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Using Near Space Vehicles in the Pursuit of Persistent C3ISR

STUDENT PAPER

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Abstract

US Air Force leaders issued a challenge to create a battlespace of the future that does not want for situational awareness. In this future, the warfighter can access up-to-date information through a network of sensors that are on duty 24/7 around the battlespace. The persistence of command, control, and communication as well as intelligence, surveillance, and reconnaissance (C3ISR) available today does not meet the 24/7 dream. Even the US dominance in the high ground of space could not meet the current appetite. A combination of manned and unmanned C3ISR platforms supported operations in Afghanistan and Iraq but they could not provide round-the-clock information to the commanders and the warfighters.

To correct those gaps, the USAF chief of staff and others propose to exploit the relatively unused portion of the vertical dimension: near space. This paper explores how near space vehicles (NSV) traversing altitudes from 20 km (65,000 feet) up to 150 km (lower confines of earth orbit) generate the C3ISR effects future warfighters require. First, the current manned and unmanned platforms are compared for effects, cost, and persistence. Manned platforms include AWACS, JSTARS, and Rivet Joint. Typical unmanned platforms include Predator, Global Hawk, and representative low earth orbit satellites. The second part of the paper looks at modifying state of the art technologies to reach and operate in the near space region. The paper compares adapted balloon, lighter-than-air craft (airships), and aircraft designs for operation in near space.

The comparison continues to the physical architecture to provide persistent C3ISR effects. Constellations for several of the NSV designs are detailed with respect to various communication, electro-optical, radar, and signal gathering payloads. The paper concludes with a final emphasis on the persistence gaps the warfighters face and the potential for Near Space Vehicles to close the gaps to meet the 24/7 appetite of tomorrow's warfighter.

Introduction

Objective Peach: This bridge was one of the most important terrain features in the theater. My battalion's mission was to take and hold that bridge. My only problem, I was blind. No network, no sensors, no intelligence could tell me what was defending it. Nothing had made it down to my level although someone above me might have known. As night fell, I arrayed my battalion in a defensive position on the far side of Objective Peach waiting for reinforcements that were overdue. Finally I received a bit of intel that an enemy brigade was moving south toward my position. However, the situation was much more threatening than he could have imagined. Facing him was not one but three enemy brigades with at least 25 tanks, upwards of 80 armored personnel carriers, artillery, and between 5,000 and 10,000 enemy soldiers. This massed force should have been easy to detect with our multitude of sensors but we got nothing until they slammed into us!¹

Was this an excerpt from a forthcoming Harold Coyle novel perhaps? Unfortunately for LTC Marcone of the 69th Armor of the 3rd Infantry Division, this happened to him in Iraq on 3 April 2003. Where was that dominant situational awareness US troops are supposed to have?

Technology and tactics conspired against LTC Marcone that day in Iraq. What is the take away from this event? The military should realize that situation awareness or rather battlespace awareness must improve. In the near future, dominant battlespace awareness will involve integrating constellations of command, control, communications, intelligence, surveillance, and reconnaissance (C3ISR) sensors providing persistent coverage of the battlespace.

Platforms exploiting near space will be part of an integrated solution to increase persistent C3ISR. First, this paper will examine the current thoughts on persistent ISR, and battlespace awareness with respect to the lessons learned in Afghanistan and Iraq. Next, this paper covers the capabilities and limitations of current C3ISR platforms supporting battlespace awareness. After identifying the deficiencies are, this paper then explores the various platform and payload combinations that can reach the near space altitudes of 20 to 150 kilometers (km). To properly frame the discussion, “near space” is defined and the challenges of using platforms at such altitudes are discussed. Finally, this paper concludes with a comparison of capabilities and concepts of operations (CONOPS) for several near space vehicle (NSV) constellations. Thus, the first step is to explore the current views on persistent ISR.

Persistent Battlespace Awareness

Department of Defense (DoD), military service, and industry leaders have focused on increasing C3ISR persistence. The war in Afghanistan demonstrated the military the value of finding, tracking, and attacking targets near-instantaneously. Former Secretary of the Air Force (AF), James G. Roche, believes the military needs to increase ISR persistence to the 24/7 threshold.² He continued the theme in a Wall Street Journal interview, maintaining that Afghanistan was “a conflict where you require persistent ISR 24 hours a day, seven days a week, 365 days a year, good weather or bad weather.”³ The enemies of the future are not likely to sit around and present themselves as targets of opportunity. Operational military sensor platforms cover the required battlespace but not all the time. Currently, the AF plans to leverage its persistent C3ISR capabilities “to ensure joint air, space and cyber-space dominance, strengthen joint warfighting capabilities, and build the future total force”.⁴ The Navy and Marines are also support increasing C3ISR persistence. The Chief of Naval Operations, ADM Vernon Clark, has a vision that persistent precision fighting coupled with persistent ISR will allow soldiers on the ground to bring precision to bear in incredible new ways.⁵ Edward Bair, Army program executive officer for intelligence, electronic warfare and sensors believes that one ISR challenge is distributing local information collected by one lower echelon to the theater level and other vanguard units.⁶

As warfighters engaged the Taliban in Afghanistan, the AF asked industry to come up with new concepts in improving persistent ISR⁷ and industry reacted quickly. Michael Keebaugh, a Raytheon vice president, said “to fight (our) new enemies, we need ISR that is fused, prompt and persistent.”⁸ Therefore, Raytheon is working on combining data from national and tactical systems to create persistence over the battlespace. Lockheed Martin also believes they have some unique approaches to situational awareness, including the idea of persistent ISR. They view satellites and unmanned aircraft as nodes feeding persistent ISR but other platforms could contribute as well.⁹ The military services agree that increased C3ISR persistence will benefit future warfighters, but how does that fit into the concept of ‘battlespace awareness’?

Gen. Richard B. Myers, Chairman of the Joint Chiefs of Staff, considers the term “ISR” obsolete. He favors “battlespace awareness” to describe the intelligence-surveillance-reconnaissance mission.¹⁰ For example, the US Army defines battlespace awareness as “the ability of joint force

commanders and all force elements to understand the environment in which they operate and the adversaries they face.”¹¹ The Army sees the key to persistent C3ISR coverage in constellations of sensors permeating the battlespace. As DoD presented the Strategic Planning Guidance in February 2004, acting acquisition chief Michael Wynne said the Pentagon’s emphasis is on battlespace awareness.¹² Thus, the DoD Joint Staff considers battlespace awareness the number one Joint Functional Concept, dedicating a Functional Capability Board¹³ focused on improving warfighter capability.

Complete battlespace awareness will become reality when the military successfully fuses data from old, current, and new technologies and pushes the resulting information down to decision makers in the field. The military services are experimenting with new technologies to improve battlespace awareness. Lt. Gen. Bruce Carlson, 8th Air Force commander and the chief of the 2004 Joint Expeditionary Force Experiment, said, “Improving communications, improving intelligence dissemination and giving total battlespace awareness are at the heart of the experiment.”¹⁴ However, future improvements in battlespace awareness must focus on weaknesses found as warfighters implement the kill chain.

