4.0 Space Missions and Their Applications to Warfighting

4.1 Reconnaissance and Battlefield Awareness

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4.1.1 Summary

This paper presents ideas and recommendations designed to stimulate thought, action, and decisions about the role of the United States Air Force (Air Force) into the next century. Its focus is Global Reconnaissance, particularly imagery and its use to support military operations. It assumes the Air Force will be aggressive in working out an appropriate role in the US hegemony of the "high ground" of space not only for combat, but also for crisis surveillance of potential battlefields. Technology adequacy is the theme, but the limiting factor to technological superiority is not the challenge of advanced technologies' availability; it is, rather, the adoption of Air Force-sponsored technologies into systems meeting operational needs, simultaneously taking full advantage of commercial technology and systems, integrating these advances into an increasingly complex "system of systems," all of this in a much improved acquisition climate and process which takes account of multiple user needs, foreign countermeasures, stringent budgets, and global use of space for commercial and military-supportive ends.

At every instance where military threats challenge the interests of the United States, the Air Force must be in a position to respond directly and promptly. The Air Force, as the designated DoD lead for space, must be ready to support all United States military and intelligence assets as our national macrostate moves from peace, through crisis, to conflict. The "battlefield awareness" enjoyed by US commanders in Desert Shield/Storm led directly to "battlefield dominance," and to a quick and relatively bloodless victory. An oft-repeated lesson of history was demonstrated in the Persian Gulf: all other things being equal, the adversary with the best intelligence wins.

The role of the Air Force in this new world is as the national crisis-through-conflict "information leader." A key change in Air Force, Pentagon and congressional perception of the Air Force mission is the necessity to broaden the term "close air support" to include "battlefield reconnaissance data." The Air Force must step up to the challenge that simple statement implies, accepting its current responsibility and broadening it as described, including successful negotiation with the national agencies and the other military services to cede some of their current power and budget. Difficult as such a challenge may seem, there is actually broad sympathy for such focused leadership. We believe it is critical to the national interest for the Air Force to accept this mantle.

Technology leadership must be a byword for the Air Force, continuing from its present strong foundation, but broadening to include stronger liaison and technology transfer roles with the National Reconnaissance Office (NRO) and the users, represented by the CINCs -- ranging from the forward-area deployed soft-copy analysis station to the National Photographic Interpretation Center (NPIC), Defense Mapping Agency (DMA), and all DoD and service-related users. The Air Force should adopt a charter and vision which at least incorporates the following:

- A system-of-systems to collect, analyze, archive and disseminate information of importance to the warfighter. This should include at least weather, maps, imagery

of possible battlegrounds, condition of roads, lines of communication, weapons types, precise location during combat, and numbers, readiness and organization structure of the probable adversary.

- An array of collectors, including at least manned aircraft, remotely piloted vehicles with loiter capability (including low observable technology to permit deep penetration and long endurance on target), with all-weather sensing (through a combination of SAR electro-optical and multispectral sensors) capability, and either a permanent high orbit long-dwell capability, a constellation of single-function small satellites, or a launch-on -demand tactical satellite system with all-weather imaging capability to supplement and enhance the coverage of upgrades to current systems. The constellation of space imaging assets should reflect the different applicability of waveband to reconnaissance requirement. Specifically, 1) frequent revisit SAR of mid to low latitudes with one meter resolution should be achieved by a small constellation at low inclination, low altitude small satellites to provide all-weather, day-night observation capability, 2) baseline one meter visible, imagery should be accomplished through a judicious baseline of commercial imagery supplemented as appropriate for reasons of timeliness, revisit, and assured availability, with electro-optic small satellites and/or use at low resolution of the "high quality" low earth heavy satellites, and possibly, geosynchronous long-dwell, large-aperture systems, 3) high quality visible imagery, 4) one-meter mid-wave infrared, two-meter long-wave infrared, and two-meter multispectral from a combination of single-purpose and small satellites, and 5) ten-meter hyperspectral resolution systems for small images of analytical interest (for example, for detection of BW/CW agents or narcotics precursors).
- An open architecture to permit easy incorporation of technology advances in collectors, data storage and transmission, including all-source fusion methodologies, algorithms, techniques, and automatic and/or analyst-aided exploitation decision support systems as they become available, proven and affordable.
- An inherent ability to deploy the forward elements of the system to any part of the world on short notice and to be ready within minutes to pass desired information from all current and archival data bases to the deploying troops, systems and smart weapons.
- A strong and well-funded team to design, develop, acquire and operate the system with suitable assignment of responsibilities within the DoD, NIA, and NRO, but under the overall guidance of the Air Force.
- A policy of cooperation with commercial developers of systems and subsystems to ensure conformance with standards and availability of data throughout the development cycle and the macrostates of crisis and conflict, importantly including Air Force understanding and potential denial of commercial imaging data to enemies or their probable allies.
- A seamless interface within the government between operational users, daily operation support, and the intelligence community to ensure sharing of databases,

commonality of objectives, and straightforward cooperation during any transition from peace to crisis to conflict.

Most of these foundation recommendations are achievable with existing technologies or low-risk extensions to them. The rest are within sight -- on the drawing board in many laboratories Not all are government-sponsored, hence the need, and desirability, of leveraging commercial technologies and acquisition practices, not only for the cost and speed of implementation advantages but also for improving interdependence and exploring commonality of interests.

We must "get on board" the developing infrastructure for alternatives to our large, expensive and vulnerable "best-in-the-world" systems. We should continue pursuing trades toward constellations of small satellites providing lower resolution, bur more synoptic and/or more frequent revisit coverage. To do this we must encourage and invest in advances in materials, sensors, stabilization techniques, and if necessary, light boosters (although we applaud the growing availability of commercial launch capability).

We must lead, rather than be led, in the shifting focus from watching the monolithic and dangerous Soviet Union and its successor states to watching hot spots world-wide, encouraging the development of automatic warning and alert methodologies, including the full participation and use of all-INT products, tasking, and tip-offs.

We must develop and learn to use effectively the triad of manned aircraft, UAV's/RPV's and satellites for synergistic as well as complementary intelligence.

We must recognize the advantages distributed architectures for collection, processing archiving, and dissemination -- and preparation of all-source product -- are virtually within reach with global systems of interconnected and intercommunication satellites just over the horizon, being provided by commercial interests, domestic , foreign, and supra-national.

We must move military user-level processing, fusion and exploitation "down the chain" from the centralized exploitation resource of a few ground stations and a few exploitation centers to the maximum dispersal consonant with advances in computer distributed storage processing and exploitation support and with the users' needs, including direct downlink to the battlefield as appropriate. There are plans to provide such data to nodes of a global grid dissemination system, but a single Do D element -- we recommend the Air Force -- should provide customized products based on USG-wide standards to all military users. The Air Force must commit to provide this information in the form desired by the user and in time for him to benefit from it.

A single authority for miliary space architecture development and streamlined acquisition is essential. The NRO model worked well for the immensely complex systems to date, systems targeted at "exquisite" performance against denied area targets, often for purposes of ascertaining enemy weapon design data. We do not face this complex a task for most of today's requirements. A new model with faster and simpler documentation appropriate to "less than perfect" relatively inexpensive small satellite constellations and launch-on-demand systems must be developed. Either the NRO or the Air Force is able to design, develop and produce in accordance with this new approach to provide this supplemental capability; the Air Force needs to lead in 1) setting DoD requirements sufficient to stipulate performance allocation across the spectrum of sensing alternatives, and 2) assuming responsibility for delivering the usable products on time.

Our advantage over the commercial sector and our enemies who will benefit from it, which we will retain if we keep moving, in the experience of 35 years of overhead imagery collection and analysis for intelligence purposes and our ability to systematize its use for warfighting purposes.

We cannot afford to lose this edge as other countries obtain overhead intelligence systems and begin watching us. In the final account, intelligence, even that obtained from the best satellites in the world, is only useful to the warfighter if he gets the right information first.

The technology is here, or on the way. The time to act is now. Our citizens want minimum life-at-risk defense at the least reasonable cost. The Air Force, with its charge to "hold the high ground of space," is in the driver's seat. The technologist will be an enabler of the visionary leader who recognizes both the challenges and the opportunity to meet them.

4.1.2 Introduction

This paper is prepared to stimulate discussion as well as to generate ideas about the future role of the United States Air Force in the area of Reconnaissance and Surveillance in support of Battlefield Awareness. It addresses the VISTAs time period: twenty to thirty years from now.

The business of predicting the state of technology twenty to thirty years from now is, at best risky, at worst foolhardy -- crystal balls get fuzzier the further one attempts to predict. However, when carefully based on past and current state of the art, analysis and projections have proven to be useful in charting a long range strategy.

It may be argued correctly that it is difficult to exaggerate the probable advances in technology, based on the pace of developments during the last thirty years. But the real issue for planning purposes is not necessarily the rate of development, but the rate at which those developments reach maturity and are ready for widespread application.

Similarly, it is a true indictment that most technical historic long-range predictions have been notoriously in error in scope, in specificity, and in utility. We counter that:

- We have a comprehensive input from participants across the entire range of both the history and the technology of US overhead reconnaissance
- The bounds of physics, economics, and utility together focus our consideration to a realistic subset of all possibilities, and
- Extensive formal in-place R&D programs, an essential underpinning of the architecture of the US overhead reconnaissance program, have been predicting the technologies available and those needing encouragement or outright sponsorship with great success for more that 25 years

Notwithstanding our confidence, however, we are in a different, more difficult to predict, world: one which necessarily reduces our confidence beyond that we would be able to assert in a similar "Cold War World" study. During the Cold War, the pace of development and application was determined almost entirely be Government (and specially DoD) spending and only secondarily by commercial application of those developments, making it easier for our fairly narrow community to "manage" as well as predict the resulting advances. This equation began

to shift in the late eighties, and by the end of the Cold War, the critical mass had shifted to the private sector.

One needs only to look at the developments in computers to make the point. There is no reason to believe that this situation will change in the near future -- there is little likelihood that Defense development spending will grow significantly. As a result, commercial development and application of technology will increasingly dominate for the foreseeable future, and, as a result, our prognostications will have to include the less well understood, quicker reaction, and broadly based (both domestic and foreign) commercial development community if we are to be as prescient for VISTAs 25 years hence as we were in 1970 for today.

Nowhere is this shift to the commercial sector more evident and more pertinent to the subject than in the satellite imaging arena. This area, shrouded in secrecy for decades, has become an actively pursued commercial space initiative, second only to communications and navigation. Once the private province of the intelligence services of the Soviet Union and of the United States, it has become a potential gold mine for commercial ventures, both here and abroad.

Much, perhaps most, of this commercial technology, both for the space and ground segments, will be either directly applicable to, or will serve as an excellent foundation for, Air Force reconnaissance technology requirements' satisfaction. All in all, we will have far greater fiscal resources and far broader interests and imagination brought to our problems but mostly not under our control, reducing the certainty of our predictions but increasing our predicted level of technological attainment at earlier times for lower programmatic cost.

4.1.3 Air Force Role in Overhead Imagery Reconnaissance

While current initiatives in the commercial sector are far less capable than the intelligence photo reconnaissance systems, buyer pressure, competition, and advances in technology will improve their capability to the point that commercial technology will be capable of challenging the performance of classified systems should the market for their products exist. This will pose a dilemma to the Defense establishment, and to the Air Force in particular, similar to that being face with the Global Positioning System: how to operate in a world in which essentially every potential adversary has access to intelligence information collected from the high ground of space -- we will no longer have an operational or planning monopoly; perhaps we will no longer even be able to protect our space segments from interference or destruction, and we certainly will face communication security challenges tasking the collectors and moving the imagery from the collector through the system to the ultimate user. And, similar to the reality facing the GPS Selective Availability (S/A) neutralization by commercial innovation, in which we recommend facing reality and abandoning S/A, so too do we recognize that our foes and friends will all have useful military space imagery available to them and that we should capitalize on that same availability and reserve our investments for the margin: for those capabilities too esoteric for commercially profitable investment but still of importance to the American warrior.

We anticipate that the Air Force will retain and solidify its designated role as the DoD lead for space operations, perhaps expanding its role, in close cooperation with the National Imagery and Mapping Agency (NIMA), to include responsibility for secondary dissemination, data fusion, post-processing product preparation, customizing, final archiving, and delivery to

all DoD users. In this model, the NRO would perform R&D, development, acquisition, and operation in support of the Intelligence Community, in partnership with the Air Force which would assume an integrated responsibility with the NIMA for enabling and facilitating tasking, collection, processing, archiving, dissemination, and display of DoD imagery. The Air Force will be critically interested in, but will not be the lead organization for, the development of mechanisms for the delivery of non-current imagery collateral imagery and current intelligence supportive of current imagery exploitation.

This view anticipates the Air Force will bear the ultimate responsibility for providing processed imagery in usable form to all legitimate military users. It assumes that all agencies needing to perform studies and detailed assessments of current imagery will be provided access to the highest quality data and that those agencies may continue their manipulation and exploitation with their own techniques and resources, but it assumes that the operational user, airborne, afloat, or on the ground, will receive imagery tailored in accordance with the requirements that that user levies on the Air Force.

Implicit in this expansion of the Air Force mission must be an unprecedented level of cooperation among the user community, the Air Force overall and operations lead, the NIMA and the NRO/industry technology development community in order to achieve technologically stressing missions such as:

- High resolution imaging, correlation to maps, and data exploitation sufficient for precision weapon laydown
- Multiple sensor data fusion to enable high confidence target identification
- Intelligent machine search, interpretation, and cueing to analysts so that high confidence can be placed by the user in the efficacy of the imagery system to search large areas at high speeds without missing anything important, and in the process detecting, discriminating, identifying, and reporting all items of explicit importance, and suggesting examination of items which the smart processor believes might be of importance

This responsibility makes the Air Force responsible for providing the appropriate imagery in a timely manner to the user. As such, it includes Air Force responsibility to promote the acquisition of invulnerable space assets, significantly improved sensor capability, assured communications, and usable, useful imagery to the many classes of users serviced by this system. And it explicitly demands that the Air Force coordinate in support of the user development community to provide its products in standardized, useful formats enabling the development by the user (or other organizations) of custom exploitation equipment and software.

4.1.4 Air Force Relationship to National Agencies

National agencies have worked together to allow all “national” user agencies equal standing in the choice of technical capabilities invested in, and the timing of, new collection systems. This arrangement has enabled “beyond the state-of-art,” relevant systems with remarkable technical performance within a streamlined procurement process -- and it has delivered the majority of its systems on schedule and within budget.

However, the increasing complexity of communications, exploitation, custom products, and the need for rapid dissemination of imagery to be used as a real-time component of warfighting and weapons targeting requires a mew model. The technology development organization is well-equipped to implement the infrastructure to create a “system of systems” and to operate it as a commodity, but responsiveness to users remains a problem. The current system provides a product on a scheduled basis. In general the receiving agencies are responsible for the exploitation equipment; the arranging of delivery of collateral information, any machinery/software/algorithms which facilitates intelligence exploitation by fusion, overlay, registration, etc.; and for the delivery of the imager-derived-intelligence to its users. A positive example for the future is the demonstrated capability which allows forwarding imagery directly to theater. Another positive demonstration system is the development of an example “universal” soft copy exploitation system (IDEX 2). Both these demonstration technologies point to a better future, one in which Air Force (or NIMA) delivers product in conformance with users’ requests; and where the military user community deals directly with the Air Force (or NIMA) for tasking, operations, and archiving. The current plan for NIMA to set standards must be closely coordinated with the Air Force. In our view, the Air Force, in accepting responsibility for delivery of its product to all users, must also lead in setting standards for archiving and delivery of imagery and imagery-derived products.

The National Photographic Interpretation Center, The Defense Intelligence Agency and other “beltway” users should be treated distinctly from the warfighters. In times of peace, these “national” users (to become NIMA, according to present plans) would generally receive the highest priority for and percentage of collection; but in times of crisis and war, the warfighting commands would take precedence. We believe the current policy should remain in force: that NPIC is an office independent of the DoD during all situations other than war; in that case, its command reverts to DoD. The wording should be changed for clarity from “war” to “state of national emergency,” to allow for more orderly, and less ambiguous, transition than has been experienced from time to time. One option proposed in the NIMA Terms of Reference places NPIC and elements of DIA within NIMA, a Combat Support Agency.

Finally, the Air Force should be places in charge of the requirements process for the day to day prioritization or warfighting and military crisis collection, and the tasking committee process now in place should be recognized as equitable but needing modernization it its implementation. Secondly, NIMA should be in charge of the requirements process, both their generation and validation, which leads to the design and acquisition go-ahead for new or upgraded collection capabilities; however, the Air Force, as operational lead, should be given a prominent voice in the implementation of the decision process on how to satisfy those new sets of requirements, and the NRO, as both technologists and intelligence professionals, should have a strong voice in the trades of utility, practicality, and affordability leading to the acquisition decisions.

