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Logistics

This section of the book addresses the lift, combat service support and education and training aspects of space in 2020. The first two papers address the ability to access space and, once in space, the capability to maintain a ready, warfighting presence. The third paper covers the implications that technological advancement and enhanced space military presence will have on our service education and training processes.

The United States must have assured access to space. This means placing payloads into earth orbits with high reliability, quickly and responsively, affordably, and with great resiliency (or the ability to recover from a launch failure). Our current space lift capability is certainly inadequate against these criteria. Both national and military imperatives dictate developing a lift capability that will protect national sovereignty from other space nations while allowing profit motivated commercial exploitation of the medium and a near seamless integration of space as a military dimension. To do this, a technologically feasible vision is provided of a composite aerospace wing which includes a squadron of rocket-powered trans-atmospheric vehicles (TAVs). These fighter-sized airframes would be capable of placing approximately 5,000 pounds in any low earth orbit or delivering an equivalent payload to a suborbital trajectory to any point in the world. The concept would entail aerial non-cryogenic propellant transfer from modified KC-135Q aircraft and maintenance, logistics and ground operations compatibility with the rest of the aircraft wing.

Full exploitation of space requires a capability to sustain operations in a timely and effective manner. Today's satellites are complex, redundant, expensive and cannot be upgraded or repaired except at extraordinary cost and under special circumstances. A vision based on space modular systems and common satellite interfaces is presented which will complement the TAV lift concept of ready space access with smaller payloads. A large satellite will serve as a motherboard to space modules by providing inclusive support of power, communications and housekeeping. The modules will be small with each having unique missions or functional capabilities ranging from imagery to communications and will be lifted individually to the motherboard. The modules and motherboard will be mated via common satellite interfaces. These modular payloads will be less complex, upgradable and provide the warfighter a responsive space capability.

To provide a sustainable infrastructure for all space assets it is envisioned that one on-orbit space depot would be established to provide the logistical support of the motherboards and their modules. In addition to depot functions the station would provide satellite refueling operations and debris removal. Servicing would be accomplished either through satellite retrieval or on-location servicing of satellites distant from the depot. These functions would be accomplished with orbit transfer vehicles (OTVs).

The potential for exploitation of space will be constrained without a permanent manned presence. A concept is offered for a manned orbiting

2,
industrial park with gravity, power, water and air. Such a facility will allow industrial processes to synergize with the benefits of the space environment and permit spin-offs into commercial and military areas.

Understanding is a prerequisite to doing. Hence, in the future space education and training and technological enhancement of educational approaches is mandatory. As our nation extends beyond its terrestrial borders our personnel, concomitantly, must be educated and trained with the power of space concepts. The third paper provides this vision.

White Paper

on

Spacelift: Suborbital, Earth to Orbit and On-Orbit

Spacelift- Team #1

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I. Subject and Problem Statement

A vision for the future: In 2020, "aerospace" forces will be a reality. A notional composite aerospace wing, based in CONUS, would include a squadron of rocket-powered trans-atmospheric vehicles (TAVs). These vehicles, derived from the Black Horse X-vehicle described below, will be fighter-sized airframes capable of placing approximately 5,000 pounds in any low earth orbit, or delivering an equivalent payload on a suborbital trajectory to any point in the world. Either mission could be accomplished within one hour, assuming that the payload was available at the base and the vehicles were on alert. When deployed or operating in support of a warfighting CINC from CONUS, the aerospace wing will thus have the capability to put mission specific payloads on orbit or on target literally within a few hours of a need being identified. Aerial propellant transfer (from modified KC-XX aircraft) will be required for most missions, but some suborbital combat and ferry/deployment missions could be done without it. These aerospace craft will use non-cryogenic propellants: standard jet fuel and hydrogen peroxide, and will be designed for maximum logistics compatibility with the rest of the wing. Maintenance and ground

operations will require no greater specialized skills than any other aircraft in the wing. TAVs returning from a mission would normally be turned in less than a day, and could be surged to fly multiple missions per day if necessary. TAVs could also be used (especially if a tanker was prepositioned in theater) to fly high priority cargo delivery missions if needed.

Some additional considerations: Most space systems will be redesigned to take advantage of the vastly lower cost per pound to orbit (roughly \$200 per pound) that the TAV concept provides. Orbital payloads that are too large to fit in a single TAV will be designed modularly, launched in pieces and assembled on orbit. Some high value satellites are serviced, repaired and updated in space by "space tugs", which move payloads brought to orbit by the TAVs to the mission orbit. With space launch and operations now routine, multiple new uses for space systems have emerged, and the design cycle for new systems has shortened so much that for most missions short lifetime satellites are preferred: they are less expensive, simpler and quicker to make, cause less harm if one does fail, and allow more rapid inclusion of emerging commercial technologies. Space operations has also changed dramatically, as a result of being able to orbit dedicated space support capabilities quickly and inexpensively. Satellites perform navigation and housekeeping functions autonomously and are "controlled" (monitored, given necessary support such as software updates, and troubleshoot) by a central ground site, but can be tasked directly by theater warfighters using ground systems that require less "lift" into theater than current communications/data display terminals. As a result, space systems and operations have finally become integrated into theater operations.

The United States must have assured and affordable access to space to expand or even sustain space operations. This means being able to place useful payloads in all relevant earth orbits

with high reliability, quickly and responsively, and with great resiliency (the ability to recover from a launch failure). It also means the ability to operate flexibly in and through space to accomplish both manned and unmanned missions in support of US national and military objectives. By almost any measure, our current space lift (earth to orbit) capability is in trouble and getting worse. Suborbital (operations through space) and orbital maneuvering capabilities are almost nonexistent, with the exception of ballistic missile delivery and limited satellite repositioning. These shortfalls must be addressed if the United States is to make full use of space in the next century.

This paper proceeds from the assumption that assured access to space is crucial for many reasons: to enable future innovative ways of supporting the warfighter, to counter threats from unfriendly space-faring nations, and to create the conditions for a commercial market that may ultimately drive space technologies. Numerous studies (SMC/XR briefing, cite others) and other white papers in the Spacecast study are available to support this assumption. Ultimately, expanded military, civil and commercial use of space depend on one thing: assured and affordable access to space, without which nothing else can occur.

A review of the limitations of current launch systems suggests several specific areas that cause problems:

- current systems have severely limited (non-destructive) abort capability thanks to their predominantly ICBM heritage, the use of solid rocket boosters, etc.
- use of disposable hardware, manpower intensive operations, and the design of US lift systems in general, causes large recurring launch costs
- there is no standardization of launch vehicles and their interfaces, spacecraft buses, payload interfaces, etc; this is a dead-end street

- tailoring rockets to fit payloads is particularly costly and wasteful
 - solid rockets and disposable hardware are generally not environmentally friendly;
- future launch systems must take this into account, particularly if the number of space launches is to expand dramatically
- a huge, archaic and highly specialized launch infrastructure (ranges, launch pads, personnel, etc.) causes high costs and lengthy, unresponsive launch schedules.
 - space launch and operations procedures are overly complex, non-standard and expensive
 - we do not have an operationally responsive space launch system, and we do not have the capability to reconstitute even a limited capability on orbit in response to a crisis and loss (deliberate or accidental) of any of our space systems

This paper does not propose a new national space policy, a new space lift policy, or a “silver bullet” solution that will allow us to operate basically as we have in the past. Rather, we intend to describe an alternative architecture of space lift, suborbital and on-orbit vehicle capabilities that will a) enable the country to perform missions in space in the mid term that we currently cannot, b) provide a responsive and resilient space lift/operations capability that is increasingly acknowledged as militarily essential (see Horner et al), c) enable us to break the current cost-weight-size-complexity-risk-delay vicious cycle that our space systems are stuck in, and d) offer the *potential* for future commercial exploitation that would not only result in vast new commercial opportunities but would in turn drive development of even better capabilities (as has happened in electronics, for example). This paper proposes a spacelift system that can put usable payloads on orbit for a reasonable cost, and has the maximum operational utility, i.e. is responsive (for launch on demand), requires little or no specialized infrastructure, operates like an

airplane, and has the potential to change the way we approach space as surely as the DC-3 changed air travel. It will also address potential suborbital missions that such a system would allow, discuss different ways of deploying, servicing and redeploying space assets once they are on orbit, and explain why this is desirable in some (but not all) cases.

II. The Capability and Its Relevance

If our nation has no desire for expansion in the use of space (either militarily, scientifically or for commercial purposes) we can no doubt muddle through by tinkering with existing systems and gradually refining procedures to gain small improvements in efficiency. To do this would be to commit ourselves to an ultimately self-defeating cycle: increasingly large and complex space systems, technologically obsolescent as soon as they become operational, and ever fewer yet higher-performance launch systems to put them on orbit. The great risk, cost and difficulty of replacement associated with failure of one such payload (during launch or on orbit), demands increasingly burdensome and unwieldy oversight focused on ensuring nothing can possibly go wrong. In other words, not only will a policy of muddling through not enable a breakthrough in the use of space, it may ultimately cause even existing uses of space to become unaffordable and unattractive.

The core of our proposed space lift and transportation architecture is an innovative space access capability operated like an air transportation system. The US space transportation capability of the future should include systems for moving payloads around within space or through space (suborbital, orbital or return from orbit) as required. We propose pursuing a

spacelift development strategy that provides solutions to our most pressing problems while encouraging but not assuming future quantum improvements in space transportation technology.

With launch of a satellite no longer a complex and costly task, we can design spacecraft for shorter lifetimes, then either upgrade or replace them with newer, state of the art systems. Since the satellites could be designed with deliberately shorter lifetimes, the consequences of an on-orbit failure could be remedied as soon as a satellite was available for launch. Much of the current cost and complexity could be designed out of the systems, creating a cycle of smaller, less expensive, more technologically up to date systems. Satellites that must be large for physical reasons (e.g. optics that do not use interferometry) could be designed modularly and assembled on orbit. To take full advantage of this capability, we would have to revisit most of our basic assumptions about space operations. Some thoughts on this are contained in White Paper X, Military Space Operations.

It's important to note that a single system will not satisfy all needs, just as we don't use variants of a single airframe for all air missions. Also, transitional measures may be necessary to preserve operational capabilities until new technology systems come on line. As we stated above, we do not intend to solve all space operations problems in one fell swoop. We do believe, however, that the approach outlined below offers the maximum payoff in the 2020 time frame.

Primary Lift Systems

Any proposed lift system must address the operational concerns and problems highlighted in section I. Specifically, to be militarily useful, a future lift system must be responsive (capable of launch on demand), highly reliable, able to abort a launch non-catastrophically (soft abort), resilient, flexible, logistically supportable, and easily operated. An overriding concern for all

users—military, civil or commercial—is that the system be affordable. Since there is legitimate disagreement on what these qualities translate to in terms of specific numbers, we have not adopted quantitative goals, but seek to propose a system that offers a recognizable qualitative improvement in the way we place payloads in space.

A key assumption is that the size of the individual payload put into orbit by a given launch vehicle should not drive the system design. Our contention is that cost per pound to orbit is the key measure, and if the cost is low enough, almost any mission payload can be repackaged to fit. Those payloads that absolutely, positively must have a specific size launch vehicle will probably never be “affordable” unless overriding national security concerns require their launch.

This strategy rests on several further assumptions:

- the technology that drives space payloads (sensors, electronics, software, etc) is advancing rapidly and even accelerating. This favors having up-to-date systems on orbit.
- these same technological advances increasingly allow good things to come in small packages; modularity, interferometry, bistatic radar techniques and other technologies may even allow things traditionally seen as requiring large monolithic platforms to be put in space incrementally.
- economies of scale have proved elusive in space systems; large boosters are not appreciably more cost effective (\$ per pound on orbit) than small boosters, and no projected demand or incremental improvements will significantly reduce the cost of current boosters
- military space operations will be increasingly subject to fiscal constraints; national security requirements will no longer justify performance at any cost

Even making these assumptions, there are several possible alternative systems, most of which are familiar. These include Pegasus, Taurus, other light expendable launch vehicles,

converted SLBMs launched from sea-based platforms, hybrid (mixed solid-liquid propellant) rockets (also expendable), a variety of reusable vehicles from NASP-derived systems to DC-X-derived SSTO's and carrier-orbiter concepts like the German Sänger, Boeing's RASV, and even cannon or railgun launch. A complete quantitative comparison is beyond the scope of this study and in any case is unlikely to be conclusive, given the number of assumptions that must be made in comparing anything but existing technology. With the objective of reducing costs and maximizing operational utility in mind, we believe we can recommend a new approach.

The following is a qualitative comparison of several different launch systems. The "JP TAV" is a concept that is described in more detail below. A more complete description of the "capabilities" and how they were assessed is included at Attachment A.

System Capability	DC-X SSTO	JP TAV	Pegasus	Taurus	Sea Launch	Gun Launch
Responsiveness	Good	Excellent	Good-Ex	Poor-Good	Poor-Good	Excellent
Flexibility	Good	Excellent	Fair	Poor	Fair	Poor
Soft abort	Fair-Good	Excellent	None	None	None	None
Resiliency	Fair	Good	Fair	Fair	Fair	Good
Logistics	Fair	Fair	Fair	Fair	Fair	Poor
Reliability	Unknown	Unknown	Fair	Fair	Fair	Unknown
Ease of op'ns	Good	Excellent	Fair	Fair	Fair	Fair
Environmental	Excellent	Good-Ex	Poor	Poor	Poor	Fair-Ex
Cost (lb to orbit)	Good-Ex	Good-Ex	Poor	Poor	Poor	Excellent

Table 1. Qualitative Launch System Comparison

Which Kind of System is "Best"?

Most of the alternative systems recommended above either offer no qualitative difference in the way we launch satellites (Pegasus, Taurus, other expendables and hybrid rockets), or require too many spacecraft design compromises (gun launch). Why is a qualitative difference important? Because even the most ambitious recommendations for improved conventional (expendable) boosters do not offer more than a factor of two reduction in cost per pound to orbit, and in most cases still rely on antiquated range support systems and (to a lesser extent) launch procedures. Cannon/railgun systems may be attractive in terms of cost per pound to orbit, but there are some severe limitations. Payloads must be designed to withstand accelerations of 1000 G's or greater (this flies in the face of our desire to build less costly satellites with fewer constraints on the use of commercial parts), and we would become more, not less dependent on specialized infrastructure: we would basically have to build one gun launch site for every orbital inclination we use (large inclination changes on orbit are prohibitively expensive in terms of Δv , the currency of space maneuvers). If something happened to the gun, we could not launch into that orbit. Barring a revolutionary advance in propulsion technology (which is as unlikely in the next twenty years as it is unforeseeable), we believe that fully reusable lift systems offer the best hope for qualitative change in space lift.

Problems With Reusables and General Design Goals

From basic intuition through the justification for the space shuttle to the most recent studies (Aldridge report, NASP studies, Delta Clipper studies), fully reusable systems offer the greatest operational flexibility and potential cut in launch costs. Three problems continually recur, however: first, how to build a system that is completely reusable and has acceptable performance, second, how to justify the enormous non-recurring costs (infrastructure investment as well as hardware development) to get the eventual benefits of lower recurring costs and third, how to reduce recurring costs to the point where an eventual payback can be expected. The space shuttle's problems in all these areas and more have disillusioned people, but we believe a radically different design may finally vindicate the reusable launch system approach.

The problems with fully reusable launch vehicles have their basis in misplaced attachment to old paradigms of space systems (i.e. we need at least 20,000 pounds of lift capacity). This drives performance to the ragged edge, creates tremendous development costs and dependence on immature technologies, fails to address operational implications, and produces huge specialized infrastructure requirements that further drive up recurring and non-recurring costs. These crippling problems can be overcome.

The negative effect that trying to get the maximum number of pounds of payload onto a given rocket has had on cost and reliability is now widely acknowledged (Aldridge conversations). Further, as discussed above, the vicious cycle of large satellite design and the opportunities provided by miniaturization and other advancing technologies argue in favor of smaller, standardized satellite designs (DARPA papers et al). Finally, AFSPACOM has expressed frustration with the custom rocket approach which comes from squeezing every last ounce of lift out of a given booster. The time is ripe to design our launch vehicle first, make sure it is operationally sound, then build payloads to fit it.

Development costs and dependence on immature technologies are linked to the performance issue. Because performance requirements are so high, only exotic fuels, engines or design concepts can possibly meet them. As a result, billions of dollars in research and development is required to validate (and sometimes invent) the enabling technologies. All too often, the success or failure of a given approach cannot be determined until the system is actually built, but even a prototype incorporating so many advanced technologies is hideously expensive. The answer lies in an affordable X-vehicle development program that has clear near-term military relevance and traceability to an operational system.

Failure to take into account the operational implications of a launch system—not just the launch crew but the support infrastructure for fueling, maintenance, logistics, basing, etc—has been crippling in terms of cost and the eventual utility of systems. NASP-derived and two stage (carrier vehicle and space plane) concepts seem particularly guilty of this, although they still represent an improvement over the huge, archaic, expensive, inflexible and manpower-intensive procedures required for our current lift systems. We believe that, from the start, operational and infrastructure considerations must be given top priority.

Toward a New Type of Lift System

To address these concerns in light of the assumptions, we start with the proposition that maximum performance (in terms of specific impulse for rockets) may not be necessary or even desirable. This in turn allows us to consider non-cryogenic propellants, which offer several advantages. If these propellants are sufficiently dense, a workable lift system can be designed (the British did so with the Black Arrow and Black Knight programs using 1950s technology). This is because factors such as a reduction in tankage volume (hence rocket empty weight), a decrease in

engine complexity and an improved engine thrust-to-weight ratio make up for much of the (propellant) performance loss. As it happens, one of the most attractive combinations of non-cryogenic propellants is jet fuel (nominally JP-5) and hydrogen peroxide (Clapp and Hunter, *A Single Stage to Orbit Rocket with Non-Cryogenic Propellants*).

The real attraction of this propellant combination is in the operational arena. The propellants are easily available—hydrogen peroxide is sold for industrial uses at 70% purity (and could be easily refined on site)—and storable, and pose no significant logistics problems. Rocket engines using these propellants also have excellent reliability histories, both on the Black Arrow/Black Knight programs and on the NF-104D research aircraft, which started such an engine three times on every flight, experienced no rocket engine related emergencies during eleven years of operation, and was serviced and maintained with “essentially conventional maintenance procedures and normally trained personnel.” (Clapp and Hunter).

If readily available and easily stored propellants are used, the only reasons why our reusable vehicle could not operate from any location are specialized requirements for assembly/loading, launch and landing. Although a vertical takeoff and landing system has advantages in terms of empty weight and choice of launch/landing sites (theoretically it only needs a small pad), we believe a horizontal takeoff and landing system is a better near-term approach. First, we believe there are sufficient airfields available for any conceivable missions, second, airfields are where our fuel supplies and logistics infrastructure are already located, and finally, a horizontal take-off and landing vehicle would almost certainly be more robust (a larger abort envelope, the ability to land with all engines out, and greater cross-range on reentry, for example). Further discussion of this issue can be found at Attachment B. There is a performance penalty

associated this approach (hence the DC-X design), but there is also an ingenious way to get around it.

