost never occur above about 40,000 ft above the earth's surface. Thunderstorms do occasionally reach the lower regions of near-space, and upward projecting lightning could be a hazard throughout near-space. Near-space assets must be designed to transit the troposphere and transmit signals through it, but in general the environment in which they will operate will be much less changeable than the lower region of the atmosphere.

The environment in near-space is harsh, much like that of space, but there are significant differences. It is cold in near-space, but not as cold as one might imagine. Between about 36,000 ft and 65,000 ft, the atmospheric temperature remains constant at about –75º. Above that altitude, temperature actually starts to increase, reaching about –10ºF at 120,000 ft.[144] Contrastingly, in space, the scarcity of molecules makes the commonly understood meaning of ambient temperature all but meaningless. Sides of an object toward the sun are very hot while sides in shadow are very cold.

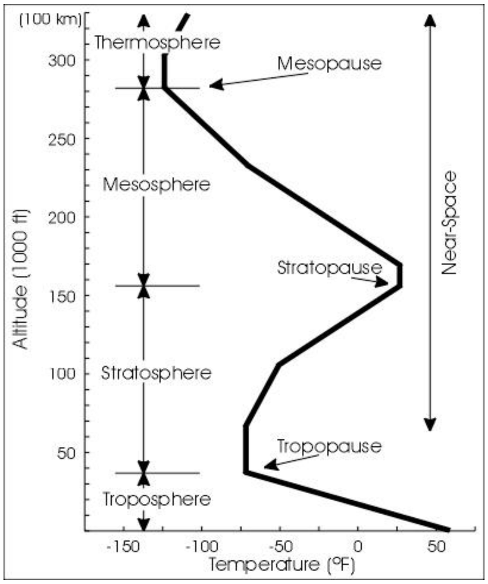

Figure 5. Temperature Profile through Near-Space.[143]

Temperature is not the only difference between space and near-space. In space there is no appreciable wind.[145] In the lower portion of near-space, wind is a significant design consideration. Although the air density in near-space is very low, wind will still be a factor, much as it is at lower altitudes; it just takes a longer time for changes in the wind to have an effect. To illustrate this point, imagine a ball sitting still in front of a large fan that can blow at 10 miles per hour. When the fan is turned on, the ball slowly starts moving until it eventually moves at the same speed as the air from the fan. Imagine the same ball held over a stream of water moving at 10 miles per hour. Drop the ball into the water and it almost immediately begins moving at the same speed as the water. The difference between the two cases is the density of molecules pushing the ball. In both cases the ball ended up moving at 10 miles per hour, but it got there much more quickly when acted upon by the denser water.

The analogy applies to near-space, where the density of the atmosphere ranges between about 7 percent of sea level at 65,000 ft to about 0.5 percent of sea level at 120,000 ft to about a ten-thousandth of a percent at 100 km.[146] The result of this discussion is that sustained winds will eventually cause an object in near-space to be accelerated to the ambient wind velocity, but in the lower reaches of near-space it will take the object 10 to 200 times longer to react to that wind than it would for an object at sea level. In near-space sustained winds will have an effect, but gusts are not as important a factor, a fact that needs to be considered when designing near-space platforms that have requirements to maneuver. Wind in near-space varies with altitude, time of year, and latitude, generally increasing with both latitude and altitude. The accompanying table shows generalized wind values in near-space.

Table 4. Generalized Wind Conditions in Lower Near-Space. [147, 148]
Polar winds are highly seasonal.

		Wind Speeds		
Latitude	**Altitude**	**Average**	**95% of the time**	**99% of the time**
Equatorial (0-20 degrees)	**65,000 ft**	**<10 knots**	**<30 knots**	**<50 knots**
	80,000 ft	**<15 knots**	**<40 knots**	**<60 knots**
Mid (20-60 degrees)	**65,000 ft**	**<15 knots**	**<30 knots**	**<50 knots**
	80,000 ft	**<20 knots**	**<45 knots**	**<60 knots**
Polar (60-90 degrees)	**65,000 ft**	**<25 knots**	**<40 knots**	**<50 knots**
	80,000 ft	**<30 knots**	**<60 knots**	**<70 knots**

Atmospheric pressure is another difference between space and near-space. In space, pressure is essentially negligible. In near-space, pressure is a significant factor, especially for structures based on gas-filled volumes. All else being equal, when external pressure decreases there must be a corresponding increase in volume. Thus, when the atmospheric pressure decreases by half, the volume of a closed balloon must increase by a factor of two.[150] This relationship and the plot of pressure through lower near-space can give us some rules of thumb for a volume-

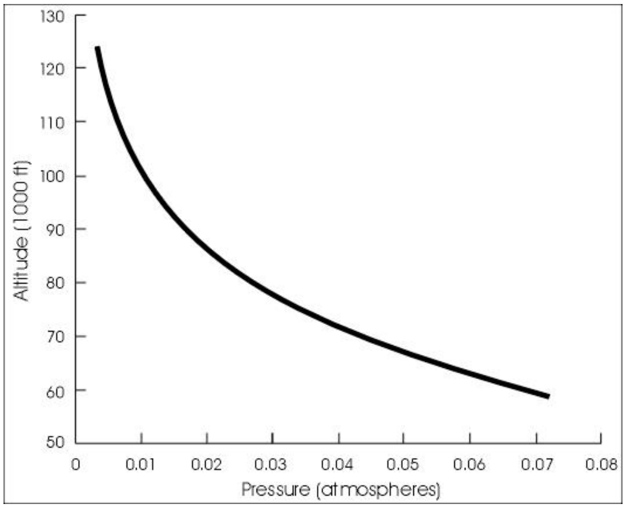

Figure 6. Pressure Profile through the Lower Portion of Near-Space.[149]

doubling altitude change. Between about 65,000 ft and 120,000 ft, the pressure halves with every change of approximately 15,000 ft, implying that such an ascent would approximately double the volume of a balloon. These large changes in volume can be a severe design constraint for near-space platforms using helium lift.

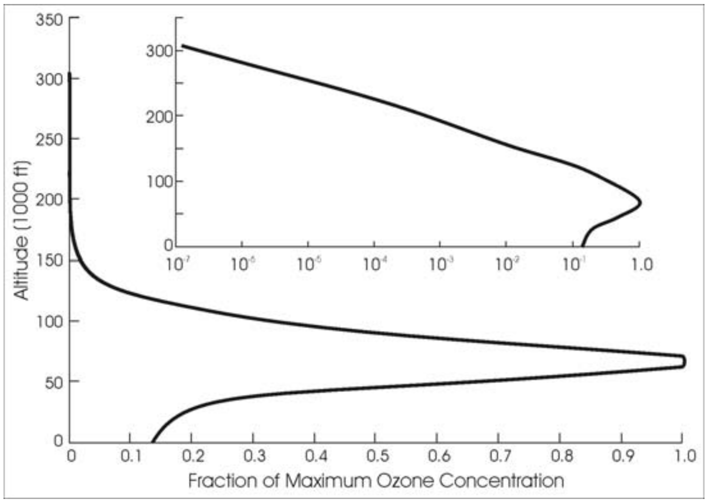

Figure 7. Ozone Concentration Profile through Near-Space.[151] The peak ozone concentration occurs at about 65,000 ft, and is scaled to unity, with concentrations at other altitudes shown as fractions of this maximum concentration. The inset shows concentrations on a logarithmic scale so that details of the concentrations above 150,000 ft can be seen.

There are other environmental factors relevant to operating in near-space. Although highly variable by season, time of day, and latitude, corrosive ozone concentrations tend to peak out at about 65,000 ft. The ozone concentration generally falls off by a factor of 10 for every 35,000 ft above that altitude, meaning that it is about 3 percent of its peak value at 120,000 ft.[152] Thus, platforms operating in lower near-space will have a great deal more ozone to contend with than higher ones. The corrosive nature of ozone is not the only effect it will have on near-space platforms.

While many atmospheric gases help shield the lower atmosphere from damaging ultraviolet (UV) radiation, ozone is the primary absorber. UV degradation can have a similar effect to corrosion on many materials, and designs must take UV damage into account. At upper altitudes, there are so few ozone molecules present that very little UV radiation is absorbed. However, as the density of ozone molecules increases as one moves lower in the atmosphere, more and more UV is absorbed. On average, the amount of UV light reaching 120,000 ft has been cut by a factor of 12 (8 percent) of the amount at 100 km. That energy is then slashed by another factor of 30 (3 percent of its 120,000-ft value) by the time it reaches 65,000 ft due primarily to high absorption by ozone.[154] It is apparent that both the ozone and UV environments are starkly different for platforms designed to operate at the bottom and the top of currently achievable near-space: higher platforms must deal with 30 times the UV radiation while lower platforms are immersed in an ozone environment that is 30 times as concentrated.

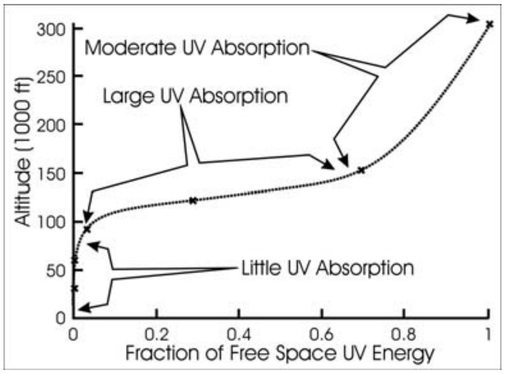

Figure 8. UV Absorption Profile through Near-Space. The greatest absorption per altitude occurs where the slope of the trend line is shallowest.[153]

It has already been mentioned that near-space assets operate below the ionosphere. However, it is important to have an elementary understanding of that region in order to compare satellite and near-space platform performance limitations. The ionosphere is a region containing several distinct layers of charged particles surrounding the earth. Its main layers occur at about 70-90 km, 95-140 km, 140-200 km, and 200-400 km above the earth. The lower layers show strong day/night variations in charged particle density, with day concentrations being markedly higher. The upper layers generally tend to increase in altitude at night.[156] Thus, near-space platforms operating below 120,000 ft (37 km) are well below the ionosphere, while LEO spacecraft operate in the heart of it. Spacecraft thus need to be designed to mitigate operations in this highly charged environment while near-space assets can avoid that cost.

For those seeking to understand space effects, an understanding of the ionosphere is critical. It affects to some degree all electromagnetic signals that pass through it. Depending on frequency and direction of propagation, some signals are slowed, attenuated, or bent slightly while others can be completely absorbed or bent so much that they never make it past the ionosphere. The ionosphere is extremely variable, with the predictable day/night cycle and unpredictable storms on the sun being two major inputs to its variability.

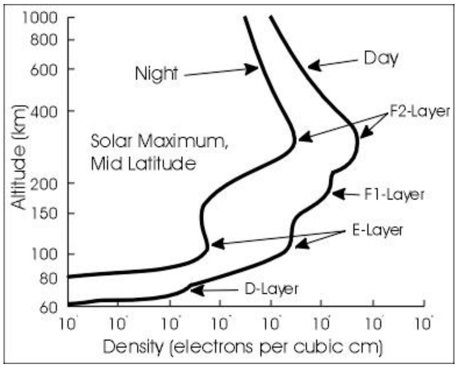

Figure 9. Typical Day and Night Electron Densities in the Ionosphere.[155]

To get a basic understanding of the ionosphere it is useful to explore an analogy with clouds. Everyone knows a little about clouds. Sometimes clouds completely obscure the sky with an overcast. Sometimes there are small breaks in the clouds, and sometimes the clouds scatter out widely or are not there at all. Many times there are different layers of clouds that obscure the sky to different degrees existing simultaneously at different altitudes, for example when a higher altitude overcast caps a low scattered layer. The ionosphere can be thought of as layers of clouds, but the clouds consist of charged particles, electrons and ions. Sometimes a layer forms an overcast and sometimes a layer can disappear completely. Just as afternoon thunderstorms are brought on by the energy of the sun heating the lower atmosphere, the charged particle clouds of the ionosphere change their character based on the amount of solar input they receive. While the reason for the formation of the distinct ionospheric layers and the reasons for their differing responses to solar input are beyond the scope of this paper, the cloud analogy is useful to help understand the effect of the ionosphere on C4ISR.