4.1.5 Air Force Relationship to Other Services

We approach the problem in phases or conditions, and for ease of analysis, we propose three, if only because in a grand scale they seem appropriate: relative peace; increased regional tension (crisis), and conflict (war, but we conceptually include in this macrostate any emergency in progress, for example, a hurricane, flood, or volcanic explosion.) While there are needs that thread through each of these phases, there are also needs in each which can be satisfied using

different methods, and it is this particular feature which lends itself to some possible savings. Taking them one at a time:

4.1.5.1 Relative Peace

The modifier "relative" is meant to imply a condition in which there is no active involvement of US troops anywhere in the world, although there may be, indeed, active conflict going on somewhere. The USS posture would be one of staying informed and aware of the situations around the world, and of being ready to move to a higher degree of awareness if a situation develops which may result in US involvement. Under these conditions, the US intelligence apparatus is concerned with obtaining world-wide data for several reasons:

- Keep the US leadership informed about developments around the world
- Update intelligence data books on potential conflict areas; i.e. update maps, information concerning weapon developments and acquisitions, deployments of weapons and troops, political activity and changes on both sides of the target area political spectrum; and
- Alert US forces or interests of potential danger

4.1.5.2 Increased Regional Tension (Crisis)

As the possibility of US troop involvement increases, either independently or as part of a coalition, the pace of intelligence operations will increase in the area of interest. High priority will be allocated to overhead collection of all types, particularly imaging systems. These data will be made available to the CINC responsible for the tense geographic area. At the same time, specialized and organic reconnaissance systems are prepared for activation: target data needs and missions are planned and readied, awaiting go-ahead from the political leadership. The CINC, as he develops his battle plan, will require the latest intelligence available. During this time, the types of specific data which will be essential are at least:

- Completely updated maps; current weather, specific weapons available to his foe, number deployment and level of experience of his troops, his goals, and his probable tactics
- Intelligence concerning the deployment and readiness status of probable allies to his foe
- Specific information concerning the condition of roads, railroads, other logistics, and all communications networks
- Intelligence relating to his foe's defensive capabilities regarding: antiaircraft types and deployments, possible electronic warfare systems and locations, surface-to-surface missiles types and deployments, probable targets other than his troops; and
- Intelligence relating to his foe's ability to affect or to interfere otherwise with his lines of communications and his intelligence systems.

4.1.5.3 Conflict (War or Other National Emergency)

In addition to all the sources and resources available to the CINC as he prepares for possible conflict, he and his field tactical commanders will require organic all-weather, day and night intelligence collectors. These will include at least ground and airborne systems which, working in concert with the national strategic systems, will provide the battle commanders with the necessary intelligence to have total battlefield awareness. Specifically, the CINC and his field commanders will need:

- Ready and rapid access to all national strategic intelligence available for the conflict area. This means a communications system which can access all intelligence data bases at all times, directly by the CINC
- Ability to task directly and immediately all intelligence collectors within the theater of operations; and
- Immediate on-line access to the analysis facilities in the CONUS for assistance to his forward intelligence processing centers.

What is necessary to fulfill these needs? What will give the battle commander the high ground of profound knowledge of the battlefield? What reconnaissance and data transmission technology is available today and what is available or will shortly be available in the commercial field which can help in this equation? What future technologies need to be pushed to further assist future warfighters? How well equipped will the foe be in negating our collection systems or through their own familiarity with equivalent systems, negate the utility of our systems?

Many systems and much technology is available today, and much more is in development and will be available in the VISTA timeframe. What is sorely needed is a cohesive plan -- a plan to bring the disparate elements available now into a system of systems; a composite plan to collect, analyze, store, and disseminate the intelligence required by the warfighter. Only when such a grand plan is put together and accepted by the services will they be ready to fight the next war with twenty-first century technology. It is in this area that the Air Force can best contribute; it can assume the sorely needed leadership. In fact, we insist that success in future conflict may well depend on the Air Force vigorously accepting and addressing this leadership opportunity.

A single warfighter organization, we recommend the Air Force, must accept leadership, including the management of all appropriate resources to define, train on, and use regularly in operational settings the overhead system of systems (and its communications and processing infrastructure,) including the customization and dissemination of its products across the macrostates: peace, crisis, or conflict/emergency. From the warfighter's viewpoint, peace is the time to develop and test the systems needed during conflict or emergency; the Air Force must be vitally interested in developing, through the requirements process and in active conjunction with the technology developers the systems which will satisfy the users' needs during the higher states of tension: crisis and conflict. Crisis brings with it increased intelligence flow and stressed systems capacity and prioritization conflicts. Special purpose, secondary, backup and redundant systems will be readied for deployment and must be seamlessly integrated into the overall system. Finally, war: all systems deployed and operating; defensive systems and hostile actions likely; Air Force countermeasures; and most importantly, an assured flow of continuous useful, usable imagery and imagery-derived intelligence to the warfighters.

4.1.6 Air Force Relationship to Industry/Commercial Development

Historically, the government team and industry have worked as development partners. The government generally required custom technology leaps and reduction to practice of devices of physics far beyond commercial interest or affordability. This situation led to US government funding of advanced technology for which there was little other interest; this specialized use led to the development of an elite coterie of high technology contractors well-paid to develop a small number of near-perfectly performing systems. The commercial opening of space has made unnecessary the custom development of most of the units necessary for a space-based collection system, particularly the communications infrastructure and the launch vehicle systems, because of a world-wide market and the somewhat decreased security sensitivity of US overhead system elements. On the other hand, the world-wide interest in these subsystems has both diminished the US lead and increased the risk to US systems. Further, enemy activity may include their own imagery overhead systems, sometimes provided by US contractors, or might include attempts to deny us imaging products either through satellite negation or communication disruption.

This world of semi-equals poses several dilemmas. In the past, an enemy observer has been neutralized by very direct and active means: simply destroy or nullify his reconnaissance systems. The problem, however, may be that these collectors may not be the property of the enemy, but in fact may be owned by US corporations or our (at least temporary) allies. Also they almost certainly will not be marketed as intelligence collectors, but will indeed be meant principally for peaceful purposes. Those peaceful purposes will likely continue during regional conflict periods, and simply "taking them out," by any means, may not be a practical alternative. Different, more creative alternatives need to be found. Meanwhile, we will need to make significant investments to provide us assured collection and communication.

This "one world village" brought to us by multi-national consumption and standardization is a dilemma calling for carefully established guidelines for all cooperating players. We applaud the careful analysis recently made of the "best interests of the United States" with respect to commercial imagery systems' sales to foreign countries. We expect that this is only the beginning of the trail, the tip of the iceberg, leading to a VISTAs world in which the government, with industry as a partner for development, will find industry as an antagonist through all levels of peace and crisis, but that in the end, US-supplied systems will retain some Air Force-cooperative mechanisms or control aspects which make those US products play on our side, or at least not against us, in a conflict. This approach, tried successfully in the civil imaging licenses granted to date, will be more difficult to elicit/coerce as the threat to our interests becomes lower, apparently more remote, and less dramatic than that of the Cold War, but we believe such cooperation must be achieved. And the effort needed to achieve it must be invested, each year, every year.

4.1.7 Air Force as Information Provider

The US-led coalition had the only eyes in the Gulf War. That fact was not lost on others, combatants and spectators alike, and every country or group of rebels in the world with less than peaceful goals toward their neighbors or real and imagined enemies is in the world marketplace seeking to acquire any technology that might improve their effectiveness. These renegades most likely will be the foes of tomorrow, and the technologies they are after rival those used during

the Gulf War by the coalition forces. The total battlefield dominance demonstrated by the coalition forces, particularly the US, during that war is their goal. Denying that advantage to US forces must be considered an equal priority from their perspective. In this probable future, the Air Force must ensure that we retain a clear advantage in future engagements; i.e., we must continue to achieve the total battlefield dominance we enjoyed during the Gulf War, but very likely against far more technologically sophisticated foes. Total battlefield dominance requires total battlefield awareness, the role of intelligence, and in particular, of reconnaissance and surveillance as subsets of the intelligence process. The Air Force should accept the responsibility to provide that advantage to all future US battle commanders.

Before we examine the probable technologies which will be available, and their effect on the needs of the military, we summarize those needs. We focus strictly on overhead reconnaissance and surveillance, and touch on others only when they have a direct impact on the theme of this paper. Communications is a good example: collecting excellent intelligence is of little use if it cannot be made available to the warfighter in the front lines. We believe that ultimately all user needs will need to be integrated, and a systematic solution defined -- systematic but customized to each user class and each intelligence problem. Only in this manner will it be possible to address properly all needs, to incorporate new technologies competitively as they become available, and to stay within what will certainly be limited budgets.

Total battlefield awareness has many components. It includes not only the obvious ability to see the enemy's deployment at all times during an engagement, but a host of other closely related and equally vital elements. Before an engagement, in anticipation of a possible conflict, there is a need for detailed intelligence. This includes at least: maps; a good understanding of the area's geography; the location and potential of weapons of threatening range and capability; weather; the size and location of weapons storage places; and the size and capability of its armies. If these are the "needs," what will be necessary to obtain and maintain total battlefield awareness and the ensuing dominance?

For the Air Force, this portends two critical issues: it will no longer define technology development paths. Instead, it will find itself in the role of consumer of commercial products and services which have been developed for non-defense purposes. Secondly, and given the first assumption, it will need to be prepared to adopt technology at a much faster rate than was required when the pace was being set by the cumbersome DoD procurement system. To do otherwise will mean a second rate system when compared to the commercial field, and a military system second rate to those countries and cartels more agile in acquiring, accepting and rapidly applying current technology.

To function effectively in this world, the Air Force will need to develop methods by which it can stay abreast of the technology rush, and most importantly, effectively and promptly examine and adopt probable applications of new technologies to its roles and missions. It will need to forge working arrangements with industry leaders to keep abreast of new developments at an early stage, and it will need to improve its procurement methods to permit rapid incorporation of desirable commercial developments while optimizing the use of its limited budgets. Inevitably, US government sponsorship of research will become a smaller part of the equation, and diminished coercive clout will accompany that diminished role. Certainly our needed technologies which remain beyond the interests of the commercial marketplace will enjoy the support of

American, and perhaps foreign, industrial development in a manner similar to that of today ... but many of today's NRO-only technologies will become easily available to our foes by virtue of their mass production and marketing through commercial sources. What we need to do for this category of technology is to ensure that our systems are made with tamper-proof components with assured resupply, and that our custom components are designed with the maximum of flexibility to allow interface to and exploitation of the more rapidly evolving "infrastructure" components available from industry. This assured access/performance integration of custom and commercial components and software for collectors, communications and exploitation equipment seems to us the only realistic route to reliable, timely and competitive battlefield information.

Notwithstanding our space-based systems' superiority, timeliness must be improved across the board for battle management lest it be our Achilles' heel: the right information too late is of no value. We suffered this criticism during the Gulf War following the incredible gift of six months of Desert Shield readiness opportunity. A similar situation today would find us at least addressing common standards for imagery communications ... but we need to improve in the following: flexibility in area covered at desired resolution, speed of processing and forwarding the data, and reproduction and delivery of that data in usable format.

We anticipate that day-night, all-weather access to entire regions of conflict will be provided by either: a) long dwell (LDI) good resolution overhead systems using sparse aperture collectors, inflatable primary mirrors, or one of several other geosynchronous orbit imaging concepts or b) a constellation of single-function small low earth orbiter satellites weighing less than 1000 kg and built on a standardized bus. Either approach can provide real-time, high resolution imagery of entire conflict areas. An alternate approach to total current coverage, certainly supportable by the data processing techniques of the VISTAS time frame, is to probe the entire area of interest on a rapid basis, providing update "stamps" into entire regional mosaics, particularly highlighting moving objects or suspicious items. This approach appears both feasible and affordable. Such real-time updating addresses, if done well, the commanders' needs. Advances in automatic target recognition, change detection, fusion of LEO phase data with LDI data, and methods of warning, advising, and archive baseline updating are needed and, we believe, well within reach. Some of these areas are now under early stages of investigation. Here, as in all aspects of the "system of systems," a coordinated, unambiguous, aggressive Air Force leadership is mandatory in conjunction with sensor developers and user developers (NIA, DIA, CIA, NPIC, services) the overall technology and people system can give us the omniscient "god's eye view" of the battlefield.

The system of systems will deliver data for all services. It will be the responsibility of the user community to decide what portion of data processing should be executed by the Air Force as a common service. For example, the Air Force will be interested in aircraft battle damage assessment (BDA) and will provide, during VISTA, automatic (no man-in-the-loop) estimates based on before and after imagery and collateral information. This same capability, and all the imagery and most of the collateral, will be available to support Army and Navy BDA. Should it, or should the systems developed by all services which come together to support Air Force BDA be made available for each service to do their own BDA? Technically, either is possible and supportable.

BDA naturally ties together with precision targeting. In this vein, how should GPS be exploited by the Air Force global reconnaissance and surveillance mission? We anticipate that a successor system to GPS will provide invulnerable US access in beacon geolocation (in 3-space). It is possible that IMINT systems will be a component of such systems for the purpose of target designation, in which case the system of systems would include a bilateral real-time link with radio, multispectral or laser designators and smart weapons on designating and attacking aircraft, missiles, tanks, and possibly, artillery shells. The opportunities for satellite participation in a closed link of sensing and shooting are extensive, but we believe that the VISTA scenario will be limited to capabilities approximating those above, but that those will still be superior to any fielded against us.

4.1.8 Focus for Future Effort

It is appropriate to review history, so as not to repeat mistakes and to learn "what worked." This paper is not intended as a detailed critique of the Persian Gulf War, but only to look at likely future requirements in similar situations. Lessons have been learned, the system of systems is beginning to evolve and new capabilities have been proposed. It is vital that needed improvements not be hobbled by bureaucratic infighting, inertia, apathy, and changing priorities ("Why bother to fix the roof when it isn't raining?"). Individual efforts by the DCI, the JCS, even Congress, to "fix" the problem are meeting with some success. It is mandatory that this system of systems continues to evolve as a team effort; we must not let the lack of a crisis allow any lack of motivation.

It is precisely this high ground as owner of the system of systems that the Air Force should fill. Not by claiming others' budgets or systems, but by designing a plan, a connectivity of all available systems and data bases, an analysis scheme and a dissemination method and system which can be exercised and activated globally, in short order (hours, not months), and which is affordable. From a position of hegemony, the Air Force can then identify solutions to shortfalls, recommendations for acquisitions, and long range plans to maintain US technical leadership and US dominance of future battlefields . Carried to its logical conclusion, such a plan would provide US Forces the infrastructure to provide the necessary "battlefield awareness" with which to achieve dominance and quick victory.

We envision the future imagery system as a matrix of the following:

- *Reconnaissance:* All-weather, day and night, large-scale imaging systems with at least four daily accesses to the conflict region, and more often for tactical purposes
  - Resolution: < 1 meter (Better, on demand, for selected areas)
  - Coverage: > 100,000 Sq. NM Contiguous
  - Revisit: < 4 times daily; < 1 hr. during conflict
  - Availability: < 1 hr. to front line intelligence centers
- *Dissemination:* Real-time access to data bases and archives to at least the Corps echelon
  - Maps

- ELINT
- HUMINT and archival text and historic reports
- Imagery (SAR, E/O, infrared, multispectral, and, on occasion, hyperspectral)

- *Analysis:* Ability by front line intelligence centers to interact with other intelligence processing centers, including those in the CONUS, civilian and military
- *Warning*: Immediate and accurate warning information to all independent US elements at risk, including air, naval and ground forces concerning over-the-horizon launch attack which imperils US and allied forces, noncombatant civilian centers, and peripheral states or cities
  - Aircraft attack

    Size of force

    Type of aircraft

    Possible armaments

    Direction and speed
  - Missile attack

    Number of weapons

    Type of missiles

    Type of warhead

    Direction and speed
- *Weather:* Immediate theater-wide (and farther, as appropriate) microweather in support of ground operations, air operations, space imaging, laser designation

The current accuracy and timelines of weather predictions for attack operations is such that the final decision about the feasibility of using laser designator weapons or other electrical-optical delivery systems must be made by the pilot after penetrating a significant portion of air defense in the target area.

There exist several sensor technologies for improving the measurement of the bottom of clouds and the moisture profiles and other important parameters. The prediction capabilities which use sensor data need better inputs but the prediction technology needs to be advanced and proven reliable in terms of the military operational needs. The current space based sensors are passive instruments in the optical, infrared, and microwave bands. The timeliness and spatial resolution of these instruments can be improved with existing technology sufficient to support many weather needs. However, the prediction models and their algorithms need development. The near-term choices regarding improved instruments and platforms need to be part of a program that involves both research and operation prospective. The NASA and NOAA Programs will be useful but the military needs will not be met without a Air Force involvement.

In the long term space based synthetic aperture radars (SAR) will play a significant role in measuring everything from soil moisture, air moisture, sea ice age and thickness, sea states,

wind profiles, cloud details etc. These radars will be multiple frequency and multiple polarization. These capabilities may be additional features of a space based reconnaissance SAR system. The current activities are primarily research instruments as part of the NASA Earth Observing System or international research instruments. The AF needs to be active in this technology. The Sensor Panels Paper on Global Weather Awareness covers this subject in more detail.