The leaders quoted presented a vision that C3ISR persistence will enable warfighters to prevail in future conflicts. However, gaps in the persistent C3ISR coverage exist as shown by LTC Marcone’s push to Baghdad. The warfighter must prosecute the kill chain, that is find, fix, track, target, engage, and assess the enemy.¹⁵ However, a break in any of the links in the kill chain provides an advantage to the enemy. Gaps in C3ISR coverage can be correlated to breaks in the chain in order to visualize relative impact of the gaps. Table 1 compares the components of C3ISR to the kill chain links. The shaded blocks represent the author’s assessment of gaps in C3ISR that could break the kill chain. One could conclude from the table that gaps in reconnaissance have the broadest impact on the kill chain. That observation will become important later in the paper as weighting factors affect which constellations of sensors in near space produce the largest increase in C3ISR persistence.

Table 1 Correlation Matrix for Persistent C3ISR Gaps vs. Kill Chain

C3						
I						
S						
R						
	Find	Fix	Track	Target	Engage	Assess

Current Capabilities

Command, Control, and Communications

Despite the challenges in persistent C3ISR pointed out above, the US military achieved success in the recent conflicts in Operations Enduring and Iraqi Freedom. Effective command, control, and communications were achieved through military satellites, commercial satellites, and standard ground based radios. Multiple airborne platforms provided intelligence, focusing on communications and signals intelligence, to the warfighters. Both satellite and airborne platforms provided the surveillance and reconnaissance effects required to track and defeat the

enemy forces. This section will explore the capabilities and limitations of current platforms to provide the desired information to the warfighter.

As discussed earlier, command, control, and communications were a challenge in Operation Iraqi Freedom. Both Army and Marine units had difficulties in maintaining their lines of communications.¹⁶ Table 2 summarizes the available satellites and ground systems available to ground units. The table summarizes the on-station or dwell time for each platform as well as the size of the data pipe.

Table 2 Communication Platforms

Platform	Constellation	Coverage	Data Rate	Comments
Iridium ¹⁷	66 satellites in low earth orbit (LEO)	Global 24/7	2.4 kbps	
Globalstar ¹⁸	48 satellites in LEO	80% global coverage ¹⁹ +/- 55 deg Lat	9.6 kbps	Covers most of the populated land masses
Inmarsat ²⁰	9 satellites in GEO	Global 24/7	64 kbps	
Intelsat ²¹	20 satellites in GEO	Global 24/7	128 kbps to 155 Mbps	
Thuraya ²²	2 satellites in GEO	20 deg W to ~100 deg E 70 deg N to 18 deg S	46.8 kbps	Satellite phone with good SW Asia coverage
Milstar I and II ²³	5 satellites in geosynchronous orbit (GEO)	Global 24/7	70 to 2400 bps 4.8 kbps to 1.544 Mbps	Crosslinks limited to low data rate
UFO ²⁴	9 satellites in GEO ²⁵	Global 24/7	24 Mbps	
DSCS III ²⁶	13 satellites in GEO	+/- 70 deg lat 24/7	200 Mbps capacity	
Microwave Based Radios ²⁷	Microwave transceivers	Stationary Line-of-sight	up to 1.544 Mbps (T1 line)	

Table 2 shows, given the current snapshot of existing capabilities, everyone with compatible hardware should be able to communicate. That does not mean everyone in a ground unit has a satellite phone. From the Army perspective, it came down to ever-increasing requirements for beyond line-of-sight (LOS) connectivity and Battle Command on the Move (BCOTM). Generally, in Iraq, Brigade and Division level headquarters (HQ) largely relied on LOS microwave with constrained data capabilities. Those subordinate units on the vanguard of the push to Baghdad became vulnerable when they stopped their communications vehicles to receive microwave transmissions.²⁸ The available satellite coverage allowed higher HQ units to talk

with other HQ units at any given time, but the leading elements on the ground did not share in that wealth of satellite communications technology.

Data transfer rates present a different issue altogether. After-action reports in Iraq pointed to inadequacies of the primary voice and data communications systems.²⁹ Warfighters in the field had difficulty gaining access to rates greater than 56 kbps (equivalent to a dial up rate). The current capabilities of military and commercial satellites cannot provide the vanguard warfighters with megabit sized files that would increase their battlespace awareness. Something better is needed and soon.

Intelligence

This section restricts the discussion of intelligence capability to signal/electronic intelligence (SIGINT/ELINT) gathering in order to keep the analysis manageable. The services have several manned and unmanned platforms capable of SIGINT collection. The current state-of-the-art cannot cover the entire Area of Responsibility (AOR) 24/7 without surging the current low-density high-demand assets. Table 3 summarizes the various platforms, their nominal frequency ranges and dwell time in a track. Most of the frequency ranges are estimates based upon the stated capabilities of communication bands (HF, VHF, and UHF) and radar bands (VHF, UHF, SHF, and EHF).³⁰ Performance specifics, that is signal detection range, are classified for these platforms. Generally, if the enemy activates a radar within the AOR, these platforms can see the signal long before the radar can engage. Some have estimated the U-2S SIGINT equipment is capable of 150 nm detection.³¹ The current platforms have the capability to ferret out the adversary's electronic order of battle and collect real time signals. The intelligence collection coverage breaks down, however, when the system tries to locate all the signals across the battlespace in real time.

Table 3 SIGINT Collection Assets³²

Platform	Frequency range	Unrefueled Range (nm) Endurance (hrs)	Comments
RC-135	0.3 MHz to 30+ GHz	3500 11	
RC-12	0.3 MHz to 3 GHz	1200 5	180 nm from ground station
EP-3E	0.3 MHz to 30+ GHz	3000+ 12+	
EA-6B	30 MHz to 20 GHz	1000 3.5	Endurance is longer with air refueling
U-2S	.3 MHz ³³ to 30 GHz	6000 9	
RQ-1	2-18 GHz ³⁴	400 24	Demonstrated payload
RQ-4	3 MHz ³⁵ to 30 GHz	12,000 35	Demonstrated payload

The SIGINT limiting factors are endurance and real-time geo-locations. Table 3 shows that

unmanned platforms have an endurance advantage over the manned platforms due to crew fatigue. Furthermore, some platforms such as the RC-12 Guardrail have no air refueling capability and therefore run out of fuel long before pilot fatigue sets in. In addition, the RC-12 ground-based processing facility tethers the standard 3-ship formation via a 150 nm data link.³⁶ Even though the Predator and Global Hawk have twice the endurance as the manned platforms, they have only demonstrated non-operational SIGINT payloads. Upgrades underway for both platforms, Predator B and Block 10 Global Hawk, include operational SIGINT payloads.³⁷ The EA-6B Prowler serves as a tactical airborne jammer more than a dedicated orbiting SIGINT platform. Even if all the platforms listed in Table 3 were airborne, the uncertainty in the geo-location data is significant without post-collection processing. If a system could tie all the collection assets together, the error ellipses around the signals would collapse rapidly. What kind of advantage might the military gain if numerous SIGINT platforms covered the AOR allowing instant signal geo-location any time of the day or night?

Surveillance

Table 4 summarizes the primary systems the US military uses for airborne surveillance. The three manned platforms can increase their endurance with air refueling. Radar coverage is significant for the E-3 and E-2C aircraft. However, a country like Afghanistan still requires two aircraft just to watch the complete country, and round-the-clock operations would triple that number. Combatant commanders would also need multiple E-8C aircraft to maintain 24-hour coverage of moving vehicle traffic. Tethered aerostats provide another option when authorities require tracking of low flying aircraft. To this end, the US currently employs TCOM and Lockheed Martin aerostats in the US and abroad. The airships carry modified versions of current ground based search radars.³⁸ No matter what platform the military chooses, persistent battlespace awareness requires a significant number of assets. Could more platforms, perhaps with slightly less capability, integrated with the current ‘eyes in the sky’, produce a deeper awareness of the entire battlespace?