At the lower frequencies such as those used for HF and VHF communications, ionospheric clouds can sometimes act like a mirror for signals.[157] This mirror can be complete when the layer is an overcast, sporadic when the layer is scattered or broken, or even absent when the layer disappears. The low-lying D-layer primarily absorbs radio signals and does not normally act like a mirror for most signals. During the day when the

D-layer is present, signals sent upward are almost completely absorbed by the D-layer and the remaining line-of-sight signals cannot travel far. At night when the D-layer disappears, the signals can bounce off the F-layer mirror and the reflected signals can travel much further. For this reason it is often possible at night to hear AM radio stations from distant cities. FM radio waves, having much higher frequencies, are not normally reflected by the electron clouds so they are rarely heard at great distances from their sources.[158]

The mirror of an ionospheric layer is not always smooth. Just like water vapor clouds, ionospheric clouds occasionally contain turbulent regions, some of which are called plasma bubbles. Turbulence causes the ionospheric layer mirrors to change the direction of radio signals bouncing off of them on a very short timescale. During times of turbulence, it is not possible to predict exactly where signals will go, leading to important operational effects such as degradation of GPS accuracy. In conjunction with ionospheric turbulence, unusual variations in the ionosphere's ability to reflect or absorb radio waves, primarily due to unusual solar activity, are the cause of HF fade, scintillation, and geolocation effects discussed earlier. It is now easy to see why the ability to operate below the ionosphere is a great operational benefit for near-space platforms. There are also many other environmental conditions that make near-space a very different place to operate than either space or the lower atmosphere, but the conditions discussed above are the most relevant.[159]

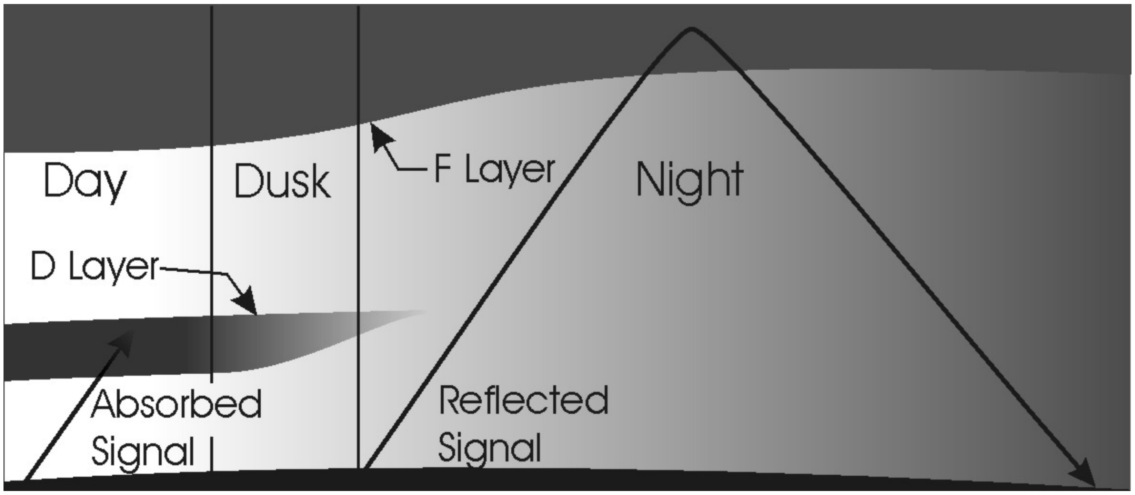

Figure 10. Ionospheric Effects on High Frequency (HF) Signals during the Day and Night.

Appendix B

Example Near-Space Platforms[160]

This appendix will examine a few representative examples of each type of near-space system, free-floaters, steered free-floaters, and maneuvering vehicles, from the many being proposed by industry within the US.[161] The example platforms cited are either currently available or could be ready in the next few years if spurred by sufficient seed money. Realize that many of the approximate numbers quoted on mass, delivered power, cost, and duration will likely improve as the technology further matures and as economies of scale begin to take over.

Free-floaters are the simplest of near-space platforms. They simply drift on the wind, employing no true maneuvering strategies. Free-floaters are already being used commercially by the communications industry. In one example, the oil and gas industry in west Texas and Oklahoma has an ongoing need to monitor data from wells spread across thousands of square miles of sparsely populated countryside. The vast distances and small population make the establishment of a cell-phone network cost-prohibitive. Instead, a balloon operator currently provides them with real-time telemetry from every one of their wells using two to three balloon launches daily, depending upon wind. About 90 percent of the sensors are recovered and reused in this operation. The platforms cost a few hundred dollars for each launch, so the price of the sensor and the ground receiving station are essentially the entire cost of the system.[163]

At considerably more expense but with considerably more capability, other companies have modified the free-floater concept to include safe recovery of payloads across significant distances. One company[164] currently launches their payload on a balloon, but encases the payload within a small, high-performance glider, essentially a hybrid balloon/UAV concept. The balloon carries the payload to altitude where it drifts with the wind like a standard free-floater. At the time of the operators' choosing, the glider is released and returns safely to a runway up to 500 km away. The payload can continue to remain functional throughout the entire two- to three-hour glider flight. During recovery, operators can command the glider to overfly preprogrammed sites or targets of opportunity. Obviously, this sort of system would be much more likely to be used for high-value payloads that require safe, secure recovery.

Figure 11. An Example Free-Floater Platform. [162]

The price for such safety and security for the payloads is in the several hundred thousand dollar range for the complete hybrid platform, with a majority of the cost being amortized across numerous launches.

Figure 12. An Example Hybrid Balloon/ UAV Platform. [165] **Clockwise from upper right: glider flying at 100,000 ft shot from tail boom; two different gliders in flight; and launch of glider/payload (glider wings folded) under a standard balloon.**

The Air Force Space Battlelab, tasked with finding and quickly demonstrating innovative solutions to top warfighter needs, is intrigued enough by the possibilities presented by these free-floater systems that they are pursuing a two-phase demonstration called *Combat SkySat*. During phase one, they plan to launch a repeater for the Army's PRC-148 (MBITR) radio on a small free-floater platform at 100,000 ft. The Army currently only counts on such a radio to be able to communicate across about 10 km. The *Combat SkySat* repeater will allow a low-power PRC-148 to extend its line of sight range by up to 350 miles, a significant performance improvement over a terrestrial solution and a significant power requirement reduction over an orbital solution. Phase two of the demonstration calls for flying a high-value classified ISR sensor on a hybrid balloon/UAV platform, where safe recovery of the payload is essential. Results from the *Combat SkySat* initiative should be available in early 2005.

Operationally, such free-floater systems could provide much-needed augmentation of national assets during times of war. Simulations based on actual winds aloft during the opening days of Operation IRAQI FREEDOM confirm that launching free-floaters from three sites twice daily to replenish the constellation would have provided complete coverage of Iraq.[166] The logistics tail for such an operation is small. All worldwide weather agencies launch such balloons twice daily from hundreds of global locations[167] and Air Force Weather Agency units already deploy equipped to do the same.[168] As simple as it is, the important thing to note about this approach is that the payload is overhead constantly, providing the operator with a very large useable footprint. Waiting for the next satellite pass, should the commander be able to actually task the satellite, is no longer required.

The next type of near-space platform in order of increasing complexity and increasing utility are the steered free-floaters. Instead of rafts merely drifting on the current, they are the sailboats of near-space. They use the different winds at different altitudes to enable reasonably accurate steering of the platform. One proposal[170] uses a large free-floating helium balloon to lift a several-hundred-pound payload to over 100,000 ft. A stealthy, lightweight, thirty-foot-tall wing and rudder are suspended below the balloon by a 15 km cable. The differential in winds between the balloon at 100,000 ft and the wing at 65,000 ft drags the wing through the air, producing lift and allowing the balloon to be steered.

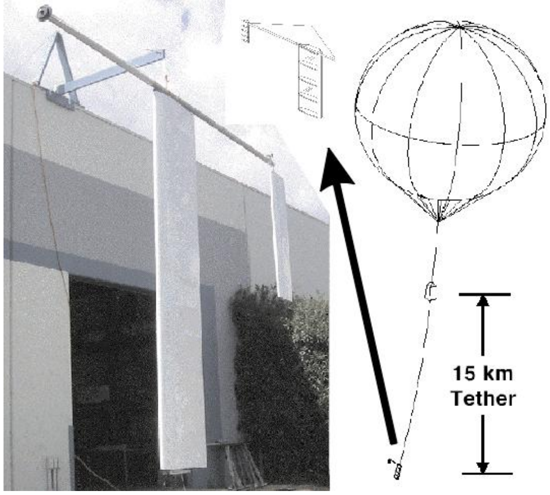

Figure 13. An Example Steered Free-Floater Platform.[169] Left: test model of trajectory control system; right: schematic of entire StratoSat showing lifting balloon, payload, tether and wing.

Simulations have shown that a constellation of three of these steered free-floaters could provide continuous coverage of missile launches through the polar regions to about 45 degrees latitude and a constellation of 30 platforms could provide similar coverage of the globe.[171] Although it may sound fantastic, a constellation of 800 could provide continuous *on-demand* communications or ISR coverage of the *entire globe*—again, no waiting for the next satellite pass.[172] Any spot on the earth the user chooses could be imaged immediately. The platforms use flocking algorithms to keep their relative spacing, and the algorithms are programmed to include avoid-zones that preclude interfering with space launches or directly overflying large cities. At several hundred thousand dollars each, the cost of the global ISR network, excluding sensors, could easily be less than $100 million, comparable to the cost of a single strategic national asset. While this proposal is admittedly a bit further off and more risky, it serves to illustrate some of the strategic possibilities of near-space.

The technology for the constellations of steered free-floaters exists today and each of the components has been individually tested, although no complete system has actually been built. The concept appears particularly vulnerable to legal overflight challenges noted previously. It is important to note, however, that the overflight issue really only applies to near-space platforms that continuously circle the globe, as is required of steered free-floaters. Basic free-floaters could be destroyed prior to entering sensitive or sovereign airspace, while maneuvering vehicles, discussed below, could be navigated away from such areas.

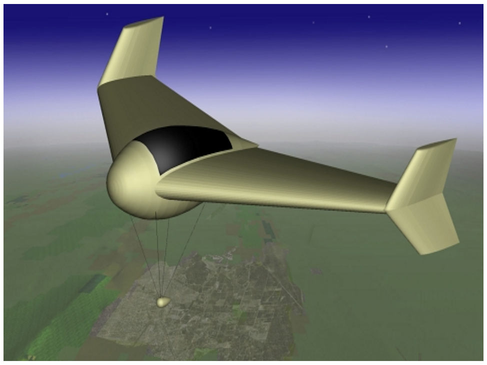

Figure 14. An Example Air-Ballasted Maneuvering Vehicle.[173] Note payload suspended below lifting body.

More complex than steered free-floaters but correspondingly more capable are the near-space platforms known as maneuvering vehicles. They are able to launch, maneuver to a specified point, and remain there for very long times providing true stay-and-stare capability. One proposal[175] consists of a large aerobody with the payload suspended below on several retractable cables. Changing the length of the cables controls the attitude of the aerobody. Changing the buoyancy of the aerobody causes it to climb or descend. Since propellers used as the sole means of propulsion are as ineffective as any other aerodynamic device at these altitudes, this project uses a novel, proprietary propulsion concept to maneuver.

In addition to the two Air Force demonstrations discussed above, the Army, Navy, and Joint Forces Command (JFCOM) all have active near-space research activities. The Naval Research Laboratory is studying specifications for its High Altitude Airborne Relay and Router (HAARR). Operating at an altitude of about 65,000 ft where the air is thicker, it uses two propellers for maneuverability. This $1 million platform is envisioned to be the future standard high-bandwidth communication link for the fleet, establishing the connection between ship and deployed forces on the ground across the "last nautical mile."[176] JFCOM's Project Alpha, an organization tasked with finding new technology and assessing its impact on joint operating concepts, has written an extensive report on how near-space capabilities can enhance JOpsC.[177, 178]

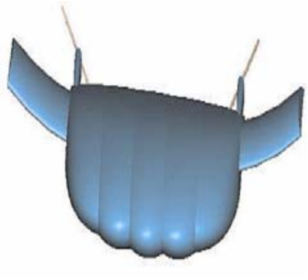

Figure 14. Conceptual Version of the Navy's HAARR.[174]

The NAVAIR Airship Advanced Program Office is currently funding a maneuvering vehicle of its own called Techsphere.[180] A low-altitude risk reduction version of Techsphere has already proven its ability to reach 20,000 ft with two pilots aboard. The 60-ft diameter balloon is currently powered by three large propellers and diesel engines. Even when fully inflated, the helium envelope only takes up about the top third of the spherical outer shell, while the shell is kept semi-rigid by blowing ambient air into the structure, much like a "bouncy castle" found at carnivals. Navy officials are planning a solar-powered 200-ft diameter version of

Figure 15. Conceptual Version of the Navy's HAARR.[179]

Techsphere to reach near-space, but the propellers could limit the useful altitude of a scaled-up version to the lower portions of the region.[181]

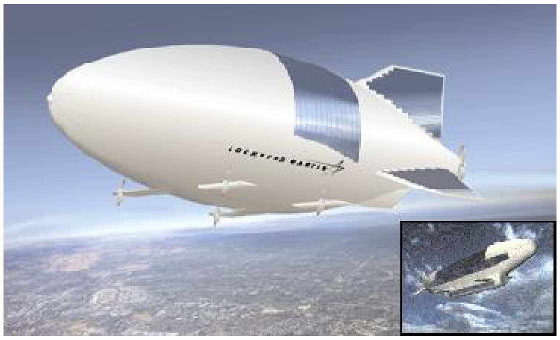

Figure 16. The Army's High Altitude Airship ACTD. Inset: conceptual production version.[182]

By far the largest current near-space project, in both size and funding, is the Army's High Altitude Airship (HAA) Advanced Concept Technology Demonstration (ACTD). The true behemoth of the near-space stable, the $10 to $20 million HAA is 500 feet long, 150 feet tall, and has the volume of over 25 Goodyear blimps. It cruises at 30 knots but can sprint significantly faster for short periods. It is envisioned to be able to be on-station anywhere between +/-50 degrees of latitude within two weeks of launch[183, 184, 185] (such latitude requirements are common to any near-space platform using solar array technology for power, since the arrays need more direct illumination than is available nearer the poles). The limiting technology for this concept is the skin. Previously, ozone and ultraviolet radiation at high altitudes caused balloon material to degrade quickly. That problem has been essentially solved and now the problem boils down to helium permeability. As with a child's toy balloon after a few days, the helium in HAA eventually leaks out. It leaks much more slowly through the HAA skin, but the limiting factor to mission duration now seems to be the ability to carry enough helium to replenish the amount that escapes.[186] It does not seem beyond the realm of possibility to build a sort of tanker for helium resupply to extend such missions.