Another problem with true single stage to orbit vehicles is that they must lift all the propellant they need to reach orbit from the ground. This in turn drives the weight of the vehicle, hence its size and the structural margins needed for safe take off and in case of a launch abort. Much of this structure is dead weight long before the vehicle leaves the atmosphere. To date, two design approaches have attempted to get around the problem: NASP, which is an air breather for much of its flight, and the carrier vehicle/space plane two stage concept. Both approaches have numerous drawbacks. We prefer another approach: to launch the TAV with minimum propellants, then *rendezvous with an aerial refueler* to load the remainder. The choice of non-cryogenic propellants is essential here, and the properties of a JP-5-hydrogen peroxide engine in particular (H_2O_2 is almost twice as dense as jet fuel, and the engine operates at a 1:7 fuel:oxidizer mix by weight) make it attractive to consider transferring the bulk of the oxidizer after takeoff.

More substantial details of how this concept would work are included in section III and section IV (for a near-term X-vehicle program). A brief sketch of notional operations indicates the possibilities. The vehicle would be readied for flight at an "aerospace" base (different only from an airbase by the H_2O_2 storage and first level maintenance equipment, all of which could be deployed), fueled (with 100% of its JP-5 and approximately 7% of its H_2O_2 capacity), have its payload (at least 1,000 pounds using 1970's technologies and assuming two crew members; 5,000 pounds is a reasonable goal for a 2020 system) loaded, taxi and take off, rendezvous with a tanker, load the entire tanker's capacity of H_2O_2 , turn to the correct heading and depart for orbit. From push-back to orbit would take an hour or less. Once its orbital mission was completed, the TAV would deorbit and return to its own (or any other suitable) base; again, a very short duration

process. A suborbital mission would be similar and there would probably be no need to refuel before returning to base. Turn-around time is somewhat speculative at this point (the X-vehicle program would answer this), but a preliminary look at the technologies (rocket engine, thermal protection etc) suggests it will be a matter of hours or days at worst.

The system described above is conceived, at least initially, as a manned system. Without getting into the issue of whether a crew is or always will be necessary, it is assumed for the following reasons: it is essential for the initial X-vehicle development program, although that same program could test technologies that would enable later unmanned versions (e.g. unmanned aerial refueling); it is desirable for several of the suborbital missions (see below); and it may be desirable for some operations in space. If the vehicle has an austere (e.g. U-2-like) cockpit and is not designed for long-duration in space missions (this will almost certainly be true for the X-vehicles), we believe the loss of payload is more than compensated for by increased operational flexibility.

The operational utility of this concept is vastly increased flexibility and responsiveness in launching spacecraft and performing suborbital missions, tremendously reduced operations and logistics infrastructure, increased reliability, suitability for manned flight, and significantly reduced cost of space launch. It also on current USAF operational strengths (e.g. aerial refueling, which we do dozens of times a day, versus airborne separation of large/manned vehicles, which we've done a few dozen times in history) in developing a new space launch capability. A summary of developmental and operational considerations for the air-refuelable TAV is included in Attachment C.

Suborbital/Force Application Missions

An appropriately configured version of the TAV can perform both ground and space force application missions with near term technologies. Some key characteristics of the air-refuellable

rocket-powered TAV that are particularly relevant are the ability to operate as flexibly and responsively as an aircraft (with similar operations, maintenance and logistics infrastructures), its inherently low observable nature from most aspects (no inlets, blended surfaces), and its ability to conduct manned missions. The vehicle has the ability to exploit the advantages of space basing (low reaction times and high energy states) with far greater operational flexibility and additional defensive capabilities to survive the future threat. This section expands on the concept by describing the requirement, the vehicle's capabilities, and finally linking the concept to other areas of the Spacecast study: spacelift; force application; C3I; and offensive counterspace operations. Although the ideas presented in this section were arrived at independently, this concept is not new. Research showed similar vehicles were recommended by several other future studies including: *Project Forecast II*, (June 1986); *Mission Applications Document*, (22 July 1990); and *Force Applications Study*, (13 June 1991).

Force Application Mission

A modified TAV contributes to our national military strategy by allowing the United States to rapidly respond worldwide to future threats with overwhelming offensive firepower. A distant goal is the capability to affect all required enemy aimpoints during a single mission. The proposed vehicle is a tremendous improvement over current United States offensive capabilities. The system offers the NCA and the warfighting CINC the capability to accomplish strategic level effects in less than one hour without using weapons of mass destruction. Rapid vehicle turn-around to follow-on missions allows the CINC to continue the offensive through rapid, decisive follow-on attacks therefore reducing the effectiveness of enemy work-arounds. This concept escalates the pace of warfighting beyond our projection of the future threat's capability. The system capitalizes on three specific offensive advantages:

Surprise. The greatest single advantage of this weapon is surprise. Strategic surprise results in immediate execution of a multi-thousand aimpoint campaign. Operational surprise

results from the rapidity of the completed attack which may catch an adversary in the process of deployment or employment of inadequately prepared forces. Tactical surprise results from a variety of suborbital profiles these vehicles can use to exploit gaps in an enemy's defense. Tactical surprise also results from a world desensitized to the vehicle's day to day use as a lift platform.

Mass, Economy of Force, and Persistence. As mentioned before, this concept is designed to rapidly complete a multi-thousand aimpoint strategic attack. This effort is accomplished with a small fleet. The exact number will depend on vehicle payload capacity, final weapons designs, and cost. Rapid revisit times allow continued pressure on the enemy until our objectives are met. Additionally, the concept contributes to solving the current concern of handling two major regional contingencies. The surge rate of the weapon system should allow destruction of both opponent's key centers of gravity within several days. Finally, the simultaneous presentation of thousands of small reentry vehicles to a surprised and defensively helpless adversary will likely overwhelm the enemy ensuring our nation's objectives are met.

Synergy. Tailored weapons effects can prepare the battlefield for other weapons systems or act as a force multiplier allowing ground, air, and sea forces unimpeded access to the battlefield to accomplish follow on missions. Effects can also be tailored to provide synergistic effects for other national instruments of power.

Design requirements

There are several alternatives for delivering weapons, including the TAV described in preceding sections, ICBMs, satellite basing, and intercontinental cannon. We believe operational flexibility greatly favors the TAV approach; a more detailed discussion of this is at Attachment D.

The system must have specific characteristics in order to accomplish the force application mission. These are outlined below:

First, the vehicle must be able to launch from a quick reaction alert status. This enables short response times critical to the concept's success. The TAV concept presented earlier is capable of fulfilling this requirement.

Second, the vehicle must be designed to incorporate modular weapons systems. This concept allows use of the vehicle for a variety of military missions from force enhancement through force application. This increases its cost effectiveness. The module must be sized to fit the payload section of the TAV. The TAV should provide necessary infrastructure requirements (basic power and comm links) to the module while the module reports fault/degradation information to the operator or controlling computer on the TAV. Necessary weapons delivery infrastructure should be designed, as much as possible, into the module and not the vehicle.

The idea of weapon modules serves several purposes. First, the vehicle is able to accomplish force enhancement missions until required for weapons delivery. Second, the modules can be preloaded and then stored until needed and transported intact to launch sites. Third, maintenance or upgrades can be accomplished on the ground based weapons ensuring maximum reliability and capability. Finally, the module concept offers quick reloads facilitating rapid turn times and therefore sustainability. By comparing it with current dispensing systems, we expect the deliverable payload to be approximately seventy-five percent of the total vehicle's capacity.

Third, for survivability and maximum offensive potential, the vehicle must have global range from a suborbital flight path. Global range provides operational flexibility while allowing the vehicle to launch and recover from secure areas. The suborbital requirement contributes to self protection tactics and will be explained more fully in the defensive tactics paragraphs.

Additionally, since the suborbital flight path uses less propellant, greater weapon loads should result. Again, the TAV satisfies this requirement.

Fourth, the TAV must allow rapid turn-around to follow on missions. This maintains the offensive advantage for the CINC and allows rapid follow on targeting. It is unrealistic to assume

the military will have enough vehicles to engage all possible target sets with a single mass launch. Actual requirements for turn-around times will depend on the number of vehicles, the payload capacity for each, the number of aimpoints, and the threat. Any attempt to fix a hard number in relation to these requirements is guesswork, but a 12 hour cycle rate is a reasonable minimum design criterion. The TAV should be able to meet this minimum requirement.

Fifth, the system should maximize the use of existing military infrastructure. This requirement is levied to allow launch and recovery from the widest possible number of bases. This provides some measure of survivability through dispersion and mobility. The TAV provides a limited solution to this requirement and is restricted only by airfield length/capacity and refueling support. Attachment B contains further discussion of the horizontal versus vertical takeoff and landing issues.

Finally, the issue of designing this vehicle for man is important only in the near term. Technology has not progressed to the state where a computer can replace man in all operations, specifically those in unpredictable or degraded modes. We recommend designing early vehicles for human operators. While this will result in higher weight and lower G capability (the latter is probably not an issue for typical mission profiles), a human operator allows for rapid, autonomous (IAW the commander's intent) decision making while facing the technologically advanced threat of the twenty-first century. When the data base is developed and hardware and software technology meets our political leadership's approval, human operators could be removed from the vehicle. Virtual reality is not a solution in the interim. Comm links are vulnerable to an advanced enemy and could be jammed or exploited.

Weapons Options

Three classes of weapons are appropriate for this vehicle: kinetic energy weapons; high explosive weapons; and directed energy weapons. These weapon types are discussed in more

detail in the force application white paper. General thoughts are presented here to tie the concepts together.

Kinetic energy weapons

This class of weapons capitalizes on the destructive effects of a relatively small, hypersonic projectile interfacing with a target's surfaces. AMaRV, TRIM, PMP, SWERVE, ITP, BRIM, DSV, ICE, GPRC are all examples of projects involved with this concept. (Force Applications Study, 13 June 1991). These penetrators work best against hard surface targets that resist the penetrator. This allows it to impart sufficient energy to the target to generate weapons effects. A wide range of sensor options are necessary for reliable target identification and guidance to precise aimpoints against fixed and moving targets under all conditions. Finally, penetrators should be developed in a variety of sizes to tailor weapons effects to a target and allow carriage of the greatest number of weapons possible per module.

High explosive

High explosive options may still be necessary. As alluded to above, thin skinned targets tend not to resist high speed projectiles. In these cases you can make up for the lost weapons effects with conventional high explosives. Additional devices for slowing projectiles might be necessary to allow independent search and targeting, mining, or for specific weapons effects. We envision a maneuverable reentry vehicle that both delivers the payload to the target area and controls the velocity prior to releasing appropriate high explosive submunitions.

Directed energy

Directed energy weapons offer significant benefits but also have numerous disadvantages over the foreseeable future. The disadvantages center around high infrastructure requirements (power generation, pointing mechanisms) and propagation of sufficient energy through the atmosphere to target surfaces.

Infrastructure means weight. This problem reduces the weapons on a vehicle to a low number. The end result is fewer targets hit on a single pass. This limitation combined with energy loss to the atmosphere results in less than optimum performance against ground targets. Until these limitations are corrected we recommend an alternate use for directed energy weapons.

We propose directed energy modules for the counter space mission. This mission offers no energy loss to the atmosphere, disables targets with minimum space debris, and could allow multiple targeting of space platforms per mission.

In summary, a TAV capable of employing modular military payloads provides the United States a sustained offensive capability for use against a wide variety of targets defended by more capable future threats.

Threat-based System

Future threats to the United States will possess far greater capability to impact offensive operations than those we currently face. We anticipate several: hostile threat satellites; ground and space based directed energy weapons; intercontinental ballistic missiles; and third world nuclear weapons. The concept of an armed TAV is designed to negate future threats through a combination of countermeasures, tactics, and survivable basing. Several of these techniques are discussed below:

First, the construction of the vehicle should include as many low observable techniques as possible. While today's low observable technologies will gradually lose their utility they will force adversaries to confine defensive systems to particular (and therefore predictable) techniques. They have the further benefit of reducing the ranges of acquisition systems and therefore making the adversary's targeting problem more difficult.

Second, on board active defensive systems are possible with this system. By using a suborbital trajectory during the attack profile, disposables (chaff, flares, towed decoys, and active defensive munitions) may be used to defeat threat weapon systems without contributing to

hazardous space junk. ECM systems should also be included in the design of the TAV, weight and power budgets permitting.

Third, surprise. Launch to a single suborbital weapons delivery pass, followed by reentry and landing, compresses the time the adversary has to respond with his threat systems--especially an adversary without intercontinental launch detection. They will have minutes to observe the mission, assess intentions, make the appropriate decision, get their defensive capabilities in place, and complete the intercept to prevent a successful attack. Multiple simultaneous inbound trajectories compound this and the next two effects.

Fourth, unpredictability. Again, we'll use the single sub orbital pass example. Since the vehicles start from ground alert, the enemy cannot predict the mission's time over target. The capability of the vehicle to establish a variety of sub orbital trajectories, as well as approaching the target from differing orbital planes, also confounds the adversary's predictive ability and may negate many of his defensive systems.

Fifth, mass. Our nation will more than likely have a small fleet of these reusable vehicles. The ability to mass several of these vehicles, from single sub orbital passes, at the time and place of our choosing, allows us to overwhelm the enemy's defensive systems as well as concentrate the appropriate amount of firepower to achieve required effects. In the absence of great numbers of vehicles, the same mass effect is maintained through the ability of each vehicle to deliver a large number of weapons.

Sixth, standoff. This assumes an appropriate family of weapons with sufficient crosstrack capability. With these, the vehicle can release its payload beyond the range of some possible threat systems.

Seventh, mutual support. Several vehicles working in concert can use advanced countermeasures as well as suppress threats for each other.

Finally, dispersed basing. While threat systems will surely have the ability to find and target aimpoints in the United States by the year 2020, their capabilities can be reduced through dispersion of the TAVs to a wide number of bases, through mobile operations, and through good deception plans. Any attempt to force this system to consolidate operations at a single fixed location is unnecessary and should be resisted as it provides the adversary the perfect fixed, high value, target. Logistics concerns can be adequately addressed by designing a vehicle that shares existing aircraft infrastructure to the maximum extent possible.

In summary, the ability of the TAV to accomplish its weapons delivery mission from a single suborbital pass while using both with passive and active countermeasures compresses the adversaries decision loop and results in increased survivability. The addition of low profile basing complicates the threat's targeting problem and ensures fewer assets are lost to their efforts at strategic attack. This combination results in a survivable system able to fight in the high threat environment of the 21st century.

Links to Other Spacecast Areas

The weapons delivery vehicle described to this point links many of the spacecast white papers. The logistics area of spacelift with a militarily capable TAV is now tied to the C3I-S white paper on C3I architecture. This combination allows the proposed architecture to identify and pass coordinates of critical targets to the TAV prior to its weapons release point. This ensures the most effective targeting intelligence is used to gain the greatest possible strategic effects.

The force application paper discusses various weapons types and their suitability. The TAV offers a platform for their use with significant military advantages over other techniques such as satellite basing. System architectures mentioned are compatible with the weapons delivery vehicle concept. Finally, the offensive counterspace area benefits from a TAV based

weapons system which allows use of directed energy weapons without concerns over fixed satellite survivability.

Summary

The concept of a reusable, suborbital weapons delivery vehicle provides our nation a flexible weapon system able to conduct offensive operations against a technologically capable future adversary. The vehicle ensures the necessary rapid response to achieve strategic effects in a high threat scenario. An integrated C2 and intel structure provides objectives, intent, and targeting information for near instant action. A variety of munitions customizes the weapons effects to the target. The overall concept is therefore capable of accomplishing all force application missions.

On-orbit Operations

Putting things on orbit (into low earth orbit in particular) does not always satisfy operational demands. Some satellites must be lifted to higher orbits, and we may need to move key space assets from one "operation" to the next (i.e., alter orbits), to retrieve high-value assets for repair or upgrade (remotely on-orbit, at a space station, or back on earth), to resupply space platforms with things like fuel, food, or weapons, or even to collect space debris and "dead" satellites from highly populated orbits. As a result, we may need a system for transportation between low earth orbit and other orbits of interest. This is essentially an extension to concepts already studied by NASA and DoD, and a vehicle of this type was postulated by the Air Force's Project FORECAST II as a potential application for nuclear rocket engine technology.

Two key issues are important to this concept: the utility of reusable on-orbit transportation systems and the utility of on-orbit satellite servicing and repair. With regard to transportation systems, a 1989 study by the Air Force Systems Command (now Air Force

Materiel Command) Directorate of Aerospace Studies (DAS) identified two basic vehicle configurations or capabilities: an Orbit Transfer Vehicle (OTV) for moving things from LEO to higher orbits, and an Orbital Maneuvering Vehicle (OMV) for moving things around within a designated orbit and docking with/servicing satellites. This architecture was found superior to the current approach (expendable upper stages and/or propulsion systems integral to the spacecraft bus) for several reasons. Expendable upper stages are, by definition and design, thrown away after use and become "space junk." More importantly, however, while their unit costs are less than those of reusable vehicles, reusable systems are "generally less expensive on a per mission basis" over their usable lifetime.

The second issue addressed by the DAS study is, given such on-orbit transportation capability, whether it is advantageous to use it to service and/or repair satellites on orbit, or continue fielding "expendable" satellites. Unfortunately, there is no clear answer. On the one hand, the authors conclude that, "it is reasonable to believe that there will be future circumstances which offer cost advantages to repairable satellites." On the other hand, the analysis was sensitive enough to the estimated characteristics of future satellites (e.g., mission duration, mass, cost, subsystem reliability, and launch costs) that the results were not conclusive for all satellites in all orbits. In general, satellite repair becomes more attractive as constellation size and satellite mass, cost and mission duration increase, and as launch costs and satellite reliability decrease. It's much more attractive from a cost standpoint if satellites use modular, standardized/common subsystems. The utility of reusable on-orbit transportation systems for satellite servicing and/or repair in the 2020 timeframe depends heavily on the types and quantities of satellites in orbit at that time, as well as on the capabilities and costs of our launch systems. Given this paper's assumptions of increasingly capable small packages and the ability to put them responsively on orbit, it's not at all clear that repair or resupply of existing satellites are attractive missions. On the other hand, if

smaller but more cost-effective launch vehicles make on-orbit assembly and fueling of larger satellites desirable, many of the technologies discussed below will be needed.

III. Potential Technologies

Primary Lift

Although a working TAV can be built with existing technologies, there are several areas where improved technologies and/or supporting capabilities will improve performance.