As stated throughout, there are many developments under way which could play an important role in future reconnaissance systems. There is a need, however, to continue to fund enabling technologies which will result in evolutionary improvements to current systems and to form the foundation for the exploration of possible future systems. Some of these are:

- Launch Vehicles -- Cost and lift capability (in the sense of dollars per pound) must improve by at least an order of magnitude.
- Materials -- Light-weighing satellites need continued development. Some good activities are under way at the Air Force and NASA, but application to intelligence community space systems is lagging. An investment account for Air Force/NRO lightweighting should be created distinct from the regular acquisition accounts to promote advanced materials technology.
- Sensors -- Significant continuing funding is required; the NRO is sponsoring some work, as is ARPA and DARO but it lacks focus for the types of warfighting systems which will be needed in the next century. Specifically, work needs to be emphasized in phased array synthetic aperture radar to push the state of the art in high efficiency low cost devices and larger, and multi-dimensional, effective apertures. The commercial world is unlikely to push this -- no real application, although we believe that they will begin to explore it as they get into mapping areas of the world which are cloud covered a large part of the year. (The commercial market may be in large-scale radar mapping, which can be done with a single image. Visible and multi-spectral imagery would be used to fill detail.)

  Frequent revisit is a standing requirement. One approach to this is high altitude is long-dwell imagery. Embryonic geosynchronous concepts have shown success in simulation, but the system concept, even for a prototype has not been successfully sold. Other concepts, such as large aperture inflatable optics, and sparse optics need to be evaluated. All of these high altitude concepts will have the advantages of survivability but will inevitably result in expensive systems and therefore must be weighed against the use of small satellites at low altitudes, generally dedicated to a single function as opposed to the multi-mission higher cost systems.

  Foreign imaging of red forces will disclose the effectiveness of their IMINT denial practices. We need to develop E/O sensors which work out to 1.5μ to defeat camouflage paints and netting. We need to provide a narrow-band tuning capability to our E-O systems (even a sub-array would be helpful). We need to implement a thermal imager (everyone thinks we already have it anyway!). While this is unproved, we believe the cost for hyperspectral imaging and the ability to handle its bandwidth (possibly with some onboard processing for detecting particular species, such as CW products) will decrease to the point where a hyperspectral

subsystem is readily accomplishable (most likely, there will also be a US government demand for such a sensor for pollution monitoring).

- Processing -- Automated target location and recognition development activities need to be pushed; much work is being done and yet much remains to be done. High accuracy, low false target rates are essential for any technique to be fully accepted in an operational environment. There are no such techniques to find, for example, gun emplacements, mobile missiles in forested areas, underground facilities, and other high value targets. As computer power grows, the power of some of these techniques improves. This is a long road, and we need to keep the pressure on. The commercial world is not likely to be much help on this.

- Dissemination --Compression algorithm development is a key in this area. The commercial world will continue to lead the way. The imagined weaknesses of many of these techniques in a Cold War environment have become an impediment to application where they would be very helpful. We applaud the early work of the NITF forum and urge the Air Force to participate with, and direct the CIO to, move forward more aggressively than currently planned. We particularly urge abandoning the mentality of lossless or "minimal NIIRS loss," encouraging CIO to make common cause with the services in determining actual needed performance to do detection, discrimination, and identification. The way to minimize problems is to work with industry to understand and to possibly improve their robustness and utility -- too much emphasis is now placed on equipment compliance with approved algorithms -- we need a return to the algorithm development with a focus on user needs, not bits per pixel.

There are several developments in the commercial segment which will have a great impact on the Intelligence business of the future[1]. Although there are many, we'll touch only on those few which have a direct and real near term impact on the issues being examined in the VISTAS study, and which if not taken into consideration will almost certainly degrade the superiority of US forces in the future. They are:

- Commercial Medium Resolution Satellite Imaging Systems

Within the next handful of months, the first commercial imaging system will become operational and launch a new era in the use of space. The service these systems will provide, i.e. near real time delivery of medium resolution imagery, will have a profound effect on the way nations look at themselves and each other. Already several nations are vying for the services promised, with some wanting outright ownership of the imaging system. While many of the uses contemplated are peaceful indeed -- mapping, resource control, agricultural management and so forth-- the potential is there for use in less peaceful areas. Also, as the marketplace develops for the services they will initially provide, there will undoubtedly be competitive pressure to improve the resolution and spectral bandwidth of the

1. Using intelligence in its broadest sense; i.e. readily available information about areas of interest — for commerce, agriculture, education or warfighting.

sensors. This scenario offers two possibilities to the Air Force, one good, the other bad.

The good is obvious: the Air Force and the NRO can piggyback on commercial developments to great cost advantage. It is not hard to imagine that within the next seven to ten years commercial initiatives will rival some of the characteristics of today's intelligence systems, motivated not by government needs, but by the marketplace.

There will be opportunities, at least with American corporations, to influence some of the design features of these future systems in ways which make them more useful in military dress, and the very least, the outright purchase of "off the rack" turnkey systems may be a very attractive alternative to custom-tailored systems. One can envision a situation where a service purchase agreement with one or several of these commercial ventures provides product for use in the more mundane applications of overhead imagery -- mapping, for example -- and reduce the tasking conflicts on the more capable military and NRO systems. In this scenario, one or more of these "off the rack" systems could be purchased or leased for use in emergencies, as gap fillers or as dedicated tactical collectors when launched into orbits which optimize coverage of areas of interest.

The bad news is also obvious: the bad guys could easily have access to the product of these wondrous systems, and the advantage the high ground has provided us for battlefield dominance would be, at best, shared. But is this inevitable, at least in the next ten to twenty years? We believe the advantage will be with the US for many years, definitely into the VISTA timeframe; the honing and refining of the use of imagery for intelligence purposes has taken over thirty years, and we still have some distance to go before the process can be called well-integrated into our own military doctrine. One needs only look at the Gulf War to see that it takes far more than pictures from space to fight a winning battle -- it takes the infrastructure, resources and training to turn fuzzy pictures as viewed by a Monday-morning quarterback into a battle winning strategy (that is, a system of systems!).

- Direct Television Broadcast Developments

  The highly successful direct broadcast systems now entering the marketplace are another area where advanced commercial technology offers a capability for distributing information to the lowest echelon in a battlefield. The term "sensor-to-shooter" can become a reality if this technology were to be adapted to military applications. Consider the possibility of transmitting data (maps, pictures, enemy deployments) on demand, to small units, each using an eighteen-inch (or smaller) antenna to receive their orders and situational information. The bandwidth and number of channels available from these systems even now would permit the transmission of tailored data to hundreds of units simultaneously. The communications technology is there; what is not is the archives and control elements to make use of it -- the system of systems discussed earlier.

- Detection of Stealthy Aircraft

  It may be possible to detect stealthy aircraft, by using space based transmitters on many LEO satellites in conjunction with proliferated surface receivers, and detecting the moving diffraction pattern signatures caused by interposition of the aircraft platform between space transmitters and ground receivers. This concept is described further in the report of the Sensor Systems Panel.

- Data Storage And Retrieval

  Data Storage And Retrieval commercial technology will almost certainly have a profound impact on our business, and its commercial development is a fundamental necessity for our primary recommendation to pursue a "system of systems." There are a number of development programs under way to increase the capacity of recording media. Laser recording of digital data on tape would increase the storage capacity of data by orders of magnitude when compared with current magnetic tape based systems. Aggressive applications of these techniques are fundamental to achieving the dissemination of current data, rapidly, to the warfighter to give him the "battle awareness" edge necessary to achieve dominance and victory. We can benefit incredibly by the commercial industry across the board, but we need to continue funding for reduction to our applications: we are still the widest bandwidth consumer and we believe we will continue to be at the time of VISTA.

4.1.9 A Vision

One need only look at recent engagements of US troops to define future needs; whether as independent actions, or as part of a coalition; the impact of technology on warfare, particularly that associated with reconnaissance, has been phenomenal. The ability for a battle commander to "see," on a grand scale, regardless of weather or time of day, the deployment of the enemy's troops, his weapons, his lines of communications and his logistics, has been the dream and quest of every troop commander in history. From hills, hot air balloons, early airplanes, and now space, the reach for the advantage of the high ground for observation of the enemy has been a constant pursuit. And it will continue into the future, aided by continued and ever more wondrous technologies. The example provided by technological advantage during the Gulf War is but an omen of the future. And the needs evolving from these technologies will continue to challenge.

These technologies which enable reconnaissance, used interactively, become part of the warfighting. Global awareness through the distributed systems of the US reconnaissance fleet become an indispensable element of the information "high ground" this panel believes is the dominant factor in future war. Whether it is real-time imagery linkage from sensor to shooter, providing automatic targeting, or automatic distillation of order of battle forwarded to the foot soldier or destroyer as icons on soft copy maps or charts, reconnaissance has passed from observation of, to participation in, warfighting.

We see a solution to the requirements stipulated above. It is based on good knowledge of the needs; of the technology now available, on the technology on the drawing board, and on the likely outcome of technology trends, both in government and commercial laboratories. And last

but not least, it is based on the elimination of political and bureaucratic impediments to an acceptable solution.

Some of the elements proposed either are under study or are actually being tested for incorporation into the DoD intelligence system, but most are not. What is still lacking is a clear and accepted vision of what the ultimate goal of all these activities -- there is no system of systems design which will meet a stated and agreed upon set of requirements. This would appear to be an ideal role for the Air Force, perhaps the Space Command, as much of what needs to be done involves the use of space.

The following is our top level idea for this system of systems, together with a description of the key elements and a status report of each:

- A well integrated multi-discipline collection system under one authority, with clear lines of authority and of responsibility for each element. This means, of course, the classic elements of intelligence: HUMINT, open source, ELINT, and IMINT. For the purposes of this paper, we've concentrated only on IMINT, and primarily from space, and touched on other venues only when they were necessary or they complemented our solution. At this juncture, we've not addressed ownership, only capability.

Its key elements are:

- A robust, full-time, multispectral high and medium resolution imagery collection system, with world wide access on an unrestricted basis. At least four times a day revisit time of any geographic area, and near-real time transmission of date to command centers in the CONUS and at designated CINC's.
- A robust, world-wide access surveillance system capable of detecting missile launches into the exosphere and high altitude high speed aircraft. This system should be capable of enhanced attention to specific geographic areas in response to crisis. Alerting information from these sensors should be available to the threatened force and to counter forces in less than one minute.
- A quick reaction surge collection system consisting of medium resolution synthetic aperture radar satellites to provide day and night and all weather imaging capability for tactical purposes. These satellites would be launched into inclination planes which optimize revisit times in the geographic area of interest, and which complement the full-time, world wide collector system. Two, three or four of these satellites would be deployed, depending on level of conflict, sophistication of foe, and geographic region. Alternatively, permanent deployment of such a constellation of low-cost collectors.
- A worldwide intelligence data super-archive accessible from anywhere in the world through a secure, broad-band communications system. This super-archive would be accumulated during periods of relative peace, using all source intelligence. It would be managed jointly by the civil intelligence community and by the DoD. To be completely useful during times of conflict, the archive would be generally available for training and for use in weapons development. Collection of data

from areas of potential conflict would intensify as the world situation warrants. This would maximize the use of the relatively reduced role of the National Collectors. The archive would contain the types of data required by the battle commander to have the "awareness" described above, including maps, annotated imagery, geographic information, weather, communications lines, political data, etc. The archive would be accessible to lower echelons, as determined and permitted by the battle commander, and limited to their area of interest. The data available from the central archive would be supplemented and enhanced by organic assets, as they deploy and begin operation (ground reconnaissance, airborne assets, tactical imaging satellites). Data acquired by organic assets which enhances or updates the archive data would he incorporated into the archive.

- An integrated data management and tasking system which would control this system of systems. Joint military and civil control during peace time, and military control during times of conflict.

"Owning the high ground" of space is indispensable to the country which leads the world. Our current ownership will be eroded by the availability of commercial systems, but our loss will primarily be in raw data comparability. We need to maintain an edge on wavelength, bandwidth, area collection rate at good resolution, flexibility of access, timeliness, and revisit ... but ownership implies value, and value can be owned outright by us during VISTA through a system of systems which optimally manages data, converting it efficiently to information, and merging, analyzing, and disseminating the appropriate subsets of that information to our users as world-class operational intelligence and battle support data in a timely manner.

4.2 Missile Warning and Space Surveillance

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4.2.0 Introduction

With the Soviet development of ballistic missiles capable of delivering nuclear warheads in the 1950's, it became apparent that in order to achieve effective nuclear deterrence it was necessary to have warning to preserve the National Command Authority and to assure retaliatory strike with our complete nuclear strategic forces including the airborne leg of our nuclear triad (aircraft, land based ballistic missiles (ICBM)and submarine launched ballistic missiles (SLBM)). While the Ballistic Missile Early Warning System (BMEWS) radars were under development in the late 50's, the need was for early detection of ICBM and SLBM launches to provide adequate warning time and dual phenomenology to eliminate false alarms and provide accurate attack assessment.

The Air Force undertook conceptual development of airborne and space based ICBM warning systems utilizing IR in 1958. The airborne approach was based on nuclear powered aircraft capable of long duration high altitude flight for detection of ICBM or SLBM launches. The nuclear airplane approach was subsequently discontinued because of the large size of the nuclear reactors which made the aircraft impractical and too costly as well as the safety issues associated with the reactor.

The space based concept was pursued with the MIDAS program which was started in 1960 and was launched in 1963 and demonstrated the utility and potential of a space based IR sensing missile warning system. Based on data acquire in the MIDAS program and the RM experimental satellites that acquired IR background data, the Defense Support Program (DSP) was initiated in 1966 and became the United States' global early warning system capable of detection of both SLBM and ICBM launches. Because of the possibility of glints off of cloud edges and other system noise, the need for second phenomenology verification was met by the BMEWS and Pave Paws radars.

Based on the MIDAS results the DSP I satellite was developed, launched an initial operations took place in 1970. This was followed by the improved phase II satellites in the period from 1974 to 1980. As part of the evolutionary improvement of the DSP, the Sensor Evolutionary Development (SED) program was undertaken which increased the number of short wave IR (SWIR) detectors for below the horizon (BTH) coverage and added mid wave IR (MWIR) detectors for limited above the horizon (ATH) coverage. This provided improved capability and new phenomenology data of significant value to follow-on system developments. The SED sensor, along with onboard data thresholding and cooling system improvements formed the basis for improved DSP satellites which have been acquired and launched from 1985 to the present and are planned to be the principal missile detection, track and prediction system, with the last launch in 2003.

We now have a missile warning system based on radars and satellite SWIR sensors. The radars are capable, if old, but are supported by software that is outmoded and an analysis system that is not physically based. Thus, they generate bothersome levels of false alarms. For many threats e.g., SLBMs, their indications can be quite misleading. It would be very expensive to modify them for the attack assessment for which they are tasked, but it is not clear that this

mission is appropriate for future threats. They key issue is whether radars are still needed for dual phenomenology. The future development of radars is unclear. If they are not modified, they will become a bit of a military museum. If they are, it should be in software and for a warning rather than an assessment function. Such an upgrade is likely only in the event of a renewed Russian threat. Otherwise, it would be appropriate to maintain only a few sensors such as the FPS-85 at Eglin and perhaps PARCS for space surveillance.

The satellite missile warning systems are also capable, if based on decades-old technology for largely single band SWIR detection. They use linear arrays of detectors with large pixels designed to produce adequate S/N against large strategic missiles; however, those arrays have provided a very useful capability against orders of magnitude smaller theater missile signatures. There are some (non water producing)fuels they might not see, but that has not been a problem yet. Their main weaknesses are the delays between revisits, which cause them to miss transient events and take tens of seconds to establish tracks. Offsetting that is the ability to integrate the outputs of several satellites for stereo and range, which makes those tracks very accurate. Their GEO positioning makes them survivable today, although their command and down links are accessible. In the long term, that could change.

4.2.1 Strategic Defense Initiative (SDI)

The SDI as initially envisioned was to be a nearly leak proof multi-layer defense against massive Soviet ICBM and SLBM attacks through combined boost phase, post boost, midcourse, and ground terminal defense layers.

The original boost and post boost defense concept required a very advanced missile warning system which detected launches and maintained precision track on each missile in a mass raid through booster and PBV burnout in order to provide near real time boost and post boost phase fire control data to a constellation of space based interceptors (SBI). These requirements resulted in the high altitude Boost Surveillance and Track System (BSTS) with very large optics, and very large and complex mosaic or scanning focal planes along with unprecedented levels of onboard signal and data processing.

The cost and risk of BSTS development, coupled with the challenge of guaranteed distribution of fire control data to thousands of interceptors, was a significant factor in the decision to substitute the more autonomous and distributed Brilliant Pebbles interceptor concept. Attack warning and authentication were still required with Brilliant Pebbles but were treated as part of the normal Air Force missile warning mission.

Subsequently, the SDI mission was scaled down from global protection against massive attacks to a National Missile Defense (NMD) against small or accidental ICBM or SLBM attacks and Theater Missile Defense (TMD) as part of a Global Protection Against Limited Strike (GPALS) mission requirement. As this trend continued, the National Missile Defense Program was relegated to a technology readiness program, and the SDI (later BMDO) program shifted almost entirely to defense against theater ballistic missiles.

4.2.2 Desert Storm and its Aftermath

Desert Storm focused attention on the value of detection, track and timely warning message dissemination for SCUD class missile attacks. The DSP was able to detect most of the launches

under the near ideal night time conditions but lacked the stereo processing and communications needed to provide accurate and timely warning messages.