At those costs and sizes, HAA is not projected to be a tactical asset, but its huge lift capability and large available power supply, 4,000 pounds and 10 kilowatts, respectively, are a big plus. Those attributes allow it to perform many missions unattainable by other near-space platforms. The envisioned production version should be even more capable, estimated to cost $50 million each, carrying 12,000 pounds to 85,000 ft, providing 75 kilowatts, cruising at 70 knots, and staying aloft for 3–5 years. Along with the standard C4ISR missions available to other platforms, HAA can carry enough payload to be an effective force application platform, possibly carrying a large number of small diameter bombs, hypervelocity kinetic weapons ("rods from God") or autonomous hunter-killer LOCASS vehicles. It has also been tagged to carry relay mirrors for the airborne laser and ground-based laser, allowing them to extend their ranges significantly over a comparable direct shot. Eleven of the HAA platforms could provide coastal and southern border coverage for homeland defense. Their large payload could augment or, in some cases where sufficient reach-back bandwidth is available for the data stream, supplant many manned ISR missions, providing much longer time-on-station, 50 to 100 percent longer standoff capability, and comparable sensor capacity.

Figure 17. NASA's Helios.[187]

The near-space platforms described above are all based upon helium lift. While by far the most common method for achieving near-space altitudes, helium is not the only way to get there. NASA and AeroVironment have designed the gossamer-winged Helios vehicle, which uses conventional aerodynamics to get to near-space.[188] Helios currently holds the aerodynamic altitude record of over 96,000 ft. It is designed to stay aloft for over a week, carry up to 500 pounds to over 65,000 ft, and provide up to 5 kilowatts of power for its payload. Helios costs approximately $15 million each[189] and can cruise at up to 70 knots. Other than the large price-to-payload ratio, the biggest drawback for this platform appears to be weather. Due to its large wingspan (247 ft) and lightweight structure, it has very stringent crosswind limitations that would require construction of a unique runway infrastructure to guarantee launch on demand. This design also makes it more susceptible to tropospheric turbulence than many of the helium-based designs.

The example platforms discussed above are just drops in the bucket of novel ideas the commercial world has for making use of the near-space environment. There are many more unique and innovative platforms being pitched for employment in the very near future. As evidenced by these many proposals and by the multi-service and joint interest in the regime, industry and military visionaries obviously feel that the time for near-space is now.

Appendix C

Near-Space Support to USAF CONOPS

"CSAF CONOPS." *Task Force CONOPS Web Site.* 21 Apr. 2004 <https://afconops.hq.af.mil/ support/csafconops.htm>. The following table lists the Chief of Staff of the Air Force's Concepts of Operations and shows which items are supported, enabled, or enhanced by near-space.

Supported /enabled/ enhanced by Near-Space?	**CONOP** *Overarching Effect* Required Capability
	Global Mobility
	Command and Control
✓	Assess global conditions and events, anticipate emerging crisis situations and gauge potential mobility requirements, opportunities and constraints.
✓	Maintain worldwide awareness of airfield capabilities to support mobility operations.
✓	Perform Predictive Battlespace Awareness relative to mobility operations.
✓	Integrate civil and military airlift operations into overall battlespace situational awareness
✓	Control global air mobility operations in support of potentially multiple and competing joint commanders
✓	Deploy independent C2ISR elements to forward, austere locations.
	Integrated Planning Capability
	Provide GMTF planning teams to serve as air mobility envoys to the combatant commanders supporting multi-modal planning
	Provide a Planning Data Base
✓	Continuously shape dynamic situations through agile, effects-based mobility planning and execution across the full spectrum of operations.
	Develop integrated/interoperable plans, orders and day-to-day taskings to fulfill competing requirements.
	Be interoperable with multi-agency partners including coalition, military, civil, and commercial organizations.
	Intelligence, Surveillance, and Reconnaissance
✓	Identification of adversary forces and facilities
✓	Provide early warning of hostile actions.
✓	Locate assault zones with the precision required to employ appropriate delivery means.
✓	Differentiate friendlies, neutrals, non-combatants, and their assets.
✓	Disseminate friendly position and identification machine-to-machine, and throughout a Joint/Coalition environment to enable audio and/or visual fratricide warning to weapons systems operators.
✓	Access global, all-weather, multi-sensor collection against all classes of targets assault zones at all times.
✓	Provide continuous medical surveillance (monitor for chemical, biological, and radiological contaminants)
	Information Infrastructure
✓	Machine-to-machine real-time interface with combat air force battle management
✓	Provide assured access and delivery, and transmission security of near real time flight planning and in-flight management data/information from fixed command nodes for mobility platforms during mobility execution
✓	Share data and information with all appropriate people and machines at any desired place and time.

Supported /enabled/ enhanced by Near-Space?	**CONOP** *Overarching Effect* Required Capability
✓	Access supporting information services.
✓	Store, manipulate, process, format and make available data on demand and through all levels of conflict
✓	Establish and maintain battlespace situational awareness.
✓	Operate, protect, and defend information and information systems.
✓	Assess the infosphere anywhere, then deny, deceive, disrupt, destroy and/or degrade enemy capabilities anywhere in support of national security objectives.
	Operational Capabilities
	Capability to perform air refueling operations
	Capability to perform cargo airlift operations
	Capability to perform passenger airlift operations for friendly personnel and personnel under US control (PUC) in and out of permissive/nonpermissive environments
	Capability to perform aeromedical operations
✓	Capability to perform combat delivery operations
	Capability to perform SOF support operations
	Capability to perform global access operations
✓	Capability for mobility assets operating in threat environments to detect, locate, avoid, defeat enemy threats, and mobility air forces real time threat data
✓	Capability to operate in a chemical, biological, radiological, nuclear, explosive (CBRNE) environment
✓	Capability to deploy, sustain and replenish assets above the atmosphere to support preplanned, steady state operations (spacelift on a preplanned schedule)
✓	Capability to augment, surge and replenish assets above the atmosphere on demand
✓	Capability to perform logistical support to on-orbit assets
✓	Capability to perform base opening
✓	Capability to conduct Airfield Operations
	Capability to rapidly receive, beddown, and support forces
	Global Response
	Conduct mobility to enable global response options
	Capability to perform airlift
✓	Capability to perform spacelift
	Capability to perform air refueling
	Neutralize fleeting and emergent targets
✓	Neutralize fixed targets
✓	Neutralize mobile targets
	Provide global command and control to enable global response options
✓	Collect and receive information on friendly forces
✓	Fuse enemy, non-aligned, and friendly forces information to provide battlespace situational awareness
	Plan response options
✓	Disseminate plans, orders, and information to execute military operations
	Provide comprehensive ISR to enable global response options
✓	Collect intelligence on enemy and non-aligned forces
	Analyze and exploit collected information and produce actionable intelligence
✓	Disseminate intelligence to enable global response options
	Provide combat support to enable global response options
✓	Provide force protection
	Provide logistical support
✓	Provide infrastructure
✓	Provide combat support C2
	Provide combat search and rescue
✓	Locate the survivor
	Recover the survivor

Supported /enabled/ enhanced by Near-Space?	**CONOP** *Overarching Effect* Required Capability
	Global Strike
	Conduct mobility to enable global strike
	Perform airlift
✓	Perform spacelift
	Perform air refueling
	Provide comprehensive ISR to enable global strike operations
✓	Collect intelligence on enemy and non-aligned forces
	Analyze and exploit collected information and produce actionable intelligence
✓	Disseminate intelligence to enable global strike options
	Provide global command and control to enable global strike options
✓	Collect and receive information on friendly forces
✓	Fuse enemy, non-aligned, and friendly forces information to provide battlespace situational awareness
	Plan strike options
✓	Disseminate plans, orders, and information to execute military operations
	Neutralize global strike targets
✓	Gain access (air, space, and spectrum superiority)
✓	Find, fix, track, target, engage, and assess (F2T2EA) anti-access and/or high-value targets to enable joint Operations
	Provide combat support to enable global strike options
✓	Provide force protection
	Provide logistical support
✓	Provide infrastructure
✓	Provide combat support C2
	Provide combat search and rescue
✓	Locate the survivor
	Recover the survivor
	Homeland Security
	Conduct counterair
✓	Detect and track all potential airborne and surface objects (fixed and mobile) of operational significance within a defined area of interest
✓	Provide early warning of hostile actions to meet employment time lines for defensive assets
✓	Attain an accurate characterization (identify) of detected objects to the extent that high confidence, timely application of defensive assets can occur
	On order, neutralize, negate, or destroy threats
✓	Provide full spectrum communications
	Conduct mobility operations
	Deploy, when directed and within the defined timeline, personnel and materiel to include the designated rapid response or quick reaction force
✓	Coordinate ground medical unit actions with aeromedical evacuation system to include enroute (hospital to aircraft) treatment in all environments
	Conduct aeromedical evacuation operations in and from contaminated environments
	Conduct air refueling operations
	Perform information warfare activities
✓	Apply Operations Security procedures to prevent our adversaries from gaining or exploiting information
✓	Apply Information Assurance measures to protect and defend information and information systems ensuring their availability, integrity, authenticity, confidentiality, and non-repudiation
✓	Conduct counter-deception efforts to gain advantage from, or negate, neutralize, or diminish the effects of a deception operation
✓	Conduct computer network defense actions to plan and direct responses to unauthorized activity
✓	Replicate targeted information, information systems and information infrastructures (adversary and friendly) and model/simulate, test and assess effectiveness of CND processes, procedures, doctrine and tools
✓	Apply psychological operations to induce, influence or reinforce perceptions, attitudes, reasoning, and Behavior
✓	Ensure public trust, airmen readiness, and dependent morale through effectively releasing unclassified

Supported /enabled/ enhanced by Near-Space?	**CONOP** *Overarching Effect* Required Capability
	information through appropriate internal and mass-media channels to inform target audiences about AF capabilities and procedures and the extent of CBRNE threats, countermeasures and recovery efforts
	Support lead federal agencies in crisis management and consequence management
✓	Provide Air Force forces with requisite capabilities to support civil authorities
✓	Liaise with federal, State, or local authorities to coordinate incident responses and integrate forces
	Conduct counter nuclear, biological, and chemical (NBC) operations
✓	Detect, identify, assess CBRNE event information
✓	Determine, real-time, the effects in terms of time, distance, coverage and destructive capability of a CBRNE Detonation
	Neutralize, defeat, or destroy CBRNE devices
	Provide CBRNE defense support including collective protection, chemical and biological contamination avoidance, chemical and biological "spot" decontamination and individual CBRNE protection (masks/CBOGs)
✓	Conduct and sustain air and ground operations in a CBRNE environment
	Perform force protection activities
✓	Detect and identify threats affecting the ability to present requisite forces to combatant commanders
✓	Provide home base patient care/health risk assessments and preventive measures within hours of a CBRNE incident, attack, or accident
	Exercise authority and direction over assigned/attached forces
✓	Provide systematic observation (timely and accurate) of named areas of interest or of all objects of interest in the space, air, surface, and subsurface environment
✓	Determine/identify the chain of command for each type of event - DoD as *supported* or *supporting* LFA
✓	Coordinate and synchronize Air Force operational and tactical Information-In Warfare and Information Warfare operations
✓	Determine and articulate continuity of command for continuous, uninterrupted mission essential operations. (Continuity of Operations)
✓	Provide processes, procedures, and resources to support the President and the SecDef in a designated national security emergency. (Continuity of Government)
	Perform information in warfare activities (includes ISR operations)
✓	Collect, exploit, and process operationally significant information
✓	Provide environmental data for military support to civil authorities (consequence management/crisis action), infrastructure protection, and fixed and mobile military operations
✓	Provide free interchange of data
	Nuclear Response
	All data classified
	Space and C4ISR
	Capability to assess global conditions and events
✓	Capability to perform Predictive Battlespace Awareness
✓	Capability to assess attacks against friendly assets in physical or infosphere battlespace
✓	Capability to assess in real-time the effect of friendly lethal and non-lethal operations at all levels of war
✓	Capability to characterize emerging threats in time to influence future countermeasure developments; includes Signals and Scientific/Technical Intelligence
	Capability to deliver the right information to the right location, at the right time, in actionable format
✓	Capability to deliver assessments to appropriate combatants in real-time via machine-to-machine interface to support decision-making and mission execution
✓	Capability to provide global, interoperable, integrated, protected, survivable and high throughput information access and bandwidth on demand
✓	Capability to perform ad-hoc, dynamic data transfer for mobile and agile forces and systems using standard interoperable information sets
✓	Capability to integrate commercial services into communications capabilities
	Capability to deliver information in priority order
	Capability to establish and maintain battlespace situational awareness
✓	Capability to receive and correlate data/information, including fused intelligence and mission planning/results, from all sources and then fuse, disseminate, and display the data/information into a tailorable presentation
✓	Capability to monitor world events, physical environments, and national policy guidance