Table 4 Surveillance Platforms³⁹

Platform	Range (nm) Coverage Area (sq nm)	Unrefueled Range (nm) Endurance (hrs)	Comments
E-3	280 246,000	5,000 11	
E-2C	>300 150,000	1300 6	
E-8C	140 50,000 (per hr)	3000 9	
Tethered Aerostats	150 70,700	Fixed location continuous	Limited look-up capability

Reconnaissance

The US has an abundance of manned and unmanned platforms to provide high-resolution coverage of specific sites. One drawback is the revisit rate or the persistence of the coverage. Using just commercial assets, a military commander could order a new picture of a spot of land just about every day. Although, that picture would not be available real time, that is often better

than not having a new picture at all. Access to those pictures simply requires a credit card number and an email account large enough to handle the file size. Satellite systems provided by the National Reconnaissance Office supposedly provide images with equal or better resolution but this paper cannot perform a direct comparison.⁴⁰

Manned reconnaissance platforms provide excellent near real time coverage of spot areas. During Operation Iraqi Freedom, the E-8C synthetic aperture radar (SAR) penetrated raging sandstorms to provide coordinates of moving Iraqi forces to Coalition attack aircraft. The Advanced Synthetic Aperture Radar System (ASARS II) on the U-2S radar provides real-time, high-resolution images of fixed and moving targets through any weather at any time.⁴¹ The aircraft passes the images back to its ground station via a LOS data link or satellite relay. Through those same connections, technicians at the ground control station can remotely direct the U-2S sensors to respond to a request for more information about a certain location.⁴²

Table 5 Reconnaissance Platforms

Platform	Data Type	Coverage	Dwell Time	Comments
Eros ⁴³	Optical/ Infrared (IR)	1 satellite at 480 km sunsynchronous 7 launches planned	1 pass twice a week constellation allows twice a day	1.8 m
Ikonos ⁴⁴	Optical/IR	1 satellite at 680 km sunsynchronous	10:30 am local pass once every 3 days	1 m color or 4 m multispectral
SPOT ⁴⁵	Optical/IR	3 sats at 832 km sunsynchronous	At least 1 picture a day	2.5 -20 m multispectral
E-8C ⁴⁶	SAR	140 nm 50,000 sq nm/hr	3000 9	
U-2S ⁴⁷	SAR	100 nm 100,000 sq nm/hr	6000 9	
RQ-1 ⁴⁸	Optical / IR / Synthetic Aperture Radar (SAR)	5.8 nm ⁴⁹	400 24 ⁵⁰	1 ft resolution @15K ft altitude
RQ-4 ⁵¹	Optical / IR / SAR	110 nm 2300 sq nm/hr	12,000 35	

Both the RQ-1 Predator and RQ-4 Global Hawk have similar remote sensor controls. The Predator flies at lower altitudes than the Global Hawk and thus has somewhat better resolution for the optical sensors. However, the Predator provides the best information in its 'stare mode' allowing the sensors to dwell on a target of interest. The Predator then sends the sensor images back to the control station or elsewhere. Some commanders viewing these restrictive images liken it to looking through a soda straw due to its limited field of view. At the other end of the unmanned aerial vehicle spectrum, the Global Hawk provides a complementary set of radar, optical, and infrared sensors to track and identify targets of interest. Its SAR radar is on par with

the ASARS II on the U-2S. During a deployment to Australia, the SAR images showed vehicle tracks on a beach while the optical sensor could spot sailors on the deck of a US aircraft carrier at a 35 nm slant range.⁵² What if military commanders could request a current image of any coordinate within the AOR?

The C3ISR capabilities available to today's warfighter are impressive. To a Desert Storm warfighter, they might appear amazing, but the military can do better. Currently, there are gaps in coverage and throughput. Even if the 'Global Information Grid' linked all the current platforms just discussed, persistence would not reach 100%. Operating platforms in near spaces offers a way to provide enhanced C3ISR capabilities.

Near Space Defined

The discussions so far describe some of the persistence problems with C3ISR. Before moving on toward defining solutions, this section will more fully define near space along with its advantages and disadvantages. General John Jumper, the USAF Chief of Staff; Peter Teets, the DoD Space czar; and General Lance Lord, head of Air Force Space Command recently defined near space as the altitudes between 20 and 300 km⁵³. The Fédération Aéronautique Internationale defines the air and space boundary at 100 km⁵⁴. Near space starts where controlled airspace ends. Over the US, the Federal Aviation Administration controls the airspace up to and including 60,000 feet mean sea level (Class A Airspace). To provide a buffer with any near space vehicles (NSV), this paper considers the start of near space as 65,000 ft or about 20 km. Near space extends up to the lowest altitude that a vehicle can maintain low earth orbit; defined as 490,000 ft or about 150 km. However, near space operations have disadvantages.

Near space is not space, and the US should recognize it as a part of a country's sovereign airspace. US Army documents claim, "there is no formal definition of where space begins." A review of international law, international treaties, conventions, agreements and tradition, reveals that a specific altitude is not mentioned; however, those same conventions define the lower boundary of space as the lowest perigee sustainable by an orbiting space vehicle. Since NSVs are aircraft and not orbiting spacecraft, by international law are in a country's national airspace, regardless of altitude.⁵⁵ For the military to exploit near space, it must be with the understanding that we have overflight rights of a country or be in a position of air dominance.

Aircraft and balloons traveling through near space are not new but the environment is quite different. The U-2 has been flying above 60,000 feet (ft) since the late 1950s. Even amateur balloonists send their payloads routinely above 100,000 ft before their balloons burst.⁵⁶ More recently, the RQ-4 Global Hawk flies operational missions above 60,000 ft. All those platforms have to contend with an atmosphere that is less dense. With that density decrease comes a number of challenges. At 65,000 ft, the atmospheric density is just 7.2% the density at sea level. For near space aircraft that means wing area has to be larger to carry the same weight. Jet engines lose thrust as the operating altitude increases. The same is true for turboprop engines. Propellers in near space require large diameters⁵⁷ or many propellers.⁵⁸ One thing that does increase around the 65,000 ft region is ozone. Ozone is a known corrosive to some rubber and fabric materials. In general, ozone is not much of a corrosive threat to aircraft, but it could be to airships or balloons exposed a month at time.⁵⁹ Higher in the near space regime, ozone concentrations drop and monatomic oxygen dominates. The single atom of oxygen is very corrosive and designs must protect the NSVs from it. In addition to protecting from monatomic oxygen, the designs should handle cosmic radiation that causes single event upsets in the

electronics. The final aspect of near space to address is the wind. Once NSVs rise above the jet stream, they may encounter average winds between 10 and 20 knots (kts).⁶⁰ The wind velocities become a factor when deciding the station keeping fuel requirements for airships.

Technology Pushes

Exploiting near space to solve the C3ISR persistence problems at first appear easy. The U-2S and RQ-4 Global Hawk fly in near space every day. However, there are challenges to be understood and overcome in using near space to increase endurance and thus persistence. Improvements in four technology areas will enhance exploitation of near space: lift, propulsion, station keeping, and power generation. However, designers and users must make tradeoffs between the NSV technologies.