Structures: a feasibility study (WJSA/CRC Paper and Briefing) concluded that using standard fighter aircraft models and aluminum structures, an F-16-sized X-vehicle TAV could place 1,000 pounds into orbit. However, careful analysis of structural requirements (the vehicle has a low wing loading, for example), and application of modern design techniques and materials could significantly reduce structural weight. Every pound gained is an extra pound of payload.

Engines: the same study baselined an engine no more sophisticated than the one the Black Arrow/Black Knight program used. A modest development program could certainly improve on this level of performance without sacrificing reliability (or maintainability).

Thermal protection system: the study also baselined "TABI" insulating material which weighs 1.1 pounds per square foot. Some NASP-derived research might help here.

Refueling vehicle: the TAV was sized around the maximum amount of propellant that a KC-135Q could transfer. These aircraft are in the inventory and are already designed with separate aircraft fuel and off-loadable propellant tanks, thus would require minimum modification). Assuming the availability of a modified KC-10 or large commercial aircraft derivative to offload H_2O_2 would greatly increase the potential size and payload of the TAV without significantly changing the costs per pound to orbit. Although this is more a programmatic than a technical issue, it is a potential area for investment.

On-orbit Operations

Technologies required to implement this architecture include:

- High efficiency, reusable space propulsion systems. Cost, performance, and operational utility analyses are needed to select from among the various potential technologies in this area.

Candidates include conventional chemical, electric, nuclear, and solar-thermal propulsion systems. Issues to be addressed would include power sources for electric propulsion concepts; radiation shielding, high-temperature materials, launch safety and waste disposal for nuclear propulsion concepts, solar concentrator fabrication and high-temperature materials for solar-thermal propulsion concepts, and long-life performance/reliability demonstrations for all concepts.

- Regardless of the propulsion system chosen, fuel will still be needed (all the above methods require heating and expelling a fuel; only the heat source is different). If we make a commitment to sustained on-orbit operations, it may be worthwhile to look at the moon as a fuel source; getting fuel from there to earth orbit could be less expensive than bringing it from the surface of the earth.
- Zero-gravity propellant transfer would be required, for both refueling the transport vehicle itself and for refueling mission satellites.
- Robotics for docking, grasping, repair, and resupply operations.
- Telepresence/Virtual Reality/Artificial Intelligence technologies will be required in some combination for on-orbit operations. Analyses are needed to determine the extent to which man is required to participate in repair/servicing operations, i.e., considering the technologies expected to be available in 2020, what tasks can be done only by human beings, what tasks can be done remotely with man "in-the-loop," and what tasks can be done totally autonomously.
- Artificial Intelligence technologies could reduce the requirement for man-in-the-loop operation in circumstances where this would be difficult or present technical challenges (such as remote

operations in geosynchronous orbit where communication time delays could present problems). Again, further analysis is required.

- Spacecraft design would have to change significantly to obtain maximum utility from this concept. Docking operations would require some degree of spacecraft bus standardization. Refueling operations would require propellant feed system standardization. Repair/upgrade operations would be facilitated by such design approaches as standard spacecraft buses, and standard, modular, miniaturized subsystems and interfaces. External structures, like solar arrays and antennae, will have to be "foldable" to withstand the accelerations associated with moving a spacecraft. It is important to note that many of these changes will happen with or without the development of on-orbit servicing, driven by the need to reduce the costs and timelines associated with the earth-to-orbit segment of the transportation system.

- Supporting "bases" may be needed in certain critical locations. For transportation to high-altitude, low-inclination orbits, unmanned, "coinclination" platforms in LEO would serve as cargo transfer and "jumping off points" for OTVs. Orbits containing large numbers of higher-cost satellites (or fewer, extremely expensive satellites) would require "co-orbital" unmanned platforms where OTV's could transfer payloads to OMV's for final orbit insertion or docking/repair. (DAS Study)

- Standardized satellite control systems and procedures to facilitate interaction with various platforms.

- Changing orbital planes is inherently an energy-intensive operation. In addition to using advanced propulsion technologies, other alternatives may be available in the future for performing plane changes (one example is aero-braking). These alternatives need to be investigated further; they will certainly introduce other technical challenges (for example, use of aero-braking would require some type of protection for the mission payload from the aerodynamic and heating effects of the aero-brake maneuver).

IV. Near Term Technologies and Operational Exploitation Opportunities

(Including Commercial Opportunities)

Primary Lift

Existing and proven technologies can be used to develop and fly an X-vehicle to prove the feasibility and operational utility of a JP-fueled TAV. The basic concept is for a crewed vehicle approximately the size of an F-16 (but with 70% of its dry weight) that could take off and land from/on virtually any runway, load the bulk of its propellant (all oxidizer) from a KC-135Q (or T) tanker and then carry out an orbital or suborbital flight as required. An experimental program can be designed that allows testing of the TAV as we have tested aircraft for decades, with a gradual expansion of the performance envelope until the necessary objectives are met (Clapp et al, *Aerial Propellant Transfer to Augment the Performance of Spaceplanes*). Some detailed characteristics of the program, which we call Black Horse, can be found at Attachment E.

The primary areas for design and development are the vehicle aerodynamic configuration, the rocket engines, and the vehicle structure. The WJSA/CRC study indicates there are no show stoppers in this area and a vehicle could be designed and tested with existing technologies, although there is room for improvement using advanced materials.

Areas that require some careful design work but no technological breakthroughs are thermal protection, the need to cycle landing gear through the thermal protective surface, and the use of structural composites. It appears that an X-vehicle program could proceed *with existing technologies*.

Cost: Although not the driving issue in this study, several comparative estimates of a two-TAV, 100 flight (including orbital) X-vehicle program were made to see if the concept could be validated for a reasonable amount of money. Using actual X-29 and X-31 cost data, the TAV X-program would cost about \$78M. A Lockheed Skunk works program cost model yielded \$96M. The RAND Corporation DAPCA IV model gave a total program cost of \$118M. Finally, a cost estimate by an Aerospace Corporation analyst came up with \$120M (Phillips Lab memo).

Although these are very much rough estimates and a vehicle of this type has never been built before, the fact that differing methodologies came up with similar conclusions gives some hope that an X-vehicle program could be conducted for a reasonable amount of money.

Operational costs: Initial estimates, using SR-71 cost data, suggest that such a vehicle could place payloads into low earth orbit at a cost of approximately \$260/lb with a per-sortie cost of \$250,000 and an annual operating budget for an 8 TAV unit (with support) of \$100M. This model was chosen because the operations of an air-refuelable TAV and the SR-71 would be similar in several ways (not least of which is using the same tanker). The model is sensitive to overhead costs (assumed to be the same as for the SR-71), number of vehicles and sorties, payload (assumed to be 1,000 pounds), and fuel costs. The assumptions and a comparison of costs using different assumptions are at Attachment F.

On-Orbit Operations

There are several near-term programs that would expand our ability to provide on-orbit services. These include the Space Surveillance Tracking and Repositioning (SSTAR) experiment (formerly called the Electric Insertion Transfer Experiment, or ELITE), an Air Force-TRW

cooperative research and development agreement, a potential flight test of the ex-Soviet TOPAZ nuclear reactor, and the Space Nuclear Thermal Propulsion program. These deal primarily with propulsion systems, but (particularly in the case of SSTAR) with supporting technologies such as navigation, autonomous operation, and potential mission-oriented payloads. Unfortunately, all of these have suffered funding setbacks and are on hold or in danger of cancellation.

Commercial Opportunities

Cheap, reliable transport to, from, and through space offers innumerable possibilities; it is the enabler for everything we do in the future in space. All of the technologies and techniques described above have potential commercial application, but it is not our place to prescribe how they should be used. Instead, we attempt to highlight some of the opportunities they may create, and why we feel a robust commercial space market is ultimately essential for government use of space.

Implications for markets: cheap spacelift is a market enabler that will open up the use of space for things not currently practical or even anticipated. Some obvious possibilities: extremely rapid delivery of people and cargo from one point on the earth to another, while the ability to carry passengers safely and at a reasonable cost would open a new market for space tourism. Cheap access to space will make things such as mining of asteroids and development of the moon economically possible, perhaps even attractive. Availability of a technology (or technologies) that enables the economical use of space will in turn spur development of a true commercial market for all things related to space flight and operations. This will eventually drive the real cost of access to and operations in space down even further, as jet transport has done in the commercial aviation market. [Add and explain \$ figures for various markets]

Implications for US manufacturers: US launch vehicle manufacturers, if they pursue innovative technologies with true market-creating potential, could find themselves in a globally dominant position, as the aircraft industry did following the introduction of the Boeing 707 and the DC-8. Dramatic expansion of the market for space transport, which will not happen without dramatic reductions in the cost of space access, is also absolutely necessary if the US launch industry is to remain commercially viable. The alternative can be seen in the current US shipbuilding industry, as an increasingly inefficient and shrinking US capability, unable to compete with low-cost and/or subsidized foreign producers, stays alive only because of government subsidies.

Government support in the initial stage of development is vital; we must recognize that the market for space is not large enough to drive the kind of productivity and creativity explosion in space-related hardware that has occurred in electronics, for example. The main prerequisite for this market is missing: the rapid, reliable, affordable spacelift mentioned above. Government and the military, whose performance requirements for launch on demand are the most stressing now, must take the lead in this area and produce the technological/operational breakthrough that will enable expanded future exploitation of space and the development of a large market to unleash the powers of commercial development. Industry cannot and will not make the investments needed for such breakthroughs on its own: they face a market similar to that for air transport prior to the DC-3, while we need an investment on the order of that required to produce the first jet transports. This would not have been possible without government investment in jet engine technology and large aircraft (B-47, B-52) despite an already fairly large air transport market.

Concept paper numbers embedded: Primarily C128U, but C052U, C084U, C108U and C171U were used for comparison. C024U, C030U, C084U, C101U, C122U, C135U; other potentially related papers: C034U, C043U, C047U, C074U, C085U, C170U, C177U.

Technology abstract paper numbers embedded: A024, A031, A035, A123, (Potential, based on titles): A0007, A0017, A0018, A0044, A0069, A0094, A0113, A0136, A0144, A0147, A0151, A0162, A0249, A0250, A0252, A0263, A0287, A0297.

Attachment A: Launch System Comparison

Responsiveness (time from request for launch to orbit)

- DC-X SSTO: good; fueling time major constraint
- JP TAV: excellent; could sit alert
- Pegasus: good-excellent given alert-type arrangement
- Taurus: poor-good depending on whether system is deployed
- Gun Launch: excellent
- Sea Launch: poor-good; could require significant time to get into position

Flexibility

- select any orbital inclination
 - DC-X SSTO: limited by launch sites, available Δv
 - JP TAV: unlimited access; some payload decrease to high inclinations
 - Pegasus: unlimited access; some payload decrease to high inclinations
 - Taurus: limited by launch sites, available Δv
 - Gun Launch: severely limited by number of launchers
 - Sea Launch: unlimited access; some payload decrease to high inclinations
- interface to multiple payload types (largely payload design dependent)
 - DC-X SSTO: excellent
 - JP TAV: excellent
 - Pegasus: good-excellent
 - Taurus: good; somewhat rough ride
 - Gun Launch: severe payload design constraints
 - Sea Launch: good
- ability to carry out other missions (suborbital, retrieval, space control, man in space)
 - DC-X SSTO: excellent; flexible payload capabilities; reusable
 - JP TAV: excellent; flexible payload capabilities; reusable
 - Pegasus: fair-poor; limited payload types; expendable
 - Taurus: fair; limited payload types, rough ride; expendable
 - Gun Launch: poor; substantial payload design constraints; one way missions
 - Sea Launch: fair-poor; limited payload types; expendable
- surge capability
 - DC-X SSTO: design-dependent; TBD
 - JP TAV: design-dependent; should have SR-71-like capabilities
 - Pegasus: limited to vehicles in inventory
 - Taurus: limited to vehicles in inventory
 - Gun Launch: limited only by number of payloads and power
 - Sea Launch: limited to vehicles in inventory

Soft abort capability

DC-X SSTO: limited; single or multiple engine failure could cause loss of control
JP TAV: excellent; engines-out landing capable
Pegasus: none; destructive abort only
Taurus: none; destructive abort only
Gun Launch: none; destructive abort only
Sea Launch: none; destructive abort only

Resiliency (return to operations following an aborted launch)

DC-X SSTO
JP TAV
Pegasus
Taurus
Gun Launch
Sea Launch

Logistics

- Requirement for unique/special infrastructure

DC-X SSTO
JP TAV
Pegasus
Taurus
Gun Launch
Sea Launch

- Consumables: storage and loading

DC-X SSTO
JP TAV
Pegasus
Taurus
Gun Launch
Sea Launch

- Maintenance issues

DC-X SSTO
JP TAV
Pegasus
Taurus
Gun Launch
Sea Launch

Reliability

DC-X SSTO
JP TAV
Pegasus
Taurus
Gun Launch
Sea Launch

Ease of operations

- Range requirements/restrictions

DC-X SSTO
JP TAV
Pegasus
Taurus
Gun Launch
Sea Launch

- Command and control

DC-X SSTO
JP TAV
Pegasus
Taurus
Gun Launch
Sea Launch

- Launch crew requirements

DC-X SSTO
JP TAV
Pegasus
Taurus
Gun Launch
Sea Launch

Environmental Friendliness

DC-X SSTO: Excellent

JP TAV: Good to excellent; combustion cleaner, more complete than jets

Pegasus: Poor: expendable, solid rocket exhaust

Taurus: Poor: expendable, solid rocket exhaust

Gun Launch: Fair to excellent depending on power source

Sea Launch: Poor: expendable, solid rocket exhaust

Cost per pound to orbit

- Recurring

DC-X SSTO

- JP TAV
- Pegasus
- Taurus
- Gun Launch
- Sea Launch
- Non-recurring (including development and test)
 - DC-X SSTO
 - JP TAV
 - Pegasus
 - Taurus
 - Gun Launch
 - Sea Launch
- Confidence in estimate
 - DC-X SSTO
 - JP TAV
 - Pegasus
 - Taurus
 - Gun Launch
 - Sea Launch

Attachment B: Horizontal Vs. Vertical Launch and Landing

Characteristics of Horizontal Systems.

Horizontal takeoff and landing vehicles require wings or lifting surfaces to provide necessary lift and control throughout portions of the flight profile. Additionally, horizontal takeoff and landing requires landing gear and appropriately stressed runways long enough for takeoff and landing. This fixed infrastructure is vulnerable to attack and is a disadvantage of horizontal launch and landing systems, including conventional aircraft. The degree to which this is a problem, however, depends heavily on the assumptions about a system's use. In the case of a transatmospheric vehicle with the ability to achieve orbit, there is little if any requirement for forward basing. If basing is primarily in CONUS, a potential enemy who could target every suitable airfield would be able to target almost any basing infrastructure.

If short takeoff ground rolls similar to those of fighter aircraft can be achieved, a horizontally launched vehicle could operate out of present day military or civil airfields. However, landing rolls may be a different matter; such a vehicle will probably require at least the NATO standard fighter runway of 8500 feet.

Although horizontal landing may reduce the number of available recovery bases, wings/lifting surfaces, they offer advantages in vehicle maneuverability (greater cross-range capability on reentry, for example). Alternate landing sites may be available throughout the mission profile for aborts or in cases where the intended landing site is no longer available due to weather or battle damage.

An additional element of operational flexibility concerns weather. A horizontal takeoff system can operate under any weather conditions that an aircraft can. Vertical systems, like current rockets, will have stricter limitations because they must fly through any weather above their launch site; this is bad news if there is precipitation, since vertical launch systems typically reach supersonic speeds while still in the weather, resulting in serious damage. The TAV

proposed in this paper will be above most weather before going supersonic, and if necessary can maneuver around weather before or during refueling to avoid the problem altogether.

Finally, there's the issue of testing. Although the DC-X program has made a breakthrough in the testing of VTOL systems, our years of experience with aircraft testing seem to argue that the horizontal takeoff and landing system would involve fewer unknowns and better understood procedures.

Characteristics of Vertical Systems.

Vertical launch's greatest advantage is its small footprint. With little requirement for a fixed runway our forces become less predictable to an aggressive, technologically advanced enemy. The best example of this was found in the Gulf War. The United States, with superior intel, C2, and weapons rapidly decimated all of Iraq's fixed air and missile attack infrastructure in the opening days of the war. Only those systems that were mobile and dispersible survived. The most successful of these systems were the Al Abbas and Al Hijarah missiles which continued operations until the end of the war. A mobile, vertical launch system may retain some of these operational advantages, though not if it is designed to be larger than current mobile missile systems (there's the small problem of bridges, tunnels, etc). The question, as mentioned above, is whether enhanced tactical mobility and survivability is appropriate or necessary for a system such as this.

Additional considerations:

Other arguments are occasionally raised in favor of vertical launch systems. Most of these are not relevant to the TAV concept discussed in this white paper, but they pose questions that deserve to be answered.

1) *Few runways in the world have suitable length or weight capacity to handle a horizontal takeoff and landing vehicle in the multi-million pound gross weight class.* This is undoubtedly true. It's also irrelevant. First, how many concrete landing pads or natural hard surfaces of any size are there that would accomodate multimillion pound gross weight vehicles? Building a vehicle of this size would create a need for its own specialized infrastructure requirements. More important, a vehicle of this size would violate the basic premise of this paper: that absolute payload size is far less important than operational characteristics. Huge aerospace vehicles have consistently proved to be costly, unwieldy and generally undesirable unless there is no other way to perform the mission. The TAV concept proposed in this paper is explicitly a product of avoiding gigantism.

2) *Horizontal takeoff and landing systems have a more severe sonic boom problem.* This argument is design dependent. If the vehicle is designed to cruise super/hypersonically in the atmosphere (like NASP), it may be a concern. The TAV proposed in this paper, however, is rocket powered and has no need to fly horizontally. In fact, the flight profile is strictly subsonic until commencement of the orbital/suborbital insertion burn, at which point the TAV basically stands on its tail and adopts a traditional rocket trajectory. The sonic boom/noise problem is, if anything, less than that of a VTOL rocket, since the burn begins at over 40,000 ft vice sea level, and the vehicle goes supersonic at a higher altitude than a VTOL system.

Summary:

The question of horizontal takeoff and landing versus vertical takeoff and landing comes down to the interconnected issues of engineering design and operational requirements. The landing gear and lifting surfaces of a horizontal system do result in a heavier empty weight, thus less payload. The need to operate from a runway does impose some operational limitations. On the other hand, lifting surfaces and the ability to operate like an aircraft offer increases in

operational flexibility in other areas, and the number of runways available to a reasonably sized TAV combined with the system's range mean that a threat to all suitable airfields is only realistic in the most extreme scenarios. In addition, it's not at all clear that a VTOL system requires less infrastructure. Deployment/transport for the launch vehicle from its base(s) to a launch area is needed, and fuel transport and storage, payload handling, maintenance and other logistics functions must all be deployed with the VTOL system to make it work. The horizontal system, on the other hand, makes maximum use of existing infrastructure. On balance, it's our opinion that in the near term and for the missions envisaged by this white paper, the horizontal takeoff and landing system is preferable.