Supported /enabled/ enhanced by Near-Space?	**CONOP** *Overarching Effect* Required Capability
	Capability to locate, identify, track, and observe/monitor friendly, enemy, non-friendly, and non-aligneds forces/actors anywhere/anytime in near real-time
✓	Capability to collect against multiple targets across all of the electromagnetic spectrum, moving or stationary, real or decoy, despite opposition
✓	Capability to fuse data and information from various sensors and sources
✓	Capability to collect information in all operational environments: physical and infosphere
	Capability to operate, protect, and defend information and information systems
✓	Capability to command and control networks in a manner that seamlessly integrates with overall C2 and battle Management
✓	Capability to protect and defend our information, information systems, and critical infostructure from all internal and external attempts to deny, disrupt, degrade, deceive, destroy or exploit our C4 systems and nodes
✓	Capability to detect any network disruption and provide timely course of action alternatives and impacts in mission terms
	Capability to assess the infosphere anywhere, then deny, deceive, disrupt, destroy and/or degrade enemy capabilities anywhere
✓	Capability to conduct offensive counter-information operations
✓	Capability to successfully apply psychological operations to induce, influence, or reinforce the perceptions, attitudes, reasoning, and behavior
✓	Capability to employ electronic warfare to manipulate the electromagnetic spectrum or to attack an adversary
✓	Capability to apply military deception while fully coordination deception operations with other operations to protect deception operations
	Capability to continuously shape dynamic situations through agile, effects-based planning <u>and</u> execution across the full spectrum of operations
✓	Capability to conduct planning and employment of ISR collection assets
	Capability to develop integrated/interoperable battlespace plans, orders and/or taskings
✓	Capability to be interoperable with multi-agency partners including military, civil, and commercial Organizations
✓	Capability to conduct battle management of forces operating above the atmosphere
	Capability to share data and information with all appropriate people and machines at any desired place and time
✓	Capability to facilitate access to information at appropriate levels of security within minutes after access permission is administratively granted
✓	Capability to enable and host global knowledge collaboration on demand
	Capability to generate and deliver supporting information services
✓	Capability to generate/deliver information required to precisely determine position in all environments from subsurface through space
✓	Capability to generate/deliver information required to precisely determine time
✓	Capability to generate/deliver all environment weather information
✓	Capability to generate/deliver precise mapping and geodesy information
✓	Capability to generate/deliver enabling aviation services such as domestic and international airspace environment, flight planning and Notice to Airman information
	Capability for appropriate C4ISR assets to take lethal action
✓	Capability for selected ISR platforms to carry and employ weapons
✓	Capability for selected C4ISR platforms to actively defend themselves
	Capability to store, manipulate, process, format and make available data on demand and through all levels of conflict
✓	Capability to manage all relevant sources of information in the infosphere in a manner that identifies duplication and ensures the relevance, timeliness and accuracy of the final information product
✓	Capability to provide a global, interoperable, multi-level secure infosphere environment to store and manage all relevant information
✓	Capability to process, correlate, and display information in all infosphere domains in forms that enable timely, actionable decisions at all levels of conflict
	Capability to deploy and employ independent C4ISR elements to forward and distributed locations
✓	Capability to provide battlespace situational awareness
✓	Capability to plan, and prepare to execute, operations

List of Acronyms

ACTD	Advanced Concept Technology Demonstration
AFRL	Air Force Research Laboratory
AFSPC	Air Force Space Command
BFT	Blue Force Tracking
C2	Command and Control
C2ISR	Command, Control, Intelligence, Surveillance, and Reconnaissance
C4ISR	Command, Control, Communications, Intelligence, Surveillance, and Reconnaissance
C4	Command, Control, Communications, and Computers
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CBRNE	Chemical, Biological, Radiological, Nuclear, Explosive
CND	Computer Network Defense
CONOPS	Concept of Operations
CONUS	Continental United States
COP	Common Operating Picture
dB	Decibel
DoD	Department of Defense
DSP	Defense Support Program
EELV	Evolved Expendable Launch Vehicle
EMP	Electromagnetic Pulse
F2AT2E	Find, Fix, Assess, Track, Target, Engage
F2T2EA[190]	Find, Fix, Track, Target, Engage, Assess
GEO	Geosynchronous/Geostationary Earth Orbit
GMT	Greenwich Mean Time
GMTF	Global Mobility Task Force
GPS	Global Positioning System
HAA	High Altitude Airship
HAARR	High-Altitude Airborne Relay and Router
HF	High Frequency
ICAO	International Civil Aviation Organization
IP	Internet Protocol
ISR	Intelligence, Surveillance, and Reconnaissance
ITU-R	International Telecommunications Union, Radio Communications Sector
JFCOM	Joint Forces Command
JOpsC	Joint Operations Concepts
JWS	Joint Warfighting Space
LEHA	Long-Endurance, High Altitude
LEO	Low Earth Orbit
LOCASS	Low-Cost Autonomous Attack System
MBITR	Multi-Band Intra/Inter Team Radio

NASA	National Aeronautics and Space Administration
NBC	Nuclear, Biological, and Chemical
NSMV	Near-Space Maneuvering Vehicle
OODA	Observe, Orient, Decide, Act
PUC	Personnel Under US Control
RJ	Rivet Joint (RC-135)
SALT	Strategic Arms Limitation Talks
SAM	Surface-to-Air Missile
SecDef	Secretary of Defense
SIGINT	Signals Intelligence
SISP	Single Integrated Space Picture
SOPS	Space Operations Squadron
SSA	Space Situational Awareness
TCT	Time-Critical Targeting
TENCAP	Tactical Exploitation of National Capabilities
UAV	Unmanned Aerial Vehicle
UV	Ultraviolet
VHF	Very High Frequency
VMOC	Virtual Mission Operations Center

END NOTES

[1] Jumper, Gen John P. From a speech given at the C4ISR Summit, Danbury, MA, 27 Oct 2004.

[2] Between May and December 2004 the author briefed the near space concept to over 100 general officers and very senior civilian defense department leaders, including the Secretaries of the Air Force and Navy, the dual-hatted Under Secretary of the Air Force and Director of the National Reconnaissance Organization, Chief of Staff of the Air Force, Vice Chief of Staff of the Air Force, Commander of U.S. Strategic Command, and Commander of Air Force Space Command. The latter then briefed the concept at CORONA, the semi-annual gathering of all Air Force four-star generals, where it was extremely well received; Jumper, Gen John P., "Adapting Air and Space Power," Speech given at the Air Force Association Air and Space Conference, 15 Sept. 2004. 14 Nov. 2004 http://www.afa.org/media/scripts/jumper_conf.asp; McLeay, Deanna, "General Jumper Discusses Transformation," Air Mobility Command News Service, 14 Nov. 2004, http://public.amc.af.mil/news/2004/November/041105.html; Air Force Chief of Staff, General John Jumper mentions near-space as a way to get persistent ISR at the Airlift/Tanker Association Symposium in Dallas; "Suicides Have AF Officials on Edge," *Military.Com Website,* 9 Oct. 2004, 14 Nov. 2004 http://www.military.com/NewsContent/0,13319.FL_suicide_100904,html; Secretary Roche discusses near-space platforms as a complement to satellites and aircraft; Erwin, Sandra L., "Air Force Prepared to Defend Space-Based Radar in 2006 Budget," *National Defense Magazine website,* Nov. 2004, 14 Nov. 2004, http://www.nationaldefensemagazine.org/article.cfm?ID=1660; Mr. Peter Teets discusses near-space as a possible alternative deployment location for the beginning Space Based Radar Program; Wall, Robert and David A. Fulghum, "USAF Devises New Reconnaissance Plan," *Aviation Week & Space Technology,* 20 Sept., 2004, p. 26; General Jumper and the Commander, Air Force Space Command, General Lance Lord, discuss how near-space can contribute to the nation's ISR capability; United States Congress; *Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005; Conference Report to accompany H.R. 4200,* Washington DC: GPO, 8 Oct., 2004, p. 559, 14 Nov., 2004 http://frwegate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=108_cong_reports&docid=f:hr767.108.pdg

[3] United States Air Force. *Air Force Doctrine Document 2-2: Space Operations*. Washington: GPO, 27 Nov. 2001, p. 4.

[4] United States Air Force. *Air Force Doctrine Document 2-2: Space Operations.* Washington: GPO, 27 Nov. 2001, p. 4. In fact, this basic space doctrine document states that there are two doctrinal views of space. "*First*, space may be viewed as a physical environment—like land, sea, and air—within which space-centric activities are conducted to achieve objectives. This view is particularly relevant at the tactical (e.g., operation of specific platforms) and strategic (i.e., space as a domain that must be protected and controlled) levels of war. …The *second* doctrinal view of space is an effects-centric view, and is primarily relevant at the operational level of war [emphasis added]." The deliberate ordering of these two views in this basic space doctrine document serves to highlight the platform/medium domination of the warfighter's view of space. *Joint Publication 3-14: Joint Doctrine for Space Operations* (United States Department of Defense, Washington: GPO, 9 Aug. 2002, pp. vii:I-4) and *Field Manual 3-14.00: Space Support to Army Operations* (United States Army, Washington: GPO, coordination draft as of 2 Apr. 2004, pp. 1-2:1-4) also define space first as a medium where satellites operate and only much later start to describe it is a place where effects can be generated.

[5] United States Navy. *SECNAV Instruction 5400.39C: Department of the Navy Space Policy*. Washington: GPO, 6 Apr. 2004. Only the Navy discusses the effects (or "capabilities" in their words) without discussing the medium or specific platforms. However, the relative sparseness of this space doctrine document (8 pages) in comparison with other service and joint doctrines (averaging about a hundred pages each) may be a reason for the lack of detail.

[6] Jumper, Gen. John P. "White Paper on Joint Warfighting Space." 8 Jan. 2004.

[7] Prebeck, Col. Steven. "Air Force Space Command Functional Concept for Joint Warfighting Space." Draft version 3.14. 13 Apr. 2004.

[8] Grossman, Elaine M. "Joint Warfighting Space: Not (Just) An Idea, Not Yet A Program." *Inside the Pentagon*, 6 May 2004, p.1.

[9] The apparent misnomer "tactical satellites" appears to be commonly used to refer to control of orbital assets at the operational level. This term will be explored in depth later in the paper.

[10] After receiving the author's briefing on near-space, General Jumper has enthusiastically endorsed adding near-space to the JWS concept. In fact, when the Commander of Air Force Space Command briefed JWS at CORONA in the fall of 2004, near-space actually played the predominant role in his briefing.

[11] "You don't have to sell me. Yours is the obvious, correct solution. You have a story. They [tactical satellites] don't." Public comments on near-space by Dr. Daniel Held, a member of the Air Force Scientific Advisory Board, after the board received three briefings on JWS ("Joint Warfighting Space," presented by Maj. Dayne Cook), tactical satellites ("Responsive Space Near-Term Plan," presented by Col. Pamela Stewart), and near-space ("Joint Concepts in Near-Space," presented by the author) at AFSPC Headquarters, Peterson Air Force Base, Colorado Springs, Colorado on 27 Apr. 2004.

[12] "MAJCOM CONOPS Transfer Message." *US Air Force CONOPS Web Site.* 17 May 2004 <https://afconops.hq.af.mil/support/index3.htm>.

[13] "SISP: Single Integrated Space Picture." *United States Army Space and Missile Defense Command Web Site*. 17 May 2004 <http://www.smdc.army.mil/FactSheets/SISP.pdf>. "The Single Integrated Space Picture's (SISP) goal is to obtain an accurate display of space objects to enable Space Control Actions."

[14] "JTIC Common Operational Picture (COP)." *Joint Interoperability Test Command Web Site.* 17 May 2004 <http://jitc.fhu.disa.mil/cop/index.html>. "The COP is the integrated capability to receive, correlate, and display the…current depiction of the Battlespace for a single operation within a [commander-in-chief's area of responsibility], including current, anticipated or projected, and planned disposition of hostile, neutral, and friendly forces as they pertain to US and multinational operations ranging from peacetime through crisis and war."