Lift

Fixed-wing NSVs have to trade wingspan and payload weight for altitude and endurance and lighter-than-air (LTA) NSVs have to trade size and payload weight for altitude. Near space vehicles obviously need to generate lift to get to and remain in that environment. Large wings or large gas envelopes provide the required lift for aircraft and LTA vehicles. Basic aerodynamics dictates that lift must equal weight for level flight. Lift in turn is proportional to the air density, the square of velocity, and the lift coefficient that depends on wing area. The RQ-4 (540 sq ft wing area and 22,000 lbs) and U-2S (1000 sq ft wing area and 35,000 lbs) routinely fly in the 60,000 to 70,000 ft regime. AeroVironment's Helios (614 sq ft wing area and 1760 lbs) reached 96,800 ft in 2001. As long as an aircraft with a large wing area provides enough velocity in the low density of near space, it can still fly. However, at some point the wings become so large that standard airfields cannot support them. If NSVs must maintain altitudes above 100,000 feet, then LTA vehicles may provide a better way. LTA airships or balloons need positive buoyancy to rise. Weather balloons rise since the density of helium is less than air. As the balloon rises the pressure and density of air decreases allowing the balloon envelope to expand. The expansion reduces the helium density allowing the balloon to keep rising. Airships have an outer skin that constrains the internal gas envelopes. To achieve lift, helium only fills part of the gas envelopes to allow for expansion at higher altitudes. The near space environment is not where industry optimized aircraft for flight. A search of current literature did not reveal any 'magic' hybrid concepts for lift combining buoyancy and aerodynamic lift to bypass some of the trade-offs. New designs will have to consider the various trade-off factors to make NSVs a reality.

Propulsion and Station Keeping

Propulsion options for NSVs are limited: turbfans, turboprops, electric engines, and the wind. Thus, the trade space encompasses fuel traded for endurance and/or payload. For free-floating balloons, gas volume replaces fuel in the trade space. Conventional NSV aircraft use turbfans or turboprops to keep the vehicle velocity high enough to stay aloft. That type of propulsion provides payload power via generators run off the engines. Newer designs for NSV aircraft and LTA airships use a few electric motors driving large propellers or many motors with average sized propellers. The electric motors imply an abundant electrical power source, but that concept is addressed later. LTA balloons rely on the wind as the propulsive force to drive them over the coverage area. With sufficient ballast and low-density gas, a balloon can achieve limited maneuverability by changing altitude to take advantage of varying wind directions.

Station keeping technologies relate closely with propulsion technologies. Line-of-sight coverage

to the ground from 65,000 ft is about 300 nm. NSVs under their own power will have to maintain their location within a certain tolerance to insure continuous coverage. A constellation of NSVs requires coordinated orbits to maintain adequate coverage. The wind limits a free-floating balloon from tight station keeping. As discussed above, balloons could change their altitude in an attempt to find a different wind direction. A constellation of free-floating balloons requires coordinated launches and replenishment on a daily or twice daily schedule.⁶¹

Power generation

Similar to the propulsion trades, NSVs will have to trade generator size and fuel for the payload size, which in turn influences endurance. Power generation is critical to achieving both adequate payload performance and endurance. The conventional NSV aircraft run generators from their turbomachinery. Those generators provide anywhere from 8 to 25 kVa. However, generation of that power requires fuel. An NSV could carry more fuel for endurance or less fuel to bring up more sensors. For instance, the Global Hawk can carry 2,000 lbs up to 65,000 ft for 35 hrs with a fuel fraction of 0.56.⁶² To increase endurance the fuel fraction must be increased. For example, the Voyager aircraft that spent 9 days flying around the world had a fuel fraction of 0.72. Less payload could provide a longer loiter time, provided extra fuel could be added.

On the other hand, industry recently proved electric power as a viable option for both payload power and NSV propulsion. At the simple end of the spectrum free-floating weather balloons carry small 6 lb payloads for hours at a time. Rechargeable or lithium batteries power those free-floating balloon constellations.⁶³ A combined photovoltaic (PV) and power storage system has the potential to increase NSV endurance to weeks and maybe even months. PV cells cover the upper surface of the NSV aircraft or LTA airship and provide power to electric engines and the payload. Batteries could store power for nighttime operations. However, the battery weight required for an average 120 kW-hr power draw each night (assuming 10 kW for cruise) may be prohibitive.⁶⁴ Fuel cells provide an alternative to batteries to keep the NSVs aloft.

AeroVironment leads the way in the design and production of PV/fuel cell systems. They have flown electric aircraft for the past two decades and their solar powered Pathfinder and Helios aircraft reached near space altitudes in 1998 and 2001. Solar cells, 61,000 of them, covered the top of the 247 ft wing of the Helios.⁶⁵ The company is ground testing a liquid hydrogen/air fuel cell system that uses PV cells to run a compressor for the air. The gases are stored until nighttime, when they recombine in the fuel cell to produce electrical power for the motors and the payload. The entire fuel cell system weighs around 400 lbs and produces up to 80 kW.⁶⁶ That is quite an advance over the Space Shuttle fuel cell system that weighs over 750 lbs and produces only 21 kW. Lockheed Martin is exploring a closed loop hydrogen/oxygen fuel cell system for their High Altitude Airship (HAA). This fuel cell relies on the excess power from the solar cells to electrolyze water into hydrogen and oxygen. They are expecting the fuel cell system to produce an average 360 kW-hr per night.⁶⁷

Electric power and propulsion sound workable but do have some disadvantages. The first downside is hydrogen handling for the hydrogen/air fuel cell. If the NSV is not deployed from the continental US, then the logistics of fueling the aircraft with liquid hydrogen becomes quite a challenge. The way around providing hydrogen is to use a closed cycle like that planned for the HAA or to use a reformer. A reformer cracks petroleum-based fuels, for example JP-8, into hydrogen and byproducts. Unfortunately, the reformer adds weight to the fuel cell system and hydrocarbon fuels are not as energetic per pound as hydrogen.

NSV Types

To this point, this discussion has focused on current military technologies to monitor the battlespace and the gaps in those capabilities. Now the paper can review current NSV designs.

Balloons

Balloons capable of operating in near space come in two types: zero-pressure and superpressure. The zero-pressure balloons are used all around world, for example weather and recreational balloons. A light gas, whether it is hot air, helium, or hydrogen, fills the gasbag. The pressure is the same inside and outside the balloon; thus as the balloon rises, the volume expands to maintain a zero-pressure differential. Balloon materials include latex, polyethylene, or a variety of other materials, but they all suffer from strength and diffusion problems. Such balloon will rise until it bursts, finds its buoyancy point, or loses lift via gas diffusion through the permeable material. If a polyethylene balloon achieves neutral buoyancy, it can stay up for a month or more.⁶⁸ Balloons made from latex allow the gas to diffuse through the balloon wall just as a child's helium balloon falls to the ground after a day.

Raven Industries has a large line of zero pressure balloons. Table 6 summarizes the specifications for their line of sounding balloons while Table 7 shows the much larger scientific balloons. The maximum payload for these sounding balloons is quite limited since Raven Industries designed the balloon to carry rather small weather sensor and telemetry equipment.