Attachment C: Characteristics of a JP-5/H2O2 Fueled TAV

Development	Logistics	Maintenance	Launch
Available technology	JP-5/8	R&M design	Gross TO weight
- engines	Commercial H2O2	Engines	Payload handling
- structure	- 70% to 98%	- reliability	Fueling procedures
- thermal protection	- purified on site	- lifetime	Pre-flight checks
- avionics	- mobile equipment	Avionics	Taxiing
X-vehicle program	- resell byproduct	Landing gear	Take-off roll
Incremental flight test	- easily storable	Thermal surfaces	Abort procedures
Verify procedures	Engines	Control surfaces	
Verify ops cost assumptions	- simple (relatively)	Composite materials	
Proof of concept	- spares req	Landing gear, doors	
Ability to crash build	- parts req		
	KC-135Q/T		
	- number needed?		
Refuel	Orbit Insert	On orbit	Deorbit
Take on 140,000 lb H2O2	Aircraft nav system	Ground control	Communications
Rendezvous time	GPS receiver	- ATC to STC handoff	Criteria
- time to altitude	Integ flight control computer	Communications links	- landing site
- fuel to altitude	Insertion setup	On-orbit fuel	Procedures
- monopropellant ops?	- lat, long	- mission dependent	Flight path
Boom time	- azimuth	Payload deployment	Reentry loads
- refuel rate	- ATC clearance	Other missions	- thermal
Refueling procedures	Precise insertion	- rendezvous	- structural
- airspeed	- computer throttling	- assembly	Cross-range capability
- latch controls to tanker	Available inclinations	- capture/repair	
- via boom connection	-virtually any	- fueling	
Visual check by tanker		Endurance	
Ability to tank JP also?		- crew ayatema	
Recovery/Turn	Suborbital Ops		
Landing	Missions		
- dead stick?	- weapons delivery		
- go-around capability?	- space control		
Wx limits?	Range		
	Fuel reserve		

- 2 suborbital flights
 - loiter time
- Payload?
- Tank at destination?
- OPSEC

Attachment D: Weapon Delivery Vehicle Type Tradeoffs

Weapon Delivery Vehicle VS. Satellite Based Weapons. The energy advantage, inherent with space basing, is equal for both systems and is an advantage of both. The operational utility and survivability of the weapons delivery vehicle is superior to satellites as described below. Satellites have positioning problems and constellations are required for guaranteed response times of less than one hour. Even with a constellation of satellites, sequential operations are required and a significant delay incurs as each satellite must orbit into position. The weapons delivery vehicle will have the ability to attack in mass and with similar first response times of a constellation.

Satellites are both observable and fixed in their orbits. This makes them predictable and vulnerable to the enemy's counter space weapons. Any sort of disposable countermeasures or active defense results in hazardous space debris. A first strike directed against our weapons satellites could deny us their capability. The weapons delivery vehicle operates in far less predictable sub orbital flight paths which can be optimized to take advantage of enemy vulnerabilities. The vehicle can use active countermeasures in a suborbital trajectory since any debris will fall back to earth.

Satellites are a fixed, obsolescing asset once in orbit. The onboard weapons failure rates increase over time and their capability will eventually limit the effectiveness of the system. Once a satellite is in orbit its payload type is fixed allowing little operational flexibility and once it expends its munitions it is useless until reloaded. These problems are not applicable to the modular weapons used with a TAV since they are stored on the ground and are available for maintenance and upgrade. The modular concept allows configuring the payload to match the target prior to each mission as well as rapid reloads following missions.

Weapons satellites also suffer from a legal and a political disadvantage. First, basing of nuclear weapons in space is prohibited by international agreement. Although we do not propose using nuclear weapons, the basing of *any* weapons in space will inevitably raise a verification issue and may be internationally viewed as provocative. Politically, space basing of weapons of any kind may be a non-starter, whereas delivery of weapons through space, especially by a TAV which is subject to positive control and recall throughout much of its flight, could be acceptable.

A satellite's main advantage is presence in those cases when a weapon delivery vehicle is unable or undesirable for use.

Weapons Delivery Vehicle vs. ICBMs. The prime advantage of converting surplus ICBMs is sunk costs. They are available and it seems like a terrible waste to ignore the capability they might offer. The TAV and ICBMs have similar delivery capabilities for kinetic energy type projectiles. However, the ICBM has no capability to bring weapons back and would therefore be a poor choice for directed energy weapons in a counter space role. In general, missiles offer less operational flexibility--basing, relocatability, deployability, targeting, flight paths, alternative missions and payloads--than a TAV. Conversion of old ICBMs also raises practical problems such as remaining life of the missiles, and the permissibility of such a conversion under the START treaties. However, if these problems were overcome, a combination between ICBMs and the weapons delivery vehicle offers an attractive long term option to combine the cost effectiveness of using paid for systems with the flexibility and sustainability of the weapons delivery vehicle.

Weapons Delivery Vehicle vs. Intercontinental Artillery. Intercontinental artillery relies on a fixed installation due to its size and is therefore vulnerable to a capable adversary. This vulnerability is minimized for the weapons delivery vehicle as explained in the defensive tactics section. Intercontinental artillery would also be limited in the number of trajectories available, unless the tubes/rails could be slewed to different azimuths.

Weapons Delivery Vehicle vs. Conventional Aviation. The weapons delivery vehicle is not designed to replace the projected fleet of combat aircraft. Its capabilities can even be seen as part of a future composite aerospace wing, as described at the beginning of the paper; the TAV's advantages of speed, security, and lower vulnerability make it a valuable complement to existing conventional combat forces. Targets requiring large amounts of high explosive, loiter time, or visual identification will still be suited to conventional aviation.

Attachment E: Black Horse Program Details



Attachment F: Black Horse Operating Cost Estimates



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White Paper
on
Space Modular Systems

Combat Support - C.A.T. # 2

Date: 22 Mar 94

This is a continuation of previous WPT second draft on Space Modular Systems, # 3.

White Paper Templates consolidated in this submission: On Orbit Space Depot, #4;
Industrial Park, #47; Automated Fabrication, #38.

I. Subject and Problem Statement

By 2020, the high ground of space more than ever must be efficiently and economically controlled to fulfill the growing demands for space information by the warfighter. Current space systems are not operationally responsive to the warfighter nor cost effective to the nation. US space systems are custom-assembled on the launch pad where they sit, sometimes for months, waiting for launch day. John T. Correll, Editor in Chief, Air Force Magazine, points out in his article, *Fogbound in Space*, that only four percent of space shots launch on time. This will not meet the future warfighting CINC's needs. Today, payloads drive the lift requirements which are both costly and require long lead times. Reducing the payload weight will reduce the need for heavy lift.

Our concept is to provide an infrastructure in space to provide responsive and flexible combat services support for the CINCs in space and on the earth. We propose to do so by addressing the lift problem through a new look at what we see as a payload problem. We need a modular approach and common satellite interface to tailor payloads that require less complex and smaller lift. This will provide more flexible responsive, survivable, and economic space combat support to the warfighter in 2020 and beyond. This concept is evolutionary not revolutionary, requiring a change in philosophy in how we deploy and support space assets rather than a change in technology. The modular satellite will employ small modules, each having unique capabilities (such as communications, imagery, energy

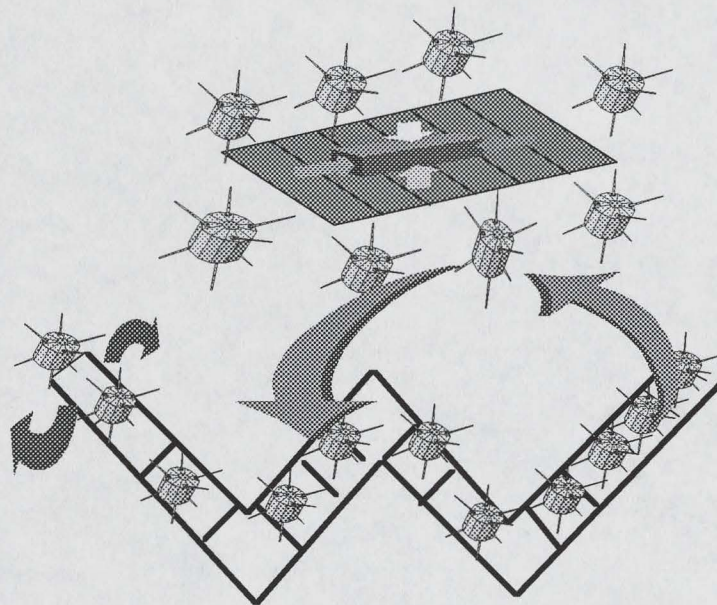
transfer, etc.) which will be needed to support the combat forces. The modules will be built as small packages which will be lifted from earth and docked to an orbiting mother board. Our intent is to position a "motherboard" in orbit which will provide all necessary support to the modules (such as power, communications, housekeeping, etc.) through a standard interface. The modules will contain only equipment necessary for their specific function (communications, navigation, imagery, weapons, etc.). The motherboards will be assembled in space, using a common configuration designed for multiple support functions (as mentioned previously). It also provides docking ports for module interface once the module arrives at the platform. This will allow for maximum flexibility in designing combinations of modules. Each satellite will be standard, yet uniquely configured for specific missions.

The concept of the motherboard represents a new means with which to operate in space. By breaking the paradigm of large, independent, heavy, and expensive satellites, the US can fully support its military and civilian needs from space more efficiently by taking advantage of the economies of scale offered by standard interfaces coupled with the motherboard. During times of crises, warfighting CINCs will have the flexibility and short-to-immediate response to crises capabilities currently unavailable. Completely standardized ports and interfaces able to support numerous small (and large) packages are central to our concept.

In order to implement the modular satellite concept, there will have to be a change in the way we think of satellites and the exploitation of space. Speed and cost must be the drivers. The capabilities required to maintain the advantage on the battlefield must be the focus for military space systems. The best systems do not have to always be the most expensive and the modular concept allows us to place in space only what we need to get the specific mission done and yet custom design each module to a specific need if desired without any systems which do not add value. Modular satellites will provide a building block approach to the most complex of systems and redundancy to the simpler ones.

Upgrades will be an evolutionary process of graceful upgrades rather than costly replacement of obsolete, less capable systems. System modification will be on-going which will be an inducement to industry to be able to stay with a project over the long term rather than heavy investment followed by a short term manufacturing requirement. A shift in thinking of space exploitation in terms of it being a big expensive adventure of enormous cost in terms of time and money is essential. This will lead a shift from long-term, complex missions to smaller, cheaper, faster ones. As Secretary of the Air Force Sheila E. Widnall said, "Customers can't afford every launch to be a unique engineering event. What they do want are dependability, availability on demand, and high reliability at a competitive price." Once this culture shift occurs the modular satellite concept will become an even more attractive choice for future satellite operations.

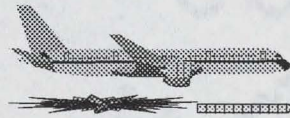
There are various possible designs for the modular satellite (Fig 1). Each offers flexibility and survivability, crucial to the satellite's mission.



One configuration could have the motherboard at the center, shaped as a flat plane with the modules arrayed around the edges. This design allows a large number of modules to be connected to a single motherboard requiring fewer motherboards. It provides greatest capacity per board. A second configuration could have the motherboard shaped like several long rods connected at their ends like joints in human limbs. The modules would be connected at docking ports which are arranged along the limbs. The docking ports would rotate along the limbs' axes to give each module its best view of the earth. The limbs themselves would also be movable at the joints to give the modules their best position. This configuration gives the satellite a "Tinker toy" appearance while providing a more survivable design than the first satellite option. If the satellite is hit by an object, only the portion directly damaged would be affected. It allows less capacity but much more survivability. Without the modular satellite capability, the cost of placing many satellites in orbit would be overwhelming.

Since the modular satellite concept will use much smaller packages versus what is used today, the lift platforms can be less complex and smaller. Also, in an effort to reduce cost and lead time for development of new lift programs, we suggest the use of some current systems and ideas. Some may require modifications and enhancements, but the idea of using what's already on the drawing board appears to make sense in today's limited budgets. Just as important is the reduced time needed to design systems for both lift and modules.

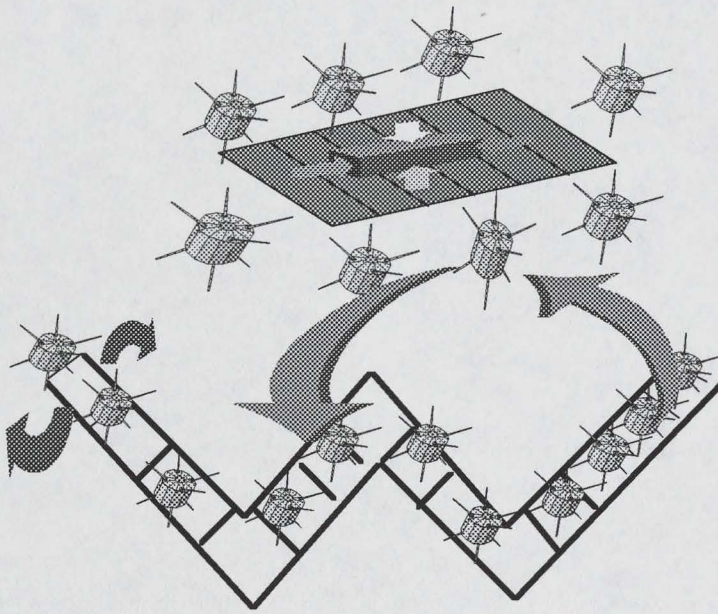
The military has pointed out a very important need to be operationally responsive. This means cutting the time between mission approval and actual launch. Today the time frame is unacceptable. If we could employ the modular satellite concept, then our lift platforms could be reduced in size, weight, and bulk (Fig. 2). Flexibility and



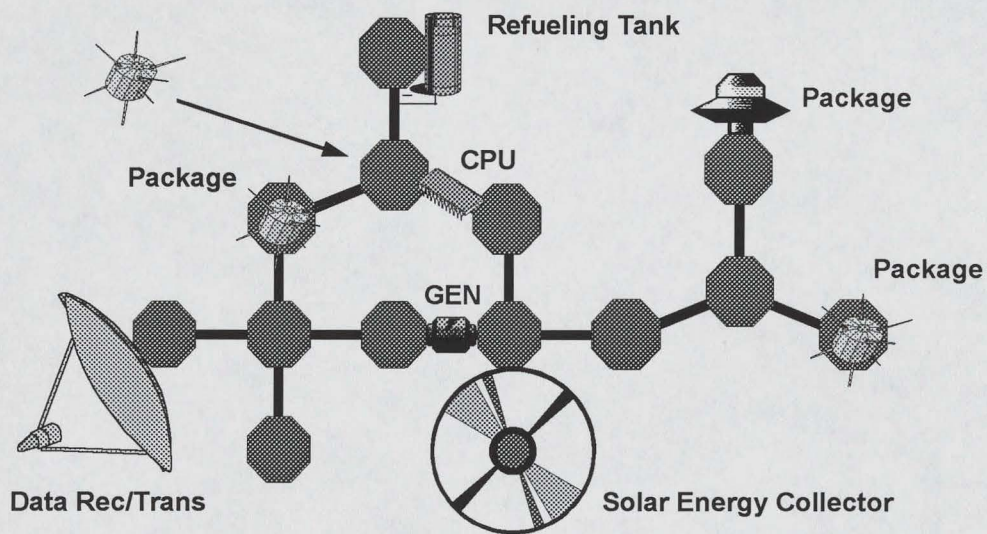
DELTA CLIPPER
ORBEX
PEGASUS
SCOUT
?

responsiveness will be the resulting hallmark. The Pegasus concept of lift is a good example. Small (600 pound) payloads are launched from a B-52 to save 35,000 to 40,000 feet of air travel and gravity pull. The modular satellites could still be sophisticated in design, yet require far less internal support systems since the motherboard will provide these services.

The modules would be small packages designed for a specific function or mission and mated to the mother board with a standard interface connection. Power and communication requirements would be standardized as well. This would allow maximum utility for all docking spaces on each motherboard. Any type of module would be able to dock at any position on any motherboard in orbit (Fig 3).

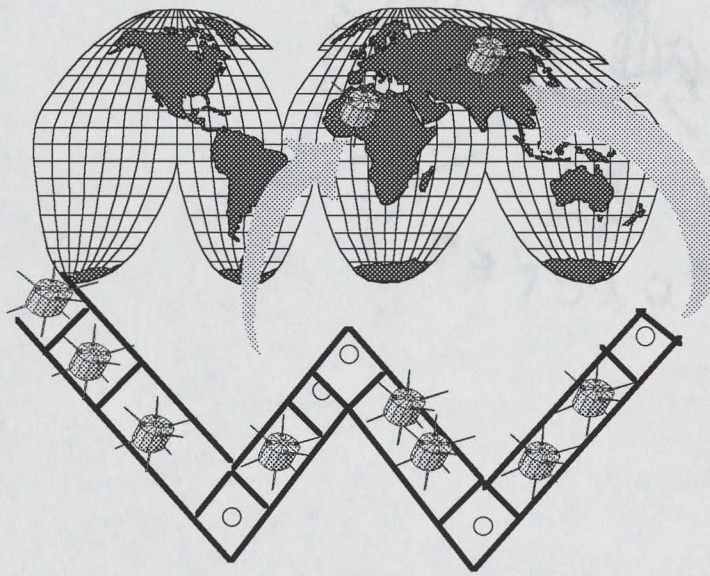


With the aid of the small lift vehicle, missions could be sent up from earth to remove, replace, repair, modify, or return modules in much the same manner as we replace light bulbs. The modules could also be fitted with small dedicated systems (such as power and communications) which would allow them to operate independent of the motherboard for short periods of time. This would aid in continued operation should the motherboard fail and repair was delayed. The modules could also be fitted with their own propulsion systems allowing them to be maneuvered in space (Fig 4).



This would give them the capability to move to different positions on the motherboard if necessary for maintenance or to achieve a better view. The independent propulsion systems could also be used to disperse modules as a countermeasure to physical attack if the satellite became a target. If the systems were sophisticated enough, the modules could be deployed from the motherboard to another orbit to view another part of the earth for a limited time. This capability would give commanders nearly immediate response to any area of interest virtually anywhere on the globe.

During contingencies, the modules could be deployed into any orbit to support the combat forces (Fig 5).



The types of modules that could be deployed for support are limited only by the imagination and the laws of physics. Some examples of modules could include services as common as communications and imagery support. Advances in energy technology could produce modules which could provide electrical power via microwave, convert naturally occurring resources and wastes into construction materials, and even control the weather and environment. All of these services would allow combat forces to deploy and fight much more rapidly. Space could provide enhanced services to the commander that would eliminate the necessity to carry bulky equipment to the battlefield. More research in energy technology, maneuvering in space, and material fabrication may yield better data on how many modules it will take to provide adequate capability. Also, more research is required on what types of orbits are required and how system weights could be reduced.