[15] Davis, Brett. "Forces Need Improved Intelligence, More UAVs, Commanders Say." *Aerospace Daily* 2 Apr. 2004.

[16] Thompson, Loren B. *"I-S-R: Lessons of Iraq."* Briefing presented at the *Defense News* ISR Integration Conference, 18 Nov. 2003, Alexandria, Virginia. "[The] 3rd [Infantry Division] saw numerous shortfalls in its organic ISR and access to joint/national assets: [communications links] can't support fast & fluid ops over long distances; divisions need organic collection & processing capacity rather than relying on echelons above division; divisions need tactical SIGINT systems that can collect & jam across the spectrum; divisions must have UAVs at division and brigade level to provide near-real time imagery & targeting." "[The] Marines [were] highly critical of ISR shortfalls. After crossing the line of departure, the division received very little actionable intelligence from external intelligence organizations. Intelligence sections at all levels were inundated with information...that had little bearing on their missions. The existing hierarchical collections architecture, particularly for imagery, is wildly impractical. Solution: procure [a] family of tactical intelligence collections platforms (ground & air) and decentralize collection."

[17] As an example of the urgent need for persistent ISR, retired Air Force Lt Gen James Abrahamson used a form of the word "persistent" 24 times in a 101-word section of a 28 Oct. 2003 speech to the Long Endurance High Altitude (LEHA) conference at the Air Force Research Lab in Dayton, OH: "…no 'we just have to wait until the aircraft leaves' persistent; long endurance, comprehensive and persistent; persistent with change detection; long endurance persistent; not deterred by bad weather persistent; no 'it's time for the satellite, so hurry and get the tarp over the vehicle' persistent; 24 x 7 persistent; always active persistent; persistent; always there to stare persistent; persistent, persistent, persistent; long endurance persistent; long loiter persistent; persistent, persistent, persistent, persistent; no 'wait till the cloud comes over' persistent; persistent, persistent, persistent; if they want to operate, they have no cover: 24 x 7 persistence."

[18] "Navy Might Be Open to Buying Larger Intel-Gathering Aircraft" *Aviation Week and Space Technology,* **160.15** (12 Apr. 2004), p. 29. Admiral Vern Clark, Chief of Naval Operations: "I want persistent, long-dwell recon and surveillance assets operating organically in support of my naval structure."

[19] "Military Satellite List." *Federation of American Scientists Space Policy Project Web Page.* 17 May 2004 <http://fas.org/spp/military/program/list.htm>. The Federation of American Scientists estimates that there are bout 50 US ISR satellites in orbit.

[20] United States Department of Defense. *Joint Publication 3-14: Joint Doctrine for Space Operations.* Washington: GPO, 9 Aug. 2002, p. I-4. "Space systems are often assets requiring careful allocation. Although it may appear there are numerous satellites available to support every mission, these resources are limited. Therefore requirements are prioritized, and a commander many not receive the unlimited support desired…Users may be preempted based on priority. Competition for bandwidth, priorities for tasking, and similar constraints, combined with satellite physical access to specific locations, impact availability of space support."

[21] Stuart, Lt Col Jack., US Air Force Space Operations School, private communication (Jun. 2004). The various TENCAP programs were established in a closed Joint Session of Congress in 1977. The actual TENCAP charter is classified.

[22] Fulghum, David A. "Intelligence agencies are looking for a cheap, flexible alternative to space-based surveillance." *Aviation Week and Space Technology* **159.32 (**22 Aug. 2003), p. 54.

[23] Kemp, Damian. "In a Tight Space." *Jane's Defence Weekly*, 5 May 2004. "Operational demand for strategic, satellite and tactical communications has increased tenfold in the past 12 years. US Air Force Space Commander Gen Lance Lord says the comparison between the combat phases of the 2003 Operation 'Iraqi Freedom' and the 1990-91 Gulf War was a sign of the future. Almost all forces during the conflicts used all bandwidth immediately available and often more."

[24] Stargardt, Capt. Beth, Air Force Research Laboratories Space Vehicle Directorate. "Tactical Space Employment." A briefing at the Joint Forces Command Joint Space Concept Development and Experimentation Workshop, Norfolk, Virginia, 31 Mar. 2004. Most LEO satellites actually orbit above 400 km or so. 200 km is the baseline orbit for TacSat.

[25] For example, simulations of satellite orbital decay times assuming no station-keeping show that a small satellite (e.g., Starshine) inserted into a 300 km circular orbit has 15 times the lifetime of the same satellite inserted at 200 km; the same satellite inserted into a 400 km circular orbit would have well over 100 times the lifetime of the 200 km orbit. For a larger, more massive satellite (e.g., Quickbird), the lifetime increases relative to a 200 km orbit are over 200 and over 1,500 times for 300 and 400 km orbits, respectively. Simulation courtesy of Delores J. Knipp, Evelyn S. Patterson, *et al.*, United States Air Force Academy Department of Physics.

[26] Wolfsen, Richard and Jay M. Pasachoff, *Physics*. 3rd ed. Reading, Massachusetts: Addison Wesley, 1999, p. 221.

[27] Orbital mechanics dictates that satellites in orbit have to obey the law of gravity while simultaneously conserving energy and angular momentum. These requirements mean that satellites in elliptical orbits will move more rapidly when close to the earth than when they are far away. It is relatively straightforward to derive many of the properties of satellites in circular orbits from Newton's Second Law of Motion and his Universal Law of Gravitation. The speed required to keep such satellites in orbit depends on their distance from the center of the earth, or, indirectly, on their altitude above the earth. The higher their altitude, the slower they can move and still stay in orbit. Thus, satellites in LEO move very quickly compared to satellites in GEO.

Using a 200-km altitude as the lower limit of sustained orbital motion based on limits imposed by atmospheric drag, the lowest LEO satellite will move at about 7.8 km/sec with a period (the time it takes to go all the way around its orbit) of about 90 minutes, while a satellite in geosynchronous orbit will have a speed of 3 km/sec and a period of about 24 hours, meaning that a satellite in GEO orbits the earth in the same time the earth takes to rotate. Thus, a satellite in GEO will appear to be stationary above the earth's surface. At the equator, the earth's rotation speed is about 0.5 km/sec. Depending on the orientation of the orbit, a LEO satellite could have a relative speed over the earth's surface of between 7.3 and 8.2 km/sec. For a satellite in a 200 km orbit, a little higher than the ones proposed for many "tactical microsats", geometry shows that the longest it could possibly be in view if it passed directly overhead is between about 7.5 and 6.5 minutes if it is orbiting in the same direction as or opposite to the earth's rotation, respectively. If there is a mission requirement for the satellite to be some angle above the horizon then these times shorten significantly. For example, for orbits traveling the same direction as the earth's rotation (the usual case) where the mission requires the satellite to be 5, 10, or 30 degrees above the horizon, then such a satellite would only be in view for 5.2, 3.8, or 1.5 minutes, respectively, and these are *best*-cases; should the satellite not pass directly overhead, the useful times would be much shorter.

Obviously, for persistence we would like to be further away, orbiting in the same direction as the earth's rotation to get us longer pass times over a target area. However, the tradeoff is that at larger distances we cannot see small details as well. The revisit time, the time between consecutive overhead passes of a satellite, or the revisit rate, the number of overhead satellite passes per time, is another parameter important when discussing satellite coverage. Revisit times are not only dependent upon satellite altitude, but on target latitude and orbital inclination (the angle between the orbital plane and the equatorial plane) as well. For the same orbital inclination, equatorial revisit rates are lower than higher latitudes (more area to cover) and higher inclination orbits have lower revisit rates than lower inclination orbits. Both of these parameters are also heavily influenced by satellite altitude, which controls the speed of the satellite.

For example, a satellite in the 200-km orbit discussed above, in an orbit directly above the equator would pass over the same spot on the earth's surface once every hour and forty minutes, but it would never be able to see any points further than about 1000 miles from the equator. The same satellite in an orbit that crosses the equator at 90 degrees would not pass over the same spot on the equator for 23½ hours, but it would pass over the poles every hour and forty-one minutes. The difference is that instead of seeing the same strip of ground every orbit, it would take about 14 orbits before approximately the same spot was revisited. Orbits with inclinations between these two limits would have revisit times and viewing opportunities somewhere between these limits. Changing the satellite altitude would change these parameters as well. Further discussion of revisit rates is beyond the scope of this paper, but a short primer, *EROS SYSTEM—Satellite Orbit and Constellation Design*, can be found at <http://www.crisp.nus.edu.sg/~acrs2001/pdf/ 334BARLE.PDF>. As can be seen, determining the appropriate orbit for any satellite is a difficult compromise between pass time, revisit rate, and sensor resolution.

[28] United States Air Force. *Air Force Doctrine Document 2-2: Space Operations*. Washington: GPO, 27 Nov. 2001, p. 11. "The advantages of satellite persistence are partially offset by the limitation of predictability. Because of the predictability imposed by orbital dynamics, a major limitation of satellites is that adversary forces may know when to respond to such overflights with either passive or active defense measures."

[29] Oberg, James. "Spying for Dummies: The National Security Implications of Commercial Space Imaging". *IEEE Spectrum* **36**(11), Nov. 1999. 17 May 2004 <http://www.jamesoberg.com/articles/spy/>.

[30] Witt, Captain (US Navy, retired) Scott. Physical Sciences Laboratory, New Mexico State University. Private Communication (May 2004). Capt. Witt is a former navy cryptologist and intelligence specialist.

[31] Notable exceptions to this altitude limit are the U-2 and Global Hawk, flying at above 65,000 ft, and the now out of service (but by no means obsolete) SR-71, which could attain altitudes of above 80,000 ft. The upper altitude limit for air-breathing, aerodynamic platforms is admittedly fuzzy, and if one spends enough money it is possible to go somewhat higher than the usual 60,000 ft limit. In general, however, airborne platforms remain well below 60,000 ft due to the difficulty in and cost of exceeding the engine and airframe limitations discussed in the text.

[32] Tuttle, Rich. "Defense, Intelligence Officials Compete For Use Of Space Based Radar." *Aerospace Daily*, 29 Jan. 2004. "Among things the Army is 'fighting for,' [Brig. Gen. Robert P. Lennox, deputy commanding general for operations of Army Space and Missile Defense Command] said, are 'direct tasking capability and direct downlink capability into the theater, so the theater commanders can take advantage of some of the capabilities that the Space Based Radar brings. The intelligence community has different desires. And there are some compromises being worked that those kind of capabilities are identified without necessarily those kind of solutions.' "

[33] Figure adapted from a similar graphic by the formerly operational Lt. Col. Steve "Topper" Alltop.

[34] The Air Force Space Battlelab's Near-space Summit, Colorado Springs, CO, 20 Nov. 2004. An invited gathering of about 100 representatives from the Department of Defense, other government agencies, industry, and academia interested in the development and exploitation of the near-space regime.

[35] "100 Km Altitude Boundary for Astronautics." *Fédération Aéronautique Internationale Web Site.* 17 May 2004 <http://www.fai.org/ astronautics/100kmasp>. This site has further discussion of the Karman line.

[36] "Balloons in the American Civil War." US Centennial of Flight website. <http://www.centennialofflight.gov/essay/Lighter_than_air/Civil_War_balloons/LTA5.htm>.

[37] "Air Force Link Fact Sheet—Tethered Aerostat Radar System." *Air Force Link Web Site.* 15 Nov. 2004 <http://www2.acc.af.mil/library/factsheets/tars.html>.

[38] Hecht, Eugene. *Optics.* 3rd ed. Reading, Massachusetts : Addison-Wesley, 1998, ch. 10.

[39] Stimson, George W. *Introduction to Airborne Radar.* 2nd ed. Mendham, New Jersey: Scitech, 1998, ch. 10.

[40] The received power advantage for near-space over GEO locations would be between 1 million and 4 million times (60 to 66 dB) for passive systems and between 1 trillion and 16 trillion times (90 to 102 dB) for active systems.

[41] Tascione, Thomas. *Introduction to the Space Environment*. Malabar, Florida: Orbit, p. 75.

[42] Johnson, Allen L. "The Effects of Ionospheric Scintillation on Satellite Communications." *Air University Review* **25.1** (1973).

[43] Carr, Dr. Stephen, Johns Hopkins University Applied Physics Laboratory, private communication (Apr. 2004).

[44] Joy, Maj. William E., Air Force Research Laboratory, Space Vehicles Directorate, private communication (Nov. 2003).

[45] Aarons, J. and S. Basu. "Ionospheric Radio Wave Propagation." *Handbook of Geophysics and the Space Environment*. Ed. Adolph S. Jursa. Springfield, Virginia: Air Force Geophysics Laboratory, 1985. Ch. 10.7.

[46] Lavan, Charles. "Preliminary Study: High Altitude Airship Survivability and Vulnerability." Lockheed Martin. Unpublished briefing (2004).

[47] "Vulnerability to Jamming Underscores Need for Navigation Back-up." *Air Safety Week* **12.36** (7 Sep. 1998).