The Army and Navy had gone directly to Aerojet, the DSP sensor and software contractor, to perform a Tactical Surveillance Demonstration based on their proposal on how to process tactical data. This program was successful in demonstrating that commercial hardware and relatively straight forward extensions of the DSP software could be used to process data coming down directly from DSP satellites in view of the ground station to provide missile launch detection and track in near real time. With more than one satellite in view at one time, this system could process stereo data to get more accurate track and warning messages. This demonstration resulted in the Army and Navy JTAGS system which now has been deployed with Army field units and on board Navy ships.

In March of 1992 the Air Force initiated the Talon Shield program that is similar to the JTAGS but is capable of fusing all data that can see the target to provide more accurate launch and impact point determination. The operational version of Talon Shield, ALERT, is in operation and is located in Colorado Springs and uses established communication networks to disseminate data to tactical users worldwide.

It should be possible to add multiple wavelength detectors in the SWIR, MWIR, and visible for better detection and discrimination. It would be desirable to shift from linear arrays of detectors to large staring array focal planes. However, that shift has been predicted in each of the last three decades, but has been thwarted in each because of problems with yield and size. Moreover, if staring focal planes were purchased at the price of stereoscopic viewing or of larger detectors or lower S/N, that would represent a step backwards in terms of tactical and strategic utility. Such a ranging capability might be retained by the addition of a laser or radar ranger, but such sensors have progressed slowly in their development for the last three decades, and are difficult to implement from GEO.

Much of the pressure for a shift to staring systems comes from increased concern with theater threats. However, such threats could be addressed more simply by additional AWACS aircraft, which appear to be the economically appropriate solution for single-theater threats. If that option is selected, the competition for funds could further delay or eliminate the Brilliant Eye (BE) option. On the whole it would appear that only modest improvements in detectors and electronics and slippage of advanced systems is likely in the next decade, largely due to lack of a really compelling technology for upgrade.

The midterm developments are likely to be what are now thought to be the near-term programs: more bands, multiple satellites at lower altitudes, large staring arrays, and active ranging sensors. There is a natural synergism between them. Using multiple satellites at lower altitudes permits them to use the largest effective arrays with detector size to be designed for the targets of interest. Active rangers restore range and hence accurate trajectories without stereo viewing. Space-based radar for all-weather search, detection, and track would then be a natural adjunct to both the other space sensors and the limited AWACs assets. With that suite of sensors it should be possible to perform much of the threat assessment, put trajectories into GPS coordinates, and possibly to direct some intercepts from space. Note that ballistic and cruise missile threats to both Allies and CONUS should emerge in force in about this time frame, so that these should be just the proper suite of sensors and weapons to address them.

The long term can be defined simply as a period beyond 30 years, as a time when technology will permit anything we can envision doing today, or as a time when we will have serious and competent adversaries for the control of space. Each definition leads to the conclusion that space is likely to become a place of greater and more lethal competition. In such a competition, non-stationary placement is likely to be an advantage, smaller and more numerous warning satellites are likely to have a distinct advantage. Hardening and decoys will be essential; self-defense capability may also be needed.

All of these capabilities will be essential in protecting the satellites' ability to perform their warning and assessment mission, which will become ever more important. There will not only be conflict in space; there will also probably be serious conflict on the surface of the Earth and in the air. Space sensors are the appropriate means for detecting and assessing all of them. Their assessments will have to be fast and fully integrated into those of ground and aerospace forces. This would appear to be the period in which those forces would have to be fully integrated to achieve their full-and required-potential. Overall, there appears to be a basis for limited, technical developments in the near term and more sweeping, but still essentially technical developments over the mid term, leading to fundamental developments in the long term that could support important new military capabilities.

4.2.3 Space Surveillance

The present space surveillance system is comprised of a number of ground sensors including radars and optical devices, some of which are in the United States and others are at foreign bases throughout the world. These include the Navy's NAVSPASUR radar fence in the southern part of the CONUS, imaging radars such as HAYSTACK, HAX ALCOR, MMV, and all the Space Surveillance Net narrow band radars. The optical devices include imaging, photo/polarimetric and conventional telescopes using electronic image tubes. The data from these devices are fed into Cheyenne mountain in Colorado Springs where orbital parameters are calculated for each of the cataloged items and sensor tasking is prepared and sent out to allow continuous update of the catalog.

The current space surveillance system is based on a number or radar and optical sensors. The radars were generally built for other purposes and have inadequate calibration for this task. The optical sensors have marginal intrinsic resolution and dated focal plane technologies. The radars have biases and resolutions that lead to the need for frequent manned intervention, and hence operation that is expensive in terms of both money and people. Both are supported by dynamic models that are based on inadequate physics that has been ported blindly from earlier computers in a manner that is not designed to take advantage of modern architectures or hardware. The result is an expensive and inaccurate surveillance system that is ripe for change.

4.2.4 Space Surveillance from Orbit

The original SDI multi-layer defense concept against massive strategic attacks employed an above the horizon space surveillance equivalent to BSTS called the Space Surveillance and Tracking System (SSTS). SSTS was dropped along with BSTS when the mission was de-scoped to GPALS and the Brilliant Eyes concept was introduced in its place to detect, discriminate, and hand over midcourse targets either to Brilliant Pebbles for early midcourse intercept or to ground

based defense for late midcourse or terminal intercept. A constellation of 20 to 30 small (around 1500 Kg) Brilliant Eyes satellites is required to perform this mission.

The BE midcourse mission is performed with a very narrow field of view (less than 1 degree) tasked, staring, visible and M/LWIR sensor. The current LEO flight test program will demonstrate intermediate wave bands adequate for detection of warmer, shorter range theater missile midcourse targets. There is also a design and an unfunded flight test option to add additional cooling and a longer wavelength IR focal plane to provide capability against strategic missile targets which are cooler and have less radiant energy.

The Brilliant Eyes system also carries a much smaller (in aperture, weight, and power) below the horizon scanning sensor to acquire missiles during the boost phase and provide a precision internal hand over to the narrow field of view tasked tracking sensor. The BTH acquisition sensor has a “horizon to horizon” field of regard but was originally designed to be operated in a tasked mode in the sense that it was assigned to detect and track launches only in a “hot spot” 1500 Km in diameter. During the 1994 SBIR study it was shown that the BTH sensor could be operated so as to detect and track launches in its entire (horizon to horizon) field of regard with minimal weight and power increases. The “horizon to horizon” capability would allow the BE system to do the missile warning mission as well as the midcourse tracking and hand off to the BMD element. This “horizon to horizon “ capability is included in the BE flight demonstration system and is the current SBIR LEO baseline.

4.2.5 Current SBIR Plan

The Space Based Infrared System (SBIRS) Single Acquisition and Management Plan (SAMP) states that the SBIRS will be a consolidated, cost-effective, flexible system that will meet United States Infrared space surveillance needs through the next 2-3 decades. The SBIRS, as approved by the Defense Resources Board (DRB) consists of a ground processing segment and a space segment. The space segment contains a High altitude component in GEO and HEO orbits, a LEO flight demonstration system, and, assuming a 2000 decision to deploy is made, a Low element in (LEO). The ground segment contains mission processing and communications systems, as well as support infrastructure, to support integrated SBIRS (DSP, GEO/HEO, and LEO) operations. This SAMP has been prepared to cover the acquisition of the High elements and two increments of the ground segment, for DSP and High elements operation. Though it is part of SBIRS, the flight demonstration system is being acquired under a separate contract. After a LEO deployment decision, the LEO element and any associated ground increment will be acquired as part of SBIRS and the SAMP will be updated as necessary.

4.2.6 Space Surveillance Upgrade Planning

The computer portion of the surveillance network could benefit most from better calibration. The next step would be better models and computers that could make better advantage of the many observations they can provide each day. Radar upgrade is essential, in that the required elements of orbits cannot be attained without active systems. That is particularly true of objects at GEO, for which the contribution from Haystack is important and should continue. However, that does not necessarily require a large number of radars. A few well-calibrated radars would appear to be much more valuable than many ill-calibrated ones.

The optical systems could benefit most from better operation. The current mode, which incentivizes the greatest number of observations rather than the most useful observations, actively impairs the effectiveness of their use. The next step would be the replacement of current TV tube focal planes with CCD detector arrays, which with the step indicated above could improve the accuracy of observations by about an order of magnitude. With improved computers and atmospheric density models, that would permit a much greater fraction of observations to be made automatically, which could reduce manpower costs by a like amount.

It should be noted that the focal plane upgrade indicated should probably take place in two steps. The first would place the 2K x 2K (4 million detector) visible CCD arrays already tested into current GEODSS telescopes, which would improve current capability by about an order of magnitude. The second would probably involve substituting 4K x 4K arrays (probably generated by butting four 2K x 2K arrays together), which would improve performance by about another order of magnitude. The development of this second generation of CCDs would push that technology about as far as appropriate for ground-based telescopes, and would also develop the CCDs needed for space-based telescopes, which would be the next logical step.

These steps are simple, but they illustrate that a number of modifications that are needed for operational effectiveness could-for a very limited amount of money-complement a number of technologies that are ripe for application to significantly improve an badly needed operational capability. Radar measurements will continue to be important in the mid term. An upgrade to Haystack may be necessary, given the increasing fraction of the catalogue at GEO. A dedicated radar fence upgrade may also be needed for low-altitude satellites.

It appears that in the mid term, two space technologies will be both needed and ready: optical and LWIR focal planes for sensors in space. The former is for very distant, sun-lit objects at GEO; the latter is for the bulk of nearby but cooler objects and for the discrimination of transient satellites. Satellites, computers, and focal planes have now progressed to the point where it should be possible to keep track of much of the catalogue from space without the need for ground-based telescopes. From space, satellites can measure objects that are several visible magnitudes smaller than they can from the ground, which also makes it possible to extend the survey to fainter objects and search for stealthy intruders. There is no corresponding advantage in space-basing for radars.

In the long term, the space surveillance system will have to search for objects that are more numerous, maneuvering, stealthy, and potentially hostile. For satellite-based sensors, the greater number of objects is a direct but probably manageable problem.

Maneuver cuts two ways: if it is seen, it is a cue; if it is not, it is the occasion for a rapid, wide-area search. Stealth impacts the search rate per satellite, and hence the number of satellites that will be needed. Hostility impacts hardening, maneuver, decoys, and other survivability measures. That would appear to force the satellites for space surveillance towards those for missile warning. To the extent that this happens, the two constellations could merge into a single constellation of sensors with a large number of small satellites that could look in all directions and maneuver enough to survive to do so and perform essential assessments.

4.2.7 Space Debris

The catalog in 1994 contained approximately 200 active items and 5500 inactive items in the near earth orbit. In the deep space portion of the catalog there were 200 active and 1200 inactive objects. The present capability for tracking space debris in LEO is 10 cm. With the advent of the Space Station there has been discussion for the need to track objects down to 1 cm size and provide accurate prediction data at least two orbits ahead in order to allow the station to maneuver out of the way. It is estimated there is approximately 100,000 debris objects equal to or greater than 1 cm and thus this represents a substantial increase in the tracking and accurate prediction requirements.

Debris is left from putting satellites in orbit. It is made up of dead satellites and pieces of man-made junk. It would appear that the latter dominate the natural environment down to sizes of about 1 cm, which is also about the largest size against which it is possible to shield against impacts with acceptable penalties.

Debris objects down to about 10 cm in diameter are maintained by the USAF Space Command in a catalog, which is updated by optical and radar measurements. Objects smaller than 10 cm are hard to measure; the catalogue's completeness is very poor for them. The only detailed survey by size and altitude is NASA's measurements with Haystack, which do not agree with the catalogue to better than an order of magnitude.

The likelihood of a piece of debris of any size colliding with an Air Force satellite is so slight that it is apparently appropriate to ignore it and self-shield against the threat, although it would be useful to know if simple and inexpensive protective measures could be developed. For the Space Shuttle, which is several orders of magnitude larger and which contains persons, the threat has be assessed to be on the order of 10% over 10 years, which is bothersome. Moreover, NASA scientists have estimated that the impact of one piece of debris on another could start a cascade of collisions, which could make all of low Earth orbit (LEO) unusable. This estimate is based on guesses at certain key parameters-primarily the number of objects produced per collision-which have not been verified experimentally. These uncertainties have made the predictions on semi-quantitative. They do not provide a useful indication as to when the problem might actually become acute.

Debris forms a background that interferes with the performance of space surveillance, so the first step would be to implement the improvements in space surveillance outlined above. CCD sensors in space would eliminate much of the bother with large objects. An upgrade to Haystack that would permit it to see 1 to 10 cm objects better would also be a useful extension of current cataloguing as well as a useful adjunct to later mitigation and reduction efforts.

The key issues needing work in the next decade appear to be cascading, mitigation, and reduction. Better analytical models of cascading could probably be developed, but the main uncertainty is the number of pieces produced per collision, which is at present primarily an experimental matter. Fortunately, gas guns with the required velocities are now available, so the needed experiments could be performed in several laboratories inexpensively. With that information, it should be possible to say whether or not cascading is a problem. Then, or in parallel, it would be possible to study the changes in operational procedures needed to mitigate the threat as well as the techniques that would be available to remove the debris.

What is done in the mid term would depend on what comes from the developments of the previous decade. If good, cheap hardening is possible, it should probably be implemented on new satellites. If not, the Air Force should continue to self-insure, and NASA should reassess the Space Station. If experiments and modeling indicate that cascading is not a problem, no further action is required on debris mitigation and reduction. If it is, experiments should be performed to test prototype measures. For mitigation, those measures take the form of limitations on operations, which are simple to formulate, if painful to implement. For debris reduction, the measures are not well defined, let alone tested.

The long-term solution to the debris problem depends on what comes out of the mid term. If cascading isn't a problem; neither is debris, to first order. If it is, the response to debris will be a more careful use of space that emphasizes fewer fragments and explosions-both of which would constitute an extension of current trends.

4.2.8 Planetary Defense

Another potential mission for space surveillance is planet defense, that is cataloging those comets and asteroids that have earth crossing orbits and at some time in the future pose a threat of striking the earth. This requirement poses a stringent requirement in terms of sensing in that some of these objects are far distant from the earth during a large part of their orbit. Also because the nature of these bodies is not well understood it is desirable to perform a fly by or impact to determine the composition and to better evaluate the options for deflecting or destroying the object to avoid collision with the earth.

4.2.9 Future Prospects

The missile warning system suffers many of the similarities with the launch vehicle problem. The follow on systems have an architecture that while they provide substantial improvements, they are immensely expensive and the threat does not urgently justify them. The FEWS was an evolutionary development of the BSTS and incorporated many of the high risk technologies of elaborate focal planes, demanding stabilization and large amounts of on-orbit signal processing and data computation. While the Air Force Space Command stood behind it to the end, it lacked credibility with OSD and the Congress.

The current SBIRS approach is far more credible in the sense of using the same sensor on the HEO and GEO satellites and a GEO bus based upon cost-effective use of existing bus production line facilities and practices. Nevertheless there is the nagging question of the need for both GEO and LEO systems since it appears both the missile warning and the midcourse tracking requirements of BMD could done from LEO. The principal stumbling block with the LEO system is the number of satellites that have to be controlled and with the present antiquated satellite control approach the Air Force is using, which looms as a major cost item. However multiple satellite distributed type systems are the wave of the future and the Air Force is going to have update its satellite control capability with modern data processing equipment and software to make this mainly an automated operation requiring only minimal manning.

4.2.10 Enabling Technologies

Enabling technologies include focal plane developments that extend the sensing of LWIR with minimal required cooling and development of light weight efficient cooling devices. There

is the need for fast CCD read outs that allow for rapid tracking of many objects. The trend toward low altitude multiple satellite constellations will put a premium on autonomous satellite operation including the management of redundant subsystems. Because of the seriousness of space debris, future injection stages need to be designed to preclude explosions from residual fuel and more thought needs to be given to deorbiting stages and spent satellites or boosting them into high benign orbits. If clearing space debris becomes a necessity, high powered pulse ground based lasers may be required. These can only be effective with an accurate pointing system which may require use of LIDAR technology. Fundamental to all future missile warning and space surveillance capability will the ability to handle ever increasing volumes of data in complex predictive computations.

4.3 Space Communications

Jerry O. Tuttle

4.3.1 Introduction

The satellite communications (SATCOM) architecture and spacecraft design for the period commencing in 2015 should be determined now and taken into consideration inter alia:

The volcanic eruption of emerging technologies

The explosion in bandwidth

The insatiable thirst and demand for information

The ever increasing demand and competition for spectrum

Commercially available and planned communication satellite constellations

Direct broadcast and asynchronous mode of operations

The commercialization of space

The role for and potential of distributed satellite systems

A changed and broader scope profile for potential enemies

The maturation of Information Warfare

Unique military survivable and enduring satellite communications requirements

The realization that the indigenous satellites at that time have not been launched.

Salient communications capabilities will include global:

Person to person connectivity

Include high speed digital data, voice and multimedia

Provide direct access to vast depositories and reservoir of information, and

Will enable virtual reality and computer simulation, rehearsal and event execution.

This SATCOM architecture must be flexible, scaleable, fault-tolerant, reconfigurable and user simple, the result of a cooperative effort by DoD, the services, NSA, NRO, DOE, DOC, DOT, NASA, the National Laboratories, industry and our allies, and viewed as complimentary to and an extension of the international fiber optic grid. Major changes must be made in space communications assignments vis-à-vis the current MILSATCOM channel allocations. Those users that can reside on fiber optic arteries must do so, freeing the bandwidth on orbit for use by the mobile, tactical users.