II - The Capability and Its Relevance

Concept Of Operations

The needs of the warrior have not changed since the beginning of time. The ability to move, shoot and communicate remain the fundamental keys to success on the battlefield. What has changed dramatically over the years is the expansion of the "Battle Space" over which commanders must move and communicate, and the speed and accuracy required to select and engage targets. A commander's ability to (O)bserve, (O)rient, (D)ecide, and (A)ct upon situations in the course of war fighting, is becoming more and more, the keys to defeating one's enemy. Col (ret) John Boyd calls this process the OODA-LOOP.

Commanders have the same basic requirements regardless of service or weapon system. In every military endeavor, the commander employs defensive and offensive measures to defeat the enemy. Commanders in Chief (CINC) today must influence entire enemy systems rather than separating air, ground and sea components. Only through cooperative engagement by all weapon systems in all services can wars be won with minimal casualties.

This "systems" approach, as clearly demonstrated in Desert Storm, requires significantly enhanced Command and Control (C²). Interoperable Command and Control Communications, Computer, and Information (C⁴I) systems among the services has become more and more essential. Electronic and communications "gateways" must be replaced by fully integrated, totally compatible C⁴I systems. Interoperability provides two key capabilities to the CINC, Command and Control of all forces, and Information Management at all levels across all the services.

The objective of the motherboard is to provide the war fighting CINC with increased operational responsiveness of space assets. The motherboard concept provides a framework to leverage existing space assets. It can be implemented using whatever space lift is available. It can also be implemented with current technology, should a government or commercial organization choose to make the commitment.

The basic motherboard hardware is an orbiting receptacle for mission specific payloads (weather, imagery, communications, navigation, etc.). The motherboard provides all the hardware and software interfaces required to maintain a space asset on orbit. These interfaces would include: power, data bus, fuel, orbital stability, and ground control.

The basis of the motherboard concept of operations is the requirements of the war fighting CINC. During deliberate planning, the CINC would identify those combat support functions required in the OPLAN. Depending on the technology, many of the functions could be provided by space based assets. These requirements will establish the orbital parameters (orbital height, dwell time, revisit time, orbital platform stability, etc.) for the motherboard, and the number of motherboards required.

During peacetime, motherboards would be propositioned in a variety of orbits (LEO, MEO, GEO, Molniya). These motherboards would be launched based on available space lift. We anticipate that a basic motherboard building block, capable of supporting a number of modules and other motherboards, could be placed in orbit by one heavy lift mission. The final constellation would include several motherboards in the various orbits of interest. These motherboards would not necessarily be populated by modules during peacetime.

During a crisis, the supported CINC would identify those specific mission payloads required to support his actions during the crisis. Additional modules would then be launched to provide the required level of support. Depending on the support required, the modules may populate one motherboard or several motherboards. We anticipate the modules would require primarily light lift, but could take advantage of whatever space lift is available at the time.

We anticipate three methods of providing the additional modules or coverage to the CINC. First, propositioned modules on-orbit may be dispersed or modules could be placed on unmanned aerial vehicles (UAVs). This could provide improved coverage and availability over the CINC's AOR. Second, modules could be "time shared" on the

motherboard. As the CINC's requirements are identified, modules in storage on the motherboard could be swapped out with modules currently active on the motherboard. This concept is similar to a jukebox. Finally, the required modules could be lifted to the motherboard. In a high threat environment, the modules could be dispersed to improve survivability.

Future Satellite Interface Standards

The modular satellite concept relies heavily on several core ideas which are essential to understanding its feasibility as a future means of using satellites in space. Among these core ideas is the need to develop and adhere to docking, electrical, data, and matter transfer (such as fuel) standard interfaces. The better these standards are enforced and implemented, the greater the flexibility and utility of the modular satellite concept. This means there will have to be some organization with the authority to develop, implement, and control the use of these standards.

The ultimate goal of the modular satellite is to be able to "plug-in" any type of module into any standard port on any motherboard. This concept can best be exemplified by the way nearly any electrical appliance is able to plug into any standard wall outlet and receive the power it needs to operate. This will allow for easy replacement and configuration of modules on any motherboard giving multiple combinations for all satellites. This will also greatly simplify repairs, testing or troubleshooting at any of the docking ports. System problems could easily be visualized and repairs accomplished via teleoperation from ground-based space operations centers.

The sooner the standards are developed, the sooner they could be incorporated into the module designs. Satellites without the standards could still have their utility extended by designing coupling devices which would enable those satellites to dock with a motherboard if required. Currently, there are several efforts underway to develop small,

light satellites and build them in a modular fashion. It would be wise to look into the efforts for standardizing their design and ability to interface with a mother board concept.

Along with the hardware standards, software standards will also have to be designed. Current estimates show that 80% of software should be considered standard and reusable as new versions are developed in order to hold costs at a reasonable level.

Basic Organic Modules

Each motherboard is designed to operate independently and offer support services for a number of packages. As a minimum, each motherboard should include organic energy, fuel, communications, and defensive capabilities necessary for its own operation and for the packages on board. An energy source is essential for all satellites. We view the motherboard as capable of supplying its own energy means and transferring that energy to packages when needed. Energy production on the motherboards could include solar, nuclear, thermal, anti-matter, inertial, electric batteries, or any future power source. Fuel is also essential for the motherboard. The fuel will be necessary to maneuver the motherboard to varying orbital positions. Refueling individual packages will be one of the primary missions for the motherboard. Bulk fuel may be flown to the motherboard occasionally to replenish fuel supplies. Ideas for fuel storage vary widely to include hydrazine storage tanks, high-density solid fuel packs, and nuclear fuel rods for possible future nuclear engines. Communicating between the motherboard and ground, air, and space stations, as well as between motherboards and packages, will also be vital for the operation of this concept. Moreover, the motherboard would have the organic capability to facilitate a JTIDS-type (Joint Tactical Information Distribution System) information network for the CINC and the war fighter on the battlefield via its own central processing unit (CPU) and communications net. Finally, a self-defense capability should be organic to the motherboard. Although the packages can separate and disperse from the motherboard when threatened, further self-defensive attributes should be incorporated within the

motherboard. Stealth technology for the packages and the motherboard would enhance their ability to perform their respective missions almost unseen by our adversaries. Additionally, self-propulsion for the entire motherboard complex would make it difficult to target from Earth. Anti-satellite weapons would further strengthen its defensive posture. In short, given the four organic capabilities of energy, fuel, communications, and self-defense, the motherboard could fully support and defend a myriad of packages and missions sent to it.

Emitter Packages

Intelligence, the foremost combat multiplier, is an essential element of the war fighter's ability to wage armed conflict. Enhanced imagery, signals intelligence, and navigation technologies have provided real time information from which vital intelligence can be garnered. As the commander's battle space grows, his ground based intelligence gathering capability becomes less and less effective. Through the years the need for space based intelligence coverage has grown. Commanders no longer have time to wait for human intelligence gathering, analysis, and synthesis. In this "come as you are now" world, instant coverage of any region is the new standard. The United States military must keep pace with Cable News Network in its ability to see the world. Until the CINC can turn on his television and see his area of responsibility (AOR), he will continue to rely on second hand information as interpreted by analysts. He is not going to have time to fly down and see for himself. Fast, accurate intelligence allows the commander to observe the situation, orient on the key elements, decide on a course of action and act at a rate that will maintain the initiative against his enemy.

We have grouped a number of packages under the categories of emitter and receiver packages as a means to simplify this discussion. Emitter packages, which we have discussed, include communications, radar, designators, illuminators, navigation, jammers, IFFs, hologram projectors, weather changes, and debris destroyers. Obviously

communications packages are necessary as organic parts of the motherboard. However, additional communications packages may be added to the motherboard to enhance its missions or to lease space for the civilian sector. Communications packages can range widely from datalink transmitters to television signal transmitters. We also envision individual communications links for the soldier on the ground to his/her commander in the field via the motherboard packages. These communications links could include mere radio transmissions, to teleconferencing, and to viewing the battlefield in real-time via a package supported by the motherboard. As mentioned earlier, the motherboard would have the organic capability to facilitate a JTIDS-type (Joint Tactical Information Distribution System) information network for the CINC and the war fighter on the battlefield via its own central processing unit (CPU) and communications net. Radar packages could monitor the entire area of responsibility (AOR) from the motherboard or an independent orbit and relay information to command and control centers instantly. One important aspect of this concept is the ability to designate or illuminate specified targets from space for smart munitions' guidance--thereby eliminating the need for separate aircraft to do the job in harm's way. Jammers on board could jam whole regions of the battle area or specific targets receiving their tremendous power needs from the motherboard. Friendly troops and equipment carrying miniature IFF transmitter/receivers could be instantly recognized by IFF packages and relayed to the motherboard's JTIDS to help avoid friendly-fire casualties. Moreover, hologram projectors could present entire battalions of US. forces in different areas of the battlefield to confuse, misdirect, and demoralize the enemy. Systems designed to generate or control weather patterns could also benefit from the motherboard concept. Finally, packages designed to destroy or decay the orbits of space debris could use the motherboard's support features.

Receiver Packages

During Desert Storm, the introduction of global positioning systems enhanced every leader's ability to pinpoint exact locations of friendly and enemy forces. This one technological advancement became a force multiplier of epic proportions. Air, ground and sea based forces were finally on the same wavelength when precise locations were required.

The current reliance on bottom up means of delivering battlefield information must be reversed. Troops on the ground, pilots flying over the area of operation, and sailors watching radars, deliver critical information to the commanders on enemy troop movements, strengths, and dispositions. Commanders of the future must be afforded the opportunity to see the battlefield themselves, from their Command Posts. Sophisticated systems of this nature will require extensive defensive measures to prevent enemy detection and interdiction. Surface and air based receivers will be impossible to detect electronically, and since transmitters will be in space, interdiction will be difficult at best.

Separate packages on the motherboard could also include receivers such as imagery, ELINT, weather, surveillance, and arms control monitoring systems. Imagery systems could be similar to those commercially available today, which simultaneously compare infrared, visible, and ultraviolet bands of the spectrum. These systems could be further enhanced in the future to present real-time imagery information in a video-type or holographic format to the war fighter or planner. ELINT receivers would include radio, telephone, television, radar, datalink, telemetry, and holographic transmissions emanating from the AOR.

Weapons Packages

Fires, the ability to deliver steel on target, has progressed at an alarming rate. Today war fighters need weapon systems based in space to provide mass or laser precise destruction of targets of opportunity in support of ground, sea, or air operations. The first nation capable of force projection from space will change the entire nature of warfare. Projectiles launched from spaced based platforms would give the flexibility of total battle

space coverage, stealth, and inherent defense. In addition, spaced based weapon systems could feasibly locate, engage, and asses targets from a single platform. No land, sea or air based system can do it all. On the current battlefield, imagery from space based systems is examined by analysts, data is synthesized into intelligence, the results are briefed to the commander, and decisions are made. Commanders need space based systems which can identify located targets, analyze, and select appropriate weapon systems. Commanders can then decide which system to use. The OODA-LOOP is significantly faster.

Weapons packages able to use the motherboard constitute a wide array of ideas and concepts far beyond the scope of this section. However, we envision weapons packages to include the following: directed energy weapons, laser weapons, plasma weapons, kinetic-kill weapons, HARM-type weapons, conventional weapons, and anti-satellite weapons.

Lift Requirements

The mother board would most likely have to be put into orbit via current heavy lift systems such as the Titan IV or Space Shuttle. As the modular technology advances in the future there would be the likelihood of using some of the same lift systems that would be used for the module payloads. Below are some details of smaller launch systems that could be used with our modular concept.

The Scout is an older system, but it has had a flight success rate of 95.5 percent since its first launch in 1963. Standard Scout is a four-stage vehicle approximately 75 feet long and can have a fifth stage for launching smaller payloads into higher elliptical orbits. It employs a dual-purpose launcher/transporter system which allows for checkout of the vehicle in the horizontal position and then launch in the vertical. The launcher has a movable base which permits control of azimuth up to 140 degrees and elevating pitch to a 90 degree vertical position.

Pegasus is a three-stage, solid-propellant, all-composite, winged rocket. It provides a cost-effective, reliable, and flexible way of placing small payloads into sub orbital/orbital trajectories. This system requires much less down range safety issues. It can be launched

over the ocean. Many factors add to the performance of the Pegasus. First, the potential and kinetic energy contributed by the carrier aircraft (NB-52/L-1011). Second is reduced drag to lower air density at higher altitudes where Pegasus is launched. Third, higher nozzle expansion ratios for improved propulsion efficiency in addition to the reduced gravity losses due to the unique flat trajectory and wing-generated lift (*AU-18 Space Handbook, Vol. I*).

Orbex is compatible with Pegasus payloads. It can carry 425 lbs to 400 mm polar orbit and 885 lbs to 200 mm equatorial orbit. Orbex has vertical payload integration and horizontal vehicle assembly. It has flexibility in launch selection and performance growth. See the attached information and diagrams on Orbex. It employs a dual purpose launcher/transporter combination which allows for check out of the vehicle in the horizontal position and launch in the vertical. The launcher has a moveable base which permits control of azimuth up to 140 degrees and a elevating pitch control to the 90 degree vertical position.

There other options to launch some of the module systems which could require involvement of the Nation Aerospace Plane (NASP) concept and the single stage to orbit (SSTO/Delta Clipper). Also, if heavy systems like Titan IV are being used for traditional payloads and there is dead space within the fairing, modular payloads could be added to the launch.

Lift could be used to make the modular concept a reality. Heavy lift systems would be needed to place the mother board/central bus into low earth orbit. For example, the Space Shuttle can lift 55,100 pounds (65,000 pounds in 1999 with use of new boosters) to a standard orbit of 110 nm. The Shuttle's payload bay is approximately 60 feet long, 22 feet wide, and 13 feet deep. It is envisioned the mother board would be first designed to fit into the Space Shuttle and would require only one launch to place it into low earth orbit. Also, the Titan IV, a derivative of the Titan 34D, and the newest and largest unmanned space booster could be used to lift the mother board. The Titan IV was

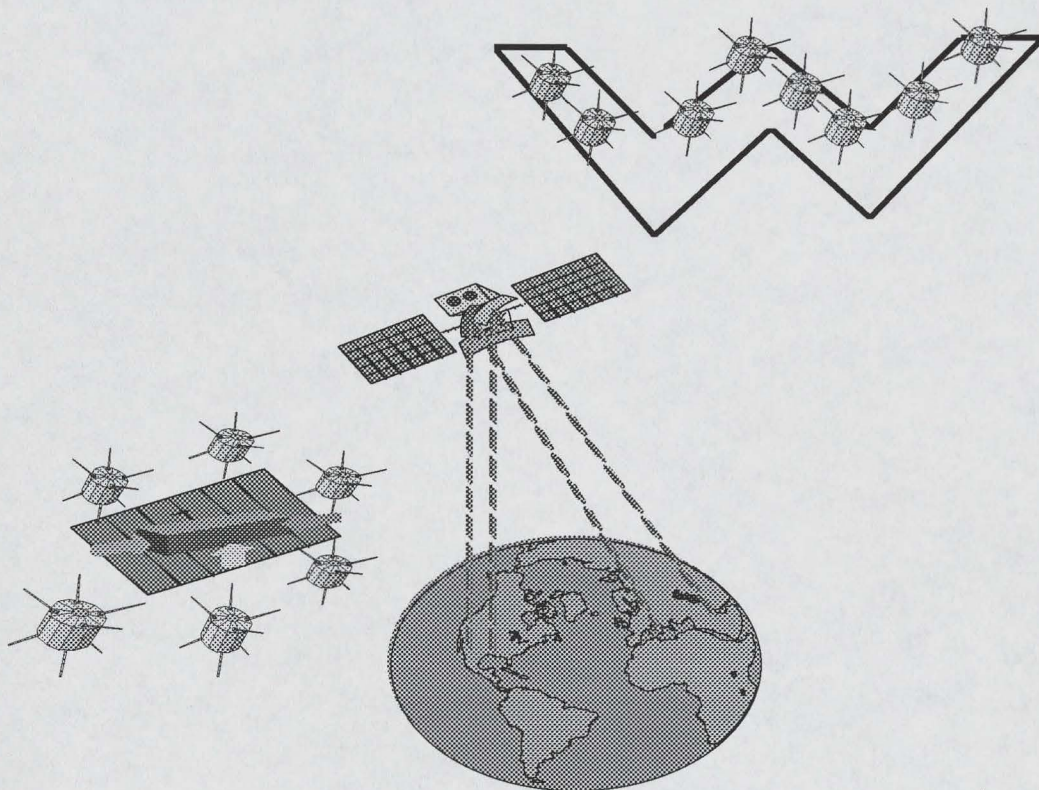
designed to carry payloads equal in size and weight of that carried on the Shuttle.

Depending on the design of the mother board the Titan IV nose payload faring could be modified and the use of current options in fairings could be applied.

Once the mother board was in place the payload packages would be added, as needed, to complete the system. To place the required payloads in orbit we suggest small lift vehicles like Pegasus/Taurus or Orbex would be used. Their payloads of 400 to 1000 pounds would require the packages to be designed to meet this requirement, but with the modular concept different packages could be placed on the mother board to work together and provide service that much larger satellites do today. By using this approach to the lift requirements for the modular payloads, we feel aerospace application would benefit in mobility (not being tied to one or two launch locations, specifically when using air launched systems like Pegasus. Also, down range requirements and personnel involved are greatly reduced). There would also be cost savings just based on the less involved launch systems. And responsiveness, flexibility and versatility would be added to our nations launch capabilities. Further, most of the lift approach discussed here is available today and would only need to be enhanced to provide the service needed by the modular concept.

Orbital Considerations for Space Modular Systems

Once the concept is operationally proven, one or more motherboards could be collocated at three distinct orbit bands of low earth orbit(LEO), medium earth orbit(MEO), and geosynchronous earth orbit (GEO). These are the most widely used orbital bands and offer the maximum benefit for the "motherboard" concept to operate in.



In order to retrieve degraded spacecraft and to transport the replacement/refueling modules from the motherboard to the degraded satellite, there are two options. First, the concept of an orbital transfer vehicle (OTV) or space tug must be pursued. The purpose of the OTV is to provide a low thrust propulsion system capable of moving within an orbital band as well as between orbital bands. Second, each individual module must have the ability to attach another standardized modular propulsion and attitude control unit with sufficient artificial intelligence to dock autonomously with the degraded satellite.

This second option is more desirable long term because it not only eliminates the requirement for another large spacecraft system(the OTV), but it also provides the maximum capability for autonomous operations for each module. For instance, if a CINC wanted a sensor to be in a more advantageous orbit of his theater of operations this option gives him that operational flexibility. Sensor X could attach a propulsion and attitude control unit, and perhaps even a data communications unit or merely cross link the data to

another satellite for immediate down link, and maneuver itself into the more advantageous orbit.