[48] Mason, William H. *Configuration Aerodynamics*, AOE 4124. Course Home Page. Department of Aerospace and Ocean Engineering, Virginia Tech. p. B-3. 17 May 2004 <http://www.aoe.vt.edu/~mason/ Mason_f/ConfigAero.html>.

[49] "America's Rogue Balloon Lost at Sea." *BBC News Online.* 31 Aug. 1998. 17 May 2004 <http://news.bbc.co.uk/1/hi/world/americas/162084.stm>.

[50] Drifting very close to the speed of the wind, many near-space platforms would be hard to distinguish from chaff, an elementary countermeasure automatically ignored by many threat radars.

[51] On-site hydrogen generation may actually be a better method for obtaining buoyant gas in the field, as it could possibly reduce the logistics tail when compared to transporting helium to the theater of operations. The reason hydrogen is not generally used for lighter-than-air applications is its extreme flammability in the presence of oxygen. That property of hydrogen makes generation and storage a much more dangerous proposition, and negates some of the survivability arguments presented in this paper. A more detailed cost/benefit analysis is required to determine whether logistical advantages exist and whether the added danger to personnel is worth those advantages.

[52] Lavan, Charles. "Preliminary Study: High Altitude Airship Survivability and Vulnerability." Lockheed Martin. Unpublished briefing (2004).

[53] Witt, Scott. Physical Sciences Laboratory, New Mexico State University. Private Communication (Apr. 2004).

[54] "America's Rogue Balloon Lost at Sea." *BBC News Online.* 31 Aug. 1998. 17 May 2004 <http://news.bbc.co.uk/1/hi/world/americas/162084.stm>.

[55] "Air Force Link Fact Sheet—Global Hawk." *Air Force Link Web Site.* 17 May 2004 <http://www.af.mil/factsheets/ factsheet.asp?fsID=175>.

[56] "RQ-4A Global Hawk (Tier II+ HAE UAV)." *Federation of American Scientists Intelligence Resource Program Web Site.* 17 May 2004 <http://www.fas.org/irp/program/collect/global_hawk.htm>.

[57] United States Department of Defense. *Joint Publication 3-14: Joint Doctrine for Space Operations.* Washington: GPO, 9 Aug.2002, p. I-4. "Current launch programs take 40-150 days to generate and launch, providing all hardware, including payload, is available at the launch site. Payload availability, pre-launch processing, positioning and on-orbit checkout are factors that can significantly lengthen the time from call-up to operating on orbit."

[58] Prebeck, Col Steve. "Joint Warfighting Space." A briefing presented to the AFSPC Science and Technology Forum, 1 Oct. 2004. According to the Commander, US Central Command, General John Abizaid, "Space-based assets do not provide persistence." Additionally, "Orbitology is not friendly to [operationally responsive space] or JWS as far as 'persistence' is concerned," according to General James Hill, Commander, US Southern Command.

[59] The term "tactical microsats" can be a bit misleading. As no satellite can be confined to one theater of operations, much less to one tactical engagement, their effects certainly seem to be much more strategic than tactical. This concept is explored in more depth later in this paper. In *Tactical Space Employment*, a briefing by Air Force Research Laboratories Space Vehicle Directorate at the Joint Forces Command Joint Space Concept Development and Experimentation Workshop, Norfolk, Virginia, 31 Mar. 2004, Capt Beth Stargardt stated that a goal of the tactical microsatellite program was to drive costs to below $15 million to put a small satellite in a 100-nautical mile orbit, an orbit that can only have a short orbital lifetime due to the effects of atmospheric drag. To obtain any useful persistence from such a system, a constellation of at least 20 of these satellites would have to be launched. Thus, between $15 million and $300 million will be expended to get well less than a year's service from the microsatellites. Additionally, the ability of any agency to convince Congress to store such expensive systems on the shelf in large numbers as war reserve materiel has yet to be tested.

[60] Prebeck, Col Steve. "Joint Warfighting Space." A briefing presented to the AFSPC Science and Technology Forum, 1 Oct. 2004.

[61] "National Scientific Balloon Facility." *National Scientific Balloon Facility Web Site.* 19 May 2004 <http://www.nsbf.nasa.gov/>.

[62] Lindstrand Technologies Home Page. 23 Jun. 2004 <http://www.inflatable-buildings.com/>.

[63] The most important of these treaties is the 1967 Outer Space Treaty, which established the principle that space is not the sovereign territory of any nation and is free for exploration and use by all states. The Strategic Arms Limitation Talks (SALT) treaties between the Soviet Union and the US, SALT I and SALT II, also prohibit interference with national technical means. The 1996 National Space Policy states the US commitment to developing, operating, and maintaining space control capabilities to ensure freedom of action in space.

[64] Nock, Kerry T. *Global Constellation of Stratospheric Scientific Platforms: Phase II Final Report.* Atlanta, Georgia: NASA Institute for Advanced Concepts (31 Oct. 1999), ch. 8. 17 May 2004 <http://peaches.niac.usra.edu/studies>.

[65] Dunn, Lewis, SAIC, private communication (Jun. 2004).

[66] Walker, Mary, Air Force General Counsel, "Legal Regime Applicable to 'Near-Space'," Memorandum for the Secretary and Chief of Staff of the Air Force, 27 Sept. 2004.

[67] It must be noted that this weakness, the lack of existing hardware, is shared by the concepts for "low-cost" space launch and "inexpensive" tactical satellites.

[68] Perhaps the most-applicable vocal minority who eventually got senior planners to adopt a completely new technology was Brigadier General Billy Mitchell. It took his very public court marshal before his airpower theories began to take root.

[69] Caterinicchia, Dan. "Iraq Offers Glimpses into ISR Future." *Federal Computer Week Web Site*, 21 May 2003. 17 May 2004 < http://www.fcw.com/fcw/articles/2003/0519/web-army-05-21-03.asp >. Keith Masback, Director of ISR Integration in the Office of the Army Deputy Chief of Staff for Intelligence said, "When intelligence personnel need something, they don't care where it comes from as long as they get it at the right time."

[70] United States Air Force. *Air Force Doctrine Document 2-2: Space Operations*. Washington: GPO, 27 Nov. 2001, p. 23. "[C]hallenges occur when one organization owns an asset while another agency performs the actual operations, or, when one organization operates the platform while another has responsibility over the sensors on board."

[71] Wellman, William *et al*. "Trade Study of Near-Space Systems." The Tauri Group, Alexandria, Virginia, May 2004. Unpublished Briefing.

[72] "Flexible Films." *Raven Industries Web Site.* 17 May 2004 <http://www.ravenind.com/RavenCorporate/eng_films/balloons_scientif.htm>. Perhaps the premier commercial supplier of large high-altitude balloons, Raven Industries of Sulphur Springs, TX, advertises the ability to take about a 14,000-pound payload to 120,000 ft.

[73] Space Data Launches First Commercial Balloon-Borne Wireless Data Network." *Offshore Source Communications* 6(5) 2004, p. 14. 3 June 2004, http://offshoresource.com/pdf/os_may_04.pdf; "Space Station Gets FCC Green Light," *SpaceDaily Web Site*, 2 Aug. 1998, 17 May 2004, http://spacedaily.com/news/Copy%20of%20skystation-98a.html; "The FCC on Thursday approved for the first time use of stratospheric platforms as telecommunications stations. The ruling states that stratospheric platforms are expected to be the dominant use of 1000 MHz of spectrum (47.2-48.2 GHz)."

[74] Lachenmeier, Tim and Ledé, Jean-Luc. "To the Edge of Space and Back to Your Feet." GSSL, Inc, Tillamook, OR and Aurora Flight Sciences, Manassas, VA. A briefing presented to the Air Force Space Battlelab, Jan. 2004.

[75] Nock, Kerry T. "Stratospheric Satellites." Global Aerospace, Altadena, CA. A briefing presented at the Air Force Space Battlelab's Near-space Summit, Colorado Springs, Colorado, 20 Nov. 2003.

[76] Witt, Scott. "Advanced High Altitude Aerobody: AHAB—An ISR Platform." Physical Sciences Laboratory, New Mexico State University. A briefing presented at the Balloon Short Course, Las Cruces, New Mexico, 29 Jan. 2003.

[77] Flynn, William. "USAF Balloon Program." A briefing presented to the AFSPC Science and Technology Forum, 1 Oct. 2004.

[78] Boyle, Alan. "Airship Groomed for Flight to Edge of Space." *MSNBC Web Site*, 21 May 2004. 3 Jun. 2004 <http://www.msnbc.msn.com/id/5025388/>.

[79] Huett, Steve. NAVAIR Airship Advanced Program Office Program Manager. Private communication (July 2004).

[80] Wilson, J.R. "A New Era for Airships." *American Institute of Aeronautics and Astronautics Web Site*, May 2004. 2 Jun. 2004 <http://www.aiaa.org/aerospace/images/articleimages/pdf/wilson.may04.pdf>.

[81] The thinking behind much of the material in this section was influenced by work with the Tauri Group during development of the following briefing: Wellman, William et al. "Trade Study of Near-Space Systems." The Tauri Group, Alexandria, Virginia, May 2004. Unpublished Briefing. The author chose to cite primary references for this paper, but many of the references were found for and arguments were polished during discussions relating to this briefing.

[82] United States Department of Defense. *Joint Operations Concepts.* Washington: GPO, Nov. 2003.

[83] "CSAF CONOPS." *Task Force CONOPS Web Site.* 17 May 2004 <https://afconops.hq.af.mil/ support/csafconops.htm>.

[84] Graham-Rowe, Duncan. "Flying air gun to shoot spacecraft into orbit." *New Scientist*, 5 Sep. 2001. 17 May 2004 <http://www.newscientist.com/news/news.jsp?id=ns99991241>.

[85] Foust, Jeff. "The Falcon and the Showman." *The Space Review Web Site*, 8 Dec. 2003. 18 May 2004 <http://www.thespacereview.com/article/70/1>. The experimental Falcon I program advertises the ability to put 650 kg in LEO for $6 million, or $9,000/kg. The follow-on Falcon V is slated to carry 4,200 kg to LEO for $12 million, or $2,900/kg. Falcon I is scheduled to fly in late 2004 while Falcon V is tentatively projected to be operational in 2005.

[86] United States Air Force. *Air Force Doctrine Document 2-2: Space Operations*. Washington: GPO, 27 Nov. 2001, p. 11. "Another limitation [of satellites] involves the cost of fielding and maintaining a space-based capability. Satellites, today, are expensive to build and operate, relying on an extensive infrastructure of ground facilities, the satellites themselves, launch support, and communications connectivity."

[87] "'Top 10' Lessons of 1990s Aimed at Preventing Space Program Fumbles." *Aviation Week and Space Technology*, **160.15** (12 Apr. 2004), p. 30. According to Admiral James O. Ellis, Commander, US Strategic Command, "Today's [space] acquisition process is slow, lean and with insufficient surge capacity or room for error or unanticipated events."

[88] "'Top 10' Lessons of 1990s Aimed at Preventing Space Program Fumbles." *Aviation Week and Space Technology*, **160.15** (12 Apr. 2004), p. 30. According to A. Thomas Young, chairman of the Defense Science Board and the Air Force Scientific Board Joint Task Force on Acquisition of National Security Space Programs, "Space is different. It's a one-strike-and-you're-out business. A single human error or technical flaw can turn a billion-dollar mission into a catastrophe."

[89] Dehqanzada, Yahya A. and Ann M. Florini. *Secrets for Sale: How Commercial Satellite Imagery Will Change the World*. Washington, DC: Carnegie Endowment for International Peace, 2000, p. 21. "Insurance costs typically range between 13 and 20 percent of the total value of the satellite plus the launch vehicle."

[90] Stewart, Col Pamela, Air Force Space Command Requirements Directorate, "Responsive Space Near-Term Plan," A briefing presented to the Air Force Scientific Advisory Board, Colorado Springs, Colorado, 27 Apr. 2004. The current TacSat 2 will cost at least $50 million, barring further problems.

[91] "Space Transportation News of November 2000." *Space Launcher Web Site,* 21 Nov. 2000. 17 May 2004 <http://www.space-launcher.com/News2000-11.html>.

[92] Wertz, James R. and Wiley J. Larson, eds. *Space Mission Analysis and Design*. Boston, Massachusetts : Kluwer Academic Publishers, 1991, p. 678.

[93] "What Is a Dollar Worth?" *Federal Reserve Bank of Minneapolis Web Site.* 4 Jun. 2004 <http://www.minneapolisfed.org/Research/data/us/calc/>. Costs converted to 2000 dollars using the calculator at this site.

[94] Dehqanzada, Yahya A. and Ann M. Florini. *Secrets for Sale: How Commercial Satellite Imagery Will Change the World*. Washington: Carnegie Endowment for International Peace, 2000, p. 21. According to Table 3, launch costs on US vehicles to LEO (100-1000 km) range from $12-15 million for a Pegasus to launch 460 kg to $22-26 million for an Athena to launch 2000 kg.