Earth will be a “wired world” whereby anyone, anywhere, including soldiers, sailors and marines, and airmen, can carry crackerjack size devices and communicate with any location in the world via multimedia and in any trackless, featureless environment know their spherical position within meters (actually centimeters) in any weather, day or night. It will be an era when parents, relatives and loved ones of every soldier, sailor, marine and airman can sit in their

living rooms and observe real time, in three dimensions, the total environment in which they are operating. This comprehensive situational awareness will be viewed in dens and bars around the world at the same time as the on scene commander, the one with the ultimate responsibility, and will have an indelible effect on how wars/conflicts are waged. Time will no longer be measured in years, months, days, hours and minutes, but nanoseconds. Information will be tagged with GPS time accuracy that will serve as its primary and basic attribute. In fact, all communications will have GPS position, time and velocity vector superimposed upon every transmission to enable all in the net to know the others exact position and their relative position.

4.3.2 Enabling Technologies

Because of great improvements in switching technology, digital signals processing, fiber optics, wavelength-division multiplexing, and digital radios, bandwidth is expected to increase from five to 100 times as fast as computer speeds. Within a year, 10 gigabit-per-second communications arteries (OC-192 trunks) will be a reality and the available bandwidth will continue to expand at an exponential rate. Today, 700 separate wavelengths can be sent over a single fiber-optic thread and in the near further it will be possible to carry 2.4 gigahertz on each wavelength which will result in more than 1,700 gigahertz on every fiber thread. Within a decade it will be possible to send 10,000 wavelength streams down a single fiber thread and emergent erbium all-optical broadband amplifiers will permit communications transport at the speed of light. Fiber circuits will provide almost unlimited bandwidth, greater reliability, less noise and at modest cost. The requirement to convert electronic pulses every 35 to 50 kilometers to be amplified and regenerated will be but romantic memories. Today lasers exists that are powerful enough to send signals across the Atlantic without amplification. And, although there will exist a plethora of trans-oceanic fiber optic cables and every theater CINC will be serviced by multiple, alternately routed fiber optic cables, restoreal cables could be laid if necessary. Cables can be laid between New York and Great Britain today in six days and this time will undoubtedly diminish in the future. This global fiber optic grid will have a profound effect on the space communications architecture, where functions will be performed and by whom. Reportedly, 98 percent of the world's major cities will be serviced by fiber optics by the turn of the century, greatly influencing what the military commanders will target and significantly complicate intelligence collection.

Asynchronous transfer mode (ATM) communications will usher in greatly expanded bandwidth that will accommodate simultaneously voice, video and data and bring a new dimension to C4I for the Warrior. Bandwidth of 2.4 gigabits is available now and will increase as the technology matures, spurred in the private sector by commerce and the multimedia entertainment enterprises. It potentially will provide every household around the world home TV entertainment via satellite. This capability unto itself would enable a subliminal form of Information Warfare.

The performance of microprocessors will continue to escalate exponentially and the power of these computers will not only be their individual computing capabilities or data storage (l4 gigabytes of RAM today with 64 bit technology), but their ability to access phenomenal network computing capability and network data storage. Video digital "pumps" will receive and distribute enormous serial bit streams to massive parallel processors for transaction computations. Span servers will permit the interchangeability of optical media, regardless of the operating systems

and the portability of objects as easily as structured data today. This will enable multimedia with all of the wonders of color graphics, high resolution satellite imagery and video.

As we enter the age of bandwidth measured in billions of bits per second, we must remain conscious that microprocessors, as marvelous as they are, still are rated in millions of instructions per second. Experts disagree on how close we are to the "limits" of Complementary Metal Oxide Semiconductors (CMOS) technology. For years, it has been predicted that the semiconductor industry will hit the limits of CMOS fabrication. So far we haven't hit these limits and in the near term increases in performance can be achieved by making things smaller, denser and faster. Chip density doubles every l8 months. However, as .05 microns (particles smaller than the size of a virus) are reached around the turn of the century, we will have reached the limits of the number of transistors (approximately 100 million) that can be put on a chip with current technology. The dissipation of 80 watts of power for 100 million transistors would have presented a challenge, but industry has migrated from 5.5 volt chips to 3.3 volt ones enroute to 300 millivolts. The smaller chip voltage needs, reduces the heat to be dissipated and microprocessor power requirements, enabling faster, cheaper and cooler devices. Smaller devices closer together at lower power is the key to speed and the faster the transport the lower the noise.

Industry promises to increase peak clock speeds by a factor of five in the next two years and chip performance by factors of several hundred. Chips at the end of l995 will function at l.2 gigahertz and perform as many as 400 gigabits transactions per second

Research is being conducted on multi-billion transistor chips, described as gigascale integration (GSI). GSI will be governed by fundamental, material, device, circuit and system physical limits. Soon teraflop microprocessors will be available in desktop variety providing teraflops of power for processing terabytes of data. These lower powered microprocessors with unfathomable performance will open entirely new vistas of generic opportunities for applications on orbit.

Over the past 35 years minimum feature sizes have declined by a factor of 50 to 1, switching energy of binary transition has decreased by a factor of 10 thousand and the number of transistors per chip has multiplied by 50 million. Yet, the price of a chip has remained virtually unchanged and its reliability has increased manifold. One can confidently predict continued leaps forward and perhaps an increase in pace in the future. Uniprocessors will give way to symmetric multi-processing and massive parallel processors.

Communication satellites in the year 2015 must incorporate these and other emerging technologies to ensure bandwidth is available to provide the warfighters the information that they will require. Massive onboard signal processing should be a major factor in the design of communications satellites to improve the signal to noise ratio and effectively increasing the power output and ameliorate the power aperture problem for the mobile, tactical users with small antennas. This quantum leap in processing capability will enable communications 30 to 40 dB, and possible greater, below the noise level. This spread spectrum, frequency agility mode of operation employed in the past, with the attendant trade-off in bandwidth, to achieve an anti-jam margin of protection, and low probability of detection/low probability of intercept communications can now permit users to operate on top of each other without interference, preserving precious frequency spectrum. This feature takes on ever increasing importance as

the competition for frequency spectrum becomes excruciating and spectrum becomes a lucrative source of revenue and takes on greater significance during this period when military used frequencies are the most vulnerable.

Small, light weight, rugged, affordable, broadband, high gain, electronically steerable antennas that are able to access multiple satellites, in different frequency bands, in different parts of the sky simultaneously must be designed and fielded for the mobile, tactical users. The single frequency, mechanical, parabolic antennas must become footnotes in the history of satellite communications.

Voice activated, controlled and operated computers are available today. Soon one will be able to communicate via polyglot computers that will translate and provide language error correction for duplex communications with most nationalities in the world. Real time transliteration of text in over 100 languages exists today and by the year 2015 will include all significant languages in the world.

Smart software will manage vast information networks far too large and complex for human control. Using genetic algorithms, software will adapt and evolve to solve changing problems, without new programming.

These enabling technologies are of mythical proportions, but are within the realm of sober scientific reality and will provide opportunities that only the most sagacious can envision. Historically, we have been quixotic in our near term estimates and myopic in predicting our more distant achievements.

4.3.3 The Anatomy of Space Communications in 2015

The tenets for the satellite communications architecture for the year 2015 will be the same as for any information system today and consist of six essential features. The system must prescribe single data entry and be:

Seamless—Information at the user's fingertips, without any air-gaps, transparent to the user.

Open Systems—A common operating environment and standards, i.e., "building codes".

User-pull—The user must be able to dynamically construct his own information domain, i.e. administratively, geographically, prarametrically, temporally, etc., so that he gets only the information that he needs, when he needs it, and in the form that he desires. We drown in data, yet thirst for information and knowledge.

Multimedia—If mathematics is the queen of the sciences, then colored graphics, images, and video are the royal interpreters and must become inseparable partners of traditional voice, facsimile, narrative messages, etc.

Scaleable—A building block system that can be optimally tailored to serve the user's needs and be able to expand in performance and capability at least linearly and preferably exponentially.

Multi-level Security/Trusted Systems—A highly desired feature today and an absolute requirement tomorrow.

There will be universal and easy access to any person, organization and enterprise in the world and to vast sources of information for personal, vocational and occupational use for commercial, educational, environmental, public services, health care, disaster relief, military, etc. benefits. This proteus of all information systems will be a ubiquitous network of networks composed of both terrestrial and space based communications systems and be transparent to the users. This hybrid communications system will provide "fiber-like-service" and optimum routing over every variety of communications satellite. Network management will be of such complexity that it will necessarily be automated and provide adaptive and alternate routing based on the bandwidth on demand requirements and the merit of the "system of systems", down to the pixel level, with a bit error rate of less than one in a 10 billion. All circuit will have full automatic standby circuits and have continuous monitoring for determining circuit status. This heterogeneous network of networks will embody inter satellite connectivity, via cross links, first within the same constellation and orbital plane, but eventually between satellites in different orbits and in different frequency bands. This decentralized satellite communications network will interconnect low and medium-Earth-orbiting satellites with geostationary satellites to form a powerful and extraordinarily high-capacity holistic satellite communications "system of systems" that will seamlessly interface with terrestrial communication networks to form a global multi-media information system. The satellite communications architecture will provide a seamless extension of terrestrial networks and provide connectivity to sparsely populated and remote areas not now serviced by fiber optics and the regions where the military is most likely to operate.

The need for dedicated military systems will diminish and increased dependence will be placed on redundancy for survivability. Today, over ninety-five percent of Defense and Intelligence Community voice and data traffic uses the public telephone system and this amount is likely to increase. Security, reliability, and availability, the traditional reasons for dedicated military communications satellites will be routinely attained in commercial systems by volume, diversity and proliferation of all transmission and processing means. The future satellite communications revolution will be driven by commercial developments and led by the explosion in bandwidth and its plummeting cost. In crafting the satellite architecture for the year 2015, the technical culture and inculcated mindset of bandwidth scarcity must be overcome. Neo-Luddities who would deter the rapid growth of this global information network must be neutralized. It is the building of the Global Information System for the 21st century that is the task at hand and not clinging to the 20th century antediluvian procedures and systems.

Commercial satellite communication bandwidth assignments and channel arrangements that historically accommodated voice and television communications, will increasingly migrate to handling data, imagery and multimedia communications. Even the Ku band which is currently focused on over land and high density populated areas, will give way to more universal worldwide coverage. Media servers will act as a multimedia library that stores, retrieves and manages all type of information, including video, audio, images, text and relational data. Interactive global television will be common place, including the Joint Task Force Commander's forward command post.

(Following two paragraphs are taken from Mr. Ivan Bekey outstanding and visionary paper.)

Extraordinary demands on the frequency spectrum will require wide use of frequency-reuse technologies and procedures such as numerous simultaneous spot beams with very small footprints, attained with antennas or arrays hundreds of meters in diameter aboard GEO satellites. Similar technology in lower-orbit satellites could be used to drastically reduce the transmitter power required for portable terminals, as well as reuse the frequencies for spectrum conservation. Insatiable appetite for more spectrum driven by market forces will force expansion into higher and higher frequencies, with their attendant increased bandwidth. Millimeter, infrared, and optical wavelength communications will become necessary for most fixed up and downlinks, utilizing geographical diversity to prevent outages due to weather.

The Global Information Infrastructure will depend heavily upon myriad commercial communications satellites in various orbits, covering the frequency bands from VHF through EHF and beyond, funded and operated by the private sectors of numerous nations and consortia and will serve as the backbone for this military satellite communications architecture. Unimaginable amounts of information will flow over this global information system and will change the world's cultures, its caste system, its social order, its economy and the face of the information infrastructure will be changed in much the same way that the interstate highways once changed the face of the commercial infrastructure. As international and multinational partnerships are created and the language, culture, currency, etc. challenges are solved we will become a more understanding, holistic and better world. Hugh bandwidth arteries will be available over direct broadcast satellites that will enable high resolution imagery, digital TV and other high bandwidth data dissemination services to be delivered to the deployed warfighter.

What has emerged from the eye of the storm is the acute requirements for multilevel security, trusted systems, computer assurance and data integrity. The requirement, actually an essentially, of making available all possible information to the operational commander is universally accepted. As this information is maintained at multiple security levels, mandatory access control and encryption are required to protect this information, particularly as Coalition Warfare becomes a defacto standard operating procedure.

Mandatory access control mediates access to information based on its sensitivity and the clearance of the user trying to access it, provides a means of controlling access to information based on the sensitivity of the information as represented by labels of operating systems objects, i.e. files, devices, areas of storage, etc., and on the formal authorization or clearances of the user accessing the data. Mandatory access control and labeling are the key features of multilevel security systems and are the quintessence for this global information system. The requirement for trusted systems is not unique to the military. The best use of trusted systems technology is not to protect military secrets, but to promote commerce. Industry must accept the face that the company that can not protect their business data can not protect their business. All of the alpha-numeric categories of trust are of little concern to industry, that is more concerned with the protection provided than the pedigree of the security system. It does us little good to win a war and then lose our way of life.

This satellite communications architecture and infrastructure must be able to support, without restrictions, global joint and combined planning, simulation and modeling, rehearsal, event execution and post strike evaluation, including battle damage assessment.

4.3.4 Conclusions

Future multimedia communications capability will provide personal communications to any point on the globe, and very high data rate capability among virtually every populated area. These universal capabilities, whose transmission medium and routing will be transparent to the customers, will be available commercially and will provide reliability, flexibility, capacity, security and quality of service. The rate of technology changes will make it difficult to match these capabilities with any government-owned systems. The international nature of many of the providers of these services will blur the "source" of the capabilities (US-owned, allied, etc.). Connections to other information systems may be more limiting than the communications systems themselves, and access to spectrum or transit may be more difficult challenges than technology. There will be a rapid expansion in available bandwidth. Advances in microprocessors and antenna technologies could enable greater bandwidth and more reliable communications for the tactical, mobile users.

4.3.5 Recommendations

1. Craft a global terrestrial and satellite communications architecture whose infrastructure would be built upon existing and planned DoD and commercial capabilities.

2. That this resulting architecture be distributed, flexible, scaleable, seamless, fault-tolerant, reconfigurable, transparent to the users and include communication satellites in different orbits, in different frequency bands interconnected by cross links.

3. That DoD users that can reside on fiber optic arteries should be required to do so, and the warfighters given priority for satellite communications bandwidth for mobile, tactical users.

4. That veritable unique military survivable and enduring satellite communications requirements be identified and the resulting satellite designs be based on projected technologies.

4.4 Global Positioning, Time Transfer and Mapping

Ivan Getting, John Darrah

4.1.1 The Role of the Air Force in the Development of Space Based World-Wide Navigation

The GPS is the current (1995) space-based navigation system of the DoD.[1] The Air Force is responsible for the GPS Program Office (JPO) whose assigned responsibilities include the development and acquisition of the space segment, the ground control segment, and common military user equipment (UE). Each service (and platform development and acquisition Program Office) is separately responsible for UE imbedded in platforms (aircraft, vehicles, ships) or in weapons and missiles. The Air Force Space Command is charged with the operation of the GPS system. Since the GPS also serves as a "time-transfer system," furnishing accurate Universal Time Coordinated (UTC) world-wide, it coordinates UTC-GPS system time with International time (GMT) through the Naval Observatory. The Air Force Space Command integrates its global positioning with the Defense Mapping Agency (DMA) which is responsible for military mapping and geodesy - and the GPS uses DMA's established world grid WGS-84.

Geographic location and determination of local time go back to antiquity - usually based on the technology available for optical astronomical observation. All-weather positioning received a major boost in the past century by technological advances in radio (direction finding and "time signals").

About 50 years ago, stimulated by urgent need during World War II for more accurate all-weather position location and supported by improvements in electronic and radio technology (higher frequency, more bandwidth, time difference circuitry, etc.), a variety of ground-based Loran-type systems came into being. Performance was limited by radio propagation and/or masking. The invention of the transistor, followed by integrated chips, and reliable higher-power solid-state transmitters contributed to smaller, cheaper, and more reliable equipment. The invention of the maser, of atomic clocks, and of quartz-crystal controlled oscillators also contributed to advances in both position location and time determination and transfer. The major technological advances in support of position and time-transfer in the last 25 years was, of course, in space technology - the ability of putting satellites into orbit and accurately determining their orbits, "space qualified hardware," etc. - in all of which the Air Force played a leading role.

The first satellite navigation system was the Navy TRANSIT (operational in 197?). It was fielded to meet a specific Naval requirement of indexing the location of the SLBM submarine. It met the all-weather global accuracy requirement. However, the service was intermittent, horizontal (lat/long) only, and subject to errors induced my user motion; and, as such, it was not suitable for use in aircraft or missiles. It did not provide accurate time transfers. Navigation depended on the availability of complementary equipment (dead-reckoning, inertial systems, gyrocompasses, etc.). Nevertheless, it found broad application in both Navy and civilian ships - domestic as well as foreign.