Table 6 Raven Industries Sounding Balloons⁶⁹

Balloon Volume (ft³)	Balloon Weight (lbs)	Max Payload (lbs)	Nominal Gross Lift (Including Balloon) (lbs)	Nominal Altitude (ft)
7,560	4.2	52	30	68,000
9,470	4.8	52	30	75,000
19,000	5.7	27	22	95,000
54,000	10.3	34	31	109,000
141,000	18.4	51	50	119,000
300,000	29.2	61	70	130,000
500,000	40.5	64	85	135,000
700,000	50.9	74	110	137,000

However, this class of balloon could carry a repeater for an Army AN/PRC-148 Multi-Band Inter/Intra Team Radio (MBITR). In fact, the AF Space Battlelab is conducting a demonstration in early 2005 called Combat SkySat to carry a repeater for the MBITR radio up to 60,000 to 70,000 ft.⁷⁰ The larger scientific balloons from Raven Industries carry 8,000 lbs of equipment during Antarctic flights. In January 2005, a balloon stayed aloft for 42 days in Antarctica supporting National Aeronautics and Space Administration (NASA) atmospheric studies.

Table 7 Raven Industries Scientific Balloons⁷¹

Volume (mcf)	Model #	Weight (lbs)	Payload (min) (lbs)	Payload (max) (lbs)
4.001	SF3-4.001-.8/.8-NA	930	100	3500
11.82	SF3-11.82-.8/.8-NHR	1611	100	2875
11.82	SF3-11.82-.8/.8/.8/.8-NHR	3038	100	7450
29.472	SF3-29.472-.8/.8/.8-NHR	3631	100	6500
39.572	SF3-39.572-.8/.8/.8-NHR	4005	100	6060
39.572	SF3-39.572-.8/.8/.8/.8-NHR	4996	100	8000

In contrast, superpressure balloons, as the name implies, have a higher pressure inside than outside. The materials are the same but they are assembled differently since they have to handle higher pressures and constant volume. Typical materials include the same polyesters and polyethylene found in zero pressure balloons. For example, the NASA Ultra Long Duration Balloon (ULDB) uses a triple layer of polyethylene and polyester glued together with two soft adhesive layers.⁷² The 1.5-millimeter thick sandwich is comparable to the thickness of a breadloaf bag. NASA partially demonstrated the 2 million cubic foot (mcf) balloon in Australia during March 2003⁷³ and a 6 mcf in February 2005. That latest demonstration attempted to lift 3000 lbs to 100,000 ft but failed at altitude when a restraining cord failed.⁷⁴ The potential of 6-month endurance flights is the primary advantage of superpressure balloons.

Propulsion is another classification method for balloons. Balloons are either free-floating or steerable. Due to their simplicity and low cost, free-floating are by far the most prevalent. The winds aloft determine the speed and direction a free-floating balloon. Alternatively, concepts exist allowing some steering. JP Aerospace developed a steerable balloon concept for the AF Space Battle Lab called a near space maneuvering vehicle (NSMV).⁷⁵ Depicted in Figure 1, the balloon suspends its payload and propulsion system between two cylinders.⁷⁶



Figure 1 90 and 175 foot Sub-scale Ascender Balloons from JP Aerospace⁷⁷

Airships

Airships encompass another platform design that can reach near space. Most aeronautical engineers define airships as lighter-than-air vehicles that have a structure, are self-propelled and

can control their flight path. Airship designs are divided further into rigid, semi-rigid, and non-rigid. Rigid airships have an internal framework to support the fabric envelope, for example *Hindenburg* and *USS Akron*. The semi-rigid airships possess a keel underneath the pressure envelope to help keep the shape. Non-rigid airships depend solely on the lifting gas to keep the shape of the pressure envelope and there may be separate internal ballonets to maintain buoyancy, for example Goodyear blimp. The airships all share an external propulsion design, usually a piston engine powering propellers.

Innovators have proposed both standard cigar-shaped and spherical-shaped designs to reach near space. In response to a Missile Defense Agency request, Lockheed Martin designed a 500 ft long, 5.6 mcf⁷⁸ high altitude airship (HAA) capable of carrying 4,000 lbs of payload to 70,000 ft (see Figure 2).⁷⁹ With a combined solar-electric / battery or solar-electric / fuel cell power system, the HAA could deploy from the US to the AOR and return to the US after a month or more on station. The HAA is currently in an extended Design and Risk Reduction Phase of its Advanced Concept Technology Demonstration.⁸⁰



Figure 2 Lockheed Martin Notional High Altitude Airship⁸¹

Alternatively, Techsphere offers a spherical, high altitude airship called the Aerosphere. Figure 3 shows an artist's conception of the airship. Only the propellers protrude from the sphere, leaving all the power, control, propulsion, and payload systems contained inside the sphere. A prototype of the Aerosphere with a 62 ft diameter reached 20,000 ft in June 2003 with a payload of over 200 lbs.⁸²

Unmanned aircraft

The last vehicle class to consider is the unmanned aerial vehicles (UAV), that is high altitude, long endurance (HALE) aircraft. One could argue that all the vehicles discussed up to this point are unmanned. Even so, this paper defines UAVs as aircraft. This section summarizes the Global Hawk, Theseus, Proteus, and Helios, which represent a variety of designs, capabilities, and technology readiness levels.



Figure 3 Artist's conception (left)⁸³ and prototype (right)⁸⁴ of Techsphere Aerosphere

The RQ-4 Global Hawk represents the first generation of HALE aircraft. Northrop Grumman has just begun delivery of operational aircraft to Beale Air Force Base in California. As discussed earlier, the Global Hawk flies at 65,000 ft with a 2,000 lb payload for up to 35 hours (hrs). A traditional Rolls-Royce turbofan engine propels the Global Hawk and a generator tied to the engine provides 10 kilovolts to the avionics payloads. Upgrades to the Global Hawk include increasing the payload capacity to 3,000 lbs and power available to 25 kVa, albeit at slightly reduced altitude and endurance.⁸⁵

Theseus, built by Aurora Flight Sciences, is a moderately capable HALE. A traditional Honeywell TPE331-14F turboprop propels the 7,900 lb aircraft up to 60,000 ft (just below near space). Theseus generates 6 kVa to power up to 1,800 lbs of sensors. Two environmentally controlled wing pods house the sensors and Aurora Flight Science claims up to 36 hrs total mission time. One unique feature of the Theseus is that it is transportable in a standard 40 ft shipping container.⁸⁶

The Proteus, built and flown by Scaled Composites, has similar capabilities as the Theseus (see Figure 4). Two Williams International FJ44-2E turbofans, modified for high altitude, power the aircraft up to 61,000 ft. The aircraft can be manned or unmanned depending on the mission. The generators provide 800 amps at 28Vdc for the payloads carried internally or externally in pods. Drag on the externally carried payloads prevents the aircraft from climbing above 60,000 ft. Scaled Composite's flight test results show the aircraft cannot cruise above 60,000 ft with much more than a light payload for any significant duration.⁸⁷ A cruise altitude of 45,000 ft provides a much better flight condition at which to trade payload weight vs. endurance.