The operational responsiveness provided by this second option is one of the greatest advantages of the space modular system. However, significant upgrades in artificial intelligence, automated docking and maneuvering, and refueling methods must occur.

On-orbit Space Depot

Current technology limits our ability to retrieve space vehicles to those vehicles in low earth orbit within the range of the space shuttle. The shuttle has already performed a number of space vehicle 'rescue missions'. The most recent example was the Hubble telescope repair mission. However, these missions were ad hoc creations which required a significant investment in time and money to accomplish. Although current space vehicle retrieval technology and operations are immature, we believe that by the year 2020 space vehicle retrieval will be very achievable and routine.

A specialized adaptation of the motherboard would be an orbiting space depot in low earth orbit. This depot may not necessarily look like the other orbiting motherboards. However, the depot would provide the primary means of logistical support of the motherboards and their modules. Only one orbiting space depot is anticipated. Each motherboard would have a limited refueling capability. In addition, each motherboard would have a storage facility for high failure components. Our support strategy would be based on scheduling repair missions based on actual failure of a space vehicle component, or an indication of near failure.

In the following paragraphs we will discuss the concepts of operations for the three main functions of the station: (1) depot functions, (2) refueling operations, and (3) debris removal. These functions would be performed either at the station or at the motherboard. The repair mission would be scheduled after receiving notification of a module component failure either from satellite ground controllers or the satellite itself. Simple repair actions

(removal and replacement of a failed LRU) would be performed at the motherboard. Depending on the orbits of the motherboard and station, either an orbital maneuvering vehicle or orbital transfer vehicle would be required to get to the module and back. The vehicle would leave the station with all the required equipment to affect the repair. The replacement LRU would be stored in the motherboard. After the repair, checkout would be performed by the module. The vehicle would then return to the station with the failed LRU for repair at the station or on earth.

More complex repair action (removal and replacement of more than one failed LRU, or subcomponent repair), modification, and maintenance would be performed at the station. The same orbital maneuvering or transfer vehicles would be required. In addition, a retrieval apparatus would be required. After repair, checkout would be performed at the station before returning the satellite to its operational orbit. To the extent possible, failed LRUs would be repaired at the station. Those that could not be repaired would be returned to earth for repair.

We expect that refueling operations would be performed at the satellite. The same orbital maneuvering or transfer vehicles would leave with a container of fuel. The fuel would then be transferred to the satellite. The mission would end with the return of the vehicle to the station.

The space debris removal function would be performed slightly different than the depot or refueling functions. Essentially, as hazards are identified, the same orbital maneuvering or transfer vehicles would be sent out with the retrieval apparatus, or possibly a powerful electro-magnet to retrieve the debris. If possible, the debris would be recycled, serving as source material for the auto fabrication process. Space debris removal missions would occur as targets of opportunity. Missions would be scheduled only if a significant, and immediate hazard was identified.

Station resupply from earth would generally occur at scheduled intervals. The concept would not be significantly different than resupplying Navy vessels at sea. Resupply

missions could be accomplished by the NASP or other lift vehicles capable of reaching the station's orbit.

Implementation of a space depot would provide enormous leverage for the US space capability. An on orbit depot would provide forward based logistical support for space vehicles. A facility which can perform the functions described above could lower the payload weight of space vehicles, extend their operational life, conduct product research, mine space minerals and ore deposits and improve space asset availability and survivability. If the depot also performs the space patrol function, improved safety of navigation is also possible.

Reduced payload weight is possible due to a refueling capability and reduced design complexity. Currently, fuel consumes a significant amount of the payload weight budget. If space vehicles could be launched empty or with minimal fuel, overall payload weight would be reduced, thereby reducing the initial lift requirement. The vehicle's fuel tank can be 'topped off' at the depot and the vehicle then placed into its required orbit. An additional reduction in payload weight may be possible by reducing the design complexity of the space vehicle. As mentioned earlier, critical systems are double and triple redundant to achieve the high reliability required by today's satellites. The ability to repair satellites on orbit would reduce the need for this redundancy, resulting in a lower part count in the satellite and therefore reduced weight.

An on-orbit refueling and repair capability would also extend the operational life of the space vehicle. Fuel capacity to perform orbital maneuvers or orbital transfers would no longer be a limiting factor on the operational life of the space vehicle. Currently, failed satellites are replaced with new full up satellites. Extending the operational life of the space vehicle could delay the need to launch a replacement satellite by years, resulting in significant cost savings.

Additional benefits would be the improved availability and survivability an on-orbit repair capability would provide. The underlying assumption in the improved availability is

that repair of the orbiting space vehicle could be accomplished sooner than the launch and checkout of a replacement satellite. Today, this would be a very valid assumption. For example, the Hubble telescope was recently repaired on one shuttle mission. By contrast, satellites often sit weeks or months on the launch pad for a variety of reasons ranging from failures during checkout to weather delays. By the year 2020, this advantage will probably not be as significant, assuming we improve our launch capabilities. However, it will still be difficult to beat repair times which could be measured in hours by the year 2020. Also, some improvement in survivability would be possible because space vehicles, no longer limited by fuel, may be able to maneuver away from potential threats.

Automated Fabrication

There will be a need to fabricate parts and pieces in space to support depot operations. This need is based on the high premium of space lift, distance and the excessive turnaround times to transport repair or replacement parts to space. In some cases, shipping parts to space may be impractical or unachievable due to weight, quantity or size. Ideally to further lessen lift requirements in support of depot operations, we would use the raw materials available in space or recycle space debris to make parts in space. The machines needed to build the parts in space will vary in size, but should be comparable in size to today's large commercial copiers and desktop laser printers. These machines will be part of an "automated fabrication" or "desktop manufacturing" system that combine the applications of CAD (computer-aided design) and CAM (computer-aided manufacture) to fabricate the parts seen on the 3-dimensional CAD screen.¹ Just as we send text on word processing programs to a printer, we expect by 2020 that CAD programs will be able to transmit a 3-D computer image to a fabricator machine where the part is manufactured molecule by molecule from metal, composite or plastic powder. Similar to how an ink jet printer sprays the text or drawing on paper, a fabricator would build a part by spraying droplets of metal powder together to form the part (or some other

¹Burns, Marshall, automated Fabrication, 1993 Ennex Corp, PTR Prentice-Hall, Inc.

material). Again, to further reduce lift requirements and cost, the database of specifications and drawings of parts and the CAD system needed to operate the desktop manufacturing programs would remain resident on earth. One of many ground stations could be used to transmit the data to the closet orbiting fabricator or space depot module.

Orbiting Industrial Park

We have long recognized the benefit of deploying to a forward location when engaging in extended operations in a Theater of Operation. As Space becomes such a theater, there will be a need for "real estate upon which to build a base of operation, for forward positioning of hardware, to reduce the time energy and costs associated with deployment, and to simply be "near the front." A continuously manned space platform will settle the primary need for "real estate." A basic infrastructure is necessary for any facility to operate: power, water, air, space, gravity. Such a facility would support exploitation of space and provide a basis for a permanent manned presence. Such a facility could be independently manned and operated by the DoD or be part of a commercial/civil industrial park. The facility could provide an "in-theater" assembly, maintenance and staging area for further operations deeper into space. Re-useable heavy lift provides the initial large scale acceleration to achieve orbital velocity and will provision the facility. Light, low thrust "space tugs" will provide propulsion for activities throughout the orbital environment.

As the national defense establishment continues to face funding pressure, economics will drive operations and systems. Initial investment (development, real estate and construction costs), production costs (operations, materials, transportation) must be reduced sufficiently to provide adequate political support. The costs associated with developing a space-based manufacturing or production process are substantial. In addition, space "real estate" is not readily usable. In current space activities, the real estate is carried with the system. This is done either with a satellite bus, which provides

all support structure and utilities, or with a support vehicle such as the Space Shuttle which has limited space and must return to earth after only a few days in orbit. The cost of miniaturizing the system, (sizing it along with necessary raw materials to fit on a launch vehicle), and ruggedizing it to withstand repeated lift-off and recovery is prohibitive for most processes. It is not now (and likely never will be) cost effective to lift a full scale manufacturing process into space in a "batch" process. This is analogous to placing a manufacturing plant inside the transport truck trailer. Conversely, the costs associated with designing, building and launching a self-contained manufacturing satellite, manned and re-supplied by robots is also beyond the capability of most start-up activities.

The solution is to establish an orbiting, manned platform or "industrial park," accessible to "friendly" commercial/civil endeavors. The park would provide the basic infrastructure to support a variety of activities. An operational facility where space is available for users to set up will encourage space based manufacturing, innovation and development. Such an industrial park would perform a wide variety of benefits. The first is a common infrastructure upon which to build. This includes both a physical infrastructure (self-contained pressurized facility, attachment points, gravity for the workers and to simplify certain processes), as well as a facility infrastructure (power, communications, docking facilities, internal transportation) with costs shared by a number of users. An industrial park could take advantage of direct access to solar power, the vacuum of space and a near zero-G environment to provide some unique manufacturing opportunities. By permanently placing the manufacturing process in orbit, the expense, risk and constraints of lift-off, performing a manufacturing cycle and then de-orbiting would be radically reduced. All that would be transported into space after initial set-up of the manufacturing process would be the raw materials; all de-orbited would be finished product.

By either constructing a very large cylindrical pressure vessel (or initially a series of large "wheels" that could be stacked or connected) or by using a hollowed-out asteroid, (captured, and placed in an appropriate orbit) the basic structure of the facility would

provide room for a large number of independent activities. Rotating the station around its axis will produce an artificial gravity of the desired strength. Basic building materials would not be acceleration or vibration sensitive. They could therefore initially be sent aloft using a rail gun or other high acceleration/high velocity lift mode. Once a basic capability was established, raw materials could be sent aloft and processed in place, using solar cell energy sources. Building materials for the structure could also be mined from an asteroid (many are high in Iron and Nickel) using high powered industrial lasers.

Manufacturing in space has a number of significant benefits that are either impossible or extremely expensive to replicate on Earth. First, in-space production allows access to a zero-G or near Zero-G environment. Theoretical predictions of superior quality microchips, high purity pharmaceuticals and superalloys not possible on Earth are some of the benefits of space manufacturing. Second, the pure vacuum of space provides an ultraclean, biologically isolated environment for advanced chemical and biological processes (reactions and separation mechanisms). In addition, space offers direct access to cosmic radiation and solar radiation. Although there is not now a significant demand for manufacturing processes using cosmic radiation, unimpeded access to solar radiation and limitless space for collecting the energy would give an orbiting platform almost limitless energy. Such clean renewable energy would be of great value to energy intensive industries such as aluminum manufacturing and fusion development and high energy physics research.

Manufacturing processes require space, facilities, power, process equipment and raw materials. They also require time to set up and optimize, as well as a degree of stability. Once established, processes could be operated in a continuous mode, greatly reducing operating costs. In addition, raw materials found in space (iron and nickel from asteroids, the moon, etc) would be processed into final product (structural beams, vehicle skin) for in-space application. At a space assembly facility, modular satellites, orbital transfer vehicles and deep space probes could be assembled, tested, repaired and launched without

the shocks and loads associated with current launch environments. Such vehicles would not be limited by the size constraints imposed by launch vehicles. Additional processes and benefits will be discovered once research and development of space processes commences.

In-space manufacturing would augment space assembly. Components or subcomponents, both manufactured in space and transported from Earth will be assembled and checked-out in an orbiting assembly facility. Currently, satellites and other "space" vehicles are designed and constructed to withstand the rigors and stresses of launch. They include the redundancy and environments specifications (i.e. Class "S" parts) consistent with the severe environment of a high G, high vibration launch. Once the vehicle is deployed, it operates in a near Zero-G environment with little if any lateral loads or vibration. In-space assembly and check-out will allow a vehicle to be designed and built for its operating environment, reducing cost and complexity. It can be tested in space, with any problems corrected prior to deployment.

A space depot would provide on-orbit repair facilities for trans-atmospheric vehicles, orbital transfer vehicles and satellites as well as providing refueling capability for these vehicles. Once again, the costs of lift, de-orbiting and re-deploying a satellite would be eliminated. However, this facility would need to work in conjunction with some form of space tug, capable of trans-orbital plane movement and capture and retrieval. This depot would also reprocess captured space junk, either repairing and redeploying it, or scrapping and reprocessing or recycling it as a raw material.

As an operating base, manned activities of all sorts can take advantage of a 1-G environment for physiological extension, for recreation, and reduced leadtime to respond to in-space contingencies. It can also act as a staging and assembly area for preparations for deep space exploration and travel, either manned or unmanned. This base could also provide support and infrastructure for an orbiting recreational complex to include hotels

and space oriented (low G) activities. Such a complex is presently envisioned by the Japanese with initial deployment in the mid 21st century.

Although it may not be necessary to attach weather and other observation platforms to this station, support and operations costs would be dramatically reduced if support elements and maintenance facilities were already available. The facility could also provide a platform for observation and control of space traffic, either by establishing the manned facilities on the station or by using the facilities to collect and relay positional data on space traffic. The park would also provide an ideal site for research and development of new, space related technologies for both civil and military application.

Some manufacturing and other processes may require a vibration free environment or have other special requirements that would preclude them from being attached to a large manned integrated complex. It should not, however, preclude them from taking advantage of some of the infrastructure provided by the space industrial park. Such mini-parks could either be tethered to the main structure or could operate in the vicinity of the park, returning to the park for resupply, transfer of products and repairs. Such transfer of hardware could be accomplished by small "space-tugs" or by docking with the space park when necessary. Higher G loadings could be produced by using a longer radius arm (extending the Park beyond the 1-G radius). Personnel and most operations could be conducted at 1 G, with higher G forces available as desired either at the end of a tether or on an extension arm.

Pursuing a manned 1-G industrial park requires a re-examination of our perspective on space. Currently, we view space as a medium through which to travel or at best as a place to leave observation platforms. Unless there is a "place" in space, a destination, there will be no reason to venture into space. Unless there is a profit to be gained, the commercial sector will not invest there. despite all the discussion of robotics, artificial intelligence and virtual reality, man in the loop will still be required for most volatile or unpredictable activities. A capability for man-in-space will be needed well into the next century.

A government-civil-industrial consortium must be established to produce the first station. As stated earlier, commercial venture capital is risk and cost constrained. Limited initial return on investment and high initial development and construction costs will likely deter industry from pursuing this approach prior to demonstration of its utility. As with the initial colonization of the New World, establishing a manned presence in space will need initial government sponsorship. However, once the colony, or in this case the industrial park is established, industry will expand upon the idea, ultimately establishing a fleet of commercially funded structures (using the manufacturing capability of the first park.

III Potential Technologies

Virtual Reality. This facility could incorporate virtual reality technology to 'virtually man' the facility if maintaining a physical presence was not possible or desirable (political or cost reasons). Virtual reality technology needs substantial development before incorporating it into the facility. A near real-time feedback capability from a great distance is required to virtually man the facility. Research breakthroughs in virtual reality technology require substantial advances before they can be incorporated into the facility. This remains a bottleneck in virtual reality technology. In addition, complex operations are required to perform the various housekeeping tasks. A substantial improvement in robotics will also be required to virtually man the facility. This is well beyond the current state of virtual reality technology at this time.

Robotics. In addition, complex movements are required to perform the various maintenance tasks. A substantial improvement in robotics will also be required to virtual man the facility.

Space Vehicle Retrieval. A retrieval apparatus or vehicle to bring space vehicles to the depot for repair, maintenance, or modification would need to be developed. Space vehicle design would also need to be compatible with this apparatus or vehicle.

Docking Mechanism. An efficient docking mechanism and procedure is necessary. The abstract on docking (A0298) indicates this technology is very possible.

Fabrication/Manufacturing in Space. The exponential integration of CAD and CAM may lead to the real-time computer generated manufacturing of parts in space from raw materials including metal, plastic, fiber and ceramic powders. Current trends in this new technology are called "automated fabrication" and "desktop manufacturing". Automated fabrication (AutoFab) is the process of generating three-dimensional solid objects by beaming light on multiple layers of photosensitive plastic polymers². Advances in this technology include computer-numerically controlled (CNC) milling; micromachining; CAD/CAM; rapid prototyping; laser sintering; droplet deposition to streamline manufacturing processes. AutoFab is driving manufacturing towards nanotechnology, where objects are constructed one molecule at a time. The leading experts in AutoFab expect this technology to become mainstream within 20 years and they believe the entire field of man-made and natural materials to be within the domain of additive fabrication, including soft organic tissues and refractory metals.

In short, automated fabrication incorporates the technologies that advance the generation of 3-dimensional solid objects under computer control. The fabrication process takes raw material in some shapeless form, such as blocks, sheets, fibers, powder or a fluid, and turn out solid objects with definite shape. Currently this process operates under three general categories of subtractive, additive and formative:

- a) Subtractive, removes material from a solid block until the desired shape is reached.
- b) Additive, material is manipulated to build objects one particle or one layer at a time.
- c) Formative, mechanical force is applied to bend or press a sheet or soft material into a desired shape. Also, the molding of molten or curable liquids into a desired object. A

²Burns, Marshall, Automated Fabrication, 1993 Ennex Corp, PTR Prentice Hall, Inc.

hybrid process is possible by combining two or all three types of these techniques to build an object.

Given the potential sources of raw materials in space, additive fabrication offers the best method for use in space. Additionally, this method compliments the overarching objective to reduce lift requirements by eliminating the need to transport raw materials to space. Of the additive processes, droplet disposition presents some intriguing ideas whereby an adhesive liquid is deposited in a controlled pattern to form an object. This concept is similar to how an ink jet printer or spray painting works today. Another space application is to construct high powered solar panels to function as a fabricator to melt, carve or cut away at chunks of space debris or meteors to form a useful object. Current fabrication technologies are immature and highly incremental but have limitless commercial and military potential especially in space. In fact, to a certain extent (although extreme) automated fabrication may reduce a significant portion of the USAF maintenance concept of two-level to one-level. If a part breaks, fabricate the replacement part or parts.

Space Assembly. In-space manufacturing would augment space assembly. Components or subcomponents, both manufactured in space and transported from Earth will be assembled and checked-out in an orbiting assembly facility. Currently, satellites and other "space" vehicles are designed and constructed to withstand the rigors and stresses of launch. They include the redundancy and environments specifications (i.e. Class "S" parts) consistent with the severe environment of a high G, high vibration launch. Once the vehicle is deployed, it operates in a near Zero-G environment with little if any lateral loads or vibration. In-space assembly and check-out will allow a vehicle to be designed and built for its operating environment, reducing cost and complexity. It can be tested in space, with any problems corrected prior to deployment.