1. 1994 DoD-DOT Radionavigation Plan

The first satellite system approach for providing passive continuous all-weather navigation position in three dimensions for use on aircraft and other highly kinematic users was the 621B study supported by the Air Force (1963). Being passive, it could serve an unlimited number of users. Being passive, the user was not subject to detection or tracking (e.g., by a military enemy). The system provided 3-D positioning by determining the range to at least 3 satellites. The system employed the most modern signal processing (pulse-code modulation; band-width compression to extract accurate range from very weak signals and support anti-jam and security requirements). Yet the User Equipment (UE) had to be inexpensive and reliable. Hence, a fourth satellite was added to allow the use of inexpensive quartz reference clocks in the UE, corrected to the Navsat system time. Three-dimensional accuracies of 15m SEP and 20 nanoseconds accurate time corrections to the UE clock were predicted and demonstrated on ground tests. It took a third of a century (31 years) to bring such a system to operational status (1994) - why?

The long gestation time was mostly "political" and government hierarchical. The performance for military applications and the multitudinous civilian uses of the system were largely predicted in early application studies; but who was to bear the costs (in billions of dollars) and who would manage and control? The 621B concept was described to the Agnew Space Task Group in 1969.[2] It was specifically labeled as a "lighthouse system in the sky" - serving not only DoD, but all mankind. It was turned down by the STG in favor of "manned stations serviced by shuttles." Within a year, Dr. Lee Dubridge, science advisor to President Nixon, reviewed the possibility of setting up a Presidential Commission to hold hearings on navigation satellites to identify: the principal civilian users and their needs; the non-DoD interested agencies of government(FAA, Coast Guard, Maritime Commission, Geologic Survey, etc.); the DoD branches, etc. In addition, the Commission would recommend an appropriate management and fiscal plan. After suitable consideration, and based on his substantial experiences, Dubridge stated, "It is too hard to get there from here; get one military department which has the greatest use, has demonstrated qualified experience in the management of large and expensive systems and run with the ball - when the performance of the system has been demonstrated, then like with past radionavigation systems, the others will climb aboard." The Air Force Research and Development Command accepted the challenge and with the support of civilians in DDR&E ended up managing (and funding) a Joint Program Office (July 1993), and the NAVSAT 621B program was renamed the NAVSTAR- GLOBAL POSITIONING SYSTEM or GPS.

The space segment of the GPS system consists of 24 satellites. With the launch of the 24th Block II satellite in March 1994, the GPS Navigation System was declared operational. (See Appendix A for a technical description.)

In the meantime, the war against Iraq (Desert Storm, 1991-1992) demonstrated without doubt that the GPS was a major "force multiplier" for all U.S. military services. This was soon followed by realization of its uses in many civilian and scientific applications.

2. The Space Task Group (STG) was established on 13 February 1969 by President Nixon to provide a post-Apollo space plan for the Nation.

4.4.2 The Responsibilities of Civil and Military Authorities in a World - Wide Satellite Navigation System

"The National Defense Authorization Act for Fiscal Year 1994 (Public Law 103-160) mandated an independent study, funded by the Department of Defense, on the future management and funding of the Global Positioning System (GPS) program."[3]

"Describing the need for this study, the Senate Armed Services Committee said: 'It is clear that GPS offers the potential to revolutionize the movement of goods and people the world over. Civil and commercial exploitation of GPS could soon dwarf that of the Department of Defense and lead to large productivity gains and increased safety in all transportation sectors' ".[4]

The independent study chartered by Congress stressed "the future management and funding" and recommended technical improvements. These recommended improvements addressed the current GPS-NAVSTAR system - and these are covered in Section III of this report. The principal management recommendations addressed civilian vs. military issues, U.S. vs. international issues, and U.S. national security. "no alternative governance and management arrangement emerged as fundamentally superior to the current arrangement at this time."[5] (Radio navigation coordination between DoD and DoT with DoD funding and operating the GPS.) Unfortunately, the "cat is out of the bag" [or genie is out of the bottle] - and mutually contradictory ongoing programs exist. For the future, the study recommended:[6]

> *The panel recommends that the President promulgate an executive order to set forth a national strategy and guidelines for GPS, establish a GPS Executive Board, reassert the policy of the United States to provide the civil GPS signal free of direct user charges world-wide, and announce that Selective Availability will be turned to zero immediately and deactivated after three years.*

Governance and policy leadership of GPS need a broader base and perspective. To achieve the national goals for GPS, the current governance and policy-making arrangement must be strengthened. *Therefore, the GPS Executive Board should be created as soon as practicable.*

> *The board, to be co-chaired by high-level designees of the secretaries of defense and transportation, should be responsible for governance oversight, highest level policy setting and policy guidance, and over all coordination for the entire GPS program, including augmentations.*
>
> *The board's membership should extend beyond DoD and DoT to the Departments of Commerce, Interior, and State, so as to be more inclusive and representative of the broad spectrum of the domestic and worldwide GPS user.*
>
> *The board should be directed to prepare and annual report for the President who, in turn, should forward it to the Congress.*

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3. "The Global Positioning System, Charting the Future", May, 1995, page vi
4. Ibid., p. vi
5. Ibid., p. 15
6. Ibid., p. 16-17

The board also should be responsible for formulating a comprehensive strategy to increase international acceptance and use of GPS that reassures foreign users of the reliability and consistency of the United States as a provider.

The board should ensure that DoD's and the Air Force's requirements processes effectively accommodate military and civilian GPS requirements and that appropriate means are established to fund non-military requirements.

The board, acting through its co-chairs, should be responsible for resolving disputes arising over GPS program management, operations, and funding.

The NAPA panel also recommends that:

DoD retain responsibility for operation and maintenance of the basic GPS, and the Air Force continue to act as executive agents; DoD also should continue to be responsible for international military cooperative arrangements.

DOT should be strengthened and become a more assertive executive agent for all US civil systems, oversee US participation in international organizations and GPS-related systems, and make arrangements with DoD to satisfy civil requirements for positioning and navigation using the civil SPS signal.

The executive order recommended above should provide a stronger charter for DOT's role, but effective leadership will be needed to carry it out. In this role, DOT should:

Coordinate civil agency requirements for and use of GPS and actively represent the civilian GPS community (including private and commercial interests, both domestic and international).

Institutionalize its consolidated requirements identification process for all civil requirements for GPS and work with DoD to formalize the mechanisms for incorporating them, where appropriate, into the current military operational requirements process for GPS.

Work with DoD to better coordinate military and civilian research and development efforts.

Cooperate with the Air Force to monitor and report on the integrity of the civil GPS signal.

Regarding use of the private sector for GPS differential services, the panel recommends:

As a general policy, the federal government should make use of the private sector for GPS augmentations beyond those specifically designed or required for public safety and national security.

The SAB-Space Applications panel differs from the report in regard to Selective Availability. While SA should be turned to zero availability - primarily to placate domestic and international civil and commercial entities, the panel disagrees that it should be "deactivated after three years." Some form of SA capability should be available to the NCA.

Technical improvements in UE, compatible with the existing space segments, can be introduced on an evolutionary schedule. However, physical changes in the space segment are necessarily gaited by the replacement schedules of the satellites. It is, therefore, necessary to discuss the future of the GPS in the near term, roughly 25 years (1995-2020 covering the current Block IIR and the Block IIF scheduled for proposal release in August 1995 with first launch in about 2005). Presumably some modifications in system operation can be introduced in Block IIF if provisions are made for switching and computer flexibility (software changes). Near term improvements are covered in Section 4.4.3

Major technological changes in the space segment of GPS Block IIF must wait to about 2020 (2025 - far term). Circumstances can arise which might require a “new start” of a purely military system or of special “add-on” satellites even in the near term. Both the “far-term” and “add-on” require pursuing new technology on a continuing technology program which is adequately funded.

There is general agreement that the GPS system will have enormous civilian economic impact - both directly and indirectly through savings on the provided services. On the other hand, national security is a key element for both U.S. survival as well as for economic well-being. Even a cursory review of history leaves little hope for a future free of strife and wars. To the long list of historic causes of strife, terrorism, and wars (nationalism, religion, economics, irrational ambition and leadership) we now must add overpopulation, depletion of natural resources, and environmental issues. To exacerbate these problems, many user technologies have recently been added of mass destruction (nuclear, biological, chemical). Recognizing these technological facts, the GPS subpanel of Space Applications Panel of the New World VISTAS endorses the footnote 3 on page 5 of the “GPS - Charting the Future” report, “As with all other federally-funded navigation systems, the ultimate decision-making authority over GPS operations, in peacetime and in wartime, is the National Command Authority (NCA), consisting of the President or, with the approval of the President, the secretary of defense.”

Nevertheless, technical questions persist. Can the U. S. deny the enemy’s use of GPS against us without doing harm to our own forces, or to friendly users of GPS (civilian and military)? Can we protect U.S. military use of GPS against international and/or non-international interference from both friendly emitters and enemy jamming equipment? Can technology produce answers?

4.4.3 Issues - The Importance of Assuring Frequency Allocation and Code Structures for the Future of Civil, Military, and Commercial Navigation

There have been radical changes in the use of the radio frequency spectrum since GPS was initially designed in the early 1970’s. Lack of a national policy for promoting the international protection of the GPS frequencies from interference threatens the long term viability of GPS as the key component of a worldwide navigation satellite system for civil and military users.

GPS occupies two Radionavigation Satellite bands designated for Space-to-Earth broadcasts by satellites. One band, extending from 1559 MHz to 1610 MHz, contains the GPS L1 signal centered at 1575.42 MHz (see Appendix A for a discussion of the GPS navigation signal structure).

This band is also allocated for Aeronautical Radionavigation, which includes safety of life systems. The second, extending from 1215 MHz to 1260 MHz, contains the GPS L2 signal centered at 1227.60 MHz. This band is shared with an allocation for radiolocation, which includes air traffic control radar.

GPS was joined in the early 1980's by the Russian GLONASS. Providers of GPS augmentation signals have hitherto been using other frequency bands (e.g., Inmarsat II, John Chance & Associates), but are now implementing or planning services in the radionavigation satellite bands occupied by GPS (e.g., FAA's Wide Area Augmentation System, Japan's MTSAT). Meanwhile, there is increasing use of the spectrum above and below the radionavigation satellite band. This trend may result in interference to GPS or other systems through out-of-band emissions, which are not as easily enforceable as in-band sources of interference. To a large extent, neither international regulation nor U.S. policy has paid adequate attention to the spectrum needs of GPS civil or military users. The accompanying figures illustrate the increasingly crowded spectrum near L1. Some systems depicted have been announced, but are not presently funded.

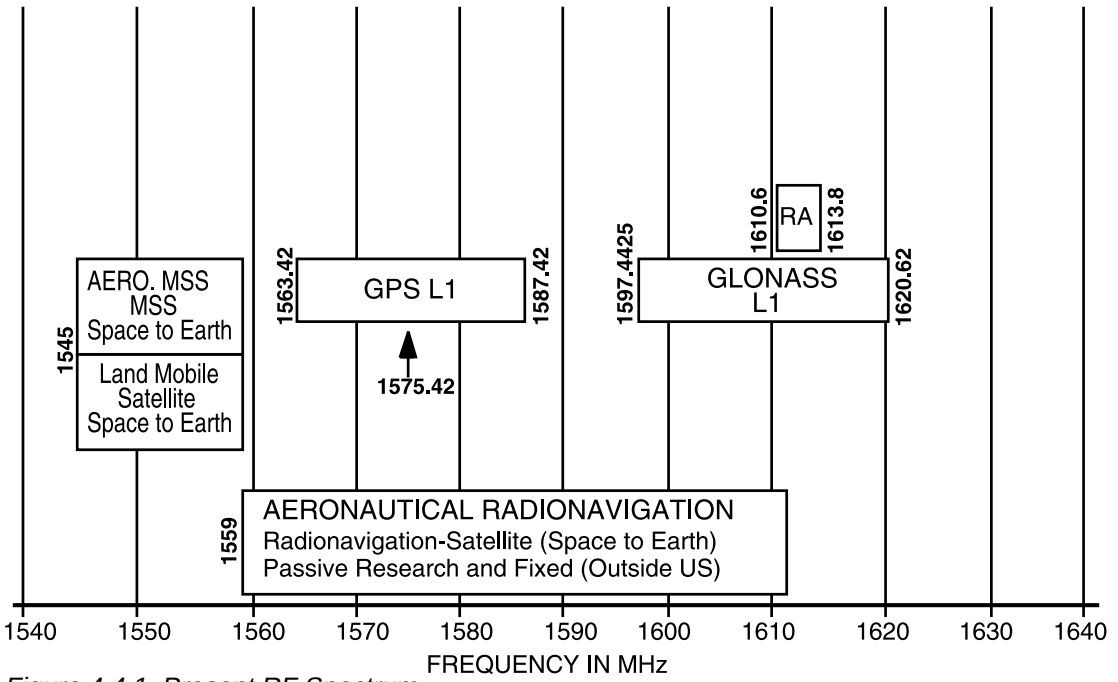

Figure 4.4.1. Present RF Spectrum

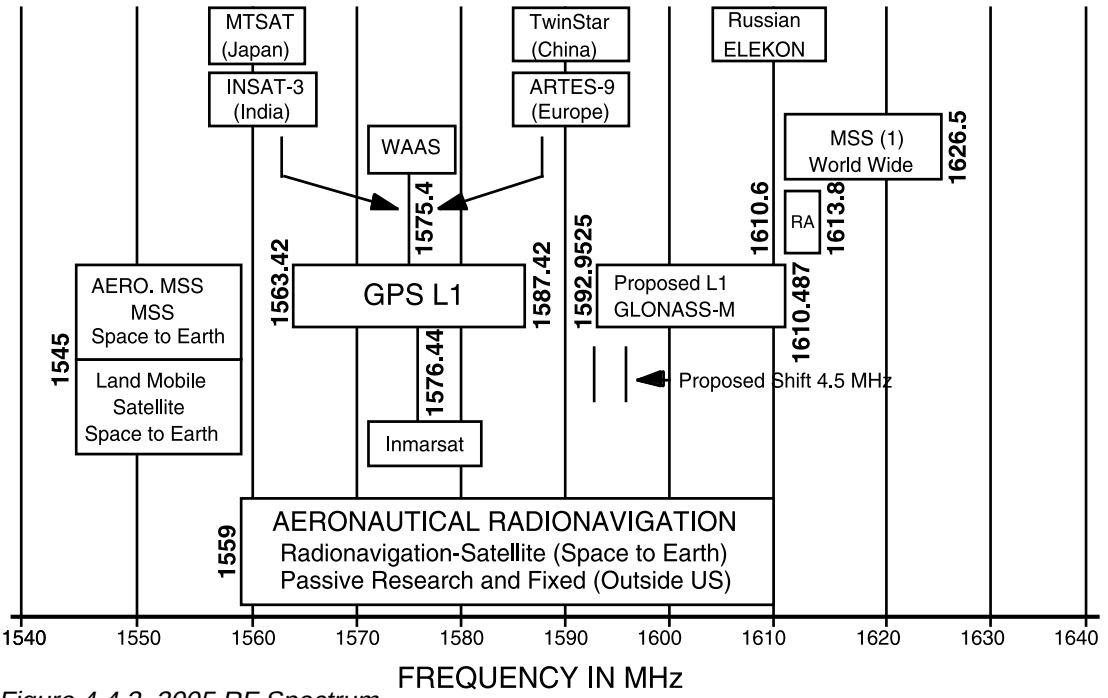

Figure 4.4.2. 2005 RF Spectrum

Use of the radio spectrum, when that use extends beyond national boundaries, is administered by the International Telecommunications Union (ITU), an agency of the United Nations. The GPS L1 and L2 frequencies are registered with the ITU as primary allocations and L1 as a safety of life service. But under ITU rules, protection of the allocation applies only within U.S. boundaries and within other nations which agree to protect GPS. The radionavigation satellite band is also explicitly for space-to-earth propagation, not space-to-space. Note that this means:

- There are no assurances that competing systems cannot operate on or near the GPS frequencies (i.e., neither DoD nor the U.S. “own” L1 or L2)
- There are no assurances of non-interference to GPS outside U.S. boundaries, and
- There is no protection whatsoever for any spaceborne GPS user

Interference to GPS occurs when the strength of the interfering signal degrades or overwhelms the GPS signal within the GPS receiver. Interference is caused by insufficient margins of relative power, frequency, or code separation between GPS and the interfering signal. The power issue is familiar to many: A very strong or very near transmitter can overwhelm a receiver, even if the transmitter is operating within specifications. In some cases, components in the receiver itself generate intermodulation products within the receiver passband from a signal source quite far from GPS in frequency.

The frequency issue is slightly more complex: The interfering signal may be on or near the GPS center frequency and hence within the receiver’s passband. The signal may be in nearby

parts of the spectrum outside the passband, but may have “spillover” that falls within the receiver passband. For example, certain types of handheld Mobile Satellite Service transceivers in the band adjacent to GPS may still interfere, if the transceiver is physically close enough to the GPS receiver. Finally, the signal may generate harmonics which fall within the receiver passband. UHF television channel 23 is frequently cited as an example of the latter; the channel 23 video carrier operates at 525.25 MHz, the third harmonic of which is 1575.75 MHz. However, tests to date have not established whether the sporadic cases of interference are due to harmonics of the TV transmitter or intermodulation products generated by the GPS receiver.

Finally, the signal modulation determines the level of interference. GPS uses spread spectrum and code division multiple access (CDMA). The spread spectrum technique mitigates the effects of narrowband and continuous wave (CW) interference. The CDMA technique allows multiple transmitters to operate on the same frequency with minimal interference by assigning each transmitter a separate code chosen from a “family”. The GPS C/A codes, used by the civil Standard Positioning Service (SPS), are from one family of Gold codes. For maximum compatibility with GPS, services on the GPS frequency should use members of the same family.