Figure 4 Proteus with NASA Langley Research Center Pod⁸⁸

Lastly, the Helios Global Observer, designed by AeroVironment, builds on the company's long line of lightweight solar powered aircraft. Designed to loiter at 65,000 ft with over 600 lbs of payload for 1 week, the Helios Global Observer meets the true definition of a HALE aircraft. The Helios hopes to achieve long endurance with a proprietary photovoltaic/fuel cell power system. The power system drives the multiple electric propeller engines and has 6 kW left for the sensor package. AeroEnvironment and its partner SkyTower are gathering funding to build their latest design iteration.⁸⁹

Payloads

The payloads destined for NSV parallel the C3ISR capabilities possessed by current platforms in the lower atmosphere and in space. Radio repeaters and "data routers in the sky" would start to fill the communication gaps described earlier. Specifically, the MBITR radio repeater demonstrated on the Combat SkySat over Texas would supplement existing satellite communication infrastructure. Beyond LOS connectivity and BCOTM enhance battlespace awareness. Advanced wireless protocols such as IEEE 802.16 (WiMax) could enable up to 75 Mbps data transfer rates with a roaming capability. Using higher power levels at 5.75 GigaHertz (GHz) extends coverage beyond the current limit of 30 miles.⁹⁰ NSVs equipped with advanced radar technologies could simultaneously produce multiple ISR effects. Low and mid band receiving antennae fused with information from current generation active electronic steered array (AESA) radars could provide 300 nm radius coverage for SIGINT. AESA radars with multiple arrays could provide 360-degree coverage for surveillance as well as on demand spot reconnaissance coverage. Optical cameras similar to Global Hawk cameras provide additional means to identify targets found via the synthetic aperture radar.

Threats

Constellations of NSVs hovering over the battlefield are not immune from various ground-based threats. Depending on their altitudes, NSVs could find themselves under attack by high performance interceptor aircraft, for example MiG-25 or MiG-31. The MiG-31 was a slightly different design than the MiG-25 but served the same interceptor role as the more common MiG-25. In either case, the MiGs can reach altitudes exceeding 67,000 feet before launching radar guided air-to-air missiles.⁹¹ The threat to aircraft like Global Hawk or other aircraft with a relatively high ground speed is real. However, airships and balloons with their near zero ground speed might escape a radar missile attack because they occupy the Doppler notch of the radar preventing tracking at slow speeds. Based on current threats, NSVs at altitudes above 100,000 feet should be relatively immune from current airborne interceptors.

Other threats do exist in the form of surface-to-air missiles. The most lethal threats today are the Russian S-300/400 and Antey-2500 systems, which can engage targets at range of altitudes and ranges up to 200 km.⁹² According to Jane's, several of the missiles used with the operational S-300PMU can reach up to 38 km (98,400 ft).⁹³ Even the veteran S-200 (SA-5 Gamon) surface-to-air missile system with its Square Pair engagement can destroy targets as high as 40 km (131,200 ft) or as far as 300 km.⁹⁴ The only protection NSVs may have is potentially slow relative velocities with respect to the engagement radars. If that velocity is below the minimum velocity cut-off for the radar, the radar cannot track the NSV without a software upgrade.

Still another potential threat is from ground-based lasers. Future adversaries may possess ground-based lasers potent enough to provide a 'mission' or 'hard' kill of an NSV. Reports from within China and analysis by the West indicate that China has a keen interest in ground-based

lasers. The Chinese research has centered on anti-satellite lasers, therefore, if the Chinese can solve laser power and satellite tracking problems, modification of the system to track and attack NSVs would be achievable⁹⁵. Work would have to begin now in DoD labs to design countermeasures for the NSVs to negate the laser threat. Now that challenges and risks have been presented, potential concepts of operations for NSVs can be discussed.

NSV Comparison and CONOPS

Up to this point the discussion progressed from our current C3ISR capabilities and the gaps in 24/7 persistence. This section presents a comparison of and concept of operations for the various near space vehicle constellations to show how they might cover the gaps in persistent C3ISR. From the information provided up to this point, four systems have the potential to perform the near space C3ISR mission in the near term: free-floating balloon constellations, flights of RQ-4A/B Global Hawks, long endurance airships and aircraft.

A constellation of free-floating balloons at 65,000 ft would provide extended coverage for ground radios. Space Data Corporation (SDC) currently uses such a system to provide two-way messaging service across the remote stretches of Texas, New Mexico, Oklahoma and other adjoining states. Each day, personnel located at small regional airports at the western edge of the coverage area release standard weather balloons with small 6 lb electronics packages. The packages contain a Global Positioning System receiver, two-way paging transponder, and batteries while SDC controls the constellation from a central location. After 24 hours aloft, the electronics packages drop from the balloon and float down for recovery. This system could easily be adapted to cover gaps in LOS communications on the battlefield. For example, a repeater for the US Army MBITR radio repeater could replace the two-way paging electronics.

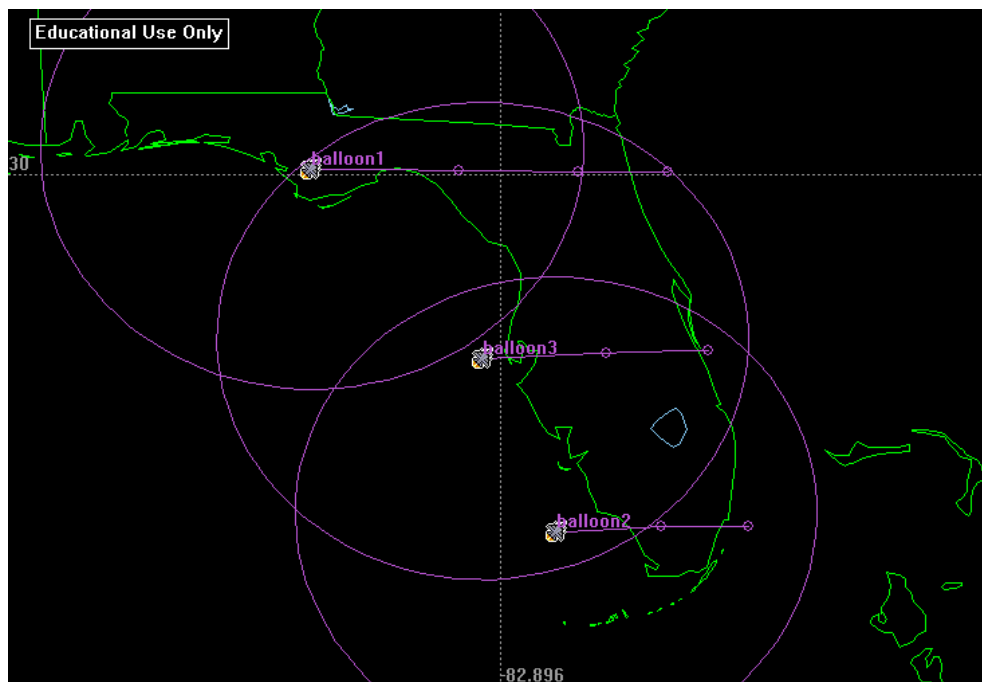


Figure 5 Three-Balloon Constellation Over Florida Peninsula⁹⁶

The advantage of this system is hardware cost and personnel. The equipment requires no new

technology development, and personnel required are one per balloon launch site, five or so in the control center, and a small team to recover the electronics if within a secure area. The disadvantages include launch/recovery locations, limited payload capability, and limited persistence.

Figure 5 shows a three-balloon constellation over the Florida peninsula. The figure assumes secure land-based and ship-based launch sites. Recovery, if practical, must occur in an equally secure location, at sea for this CONOP. The snapshot is 12 hours after release from three locations outside the area of responsibility. The circles assume an omni-directional antenna on the balloons and a 5-degree masking angle from the ground. Continuous coverage requires replenishment after about 12 hours assuming a 10-knot wind at 65,000 ft. Again, the balloon size restricts the payload to 6 lbs, which limits the ability to cover gaps in anything but beyond LOS communications. Larger balloons carry larger, more expensive payloads, but those expensive payloads would make recovery more of an imperative.