Observation/Research. Although it may not be necessary to attach weather and other observation platforms to this station, support and operations costs would be

dramatically reduced if support elements and maintenance facilities were already available. The facility could also provide a platform for observation and control of space traffic, either by establishing the manned facilities on the station or by using the facilities to collect and relay positional data on space traffic. The park would also provide an ideal site for research and development of new, space related technologies for both civil and military application.

Substations. Some manufacturing and other processes may require a vibration free environment or have other special requirements that would preclude them from being attached to a large manned integrated complex. It should not, however, preclude them from taking advantage of some of the infrastructure provided by the Space Industrial Park. Such mini-parks could either be tethered to the main structure or could operate in the vicinity of the Park, returning to the Park for resupply, transfer of products and repairs. Such transfer of hardware could be accomplished by small "space-tugs" or by docking with the Space Park when necessary. Higher G loadings could be produced by using a longer radius arm (extending the Park beyond the 1-G radius). Personnel and most operations could be conducted at 1 G, with higher G forces available as desired either at the end of a tether or on an extension arm.

} Angular Momentum

Vibration Control. Refueling capability of major concern in the modular satellite concept is the vibration and transmission of disturbances to other operating modules on the motherboard during docking and positioning of neighboring modules. Technology advancements in techniques, materials, and component isolation will be required in order to reduce these self induced vibrations that could interfere with other modules. This will undoubtedly drive research in determining what types of modules will be able to work together on the same motherboard. It will then lead to configuration management standards for the satellites. Research in soft coupling techniques, laser radar docking, docking mechanics, and sensors will have to be standardized. Further development in manufacturing in small tolerance fittings and micro component machines

will be necessary. At this time it is expected that machining will have to be accomplished to within 0.01 in. of design. Standard designs and tolerances will actually simplify the manufacture of replacement components and result in quicker design to production times when used in conjunction with rapidly advancing CAD/CAM techniques.

The motherboard concept is achievable with current technologies. Contractors however, must standardize current and future designs to gain maximum benefit. The miniaturization achievements during the Apollo space program are being applied exponentially across the full spectrum of space and electronics research and development. The focus must include the manufacture of relatively small modules. The modules must be designed to take advantage of low cost lift options (Pegasus/Orbex) and to maximize flexibility in launch operations (responsiveness). The modules must also realize a high cost/benefit ratio. This effort requires adaptation of standard power interfaces (e. g. Apollo-Soyuz AIAA Paper 90-3461, and A0022) and the use of soft docking and computer vision-based guidance and control techniques (Abstract A93-31994). Current research for the Space Station Freedom is addressing miniaturization and other material problems. Solutions will most likely see the same technology spin-offs as previous space programs. Advances in the development of lightweight materials (Abstracts A0033 Materials in Space and A0010 Micro mechanical Systems) and the resulting miniaturization of major components will prove ideal for applications where weight and volume are essential.

Innovative applications of the modular approach to technology was "on target" according to VAdm Ramsey, former DCINCSpaceCOM. VAdm Ramsey, now with CTA, acknowledged that further miniaturization coupled with the modular approach maximizes the use of the Orbex small satellite launch capability which CTA endorses.

Finally, modular fuel and propulsion packs will increase module manipulation. Bus repair, maneuverability of the mother board, and space vehicle recovery will be significantly enhanced by these fuel packs.

IV. Near Term Technologies and Operational Exploitation Opportunities

Pursuit of standardized, modular, miniaturized components and virtual reality technology are beginning to provide a significantly improved way of doing business. The flexibility of being able to travel with and use electronic equipment world wide that adheres to a common set of standards is coming of age . It is logical that similar approaches will be taken towards space assets. Standardization will be a shot in the arm to commercial space endeavors. The parallel is made to the computer industry and the RS-232. Modularity would allow the trend in product specialization to further enhance commercial enterprise. The parallel again made to the computer industry is the motherboard approach that accommodates a variety of chips, allowing you to upgrade to newer chips as they become available. Miniaturization whether in space or on earth translates to mobility and flexibility and sheer power to do more with less. Again the parallel in the computer industry is the ever shrinking yet increasingly more powerful microchip.

Can be commercially operated. The facility could be commercially operated, commercial space assets that implemented the standardized, modular design concepts could also take advantage of the support operations.

Commercial applications. Commercial spin-offs might include prototyping for; film propmakers, architects, urban planners, and surgeons (prosthetist); solid-imaging for chemists, physicists, biologists, police artists, terrestrial topographs; pattern molds for; manufacturers, industrial engineers, jewelers, and job shops.

Can provide support to commercial space vehicles. Commercial space assets that implemented the standardized, modular design concepts could also take advantage of the support operations.

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Concept Papers Numbers Embedded: 3, 10, 21, 30, 33, 34, 35, 38, 40, 43, 47, 74, 83, 89,
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White Paper
on
Professional Military Education in 2020

C. A. T. Education and Training - C. A. T. Team 14

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"The effective employment of air- and space power has to do not so much with airplanes and missiles and engineering as with thinking and attitude and imagination."

-- Gen. Merrill A. McPeak

[Gen. Merrill A. McPeak, "The Key to Modern Airpower," *Air Force*, September, 1993, 46.]

Picture this: its 15 April 2020. You are the wing commander at Osan AFB. All number two positions have long since disappeared. TDY travel for PME, specialized training, and conferences is an unusual occurrence and only approved under extraordinary circumstances. Now you receive nearly all this type of information at your office or home. As space information and new technology are doubling at the rate of every few weeks to every few days you are required to attend a space update briefing on a regular basis. The NAF Commander is required by regulation to chair these meetings and address how this technology will impact the war fighting capability of each wing under his command. His travel constraints are similar to yours. Question: how do you, your fellow wing commanders, and the NAF commander get together to discuss this information and the training required to update your operational procedures. Answer: PME 2020!

The PME 2020 system is a world of virtual reality and distance learning and is a mandatory requirement for all military members. As the Osan wing commander, you have

been researching the viability of modifications to weapon systems in your wing. Today, you are responsible for briefing those findings. During today's PME session you, your fellow wing commanders, and the NAF commander don virtual reality helmets and are "transported" to a computer-generated conference room. Also in "attendance" is a non-resident instructor specializing in distance learning who will be your facilitator. Since human-computer implants provide complete basic knowledge on the modifications, today's lesson concentrates on application of the modifications and its impact on operational considerations. The facilitator is prepared to guide your learning experience. Computer simulation combined with virtual reality must be a part of PME 2020. The real question becomes, how do we get there from here. Will the PME 2020 system ensure that future war fighters are prepared to perform their mission.

I. Subject and Problem Statement:

This paper will focus on why and how the current PME system must change now by examining the information explosion, individuals involved, the fiscal constraints, and the technological environment. The PME system - its people, academics, technologies, and processes - must change today to ensure a viable system is in place by 2020. This will ensure future war fighters are able to perform their mission.

By the year 2020, the characteristics of military members will be significantly different than they are today. Fiscal constraints will continue to impact and change the size, location, and flexibility of military forces to attend or enroll in PME. [McPeak, 43-46.] The technology environment surrounding the military members will be different than the one surrounding them today. [McPeak, 44.] PME must respond to current and continued changes in military characteristics, fiscal constraints, and changes in the technological environment.

Consequently, PME 2020 will have an entirely new look, feel, and responsibility. This paper will focus on the impact of each of these areas as we discuss current and future capabilities and relevance of PME to the war fighter.

II. The Capability and Its Relevance

"If we should have to fight, we should be prepared to do so from the neck up instead of from the neck down."

-- Jimmy Doolittle

While the present PME system is adequate today, it will not be effective in the future without significant changes. PME must have new and different capabilities to meet the military challenges in 2020 and beyond. These capabilities will be in response to the emerging information explosion, the changing characteristics of military members, fiscal constraints, and the technological environment.

"As muscle work declines, large numbers of unskilled laborers are increasingly replaced by smaller numbers of highly trained workers and intelligent machines. ... This process, too, is perfectly parallel in the military, where smart weapons require smart soldiers. ... The idea that the Gulf War was a 'high-tech' war in which the human element in combat was eliminated is a fantasy. The fact is that the forces sent by the allies to the Gulf were the best educated and technically expert army ever sent into battle. ... The new military needs soldiers who use their brains, can deal with a diversity of people and cultures, who can tolerate ambiguity, take initiative, and ask questions, even to the point of questioning authority. ... The willingness to ask and think may be more prevalent in the U.S. armed forces than in many businesses. ... As in the civilian economy, fewer people with intelligent technology can accomplish more than a lot of people with the brute-force tools of the past." [Alvin and Heidi Toffler, *War and Anti-War* (Boston, Mass.: Little, Brown, and Co., 1993), 73-77.]

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By 2020, information needs will grow exponentially, and the amount of new information will be astronomical. Without careful planning and information-handling skills the decision-makers of that future will be susceptible to "analysis paralysis." [Toffler, 158] It is estimated that new information will double every few weeks (or days) due to quantum leaps in technology and the number of people using that technology. Instant access to the Information Super Highway, the Library of Congress, and numerous other sources worldwide will create an information overload almost unimaginable today. PME must teach individuals how to deal with unlimited information and prepare them to take advantage of this new environment. Searching or information navigation skills will be critical for all who expect to navigate the rapidly increasing sea of information. PME 2020 problem solving techniques will emphasize those skills required to narrow the search for critical information in the cockpit, ship, or tank. PME systems must be much more adaptive to respond this ever increasing and changing world of information. PME will have to be divided into smaller blocks of instruction which address specific needs of individuals without regard to rank or position. In addition, PME will have to be accomplished more quickly and efficiently to keep pace with this information explosion. PME will also have to teach people how to ask the right questions since knowledge navigation skills will become more important than knowledge acquisition skills. "In short, knowing the knowledge terrain will be as important for Third Wave armies as knowing the geography and topology of the battlefield was in the past." [Toffler, 158]

Information availability and accessibility will revolutionize the work place. Flexible-place, flexible-topic, and flexible-job offerings will become the norm. Industry and the military are exploring them now. This situation will demand changes in PME 2020 systems as we develop better ways of preparing personnel for a variety of job vacancies. Increasing numbers of challenges such as Bosnia and Somalia, combined with a technical environment which is "dynamic to a degree different from anything in human experience,"

and added to our "getting smaller quite quickly," will mean that our people will have to be "more comprehensively trained, less specialized," with cycling back through school during their careers. They will need a "broader range of skills," in order to be "more flexible."

[McPeak, 44] To prepare individuals for this new concept of job, all military personnel will need to be "connected" to the PME system. Furthermore, PME will be available to all personnel, including those working in remote locations. Being connected to the PME system will allow those interested to use their own time to seek the appropriate knowledge and then be able to work on projects of their choice. This capability will allow individuals to broaden their expertise and become educated in areas they may not have been exposed to previously. Additionally, the unique combinations of backgrounds and interests working within the same system or network, will reap fruitful rewards in continuing the process of allowing creative minds to maintain a dynamic educational and training experience. This will become one of the salient points from which to increase job satisfaction, and continue to attract the best and the brightest individuals into the military. The military has already started new recruitment strategies in over 50 career areas aimed at individuals who already possess the basic skills needed for various specialties, and thus not needed any or as much training in the basics. [Tom Philpott, "Less field training forcecast," *Air Force Times*, 27 April 1992, 10.] And to keep those highly qualified people, we might do well to look at such research as the survey quoted in CIO magazine, where the importance of various factors in attracting and retaining technology professionals were rated by those professionals. Opportunity to work with leading-edge equipment was rated as very important by 64% of those surveyed, opportunity to work on important projects -- 62%, enthusiasm for the mission of the business -- 57%, and opportunities for promotion into management got only 36%. [CIO, march 1992] How can we apply these type results to our education system to keep the best and the brightest?

To meet the future challenges, PME must also take advantage of the changing characteristics of its people. The mind set of 2020 military personnel will enable them to feel comfortable with technology and more readily accept technological changes. The current 20-something generation already consider themselves as "masters of technology" and they "use computers the way other generations use the phone." [Joseph P. Shapiro, "Just Fix It," U.S. News, 22 February 1993, 50-54.] Succeeding generations will only become more so. Regarding the shift to interactive simulations for training, Gen. Carl E. Mundy, Marine Corps commandant, stated "...it's very exciting for these young people, sitting down to work in arcades like they have in shopping centers. The Stinger (missile) trainer, for example...It's fun. ... It (increased use of simulations) will save us a lot of money in the long run." [Philpott, 10] As previously discussed, limitless information and, therefore, knowledge received through technological changes will be at one's fingertips or brain waves (thoughts). 2020 war fighters definitely will expect instantaneous answers to their questions, but they may or may not come into the military fully prepared to use that information. The current college generation is characterized as "victims of declining educational standards. ... Three quarters of college professors say students are 'seriously unprepared' in basic skills." [Shapiro, 53] This may be fixed by 2020, or it may still be with us. PME must be able to respond to the education and training needs of these individuals.

How Compared to today's individual, one of the more outstanding characteristics of the 2020 individual is his/her capacity and need to comprehend a larger range of basic concepts, and a better capacity and need for logic and reasoning. PME can exploit this by building comprehensive lessons which will teach a broader range of skills. PME 2020 must expand its individualized educational outlook by including basic level training in many general [McPeak, 44] areas while providing specialized training in a more narrow range. PME must teach students how to learn differently from their primary or natural style, thus

How

making them multi-lingual in learning methods and increasing their ability to cope with change. When examinations are used, they will be at the integration/synthesis level.

PME 2020 will ensure students understand the technology of the time by incorporating OJT for systems specifically needed to accomplish their mission. PME 2020 will provide the means for transferring this specialized or general "OJT" directly to the war fighter by beaming it into planes, tanks, or ships. PME 2020 capabilities then include synthesizing skills necessary to derive new pertinent information by combining existing data, teaching personnel to effectively use automated assistants, and continually adapting and upgrading its own systems and data bases.

All 2020 military personnel will be "connected" to data bases through wide area networks such as InterNet. Regardless of unit location, military personnel will have access to worldwide information networks capable of two way data, image, and simulation transmission. Technology will present more opportunities for military members to interact together even when geographically separated. PME 2020 must remain flexible to take advantage of this situation and be brought closer to the individual on a daily basis to ensure education or training requirements are met. Individuals thus trained will have the flexibility to be stationed wherever needed and know the job requirements or be capable of learning them quickly. PME 2020 trained individuals will become a "force multiplier" to the military.

PME 2020's potential accomplishments are limitless; however, dollars required to educate and train war fighters are not limitless. There are fiscal constraints to consider and worked within wherever possible. Fiscal constraints will continue to cause changes in the size, location, and capability of military forces. Consequently, the PME system must adapt to those fiscal constraints and improve its effectiveness in spite of them. Otherwise, it will

lose its relevancy for the war fighter. For example, due to fiscal constraints, there will be fewer high priced weapon systems developed and more frequent, incremental, technological upgrades to existing systems. This will require rethinking uses and retraining users. A very relevant issue for the war fighter.

Available dollars will have caused military forces and other DOD resources to shrink by 2020. Fewer numbers of personnel will be widely distributed in the CONUS, but in fewer locations. Consequently, there will be fewer personnel available to participate in PME as "students", "faculty", or academicians to author courses, and fewer senior officers or enlisted to perform "formal" or "informal" on- the-job training. With fewer human and materiel resources, the value of each will increase. This will place a premium on more effective educational and training programs. Costs in loss of personnel to resident PME programs directs a strict examination concerning unique benefits of attending a non-resident, PME 2020 course. An enhanced PME system, limited by fiscal constraints would necessarily put more emphasis in a solid, adaptable, non-resident education and training program.

PME 2020 will be an open education and training program. To efficiently utilize our resources, information will be shared with the other Services and civilian institutions, especially in research and curriculum development. Military and civilian educational institutions have much to share that would benefit both. For example, Civil War lessons could be developed by PME resources or civilian institutions, and then shared with the other. Military methodologies and techniques may have commercial value and our system would allow better "testing" capabilities and opportunities. For example, the CD-ROM lesson based Air Command and Staff College is integrating into current curriculum use may have value at civilian institutions as well. This process or product could be sold or traded. As the military develops expertise in authoring in the virtual reality and simulation

areas, we will no doubt have opportunities to sell actual or modified products to civilians, or entice them to develop items we require by opening a less risky, guaranteed, military market.. This open education concept would have the additional benefits of facilitating more cross-discipline activities. Military education and training work groups would be include participants from different bases/continents with non-traditional participant mixes, including more mixing between ranks, services, and non-military personnel.

To increase understanding and support for the military, PME 2020 will have the capability to reach larger audiences, such as the media, Congress, John Q. Public, and potential adversaries. Keeping the larger audience and fiscal constraints in mind, only a very effective, up to date, flexible, informative, non-resident PME program can accomplish the task. PME 2020 is an enhanced non-resident program. It will educate the press to ensure they are more objective and provide better positive and negative feedback. It will educate Congress to help them make better decisions affecting the military. PME 2020 will also educate the American public. A public, better informed on military capabilities, competence, and needs can be beneficial for America, resulting in continued public support for the military. "... smart generals understand all too well that wars can be won on the world's television screens as well as on the battlefield. ... Media policy, therefore, along with policies for communication and education, will together comprise the main distribution components of any overall knowledge strategy. " [Toffler, 147] Finally, PME should educate our potential adversaries. Although foreign officers already attend intermediate and senior service schools, this concept should be greatly expanded and open to military officers from all nation-states. The negotiation process would be easier with "informed" opponents. They would understand and perhaps begin to share our ideals and values, and more importantly, think and solve problems in ways familiar to us. One example of the benefits this type of information can reap would be in trying to convince possible opponents of the benefits of non-lethal warfare. In addition, it should convince

them that the America is their friend and the US military is extremely competent and capable.

To meet the expected challenges and opportunities discussed in this paper, the PME infrastructure must change to bring it in line with the rapid changes in educational requirements. The timing of linkages between course content and evaluations needs to be greatly reduced to create a flexible, adaptive PME curriculum. Assessing progress in PME 2020 will be accomplished by completing the required course work; however, each course will be taken via distance learning and will have to be completed within a specified amount of time. Furthermore, with the incredible increase in information, course material will be updated frequently by electronic media.

PME 2020 will be a Service consolidated system, integrating core curricula for land, sea, air, and space warfare. PME 2020 institutions will be consolidated where practical and will be highly integrated electronically. The Air Force Institute of Technology (AFIT) began their nationwide distance education course in systems planning and management last year. Serving over 7200 students, it has a cost benefit of \$20 million over 6 years.

[G.Ronald Christopher and Robert R. Bergseth, "Meeting Air Force Educational Requirements Through Media," Orlando Multimedia '93 Conference Proceedings, 24-26 February 1993, 68-70.] And AFIT (part of Air University) has an ongoing Professional Continuing Education program, making use of satellite links throughout the Air Force. This type of arrangement, in addition to being more cost efficient, will be more effective in accomplishing joint education and training. More and more, the services are looking at sharing education tasks and resources to achieve those cost benefits, especially with distance education. [Philpott, 10] Maj Gen. Larry Day, deputy chief of staff for technical training at the Air Training Command, stated in 1992, "In the next decade, more and more training will occur away from traditional training sites. ... The concept [distance

very nice -- but where the
the curricula come from?