Current international procedures fail GPS in four ways. First, the Department of Defense carries no weight in the international bodies. Those bodies focus solely on the protection of allocations with current or near-term utility to the general international community (e.g., the civil SPS signal). Second, they treat GPS as one more system that is privately owned or owned by a single nation. This treatment ignores its potential as a worldwide international system. Third, there is no procedure for coordinating the common use of compatible codes to mitigate interference. And finally, the procedures fail to provide guidelines for protection of the growing spaceborne use of GPS.

Given the vanishing spectrum available for use and the growing number of potential new systems, strong national leadership is needed in developing procedures for the protection of the U.S. investment in GPS.

4.4.4 Issue - Wartime Use of GPS

Closely related to the previous issue of frequency allocation and code structure are:

1) Can the U.S. deny the enemy’s use of GPS against us without doing harm to our forces as well as to friendly users of GPS (civilian and military); and

2) Can we protect U.S. military use of GPS against interference by enemy jamming equipment?

In regard to item (1), the problem of denying the enemy’s use of GPS is somewhat simplified if SA does not exist - all that is currently required is to locally jam the enemy’s C/A UE since the P(Y) code and associated frequencies are not available to the enemy. Various schemes for such jamming are available; but the Air Force should continue the development, test and acquisition of such equipment. Some peripheral civilian jamming may result.

In regard to item (2), the P(Y) should be exploited by the military for wartime use, e.g. acquisition in the P(Y) code by all moving platforms prior to take-off (fighters from airfields or carriers; cruise missiles from launch vehicles; bombs and other missiles from aircraft); electronic distribution of crypto keys should be implemented at earliest possible date, etc. Additional

improvements suggested in Task 2:" Recommendations That Enhance GPS Performance for Military Users:[7]

The development of receivers that can rapidly lock onto the Y-coded signals in the absence of the C/A code should be completed. The deployment of direct Y-code receivers should be given high priority by the DoD.

Nulling antennas and antenna electronics should be employed whenever feasible and cost effective. Research and development focused on reducing the size and cost of this hardware should actively be supported.

The development of low-cost, solid-state, tightly-coupled integrated inertial navigation system/GPS receivers to improve immunity to jamming and spoofing should be accelerated.

The development and operational use of GPS receivers with improved integration of signal processing and navigation functions for enhanced performance in jamming and spoofing should be accelerated.

Military receivers should be developed that compensate for ionospheric errors when L_1 is jammed, by improved software modeling and use of local-area ionospheric corrections.

4.4.5 Issue - Continuing Improvements of the GPS System

The Congressionally chartered GPS study also recommended continuing improvements in the GPS leading to horizontal accuracies of a stand-alone GPS accuracy of 6 meters. Such improvements would reduce the use of differential GPS to special localized uses: Category III precision landing, maritime harbor pilotage, etc. Their recommendations are here, quoted verbatim - and this panel believes the Air Force should review those recommendations:[8]

Additional GPS monitoring stations should be added to the existing operational control segment. Comparison studies between cost and location should be completed to determine if Defense Mapping Agency or Air Force sites should be used.

The operational control segment Kalman Filter should be improved to solve for all GPS satellites clock and ephemeris errors simultaneously through the elimination of partitioning, and the inclusion of more accurate dynamic models. These changes should be implemented in the 1995 OCS upgrade request for proposal.

Procurements for the replacement of the monitor station receivers, computers and software should be carefully coordinated. The new receivers should be capable of tracking all satellites in view and providing C/A code, Y-code, and L_1, and L_2 carrier observables to the OCS. Upgradability to track a new L_1 signal also should be considered. OCS software also should be made capable of processing this data.

Firm plans should be made to ensure the continuous availability of a master control station.

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7. Ibid., p. 24
8. Ibid., p. 24-25

A simulator for the space and ground segment should be provided as soon as possible to test software and train personnel.

The operational control segment software should be updated using modern software engineering methods in order to permit easy and cost-effective updating of the system and to enhance system integrity. This should be specified in the 1995 OCS upgrade request for proposal.

The planned Block IIR operation should be reexamined and compared to the accuracy advantages gained by incorporating inter-satellite ranging data in the ground-based Kalman Filter and uploading data at some optimal time interval, such as every hour, to all GPS satellites.

Block IIR satellite communication crosslinks should be used to the extent possible with the existing crosslink data rate to support on-board satellite health monitoring for improved reliability and availability and in order to permit a more rapid response time by the operational control segment.

The Block IIR inter-satellite communication crosslinks should be used to relay integrity information determined through ground-based monitoring.

The DoD's most frequent satellite navigation correction update strategy should be fully implemented as soon as possible following the successful test demonstration of its effectiveness. In addition, the current security classification policy should be examined to determine the feasibility of relaxing the 48-hour embargo on the clock and ephemeris parameters to civilian users.

4.4.6 Issue - Long-Time Evolution of Global Positioning and Time Transfer

As stated on page 3, major changes in the space segment may not be economically feasible until about 2020. This does not preclude adding complimentary satellites to enhance the role of space for global positioning and time transfer. For example, it is possible to add "special satellites" even into the current constellation which might radiate substantially higher power in support of the P(Y) code and which might illuminate the entire earth's disc or alternatively, using higher gain antennae to illuminate just the combat area, etc. There is room for analysis on other orbital options.

With time, the determination of satellite orbits will improve, atomic clock technology (maybe using masers) will improve, compact accurate INS will become available, better "GPS"-"INS" integration and receiver tracking of both range and range-rate (Doppler) will result. Such expected improvements when integrated in UE, together with more accurate data on the troposphere[9], lead the panel to conclude that in the 2025 period the horizontal accuracy of the PPS can be brought down to 30 centimeters and time transfer to 1 nanosecond.

9. John McLucas (703-765-9310), letter to Space News dated May 11, 1995 titled "GPS/MET Lives!"

4.4.7 Conclusions and Recommendations for the Future System

The fundamental aspects of the design of the current GPS system were frozen in the 70's. There are many technical improvements which can provide the international, as well as the US, civil and national security needs.

We believe that there are new system designs that can significantly improve the warfighting capabilities (accuracy, security, anti-jam, anti-spoof) for the military users and the abilities to deny capabilities to international terrorists, rogue nations and those in active conflict with the U.S. and its Allies. These capabilities need not interfere with international peaceful civil and commercial needs for very precise location, time transfer and mapping needs.

The technology for incorporating many of these improved capabilities is currently available. The Air Force should incorporate changes as soon as they deem it practical in the satellite procurement. The new systems can be backward compatible for the civil users. We recommend that system design trade studies begin immediately to support future decision making. Laboratory and on orbit demonstration can be used to further reduce risks and increase confidence that there is a win-win system that is feasible and affordable.

One of the most important steps which needs to be taken is to protect the PPS frequencies. This is a complex national and international process which was developed prior to mobile and satellite transmitters. The result is an arrangement that takes a very knowledgeable staff and interagency cooperation to protect U.S. futures.

There are several system designs which could compete for the best solution to future civil and military needs. A strawman set of features which might characterize a new system based on the current system are:

Two frequencies for civil as well as military users to give them ionospheric propagation corrections.

Real time tropospheric moisture propagation corrections.

A combination of bandwidth, power, and orbital parameters that increase by a large factor (perhaps 1000) the signal that military receivers would have available.

Fast electronic distribution of cryptographic keys and wide availability of different keys would enhance security and flexibility.

Flexible signal generation that permits future satellite improvements via reprogrammable hardware and software.

4.5 Space Control

George A. Paulikas, Ivan. Bekey, J.G. Gee

4.5.0 Introduction

The totality of US spacecraft in orbit twenty to thirty years from now, military and commercial, together with their ground-based control nodes and launch sites will form a high value element of the national military capability. During the time period of interest, there will also be constellations of spacecraft operated by other nations and international consortia. Adding to the complexity of the situation expected to exist 20-30 years from now, is the likely presence of several, if not many, larger, manned space stations and space power stations. It may be in the national interest of the US to develop and deploy capabilities to disrupt, degrade or even destroy the space assets of adversaries with great precision and discrimination while also having the capability to protect U. S. national security and commercial assets by passive and active means.

4.5.1 Likely Threats

4.5.1.1 Jamming

Introduction

Electronic warfare jamming represents one potential method to be employed against space assets because the required technology is available worldwide. The development of jammers targeted against specific systems would depend on the importance the U.S. attached to attacking the system and how vulnerable we perceived the system to be to this form of attack. Jamming could be used to perform uplink and downlink jamming. These topics will be discussed below.

Uplink Jamming

In an uplink jamming role, the jammer would attempt to inject brute force noise or other selected jamming waveforms into the satellite receivers or transponders in orbit. The uplink signal to be jammed could be vehicle commands or the forward communications path for a satellite communications system. Interference with the vehicle command uplink might prevent the vehicle from performing its intended mission. Jamming against a communications signal would be intended to prevent the dissemination of the signal's information content to the intended recipients. Either option is attractive because interference with the command link can potentially deny the entire mission function of the system while interfering with a communications uplink can degrade or deny communications to many users simultaneously while not requiring the jammer to be located near the intended victims.

Jamming the command uplink of military satellites would require the jammer to be within the command uplink reception main beam because power entering through the sidelobes would not be sufficient. The use of high uplink frequencies and highly directional uplink reception antennas would result in small reception beam footprints and thus complicate the placement of a high powered jamming source.

Jamming the forward communications path of a satellite communications system is another potential application of uplink jamming. The potential uplink sources can be dispersed over a wide geographic area resulting in a large number of potential jamming locations. Satellites

using high frequency (SHF or EHF) uplinks have anti-jamming capability because the reception footprints are small, the wider available bandwidth complicates the jammer's mission, and nulling antennas can be used to further combat jamming attempts. Satellites operating in the UHF spectrum are much more vulnerable to uplink jamming because of their large reception footprints, limited bandwidth, and inability to use antenna nulling due to the prohibitive physical size of the required apertures.

Uplink Jamming Systems

An airborne system has no significant range advantage over a ground based jammer when targeted against space systems and would require an extremely complex system with high gain, steerable antennas. High power would be difficult to achieve because of the constraints imposed by the aircraft basing. A spaceborne jammer would have a significant range advantage over a ground based jammer but would suffer from extreme power constraints. These power constraints would require the jammer to stay within close proximity to the intended target which implies a sophisticated space launch, tracking, and control capability. For these reasons, airborne and spaceborne uplink jammers are considered unlikely candidates for development. Potential uplink jammers will likely be mounted on fixed, transportable, or mobile terrestrial systems.

A fixed ground based jammer would be effective because of its greater power but it would be technologically complex, expensive, vulnerable and would require a highly trained crew of technicians to maintain and operate. Such a jamming station would be deployed in very limited numbers. The lack of mobility of a ground fixed station results in the least tactical flexibility and the system's location can be determined rapidly and accurately once it is employed operationally (or during testing.) Thus this system would be most vulnerable to direct physical attack.

A transportable jamming station is defined as a single, high powered jammer which can be mounted on a large vessel or can consist of several trucks. The station is considered to be technologically complex and expensive and to require a large amount of logistical support. The setup/tear down time is postulated to be on the order of several hours. A trained crew of technicians is also required to maintain and operate the system. This type of jammer would most likely be deployed in limited numbers. The transportable nature of the system would provide increased operational flexibility and survivability at the expense of reduced transmitted power.

A mobile jamming station is defined as a high powered jammer which can be mounted on a small vessel such as a fast frigate or can consist of two to four trucks. This type of jammer is considered to be the least complex and expensive of the three classes. Potentially we could deploy a large number of mobile jammers to provide a distributed jamming threat rather than a single point, high powered jammer. The setup/tear down time is postulated to be less than several hours. Since mobile stations are prime power limited the jammer output power would be the smallest of the three types. However, this system would provide maximum tactical flexibility and maximum survivability to direct physical attack.

Downlink Jamming

Downlink jamming is sometimes the only way to effectively jam a space system. In the downlink jamming role, the jammer would attempt to inject brute force or other selected jamming waveforms into the satellite user receivers located on Earth. Effective jamming of the

ground receivers is dependent on power, time, and geometry. The jamming signal must be directed toward the target receivers with sufficient strength and at the proper time to block or confuse reception of the intended message. The jammer must be within line of sight of the target receivers. Downlink jamming might be employed against any space systems supporting force enhancement functions such as navigation, communication, environmental sensing, and reconnaissance/surveillance. Generally, multiple intended receivers must be targeted. These receivers would typically be located in areas of regional conflict or crisis. Thus jammer deployment would be simpler than uplink jamming targeted against command transmitters located in other countries.

Downlink Jamming Systems

Airborne systems make the most sense for potential downlink jammers because they can provide simultaneous line of sight to a large number of potential earth based receivers. Spaceborne jammers in low earth orbit could potentially see many more downlink receivers than an airborne system at a given point in time but they would require higher power for the same effectiveness as an airborne platform due to their greater range from the intended targets and a single platform would have only several minutes visibility to any particular operating region, necessitating multiple platforms for effective regional jamming. Thus space based downlink jammers are no an attractive option due to the requirement to operate at appropriately high altitudes with a formidable aperture. Another viable alternative is a low powered, expendable jammer that could be placed in limited numbers to accomplish specific mission objectives as described below.

The technological issues involved in building a credible brute force jammer against satellite downlinks are relatively simple. It would be feasible given sufficient time and a number of suitable fixed or rotary wing aircraft, to configure a challenging noise jamming capability. The challenging part of developing this threat capability is commitment of the airborne platforms and integration of these jamming systems into overall air operations. Although these systems would be power limited, their enormous range advantage over the satellite transmitter makes them viable concepts. The current and near term trend is the acquisition of small/medium, dedicated fixed and rotary wing aircraft to perform conventional airborne jamming missions. Unmanned air vehicles are being increasingly used in this role. These same type of systems could be modified for use in the downlink jamming role.

4.5.1.2 Kinetic Energy and Directed Energy Systems

Introduction

A variety of kinetic energy and directed energy systems could be used to threaten space assets. These threats are all technically more challenging and expensive than electronic warfare jamming, information warfare, or ground station attack. Amplifying material on these potential systems are provided below.

Kinetic Energy Weapons

Kinetic energy weapons employ high speed projectiles to damage or destroy targets through the mechanism of kinetic energy transfer without the use of any type of explosive warhead. A variety of mechanisms can be used to deploy kinetic energy weapons against space systems.

Examples might include satellites maneuvered to act as weapons (co-orbital interceptors or space mines,) missiles launched from aircraft or other satellites, and ground based missiles used in direct ascent attacks. A key requirement for these type weapons is the ability to get the weapon in close proximity to the target. Such a weapon would require surveillance and identification capability to acquire and track the targets with sufficient accuracy and timeliness, and some maneuvering capability to perform the engagement end game. Direct ascent missiles are the most likely delivery options for regional type adversaries. Space or aircraft based missile systems would have some advantages over ground based systems (reduced engagement timelines, potential covert employment) but their development would imply considerably increased system complexity and system integration risk. The constraining factor in developing a comprehensive low altitude kinetic energy capability is the required infrastructure and the development of the kill vehicle.

Directed Energy Weapons

Directed energy systems conceivable for attacking space systems include lasers and radio frequency weapons. Two types of laser ASAT systems could be developed An out-of-band system is designed to inflict physical damage on a target satellite due to the exposure to high powered laser radiation. An in-band system is intended to spoof, jam, or damage sensors carried on the satellite whose operating frequencies include the laser weapon's frequency. An in-band system can be effective at a much lower power level than an out-of-band system but it requires the ability to ensure the laser can illuminate the target sensors. Lasers could potentially be ground based or housed in airborne or spaceborne platforms.

Out-of-band systems in particular are technologically complex and expensive and would require lengthy and expensive development efforts. In-band systems might be a more viable option because of the lower level of technology and expense required. However, an in-band system is not a trivial development because of the requirement to accurately point and maintain the beam on the targeted space based sensors. This aspect of the problem is particularly challenging for rapidly moving low earth orbiting targets. Targeting electro-optical missile launch detection sensors based on geosynchronous platforms might simplify the target acquisition and pointing problems.

Any laser ASAT system developed would probably be ground based. An aircraft system could fly above the weather that can prevent propagation of laser radiation from the ground to space, it would suffer less from atmospheric effects that attenuate or distort the laser beam, it would provide more tactical flexibility, and it would have increased survivability. However, such a system would have reduced power levels (and no appreciable range advantage over ground based systems) and have considerably more difficulty in acquiring the target and pointing and maintaining the weapon beam because of the rapidly moving platform. A space based system could operate at much lower power levels due to decreased range to the targets and would eliminate any atmospheric impacts but would require a major, expensive, and risky development.

Large amounts of radio frequency energy directed at a target satellite can produce damage, upsets, and disturbances. The required amounts of energy are much greater than would be required for satellite communications or jamming. A ground based system would require a large power source and a large antenna. These requirements in turn would require a fixed site that

could easily be located and thus subject to physical attack. The requirement for high powers and large antennas preclude air based options because the required powers are not significantly less than ground based weapons. A spaceborne or missile borne weapon could get much closer to a target and so operate at considerably reduced power levels but the development of such a capability by any potential adversary would require considerable technical expertise, development, and expense.