The RQ-4 Global Hawk provided outstanding surveillance and reconnaissance in Afghanistan and Iraq, although the number of aircraft was insufficient to provide 24/7 coverage. With a full squadron of 24 RQ-4s, that includes a mix of Block 0 and the upgraded Block 10 aircraft, persistent coverage of an AOR is within reach. The mix of aircraft closes gaps in persistent ground surveillance, ground reconnaissance, and SIGINT capabilities. Furthermore, with multiple SIGINT capable RQ-4Bs overflying the AOR, instant geo-location of radio frequencies is possible. Future upgrades to the payload should include joint tactical radios as well as WiMax type capabilities to cover further the C3 gaps. That would leave only an air surveillance gap, hopefully, covered by E-3 and E-2C aircraft.

The RQ-4 constellation has its advantages as well as disadvantages. Current aircraft performance allows it to reach near space and stay there for over 24 hours. Operators at remote locations control the ground surveillance and reconnaissance sensors. Twenty-five personnel launch, recover, and control the aircraft during 24-hour operations.⁹⁷ Unfortunately, the AF needs runways close to the AOR to permit 24-hour endurance. In addition, the aircraft has not reached Initial Operational Capability, limiting the number of regional ISR tracks the aircraft can support. Finally, the RQ-4 avionics cannot find and track airborne targets so air surveillance has to rely on manned platforms.

Figure 6 depicts the Global Hawk constellation over a Texas sized AOR. The four aircraft provide coverage for communications assuming a 5-degree masking on the ground. This constellation allows beyond LOS communication for the Army and beyond LOS command and control to include high data rates. Assuming the communications package is mutually exclusive with the SAR and optical sensors, approximately four more aircraft could meet surveillance and reconnaissance needs.

The long endurance (LE) airship has the potential to fill all the C3ISR gaps identified. Lockheed Martin hopes to produce the High Altitude Airship for the Missile Defense Agency ACTD. That airship will carry 4,000 lbs to 65,000-70,000 ft, which is the largest payload of the systems considered by far. That lifting capability enables the airship to lift equipment to address all the C3ISR areas. Aerostats currently use surveillance radars that can see out to 200 nm,⁹⁸ and the HAA could house a similar design with plenty of space for other payloads. Communications avionics, optical cameras, SAR, and SIGINT sensors round out the technologies required to meet the C3ISR gaps. The other advantage is an endurance of at least 30 days with a regenerative

solar/fuel cell system. The number of HAAs in a theater still depends on the area covered, and Figure 7 shows the constellation over a Texas-sized region. Unfortunately, the future for airships is not without its limitations.

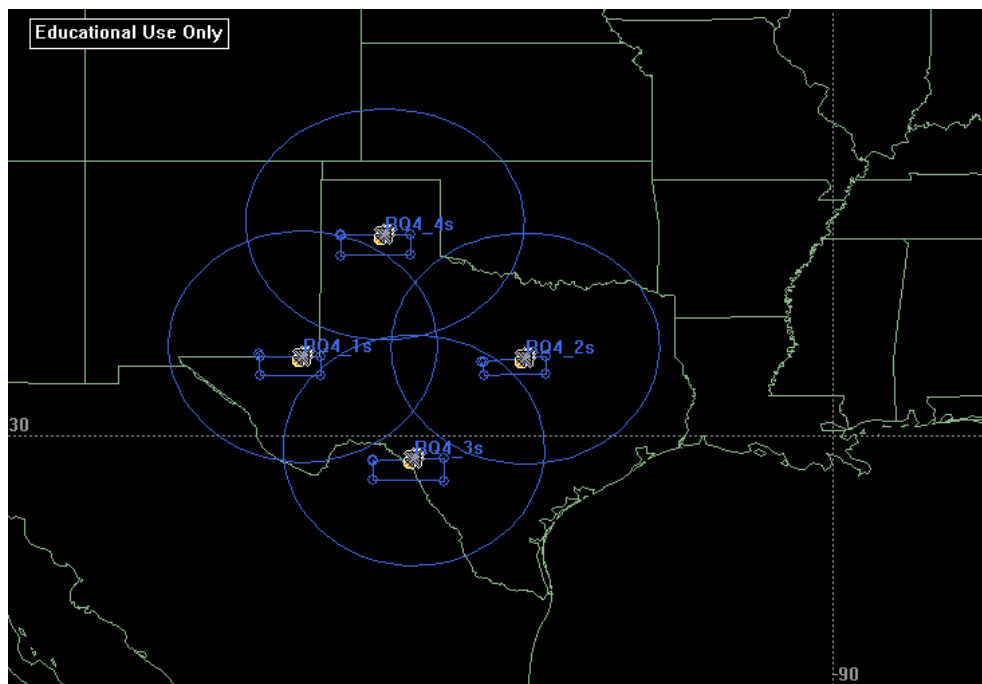


Figure 6 Global Hawk Constellation

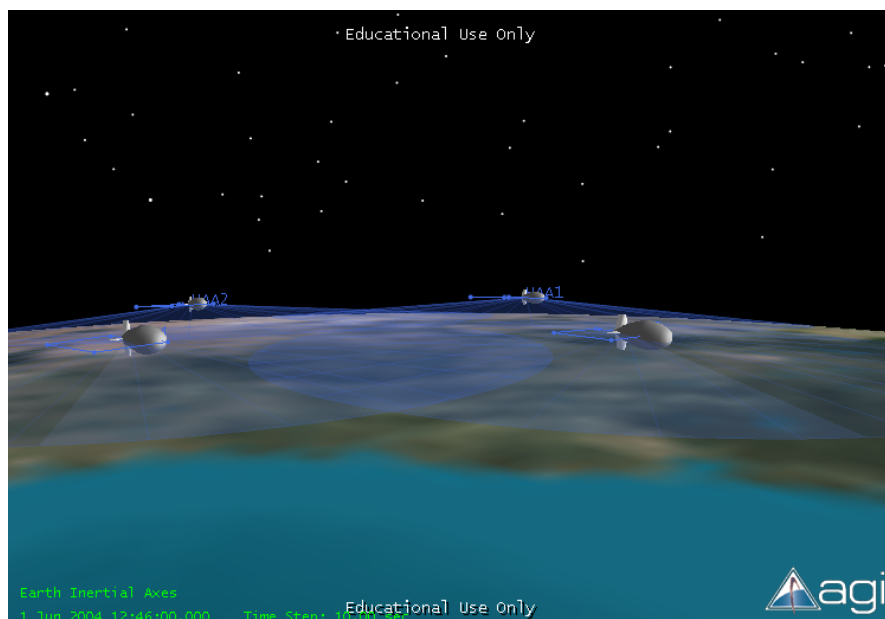


Figure 7 High-Altitude, Long-Endurance Airship Constellation, 3D Perspective

The HAA concept has its difficulties, and size is the first. For example, the Lockheed Martin HAA is nearly 500 ft long, which restricts the launch locations. Fortunately, Lockheed Martin

has use of the old US Navy dirigible hangar in Akron, Ohio. However, more HAAs would require construction of additional large airship hangars. With such a large infrastructure, deployment from US bases would be the norm. There would likely be no forward basing options, and like other airships, ground handling presents a manpower challenge. Every launch and recovery would require a large ground crew to wrestle the vehicle to the ground and into a hangar or to a mooring pylon for refurbishment. Another challenge for the airship is wind speed at altitude. The near space section defined winds at 65,000 feet as less than 30 kts; however, maximum winds can exceed 100 kts at higher latitudes.⁹⁹ The HAA could no longer station keep at those wind speeds.