[95] Butler, Amy. "Air Force Says EELV Competition Not Needed Anytime Soon." *Defense Daily*, 19 May 2004, p. 4. Even the Evolved Expendable Launch Vehicle costs between $150 and $200 million each just for the launch vehicle.

[96] Stewart, Col. Pamela, Air Force Space Command Requirements Directorate. "Responsive Space Near-Term Plan." A briefing presented to the Air Force Scientific Advisory Board, Colorado Springs, Colorado, 27 Apr. 2004. The words "highly optimistic" are used to describe the AFRL goal due to the fact that the "low-cost" TacSat 2 program is already budgeted at almost $50 million, and that number did not include the procurement costs associated with several major subsystems such as the satellite bus that were obtained at no cost from surplus.

[97] Stargardt, Capt. Beth, Air Force Research Laboratories Space Vehicle Directorate. "Tactical Space Employment." A briefing at the Joint Forces Command Joint Space Concept Development and Experimentation Workshop, Norfolk, Virginia, 31 Mar. 2004.

In this paper we have primarily discussed the 200 km. circular orbits that are the advertised baseline for the TacSat program. This may seem to some to be a very simple strawman set up for unfair comparison with near-space assets. To be fair, there are a number of alternate orbits and employment schemes being investigated for this system. The one with the most promise for persistence uses the so-called Magic orbit, essentially a sun-synchronous, highly elliptical (7800 km. apogee, 500 km. perigee) orbit that requires only a few satellites to provide continuous coverage of a region on the ground. Orbital mechanics require a satellite in a highly elliptical orbit to move very slowly when far from the earth, allowing it to remain above the horizon for a significant amount of time over a region. However, such an orbit requires significantly more boost energy than the low-altitude circular solution. This additional boost energy is extremely expensive. A common way to avoid the extra boost cost is to sacrifice performance by significantly decreasing payload mass. Some estimates show that the baseline 1000-pound payload would have to be reduced to about 300 pounds to achieve the Magic orbit with the same launcher.

Additionally, because satellites in such orbits have to be far away from the region of interest in order to get the necessary dwell, sensor costs increase markedly since the required size for optics increases linearly with the distance between sensor and target. Communications solutions become even more expensive or less capable since signal strength decreases as the *square* of the distance between transmitter and receiver. Steerable antennae must be used on the ground since the locations of the satellites are constantly changing. Thus, for satellites in other than very low altitude circular orbits, the costs rapidly escalate and the standard problem with space returns: the prices are so high that the assets become strategic and the theater commander can't afford to own and operate the assets he needs. It's an interesting catch-22: put the satellite low enough that it's affordable and it's only marginally useful due to limited pass times, but put it high enough to be useful and it's no longer affordable. Information on Magic orbits from Space, Capt. Thomas R., Space and Missile Command Technology Development Directorate. "Point Paper on Magic Orbit RF (MORF)." A briefing at the Joint Forces Command Joint Space Concept Development and Experimentation Workshop, Norfolk, Virginia, 31 Mar. 2004. Additional information from AFRL Space Vehicles Directorate's draft "Tactical Satellites Concept of Employment", 28 July 2004.

[98] "RQ-1 Predator Medium Altitude Endurance (MAE) UAV." *Global Security Web Site.* 17 May 2004 <http://www.globalsecurity.org/intell/systems/predator.htm>.

[99] "$500 million UAV EO sensor market by end of decade." *Defense Systems Daily Web Page*, 18 Jun. 2003. 17 May 2004 <http://defence-data.com/paris2003/pagep147.htm>.

[100] "RQ-4A Global Hawk (Tier II+ HAE UAV)." *Global Security Web Site.* 17 May 2004 <http://www.globalsecurity.org/intell/systems/global_hawk.htm>.

[101] "Air Force Link Fact Sheet: RC-135V/W Rivet Joint." *Air Force Link Web Site.* 17 May 2004 <http://www.af.mil/factsheets/ factsheet.asp?fsID=121>.

[102] "Rivet Joint." *Global Security Web Site.* 17 May 2004 <http://www.globalsecurity.org/intell/ systems/rivet_joint.htm)

[103] "Air Force Link Fact Sheet: KC-135 Stratotanker." *Air Force Link Web Site.* 17 May 2004 <http://www.af.mil/factsheets/ factsheet.asp?fsID=110>.

[104] Boyd, John R. *A Discourse on Winning and Losing.* Air University Library document number MU 43947, Aug. 1987. Unpublished briefing notes and essays.

[105] Parker, Lt. Col. Dewey. "Advanced Astrodynamics." A lecture given as part of the USAF Advanced Space Operations Course, Colorado Springs, Colorado, 2 Mar. 2004.

[106] Dembowski, Tom. "US Space Lift" A lecture given as part of the USAF Advanced Space Operations Course, Colorado Springs, Colorado, 2 Mar. 2004.

[107] Darnell, Major General (select) Daniel J. Private communication (Nov. 2003).

[108] Ball, Danny R.J., Site Manager, National Scientific Balloon Facility. "Operational Life Cycle Overview." A briefing presented at the Balloon Short Course, Las Cruces, New Mexico, 29 Jan. 2003.

[109] "ITU Radiocommunications Sector Mission Statement." *International Telecommunications Union Web Site.* 17 May 2004 <http://www.itu.int/ITU-R/information/mission/index.html>. "The specific role of [The International Telecommunications Union, Radio Communication Sector] within the framework of this mission is as follows. ITU-R shall: effect allocation of bands of the radiofrequency spectrum, the allotment of radio frequencies and the registration of radio frequency assignments and of any associated orbital position in the geostationary satellite orbit in order to avoid harmful interference between radio stations of different countries; coordinate efforts to eliminate harmful interference between radio stations of different countries and to improve the use made of radio-frequencies and of the geostationary-satellite orbit for radiocommunication services."

[110] "US Condemns Cuba's Jamming of Satellite TV Broadcasts to Iran." *US Embassy, Islamabad, Web Site.* 17 May 2004 <http://usembassy.state.gov/islamabad/wwwh03071804.html>. A Broadcasting Board of Governors' statement quoted on this site states that Radio Farda, a Persian-language broadcast directed at Iran, was jammed from a site near Havana, Cuba, almost a hemisphere away. The footprint for jamming of a geosynchronous satellite is enormous.

[111] *Global Vigilance, Reach, and Power: America's Air Force Vision 2020,* p. 6. 17 May 2004 <http://www.af.mil/library/posture/vision/vision.pdf>. F2AT2E is a building block of the Air Force's core competencies.

[112] Lambeth, Benjamin S. *Mastering the Ultimate High Ground.* Santa Monica, California: Rand, 2003, p. 14. "In a policy approach characterized…as far more sophisticated, secretive, and complex . . . than many at the time

appreciated, the Eisenhower administration professed a determination to forestall the militarization of space as long as possible and instead to stress peaceful applications. This approach, however, was a clever ploy, its altruistic declarations masking the administration's real underlying intent to develop secret satellite reconnaissance systems… It also decreed, however, that a civilian scientific satellite had to precede a military one into space in order to establish the legitimate right of unmolested overflight in space. With a view toward ensuring the success of this stratagem, the Eisenhower administration adamantly opposed any discussion by the services of military space operations that might possibly prompt a public debate over the legitimacy of military space flight."

[113] Roberts, Charles A. "Outer Space and National Sovereignty." *Air University Quarterly Review* **12.1** (1960), pp. 55-56.

[114] United States Department of Defense. *Joint Publication 1-02: Department of Defense Dictionary of Military and Associated Terms.* Washington: GPO, 12 Apr. 2001 (as amended through 23 Mar. 2004), pp. 653, 564-565, and 677-678.

[115] Nulles, Claire. "Russia, China Make New Push To Ban Arms in Space Over U.S. Objections." *Space.com Web Site*, 27 Jun. 2002. 17 May 2004 <http://www.space.com/news/russia_china_ 020627.html>.

[116] Lallanilla, Mark. "Shooting Stars: U.S. Military Takes First Step Towards Weapons in Space." *ABCNEWS.com Web Site*, 30 Mar. 2004. 17 May 2004 <http://abcnews.go.com/sections/SciTech/US/ space_weapons_040330.html>.

[117] De Maeseneer, Guido. *Peenemunde: The Extraordinary Story of Hitler's Secret Weapons V-1 and V-2*. Vancouver, British Columbia: AJ Publishing, 2001.

[118] Tirpak, John. "In Search of Spaceplanes." *Air Force Magazine* **86.12** (2003).

[119] "RQ-1 Predator Medium Altitude Endurance (MAE) UAV." *Global Security Web Site.* 17 May 2004 <http://www.globalsecurity.org/intell/systems/predator.htm>.

[120] "Experimental Satellite System (XSS)." *Global Security Web Site.* 17 May 2004 <http://www.globalsecurity.org/space/ systems/xss.htm>.

[121] "XSS-10 Microsatellite." *Air Force Research Laboratory Web Site.* 17 May 2004 <http://www.vs.afrl.af.mil/Factsheets/ XSS10.html>.

[122] Scott, William B., "U.S. Spacecraft at Risk of Attack, Say Milspace Leaders.", *Aviation Week & Space Technology*, 1 Nov 2004, pp. 58-59.

[123] Andersen, Dr. Geoff, United States Air Force Academy. Private communication (Mar. 2004).

[124] "Rumsfeld Hits Two Home Runs." *Center for Security Policy Web Page*, 12 Jan. 2001. 17 May 2004 <http://www.centerforsecuritypolicy.org/index.jsp?section=papers&code=01-F_04>. "Anyone who doubts that space is where this century's wars will take place would do well to take a look at the Chinese space program. The Hong Kong newspaper Sing Tao Daily reported last week on China's ground test of a scary satellite weapon called a 'parasite satellite.' This is a micro-satellite that could attach itself to just about any type of satellite with the object of jamming or destroying it if it received a command to do so. As Sing Tao put it, 'to ensure winning in a future high-tech war, China's military has been quietly working hard to develop asymmetrical combat capability so that it will become capable of completely paralyzing the enemy's fighting system when necessary by 'attacking selected vital points' in the enemy's key areas.'"

[125] "China's Space Capabilities and the Strategic Logic of Anti-Satellite Weapons." *Monterrey Institute of International Studies, Center for Nonproliferation Studies Web Site*, 22 Jul. 2002. 17 May 2004 <http://cns.miis.edu/pubs/week/020722.htm>. "There is a clear strategic logic for China's interest in anti-satellite weapons. Chinese media and military analysts have highlighted the growing importance of space in future warfare and paid increasing attention to U.S. military efforts to ensure future space dominance. As the Gulf War, the Kosovo conflict, and the recent Afghanistan campaign have demonstrated, the United States increasingly relies on space-based assets to support military operations. China's inability to compete directly with advanced U.S. technologies may lead the Chinese military to focus on asymmetrical methods such as ASAT weapons in an effort to counter U.S. military dominance."

[126] "Space Program." *Chinese Defense Today Web Site*. 17 May 2004 <http://www.sinodefence.com/ space/default.asp>. "Washington's determination to pursue the ballistic missile defence system have all shown that the US is seeking to undertake asymmetric operations by exploiting various space technologies that its opponents do not possess. This has driven China to shift its focus more towards the fourth environment of military operations."

[127] Parmentola, John. *High Altitude Nuclear Detonations Against Low Earth Orbit Satellites*. Defense Threat Reduction Agency Advanced Systems and Concepts Office, Apr. 2001. 17 May 2004 <http://www.fas.org/spp/military/program/asat/haleos.pdf>.

[128] United States Air Force. *GPS Airborne Pseudolite After Initiative Report*. Pensacola, Florida: Air Force Unmanned Aerial Vehicle Battlelab, Mar. 2001.

[129] United States Air Force. *Air Force Doctrine Document 2-2: Space Operations.* Washington: GPO, 27 Nov. 2001, p. 23. "…[C]hallenges occur when one organization owns an asset while another agency performs the actual operations, or, when one organization operates the platform while another has responsibility over the sensors on board."

[130] United States Air Force. *Air Force Doctrine Document 2-2: Space Operations.* Washington: GPO, 27 Nov. 2001, p. 8. "Space assets enhance operations across the globe…For this reason, space operations are generally best planned and controlled in a centralized manner."

[131] Stargardt, Capt. Beth, Air Force Research Laboratories Space Vehicle Directorate. "Tactical Space Employment." A briefing at the Joint Forces Command Joint Space Concept Development and Experimentation Workshop, Norfolk, Virginia, 31 Mar. 2004.

[132] Lambeth, Benjamin S. *Mastering the Ultimate High Ground*. Santa Monica, California: Rand, 2003, p. 45.

[133] Brown, Lt. Kirk, 4th Space Operations Squadron, private communication (Jun. 2004).

[134] Prebeck, Col. Steven. "Air Force Space Command Functional Concept for Joint Warfighting Space." Draft version 3.14. 13 Apr. 2004.