4.5.1.3 Threats to Ground Elements

Introduction

Perhaps the simplest method to attack space elements are attacks aimed at the ground elements required to support all space operations. Elaborate weapons and space systems capability are not required. The locations and functions of a number of critical space support facilities are widely known. Information warfare options directed against these space support facilities were addressed above. This section only considers physical threats to the various space support facilities.

Launch Complexes

The locations of launch complexes are widely known. Preventing the replenishment or augmentation of space capabilities can be accomplished by an effective physical attack against these limited number of complexes. Our with strategic power projection capability could target the complexes with ground or sea based ballistic missiles. Air assets could also be used. We could use special operations forces and conventional means although this approach would presumably be more difficult. It is unlikely that potential adversaries would have the ability to reconstitute critical launch facilities if they were attacked and destroyed.

Command and Control Facilities

Targeting launch facilities would be perhaps not be an effective strategy if the adversary's launch systems were not intended to provide rapid combat support. The most effective strategy to neutralize a large number of on orbit space assets is to target their command and control sites. If the location of these sites were known, they could be subject to the same physical threats as the launch complexes. An effective countermeasure to this type of attack would be the use of mobile ground stations to perform the command and control function.

Data Processing Centers

Military space support systems that provide data to central sites for processing and subsequent dissemination to users are vulnerable to attacks on such sites. The same threats apply as those listed above. Dissemination directly to the end users would thwart this approach but such a countermeasure impacts the system architecture and requires the development of equipment that can be deployed to the user locations and provide adequate functional capability. If multiple users desire to directly control the satellite's data collection and reporting capabilities the complications increase.

4.5.2 Space Traffic Control

Space traffic will increase dramatically in the next decades, principally due to the proliferation of LEO satellite systems, both commercial and military. There will also exist an

international space station, and one or more commercial industrial parks. In addition, there will exist naturally occurring and man-made debris objects in orbit. This section examines what must be done to ensure an ability to operate effectively in space in this environment.

Current traffic to space amounts to somewhat less than one million pounds annually, represented by some 50 spacecraft launches worldwide. The future will be very different, due to the onset of small, proliferated, mainly low altitude satellites. Foremost among these will be commercial communications systems such as Iridium (66 spacecraft) and Teledesic (850 spacecraft), but will also increasingly include military systems such as Brilliant Eyes (30 spacecraft). These will be replaced periodically with more advanced systems, and the old commercial constellations likely be sold to second tier users. Thus, in contrast to today, in 20-30 years there will likely be hundreds to thousands of small-to-medium-sized satellites in orbit. In addition, very large and probably manned systems will exist, such as an International Space Station and one or more Industrial Space Parks. As space operations mature and servicing/ upgrading of reusable space systems becomes routine, there will be a need to control approach and departure corridors, at least around the large space facilities and in the more heavily populated orbits, in a way akin to air traffic control today.

In addition to active spacecraft, micrometeorites and an extensive population of man-made orbital debris population exists, principally in low altitude orbits. The most troublesome of these is the orbital debris, since it is easy to shield spacecraft against micrometeorites. There are today about 150,000 debris objects in orbit in the size range of 1-10 cm diameter, which represents the greatest thread to damage to spacecraft due to hypervelocity impact. Though the frequency of impact of smaller particles is larger, they are relatively inexpensive and easy to protect against. Impact with debris objects much larger than 10 cm is probably not survivable, but the number of such objects in orbit is fairly small. Therefore a few high value spacecraft can be given warning by a surveillance network to make minor maneuvers so as to cause a miss of a few hundred feet. But the 1-10 cm size debris, which are too numerous to maneuver against and too expensive to protect against, will require some action.

Most orbital debris is so long-lived that even if near-perfect mitigation techniques were implemented, the existing debris population might not be reduced significantly for decades. There are also controversial models of secondary collisions which could cause an exponential increase in the number of objects. It is possible to reduce or essentially eliminate much of the orbital debris threat. A moderately sized ground pulsed laser can be targeted against individual debris objects, causing a surface plasma blowoff. This blowoff creates an impulse which, if applied at the proper orbital location, can reduce the debris object's perigee and therefore its lifetime.

It is estimated that most debris objects between 0.5 and 10 cm. in size can be completely cleared from low altitude orbits in 4 years by only one laser site. The laser system requires a surveillance sensor system to detect the debris objects, track them, and point the laser at the objects. The accuracies required are demanding, but attainable. This kind of a laser debris-clearing system is being defined in a NASA study just getting underway, and could be a practical solution.

Though debris at GEO altitudes is less of a problem, it may grow to significance, particularly if very large communications spacecraft are fielded there. Ground-based lasers are not a practical

way to clearing such debris, though a space-based laser may be. However, for both low and high altitudes, passive sweeping using maneuverable spacecraft dragging large balls of Styrofoam or aerogel on a tether may also prove effective. Ultimately, these may have to be augmented by active spacecraft to capture and change the orbits of larger debris and the increasing number of dead satellites.

An active space surveillance system will be needed to control this environment. Such a system could well be an outgrowth of the current Spacetrack system, but may need sensitivity, coverage, and other augmentations. These augmentations could be spaceborne, and indeed could be dual functions of spacebased surveillance systems whose primary functions are aimed at airborne or surface targets.

In addition, the capability will have to be developed to communicate with all active spacecraft via standardized commands, much as is the practice for aircraft under positive control. Due to the proliferation of spacecraft owned and operated by other nations and by international consortia, this surveillance and command system may have to be internationally operated, or at least various national systems will have to be internetted. In essence, a space traffic control system will be needed, controlling traffic in and around high value spacecraft such as the Space Station, and in populated LEO and GEO orbits. A number of security issues will have to be faced if an effective space traffic control is to be adopted.

4.6 Force Projection from Space

Ivan Bekey

4.6.0 Introduction

The natural use of space is to move and deliver energy, not mass, due to the cost of getting mass out of the earth's gravity well into space. For this reason communications, observation, and other information applications of space have been the first to be widely exploited, and why these functions of space are currently the only ones used to support the warfighters. However, advances in technology expected to be available in the next two decades, in concert with greatly reduced cost of access to space expected to occur in the next decade, will also permit practical uses of space to include delivery of much larger amounts of energy, as well as small amounts of mass. This will therefore allow the use of space assets to project force against surface and airborne threat elements, as well as against space objects and ballistic missiles.

Satellites present a presence over battle areas that is difficult to deny, and do so repeatedly and frequently enough from LEO, or continuously from GEO, so that force application using them could have a marked strategic as well as tactical effectiveness on the conduct and outcome of conflicts. This force can be applied anywhere rapidly, with minimal risk to U.S. forces, and at all levels of conflict. It is equivalent to artillery and strike support with infinite range and moving at 25,000 mph., with the added advantage of enjoying complete surprise.

New technologies will allow delivery of very large amounts of precisely aimed and focused electromagnetic energy at microwave and millimeter wavelengths from electromagnetic weapons; as well as optical energy from lasers with much lower cost and greater number of shots than past designs. In addition, they will actually allow small but very effective amounts of mass to be delivered against surface and airborne targets precisely enough as to have locally devastating effects.

4.6.1 Delivery of Munitions from Spacecraft

Developments pioneered by the SDIO/BMDO in space based precision guided, small, lightweight hit-to-kill interceptors with large divert radius can be adapted for interdiction of surface or airborne targets. With application of a small deboost rocket, and inclusion of large l/d rods made of depleted uranium, these munitions are able to deorbit autonomously or on command, and guided via GPS to a precision strike at hypersonic velocities essentially anywhere on earth.

The extended rods of these munitions would be able to penetrate hundreds of feet into the earth to destroy hardened bunkers or other buried facilities. Used in the divert/homing mode, and fitted with multiple pellets, these weapons would be deadly against high value airborne targets as well, such as AWACS-type aircraft.

These weapons could be used sparingly, but with devastating accuracy and effect, and little collateral damage or exposure of friendly forces. This ability to call down and accurately deliver mass from orbit on surface or airborne targets with complete surprise amounts to munitions with ultimate stealth, for which there is little effective passive defense. Cost effectiveness compared to delivery of similar capability via artillery for from the air may show favorable

ratios when the entire cost of placing and supporting more conventional capabilities is taken into account.

4.6.2 Delivery of Electromagnetic Radiation from Space

The technology of high RF power and large antennas is about to greatly expand. This technology would enable very large diameter thin film antennas, or the formation of very large coherent essentially-filled arrays controlled by cheap, small super-processors. When combined with large sources of RF power, on or off-board, such spacecraft could project very narrow beams of extremely high power density long distances to space, airborne, or surface targets. Their availability and use would greatly overpower electronic equipment so as to either incapacitate them for extended periods or destroy their front ends. In addition, they could jam or spoof them, introduce network saturation, disruption, viruses, disinformation; or all of these effects.

Such spacecraft would constitute a quintessential electromagnetic warfare and information warfare capability, that could operate over battle or denial areas with impunity. In fact, the power densities available would be so large that the spacecraft could well be placed in GEO, so that one or at most a few of them would have the ability to operate continuously as a strategic or tactical weapon of great effect.

As an example consider an ability to generate as little as 100 kW of power, about what is used on the NASA Space Station. Thin-film membranes supported by inflatable structural elements or electrostatic forces are now being developed. These techniques lend themselves to formation of filled apertures perhaps in the high tens of meters diameter, with surface accuracies usable up to Ka band. These antennas would be an order of magnitude lighter and less costly than those with conventional deployable structural elements.

In addition, techniques now being developed at JPL will allow precision station keeping of separate elements of a phased array, with control to enable all elements to radiate or receive coherently. These techniques dispense with structural members altogether, creating a “virtual structure”, which is the lightest of all. In essence, structural webs are replaced by information webs—a perfect application of the natural characteristics of space. With these techniques, it is planned to emplace elements that can be separated by tens or hundreds of kilometers. These would form thinned or sparse arrays, which have exquisitely fine resolution, comparable to that attainable in the optical regime, and could be useful for many intelligence applications.

However for power transmission it is necessary to have an essentially filled array, lest the power be placed into the sidelobes. For force projection beam applications the elements would be moved together, and stationkept such that the gaps between them are less than half the wavelength, which is quite feasible up to the high tens of gigahertz. The resulting array is filled, and its size is solely determined by the number of elements fielded. Array sizes of many hundreds or meters diameter or more will be feasible, limited mostly by the budget available. In this context, a small array can be fielded, and as more money is available, additional elements added. This creates an antenna for a weapon that has incrementally increasing performance as funds are available.

With either type of large antenna, the ability to project RF power with such a system would be awesome. Consider an antenna of 100 meters (330 ft) diameter. It would have a gain

of almost 80 dB at X band, and if a power source of 100 kilowatts were used, the effective radiated power (ERP) of the system would be about 130 dB. This is 10 million megawatts! If the system were deployed in GEO, its footprint on a battlefield would be 6 miles diameter. The power density over this area would be 10 w/sq. m, and the field strength about 1 volt/meter. These power densities and field strengths are about 13 orders or magnitude above the sensitivity of typical communications receivers, and about 6 orders of magnitude greater than that of typical radar receivers and optical or IR sensors. They are far above the damage threshold for these receivers.

Thus in use, all radar receivers in a 6 mile area would be totally blanked out, and all unprotected communications sets either burned out or damaged. Larger arrays of film antennas or stationkept arrays would reduce the footprint. 1,000 meter antennas are entirely possible, which would have a footprint of about 1 mile from GEO. These systems could have a multiplicity of beams, all electronically steerable and independent. Their use in the field would constitute a "jam-on-demand" capability, if not a "burnout enemy sensors on demand" capability which could be used with surgical precision, in real time, and all the time. The small footprint and sidelobe control would allow them to be used with surgical precision, and with little collateral effect on friendly sensors or forces.

In addition, the awesome power densities would allow certain injection of signals into even heavily shielded communications networks, which would allow information warfare to be waged at will. Network viruses, disinformation, memory erasures, false signals, and other forms of information warfare could be injected where desired. The high energy density of the signals would assure their penetration into many nodes of a network, and could block signals as well as operate on their information content.

All of these capabilities could be attained with lower altitude satellites, of course, but at the cost of more satellites and intermittent coverage. Lower altitude satellites would be more susceptible to attack, and would have to be proliferated at great expense. This favors placing one or two systems in GEO. It goes without saying that such powerful weapons platforms would be able to destroy any incoming interceptor, and thus would be extremely difficult to disable.

The ability to perform such battlefield electromagnetic chaos at will is unlikely to be allowed to exist for very long before countermeasures are attempted. However, while front ends of receivers can be protected against burnout by careful design and use of front end shorting devices, they will not be able to operate while the jammer is on. Attaining jamming suppression ratios of 130 dB or more is not currently possible, as we see from the GPS problem at much lower attempted rejections. Thus while it may be possible for most enemies to prevent a second wave of burnouts after losing a generation of field systems, we can prevent them from operating as long as desired, or at the very least very seriously degrade their operation.

The already awesome capability of such systems could be made even more so by radiating greater power at lower weight and cost. It is highly likely that very large orbiting solar power stations capable of delivering energy to the earth will be build in space in the next several decades by the commercial sector. These system will be designed to collect and deliver hundreds to thousands of megawatts driven by market forces demanding clean, inexhaustible energy. These systems will likely use microwaves or millimeter waves for power transmission. It is not

likely that we could use such systems in a dual-use mode as space weapons, because they will be designed with broad beams in order to keep the energy density at earth low to minimize damage to people. However, if these systems sent their power to the space based weapon, and the weapon received only a fraction of the beamed energy due to the beam size at intercept, the weapon spacecraft could avoid the expense and weight of a power system, receiving and reradiating the beamed power from the power station instead.

A likely scenario is that these commercial systems will be developed in increments, with the first steps being orbital development test spacecraft capable of beaming “only” a megawatt or so, with following models at 10 to 100 megawatts. These will be used by the commercial sector as an “Orbital Power and Light “ company, selling power to the Space Station and to orbiting commercial industrial facilities, after their test period is complete. The DoD could purchase power on demand from such systems, avoiding the need to develop and orbit huge power systems, or develop and emplace similar beam powering systems in orbit or on the ground. Under these conditions, the space based weapon spacecraft could well radiate a sizable fraction of the power beamed to it, which could be 1-10 megawatts or more, making it even more deadly that the 100 kW device assumed in the above example.

4.6.3 Space Based High Energy Lasers

High energy laser weapons, have been thoroughly analyzed and much laboratory work was done under the SDIO/BMDO program, however no such system has been fielded. This is for a number of reasons, some obviously political, but not a small factor is the high cost, large weight, and relatively few shots available from such systems. These weapons will become much more attractive in the future as a result of new technologies such as 20+ meter thin film mirrors and other techniques described in the EM weapon section, but used in conjunction with new technology phase conjugation correctors, shorter wavelengths, more accurate pointing and tracking techniques, and others. In addition they will greatly benefit from the expected major lowering in the cost of access to space.

These advances will enable lasers to attain much smaller spot sizes at longer ranges, lowering the energy per kill, and thus resulting in systems with reasonable mass and cost with capability for very many kills compared to current concepts. As a result, they could be utilized against a large number of high value surface, airborne, and space targets, and accomplish the attainment of complete denial of airborne superiority as a result of being able to destroy all high-flying aircraft at will.

In addition, and not the least, these lasers will of course be highly effective against tactical and strategic ballistic missiles in conjunction with a surveillance and cueing system, and attain a very favorable exchange ratio. If this surveillance system is integrated with the weapon platform, the true space “battle station” will have been born.

4.6.4 Disruption or Destruction of Enemy Satellites from Space

The ability of EM weapons to destroy sensors and receivers is more easily applied against unfriendly spacecraft, which cannot be shielded for long lest they not be able to carry out their function. Thus an EM beam force projection spacecraft is useful against space targets as well. This obviously also applies to laser weapons. In fact either weapon could be used in a

time-shared mode, since the number of spacecraft they would have to disable in time of conflict is probably far smaller than the number of surface targets against which they would operate.

Force application against other spacecraft can take other forms than beam power projection or physical attack. A number of techniques applicable from rendezvous space weapons have been known for many years though not yet implemented. Following rendezvous and station keeping with the spacecraft in question, paint can be sprayed onto optics, solar arrays, or radiators to disable the spacecraft covertly, assuming that our approach has not been detected. Likewise the spacecraft can be nudged or tipped gently in order to exhaust control fuel. Electronic interference is extremely easy from a few feet away, and takes negligible power. In short, homing interceptors may not needed, nor special warheads, if a capability is developed for a space weapon spacecraft capable of on-orbit control, with some form of proximity sensor and the specialized devices to cause the disruptive effects to other spacecraft.

This is one version of a space mine, albeit a nefarious kind because its action may never be detectable or provable, since its action results in failures much like normal failure modes of satellites.

4.6.5 Summary

In summary, in the next decade or two, new technologies will allow the fielding of space-based weapons of devastating effectiveness to be used to deliver energy and mass as force projection in tactical and strategic conflict. This can be done rapidly, continuously, and with surgical precision, minimizing exposure of friendly forces. The technologies exist or can be developed in this time period. The resulting capabilities would include denial of air supremacy at will, defense against ballistic missiles, and ECM/ICM on demand, and could radically increase the cost-effectiveness of the US forces in future conflicts.