An LE aircraft, similar to the Helios Global Observer (HGO), provides seven times the Global Hawk endurance but has less than half the payload capacity. That is good news and bad news. Under the latest CONOPS, HGO platforms would be needed once a week rather than once a day for Global Hawk. The HGO could self-deploy from the continental US due to its large wingspan of 297 ft (747 has a 212 ft wingspan) and then operate from regional bases. Basing within 2,000 nm of the AOR requires only three aircraft for 24/7 coverage,¹⁰⁰ which is roughly a quarter of the Global Hawk required for the same scenario. The reduced payload capacity compared with the RQ-4 may not be as bad as it sounds. The latest generation of avionics compresses optical, SAR, and SIGINT sensors into a 600 lb package. Data and voice communications boxes weigh about 100 to 200 lbs, allowing the HGO to address most of the C3ISR gaps. The LE aircraft constellation appears almost identical to the Global Hawk constellation in Figure 6. The difference between the two is the slower airspeed of the LE aircraft in the station keeping tracks.

Table 8 NSV Concepts Weighted Effects Matrix

	C3	I	S	R	Personnel	TRL	Sum
Balloon	3	1	1	1	5	5	16
RQ-4A/B	2	4	4	4	3	5	22
LE airship	4	4	4	4	1	2	19
LE aircraft	4	4	2	4	4	3	21

In summary, Table 8 addresses the impact or the ability of each NSV concept to close the C3ISR gaps identified in the first section. The numbers in each block provide a relative weighting scale with 1 providing the least impact and 5 providing the most toward closing the gaps. The matrix also contains a personnel and technology readiness level (TRL) to qualitatively weight. The information provided in Table 1 provides additional weighting factors for Table 8. Gaps in reconnaissance had the greatest affect on the kill chain. In this case, weighting reconnaissance more than the other C3ISR areas has no impact in Table 8. Based on the information presented, building up the number of RQ-4 aircraft would be the most appropriate step to take at this time. The other options provide either too little capability or are not mature at present. As technology matures, the long endurance aircraft powered via a solar/fuel cell system would provide the most C3ISR effects for the smallest resource set. However, the table does not take into account any additional weighting of the C3ISR areas. For instance, if the combatant commanders requested improved C3 persistence ahead of ISR then the free-floating balloon system has the potential to rise to the top (pardon the pun).

Conclusion

The transformed battlespace of the future will include constellations of sensors in orbit, in near space, and in the air. As of today, the air and space platforms do not provide persistent coverage of C3ISR or in the words of Joint Chiefs of Staff, Gen Ryan, persistent "battlespace awareness". The military voice and data links to vanguard units on the ground are intermittent and slower than a dial-up modem. Intelligence coverage (SIGINT) all day, every day, requires manned platforms that the AF just does not have available all the time. Manned reconnaissance and surveillance platforms have the same low-density, high-demand challenge as the intelligence platforms. Unmanned platforms are beginning to fill the gaps but not quickly enough.

Placing advanced platforms in near space (65,000 ft to 490,000 ft) lowers the sensors from the ultimate high ground of space. The sensors are closer and thus have better resolution. Several concepts exist to exploit near space to close the gaps in C3ISR capabilities and ensure the warfighter has an unbroken kill chain. Free-floating balloons offer ease of deployment but lack station keeping and payload capacity. Balloon communication payloads extend connections beyond LOS but only a few channels at a time. Larger balloons offer more payload capacity but that forces recovery efforts to recycle the payloads. Airships with station keeping propulsion can potentially carry 2 tons to near space; however, no blimp has ever flown that high. Nevertheless, with additional development, the airship could prove to be a potent near space vehicle. Airships could easily carry avionics to provide multi-channel beyond LOS with bandwidth to spare. SIGINT antennas, surveillance radar, and reconnaissance sensors fill out the remaining payload capacity preventing gaps in ISR. Unmanned HALE aircraft provide the best near term solution to exploit near space. A detachment of RQ-4 Global Hawks sent to the theater with a mix of fielded reconnaissance sensors and future communications and SIGINT avionics can cover the gaps left open from manned and space platforms. The future of HALE aircraft belongs to concepts that can increase endurance with efficient propulsion, regenerative power systems, and compact, integrated sensor packages. Endurance of a week combined with a mix of C3ISR sensors creates a buffer to protect the kill chain from weakness as the warfighters accomplish their objectives. With the right mix of near space vehicles 24/7 achieves the ultimate vision of persistent battlespace awareness.

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⁸ Michael Keebaugh, *Intelligence Integration Gives the Big Picture* [Web Site] (Defense News, 22 Nov 04 2004 [cited Jan 15 2005]); available from <http://www.defensenews.com/story.php?F=513690&C=commentary>.

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¹² Amy Butler, "Wynne: Net-Centricity, Battlespace Awareness, Force Protection Key for Budget," *Defense Daily*, Feb 13 2004.

¹³ Hugo Keyner, "Evolving Mission Capability Acquisition Practices Panel" (paper presented at the 2004 PEO/SYSCOM Conference, Ft Belvoir, VA, 17 Nov 2004).

¹⁴ JEFX 04 had several concepts aimed at improving battlespace awareness for the warfighter. Jim Garamone, "Air Force Tests Future Concepts," (Washington DC: Air Force News Service, 2004).

¹⁵ *Global Strike Joint Integrating Concept*, Version 1.0 ed. (Department of Defense, 2005).

¹⁶ Talbot, ""We Got Nothing until They Slammed into Us.""

¹⁷ 66 + 6 spares. Tamar A. Mehuron, "2004 Space Almanac," *Air Force Magazine*, Aug 2004.

¹⁸ Ibid.

¹⁹ Most of Africa and India, part of Russia, SE Asia, and China are excluded. Globalstar, *Globalstar Coverage Map* [Web page] (Globalstar Corporation, Jan 7 2005 [cited Feb 15 2005]); available from <http://www.globalstar.com/en/satellite/>.

²⁰ Mehuron, "2004 Space Almanac."

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²² Satellites at 44 deg and 28.5 deg E. Thuraya Satellite Telecommunications Company, *Technology* [Web Page] (2004 2004 [cited Feb 15 2005]); available from http://www.thuraya.com/tech/space_industry.htm.

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²⁷ Personal communication with Army Signal Officer, Maj Mike Brown, Feb 05.

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- ³⁴ Northrop Grumman factsheet for LR-100 quotes use in Predator. Northrop Grumman, *LR-100 Receiver* [Brochure] (2005 [cited Feb 15 2005]).
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- ³⁶ Guardrail can operate untethered but has to return to within range of the datalink to send SIGINT data back for processing. Modern Technologies Inc., *Guardrail Common Sensor Program Summary and System Description* (Apr 15, 1994 1994 [cited Feb 15 2005]).
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- ⁴⁵ *The Spot Satellites* (Spot Image Corporation, 2004 [cited Feb 15 2005]); available from http://www.spot.com/html/SICORP/_401_444_445_.php.
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