[135] VMOC is an AF Space Battlelab demonstration that uses standard secure Internet protocols (IP) to allow control of satellite sensors. The larger goal of the project is to allow real-time access via IP to ISR information regardless of its electronic storage location. The Army Space and Missile Defense Battlelab is contributing to the demonstration and has selected VMOC as the sensor command and control mechanism for the HAA.

[136] The Army and Navy also have their own indigenous UAV assets, but most of these are designed to provide tactical effects.

[137] Solomon, John. *Air Force Touts Post-Iraq Combat Flights.* Associated Press, 21 Apr. 2004.
17 May 2004 <http://customwire.ap.org/dynamic/stories/I/IRAQ_AIR_WAR?SITE=CANAP&SECTION=HOME&TEMPLATE=DEFAULT>**.** Vice Chief of Staff of the Air Force, Gen. T. Michael Moseley, points out the seamlessness of space effects and the unity of the space mission as he knows it by saying, "I love UAVs…[A UAV is] the equivalent of a low-altitude satellite. It just parks itself out there except that you can task it in a different way than a satellite."

[138] Grossman, Elaine M. "Air Force May Expand on Army Tracking Tool." *Defense Information and Electronics Report.* 7 Nov. 2003, p. 1. Lt. Gen. Dan Leaf, Vice Commander of AFSPC: "Perhaps a long-endurance unmanned aerial vehicle might be used 'as sort of an atmospheric satellite to pick up the Blue Force Tracking data and transmit it, decrease the burden on very valuable orbital communications platforms, and at the same time, decrease the latency of the data—have it fresher, nearer to real time.'"

[139] Dr. Daniel Held, Air Force Scientific Advisory Board, 2004. See note 11.

[140] A notional 2020-timeframe near-space asset has recently been programmed to play in Schriever III, the primary USAF space war game.

[141] Palka, LTC Greg. US Army Space and Missile Defense Battlelab, High Altitude Airship Advanced Concept Technology Demonstration Manager. Private communication (Feb. 2004). In the Unit of Action Combined Arms Battalion Experiment, the High Altitude Airship used as a SIGINT platform collected over 80% of all electronic hits recorded, including being the only sensor to collect a number of hits and populate them to the common operational picture.

[142] In addition to *Air Force Doctrine Document 2-2: Space Operations* (United States Air Force, Washington: GPO, 27 Nov. 2001), these documents include *Joint Publication 3-14: Joint Doctrine for Space Operations*, (United States Department of Defense, Washington: GPO, 9 Aug 2002); *Field Manual 3-14.00: Space Support to Army Operations* (United States Army, Washington: GPO, coordination draft as of 2 Apr 2004); and *SECNAV Instruction 5400.39C: Department of the Navy Space Policy*, (United States Navy, Washington: GPO, 6 Apr 2004).

[143] Champion, K.S.W *et al*. "Standard and Reference Atmospheres." *Handbook of Geophysics and the Space Environment*. Ed. Adolph S. Jursa. Springfield, Virginia: Air Force Geophysics Laboratory, 1985. Ch. 14.3.

[144] Champion, K.S.W *et al*. "Standard and Reference Atmospheres." *Handbook of Geophysics and the Space Environment*. Ed. Adolph S. Jursa. Springfield, Virginia: Air Force Geophysics Laboratory, 1985. Ch. 14.

[145] The solar wind, a stream of very fast particles emanating from the sun, is present but the extremely small number of particles compared even with the number at the top of near-space puts this wind into a different category than the wind discussed here.

[146] Champion, K.S.W *et al*. "Standard and Reference Atmospheres." *Handbook of Geophysics and the Space Environment*. Ed. Adolph S. Jursa. Springfield, Virginia: Air Force Geophysics Laboratory, 1985. Ch. 14.3.

[147] Heun, Matthew K. “Maneuverable Platform Wind Environment.” Global Aerospace Corp. Jun. 2000. Unpublished briefing.

[148] Jaska, Esko, Defense Advanced Research Projects Agency. Private Communication (Oct. 2004).

[149] Champion, K.S.W *et al*. “Standard and Reference Atmospheres.” *Handbook of Geophysics and the Space Environment*. Ed. Adolph S. Jursa. Springfield, Virginia: Air Force Geophysics Laboratory, 1985. Data adapted from Ch. 14.3.

[150] This analogy is not strictly true, as any energy required to increase the size of the balloon structure will take away from its volume increase. The effect of atmospheric temperature change as the balloon changes altitude are also not considered for this illustrative example.

[151] Fenn, R.W *et al*. “Optical and Infrared Properties of the Atmosphere.” *Handbook of Geophysics and the Space Environment*. Ed. Adolph S. Jursa. Springfield, Virginia: Air Force Geophysics Laboratory, 1985. Ch. 18.3.

[152] Fenn, R.W *et al*. “Optical and Infrared Properties of the Atmosphere.” *Handbook of Geophysics and the Space Environment*. Ed. Adolph S. Jursa. Springfield, Virginia: Air Force Geophysics Laboratory, 1985. Ch. 18.3.

[153] Huffman, R.E. “Atmospheric Emission and Absorption of Ultraviolet Radiation.” *Handbook of Geophysics and the Space Environment*. Ed. Adolph S. Jursa. Springfield, Virginia: Air Force Geophysics Laboratory, 1985. UV absorption factors based on an analysis by the author of figures 22-4 to 22-6. Factors quoted for the wavelength range from 200-300 nanometers. Shorter wavelengths were not present in significant quantities at any altitude (down by a factor of 10^4 to 10^5 from the 300 nm values) and longer wavelengths were not absorbed significantly.

[154] Huffman, R.E. “Atmospheric Emission and Absorption of Ultraviolet Radiation.” *Handbook of Geophysics and the Space Environment*. Ed. Adolph S. Jursa. Springfield, Virginia: Air Force Geophysics Laboratory, 1985. Ch. 22-4 to 22-5.

[155] Rich, F.J. and S. Basu. “Ionospheric Physics.” *Handbook of Geophysics and the Space Environment*. Ed. Adolph S. Jursa. Springfield, Virginia: Air Force Geophysics Laboratory, 1985. Adapted from Fig. 9-1.

[156] Rich, F.J. and S. Basu. “Ionospheric Physics.” *Handbook of Geophysics and the Space Environment*. Ed. Adolph S. Jursa. Springfield, Virginia: Air Force Geophysics Laboratory, 1985. Ch. 9-1.

[157] Actually, the physical effect causing the return of signals from the ionosphere is refraction, or the bending of electromagnetic waves, not reflection as off a mirror. However, the mirror analogy is accurate enough to give a reasonable understanding of the phenomenon.

[158] Witt, Scott. Physical Sciences Laboratory, New Mexico State University. Private Communication (May 2004). “Some environments are capable of ducting VHF frequencies for hundreds of miles. This occurs when “ducts” form in the atmosphere, caused by layers of different electron densities that ‘trap’ the radio signal and allow it to travel down the duct by being reflected between the two layers. The Middle East/Arabian Gulf is famous for this, and it plays hell with geolocation and [direction finding].”

[159] For more detailed information on the near-space environment, see Tascione, Thomas. *Introduction to the Space Environment*. Malabar, Florida: Orbit; or *Handbook of Geophysics and the Space Environment*. Ed. Adolph S. Jursa. Springfield, Virginia: Air Force Geophysics Laboratory, 1985.

[160] The thinking behind much of the material in this section was influenced by work with the Tauri Group during development of the following briefing: Wellman, William et al. “Trade Study of Near-Space Systems.” The Tauri Group, Alexandria, Virginia, May 2004. Unpublished Briefing. The author chose to cite primary references for this paper, but many of the references were found for and arguments were polished during discussions relating to this briefing.

[161] There are many other international projects being proposed such as the British HALE (High Altitude Long Endurance) aerostatic platforms by Lindstrand Technologies (15 Jun. 2004 <http://www.hiflyer.info/Inflatable/hale.htm>) and the German Airworm from the University of Stuttgart (15 Jun. 2004 < http://www.isd.uni-stuttgart.de/arbeitsgruppen/airship/halp/akron_rk.pdf>).

[162] Image courtesy of Space Data Corp.

[163] Frische, Eric. “Developments in Commercial Near Space Systems.” Space Data Corp., Tucson, Arizona. A briefing presented at the Air Force Space Battlelab’s Near-space Summit, Colorado Springs, Colorado, 20 Nov. 2003.

[164] Lachenmeier, Tim and Ledé, Jean-Luc. “To the Edge of Space and Back to Your Feet.” GSSL, Inc, Tillamook, OR and Aurora Flight Sciences, Manassas, VA. A briefing presented to the Air Force Space Battlelab, Jan 2004.

[165] Images courtesy of GSSL, Inc. and Aurora Flight Sciences.

[166] “Iraq Every Six Hours.” Computer simulation courtesy of Space Data Corporation, 2003.

[167] "Radiosonde/Weather Balloon Observations." *National Weather Service Forecast Office Web Site.* 17 May 2004 <http://www.srh.noaa.gov/ mob/balloon.shtml>. "Radiosonde observations are taken twice daily at 0000 hours and 1200 hours Greenwich Mean Time (GMT), or at 6 pm and 6 am CST [central standard time]. All worldwide agencies launch their radiosondes at approximately the same time, and over 1500 such observations are taken daily."

[168] Rosbach, Jeff, Air Force Weather Agency Forecaster, United States Air Force Academy Airfield. Private Communication (Apr. 2004).

[169] Image courtesy of Global Aerospace.

[170] Nock, Kerry T. "Stratospheric Satellites." Global Aerospace, Altadena, CA. A briefing presented at the Air Force Space Battlelab's Near-space Summit, Colorado Springs, Colorado, 20 Nov 2003.

[171] "Missile Detection Polar" and "Missile Detection Global." Computer simulations courtesy of Global Aerospace Corporation, 2003.

[172] "Global Constellation." Computer simulation courtesy of Global Aerospace Corporation, 2003.

[173] Image courtesy of New Mexico State University's Physical Science Laboratory.

[174] Image courtesy of Naval Research Laboratory.

[175] Witt, Scott. "Advanced High Altitude Aerobody: AHAB—An ISR Platform." Physical Sciences Laboratory, New Mexico State University. A briefing presented at the Air Force Space Battlelab's Near-space Summit, Colorado Springs, Colorado, 20 Nov. 2003.

[176] Crowder, Douglas. Naval Research Laboratories. Private communication (Apr. 2004).

[177] Frisbie, Lt. Col. Kevin and Gary Trinkle. Joint Forces Command's Project Alpha. Private communication (Apr. 2004).

[178] Trinkle, Gary *et al*. "Rapid Assessment Process #04-02: The Joint Transformational Potential for High Altitude Long Loiter (HALL) Capabilities." Norfolk, Virginia: Project Alpha, Joint Forces Command, (May 2004).

[179] Image courtesy of NAVAIR Airship ADPO.

[180] Swanson, Bill. "NAVAIR Evaluating Novel Airship for Force Protection Missions." *Tester*, 15 Jul 2004. 14 Nov. 2004 <http://www.dcmilitary.com/navy/tester/9_28/features/30137-1.html>.

[181] Huett, Steve. NAVAIR Airship Advanced Program Office Program Manager. Private communication (July 2004).

[182] Images courtesy of Lockheed-Martin.

[183] Palka, LTC Greg, US Army Space and Missile Defense Battlelab, High Altitude Airship Advanced Concept Technology Demonstration Manager. "HAA ACTD Information Brief." A briefing presented at the Joint Forces Command Joint Space Concept Development and Experimentation Workshop, Norfolk, Virginia, 31 Mar. 2004.

[184] "HAA: High Altitude Airship." *US Army Space and Missile Defense Command Web Site.* 17 May 2004 <http://www.smdc.army.mil/factsheets/haa.pdf>.

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Biographical Sketch

Lt Col Ed “Mel” Tomme is the only combat pilot in the Air Force with a doctorate in physics. A Distinguished Graduate of the United States Air Force Academy (USAFA) in 1985, he attended pilot training at Reese AFB, remaining there for his first operational tour instructing in the T-37 Tweet. He was then selected to fly the F-4G Wild Weasel at George AFB; Spangdahlem AB, Germany; and King Abdul Azziz Air Base, Saudi Arabia. He holds a Masters Degree in Physics from the University of Texas at Austin and a Doctorate of Philosophy in Plasma Physics from the University of Oxford in England. Lt Col Tomme taught physics at USAFA for several years while also instructing in the T-3 Firefly and TG-7 Motorglider. He is the only officer at USAFA to ever have been recognized as both the Outstanding Academy Educator by the Dean and as the Outstanding Associate Air Officer Commanding by the Commandant. He currently works in Air Force Space Command’s Space Warfare Center at Schriever AFB, CO, serving first as Concept Development Branch Chief for the Air Force Space Battlelab and now as the Deputy Director of Air Force TENCAP. Championed by the Commander, Air Force Space Command, he personally briefed his concept for utilizing the near-space regime for military purposes to over 200 stars and between April and December 2004, including the Secretary of the Air Force, Secretary of the Navy and Chief of Staff of the Air Force.

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