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education] will save on travel and per diem costs and should be a routine training techniques for all the services within a decade... The effort [to share training across services] is led by a little-known group called the Interservice Training Review Organization." [Philpott, 10] Furthermore, *as previously discussed*, fewer faculty and academic resources will necessitate sharing among the remaining military and civilian institutions. Finally, since Space is critical to our national security, space education and training will be a significant part of PME 2020 at all levels. According to a letter from Lieutenant General John S. Fairfield, Vice Commander of the Pacific Air Forces, dated 28 Feb 94, "As part of SPACECAST 2020, my staff and I discussed the importance of space education and training to the success of the Air Force mission. We feel it is critical to address space education and training needs beginning with accession and commissioning training. It should continue through all levels of Professional Military Education and be included in appropriate technical training." The technological environment will allow us to do this in the future. Yet, space is the perfect example of how we must change to cope: one system of satellites alone, set to launch in 1998 - 2013, will generate more than 10 quadrillion bytes of information on the Earth, "equal to about 10 billion books (the Library of Congress holds a mere 27 million)." [Garrett Culhane, "Mission to Planet Earth," *Wired*, December 1993, 94-97.] How will future military analysts sift out the details which mean life-or-death on the battlefield? We need to figure that out now, and start teaching it soon.

The need to have a better educated and trained force requires that all military personnel receive their education and training through a quality PME system. Fewer numbers of personnel attending PME in residence forces the non-resident PME 2020 system to incorporate some form of resident continuing education. The non-resident PME 2020 system will continue the "seminar" experiences through "on-line" work groups, distance learning, and virtual reality. Work groups, or seminars, meet periodically, via on-line

video teleconferencing centers at their home units. All groups in the PME 2020 system may share in these on-line seminars, which also provide for contacts across rank lines among services, and the civilian world.

PME 2020 will be a two-way gathering and sharing between students and faculty while simultaneously building an infrastructure on the expectations and experiences from personnel at all levels. "Healthy dialogue is important to any organization. ... By the way, a healthy dialogue includes listening to opposing views inside the organization. Openness is a two-way, and often rough and tumble process." [Gen. Merrill A. McPeak, *Air Force Policy Letter for Commanders*, December 1990]. Computers would automate the capturing of life experiences from those attending PME and from outside experts. Experience with computer interviews in the classroom environment would also prepare people for, and serve as research in, developing on the job computerized debriefing and interviewing processes.

We will need self-modifying education systems. These would not only take into account the learning modes of each learner, but also adjust themselves as the answers change from day to day -- thus freeing faculty from continually updating details. Faculty would only need become involved in periodic reviews or as approval agents for changes suggested by the computers. Thus, faculty could concentrate on teaching at higher levels of learning and developing new courses for entire areas of instruction.

The proper use of emerging technology will allow us to effectively deal with the incredible increase in new information with fewer resources in a more demanding technological environment. All military personnel and organizations must be connected to the PME 2020 system. PME institutions must be the first to change, to set the pace rather than react. It will not be easy. Paradigm shifts will be required. We will have to rethink

cognitive levels in terms of new information to ascertain what role the computer, or other technology, will play, and what will be expected of the individual. This will subsequently require a new approach to education and training. Fiscal constraints will impact our ability to obtain the latest technology. To initiate these paradigm shifts, we must market the benefits of creating a more responsive PME system. In the final analysis, we have four customers to convince of the relevance of the PME 2020 concept: the PME student, the senior commanders, the academicians (faculties), and the Services. If all players are not convinced, PME will slide to a react mode, never catch up, be fiscally drowned, or at the very least, be pushed around by an impatient technological environment.

PME must begin to adapt the different military member characteristics relating to changing job skills, boldly push forward despite fiscal constraints. It must accommodate the changing environment.

III. Potential Technologies.

Overall, technology is one of the two main factors necessary to meet the capability requirements of PME 2020. The other is a change in the processes. Trends in technology today in general indicate that the necessary capability will be available. Additionally, there are numerous specific examples of technology today developing to meet the capability requirements of tomorrow.

The technology of 2020 is not a limiting factor for ideas we have now. For instance, comparing the 64K RAM computers of the early '80's with the desktop computers of today, we have witnessed an over 100 fold increase in computer memory since 1982. This increase follows the principle of Moore's Law. This rule, used by one of the founders of the Intel Corporation, states that the number of transistors on the main microchip in a

desktop machine will double every two years. So far the rule has been remarkably accurate. [Kenneth M. Sheldon, "Micro 2000," *Byte*, April 1991, 132.] Since the number of transistors is a rough measure of computer power, we can roughly predict that our desktop computers in 2020 will have about 16,000 times the power of today's computers.¹ This prediction is considered a conservative estimate by other industry experts. They predict the computers of the next century may have billions of times more power. Some believe Moore's Law describes only the slow beginning of a curve which is becoming increasingly steep. Others believe Moore's Law doesn't take into account the replacements for the transistor. This new device will squeeze even more power onto whatever replaces the computer chip. In other words, industry experts agree, we will have plenty of power for whatever we can dream up in 1994. Extensive telecommunications, virtual reality, and computer simulation for PME 2020 is assured.

Then, the next question is will PME 2020 be able to afford the technology needed to meet its capability requirements. Again, analysis of today's technology cost trends may predict the future costs. Currently the price of computer hardware is declining between 30 and 68 percent per year. Using the more conservative rate of 30 percent per year means the \$5,000 desktop computer system of 1994 would have the technological capability in 2020 of equipment which costs \$45,547,738 today. Even if no new technologies were to develop between now and 2020, being able to use current technology in that price range would mean a significant difference in the office, home, and school. To be able to plan effectively, we must unshackle our minds from today's limitations. Shopping in that price range would give us greater technology on our desktop than that which currently produces all the special effects in the latest science fiction movie. It would give us better imaging and virtual reality capability. It would give our desktop machine greater

¹ 26 years divided by 2 = 13. $2^{13} = 16,384$.

simulation capability than the latest simulators used by the airlines, with surround picture and close-to-reality simulation.

Today's existing technologies also provide some specific examples and insight of what is possible in 2020. These potential technologies will solve the people, location and environment problems of PME 2020. For example, potential technology exists today to solve the information overload problems of tomorrow.

As previously discussed many current Air Force personnel already belong to wide area networks such as InterNet and bulletin board services such as Compuserve. These connectivity providers are currently developing the next generation network technologies. This includes automated aids used to find information and people over the networks. These automated aids are the beginnings of personally tailored automatic assistants. In PME 2020 automatic assistants will help us navigate the information highways without becoming overwhelmed. Edify Corporation has announced their 'Information Agent' which give users the ability to train computer networks to automatically gather and analyze data based on use demands. ["Special Deliverer," *CIO*, 1 June 1992, 71.] And Professor Negroponte, founder of MIT's Media Laboratory says we will soon have personalized "newspapers" coming over the computer networks, with not only the news, but also the ads, aimed at the individual. [Bob Metcalfe, "Get ready for personalized newspapers," *InfoWorld*, 5 April 1993, 52.] But even with such assistants, we will still need to ensure that the information military people need is available, and that our PME schools teach the skills to find it and use it appropriately.

We must also teach people how not to waste time and money doing inappropriate things with information, such as spending inordinate amounts of time and effort massaging

Overall - InterNet - the backbone of
examples - place
content in computer
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information and slides, until all that remains is very expensive "glitz." [Ivars Peterson, "Going for Glitz," *Science News*, 9 October 1993, 48]

Nintendo and Sega are already reaching into the home with virtual reality games and encyclopedic lessons. By 2020, we have to assume that virtual reality, or whatever its follow-on is called then, will be ubiquitous. Military personnel will be used to the technology and to the capability it provides, a capability that will be a natural part of their lives. Thus, there will be an expectation on the part of military personnel of 2020, an expectation which will drive PME to react, unless we take steps now to become proactive -- leading the way, instead of being dragged into the next century.

Human-computer interaction in 1993 already included strain-gauge connectivity for movement communication, embedded-under-the-skin transceivers between computers and humans, and experiments in controlling computers by thought (although so far only a few dozen commands can be "thought" to the computer). Already under development are smart machines with built-in intelligence, and automatons such as a maintenance follow-on to the Advanced Research Program Agency's Pilot's Associate program.

Commercial enterprise is about to put into orbit a constellation of 66 satellites which will enable instant contact anywhere on the globe, "a cellular system with very tall towers called satellites." [Joe Flower, "Iridium," *Wired*, November 1993, 72] PME should assume two-way access to any military personnel anywhere in 2020.

Technological hurdles to overcome include current regulations and manuals, which have yet to adapt to the rapid change of pace to which we must acclimate ourselves and the PME system. Also, due to funding limits and personnel limits, the Air Force finds itself behind in many areas of adopting the best (not necessarily newest or fastest) technologies

to our needs. If we are to progress toward a primacy of continuing career-long education, usually done through distance education, we must begin changing the infrastructure which channels our efforts.

We need to immediately acquire the ability to begin making Air University into a central repository of answers researched by others (military and civilian) and a source of solutions, such as on-line lists of names of who to talk to get the fastest start in researching a particular area of expertise. We can do this with current technology, needing only computers, large storage devices and on-line connectivity for incoming and outgoing information and questions.

IV. Near Term Technologies and Operational Exploitation Opportunities

"Victory smiles upon those who anticipate the changes in the character of war, not upon those who wait to adapt themselves after the changes occur."

-- Giulio Douhet

A successful PME 2020 system depends upon taking advantage of existing or emerging technology, and the resulting changes this technology brings to PME. Changes in both the current PME system, and in the mind set towards that system are critical to future success. The teaching infrastructure will have to be won over to a new way of teaching. Finally, military and civilian educational institutions must be prepared and willing to share resources in order to reap the benefits of each others' spin-on's and spin-off's. PME 2020 must initiate the integration of emerging technology on an evolutionary scale, to prevent chaotic, revolutionary changes from occurring, thus ensuring a successful PME 2020 system.

PME must initiate changes now to meet the demands of 2020. If it doesn't, mandatory, revolutionary changes will breed chaos within the system and detract from the positive push forward. The easiest way to integrate changes in new technology is to appoint a responsible office to oversee and implement these changes. This "OPR" will be a liaison between the PME and civilian education systems and emphasize useability and commonalties to both worlds. To meet the expected challenges and opportunities discussed in this paper, we need to initiate a restructuring of the Professional Military Education infrastructure to bring it in line with the rapid changes in educational requirements. The timing of linkages between course content and evaluations needs to be greatly reduced to create a flexible, adaptive PME course.

Initially, we should employ existing telecommunication technologies in PME. This will involve the integration of present stand-alone telephone, audio, television, computer, and satellite communication systems with interactive video capabilities and real-time access to the emerging Information Super Highway and other information-rich nodes such as the Library of Congress, colleges, and universities. We must also be prepared to take advantage of future technologies. We believe the next generation technology will involve virtual reality capabilities. By 2020, some future form of artificial intelligence technology will be part of the 2020 version of a telecommunication system.

The first requirement for initiating infrastructure changes is to research the educational and technological environment and determine which structures would lend themselves best to rapid adaptability to technology and to a close fit with future PME needs. PME

working groups made up of various career fields, having a variety of skills and interests, needs to be formed to serve as the initial catalyst for the forming of PME 2020. Facilities, and funds to purchase technology are required. Points of contact at military and civilian institutions are necessary for sharing the discovery process and to serve as funnels for

discoveries as they are made. In building on the experience of SPACECAST 2020, including the information gathering process, PME would become essentially a university that virtually knows few limits in space or time. Education will become available in portions, tailored to the needs of the civilian and military communities and services. Questions such as how important is residence versus non-resident courses, and what taxonomy, if any, should replace Bloom's, will be answered when we begin to incorporate emerging technologies into the PME system.

Implanted devices "connecting" humans to remote computers, and computers responding to thoughts, although limited at this time, are only two examples of emerging, evolutionary technologies which, in particular, are allowing knowledge level information to become largely the responsibility of computers vice the responsibility of individuals. Emerging technologies, in general, need to be the driving force behind development of instructional, PME programs that will educate people to effectively and efficiently manage the flood of raw data. Technology already exists which presents the opportunity for people to work and interact together even when geographically separated. Taking advantage of this technology is absolutely essential. Col. Jack Thorpe, special assistant for simulations at the Pentagon's Defense Advanced Research Projects Agency, stated "We will expect a smaller military to be masters of a wider ensemble of skills. This (interactive simulations) is an idea whose time is right." He pointed out how using this technology drastically improved tank crews scores on real-world tests. [*Business Week*, 5 October 1992, 96-100] As military resources decrease, the need for military and civilian personnel to maintain connectivity to ensure pooling of resources, whether physical or cognitive, is paramount.

PME's support, and harnessing of, integrated telecommunications and distance learning, might encourage an individual or group to pursue an overlap of interest areas. If this were

the case, personnel would be better prepared for smoother transitions between phases of one career, or between completely different careers. Comparatively speaking, this would place military personnel in a better situation than their civilian counterparts, since experts predict individuals holding multiple careers, or career interests in the future. The military organization would benefit as well. If its personnel understand a few, to perhaps, several different areas, it would directly contribute to, and enhance the military's flexibility to adapt to massive changes in organization and emerging technology, not to mention its increased flexibility to adapt to any crises requiring an increase in the number of people working in a specified field, on a specialized device, or improved methods. Overall, people with broader backgrounds can augment a team better; therefore, PME needs to harness the changes emerging technologies bring about, like integrated telecommunications.

Quality improvement processes will generate discoveries of better ways of doing things, resulting in dollar savings or saving lives throughout the Department of Defense.

The success of PME 2020 is critically and directly related to a change in the mind set towards the traditional education system as a whole. We must re-evaluate the question, "Who are we going to educate?"

Conclusion:

Implementing the concepts outlined in this paper will mean taking the first step in initiating a flexible, adaptable, up to date, state of the art, education process which keeps the military and civilian communities at pace with information discovery within the educational system.

Our military forces and will be much smaller in 2020 yet the world will continue to be a dangerous place. In addition, space will be added to the land, sea, and air as a conflict medium as competition among nations in space increases. This environment, coupled with the information explosion, the changing characteristics of military personnel, fiscal constraints, and significant technological advances will require a much more educated and trained force if America is to remain a military superpower in the twenty-first century.

We have identified several needs that must be satisfied if the US military will continue to fulfill its unique national security role in the future. The primary method of satisfying these needs is through the efficient and effective use of leading edge technology. This technology, of course, will be used to accomplish military missions, but it also should be used for PME as a force enhancer. Colonel John Warden, Commandant of the Air Command and Staff College, summed it up best when he said: "PME must be on the cutting edge of technology if it is to survive as an institution in the future."

Fiscal constraints will always exist, but can be overcome through creative thinking.

NOTE for Section 3 ??

The information glut may necessitate subconscious systems which trigger learning strategies and support structure when needed, but stay out of the way the rest of the time to reduce overhead and overload. These could be induced through self hypnosis, drugs, or implants. We may need a means of brain purging to clear room for new items and clear out old and dated information or methods.

War fighters' missions and technical expertise required to perform those missions will continually change based on new emerging technology.

Not the right way to go about it.

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F

Monitoring and Reporting

Summary

The means of warfare have changed radically over the centuries but the basic needs of the warfighter for information have scarcely changed. Over 2,600 years ago, Sun Tzu wrote,

If you know the enemy and know yourself, you need not fear the result of a hundred battles. If you know yourself but not the enemy, for every victory gained you will also suffer defeat. If you know neither the enemy nor yourself, you will succumb in every battle.¹

In the information-intensive "infosphere" of 2020, knowing the enemy and knowing yourself will unquestionably be essential for victory but may not in themselves be sufficient to ensure victory. The temporal dimension of a warfighter's decision cycle will be as important as the information that feeds it. The side that knows the information on enemy and friendly forces first and can act on it faster than their opponents will be the side that need not fear the result of battle. Space offers great advantages to the warfighter in both the temporal dimension and information availability aspects of decision-making and command and control in war and peace. The fundamental characteristics of space such as vantage point and speed advantages that make it useful for military purposes today must be further exploited and leveraged to provide the warfighters of 2020 the ability to sense greater portions of the earth more rapidly, communicate more effectively and decide more quickly than their adversaries. This section of the Spacecast study proposes an architecture for command, control, communications intelligence and sensors (C3I-S) and examines the areas of surveillance and reconnaissance, navigation, space traffic control, weather and the use of holograms that capitalize on the characteristics of space to support the needs of the warfighter in 2020.

Global View: An Integrated Joint Warfighters Command, Control, Communications and Intelligence System Architecture proposes a design for a C3I system building on present capabilities to provide the warfighter near real time global access to all available information relevant to his/her mission. This information would consist of both raw and processed data and be available to battlestaffs, weapons systems and forces down to the soldier at the platoon level. The architecture envisions interactive mass data base storage, on-board and on-line interactive distributed processing, queuing and query capabilities to enable dissemination of time-sensitive information directly to the user.

A Look at Surveillance and Reconnaissance proposes a concept that uses ground and space based systems incorporating hyper spectral and other imaging and sensing technologies to detect and provide real time, fused information of all types to the user. This concept combines sensing techniques such as imagery, signals, laser, and radar with advances in high resolution, remote surveillance and hyper spectral sensing in areas such as acoustic, seismic, olfactory, and gustatory. Data from all sensory inputs are used to identify objects by comparing their structural sensory signature with existing data bases.

GPS Follow-on Systems & Denial of GPS Use examines the concept of a super Global Positioning System (GPS) providing three-dimensional navigation capabilities, fully integrated into real-time C3I battle management and dissemination to all levels of users. Super GPS increases current GPS capability, refines its accuracy and effectively fuses it with other sensor information including navigation, geographic spectral imaging and weather. The system uses on-board processing and fusion to provide near real time information availability on demand. It explores the concept of "pay-per-view" type codes and keys to control civilian users access as well as resolve information distribution challenges in battlefield use.

As the boundaries between space and atmospheric travel become less distinct and as the environment of space becomes increasingly crowded, there will be a growing need for tracking and traffic control of space vehicles. Space Traffic Control proposes a system employing space based sensors to provide continuous, in-flight deconfliction of orbital space systems without operator manipulation. Under this concept, space operators in the future would have a system into which they could enter a flight plan and automatically receive preliminary deconfliction clearance. A key theme in the design of this system will be increased satellite autonomy to include navigation and housekeeping functions as well as new techniques for tracking and controlling the activities of systems in space or transiting space.

Weather conditions will continue to have a significant impact on mission accomplishment. Timely knowledge of potential weather impacts can enhance military decision-making capabilities at all levels. Warfighters will need near instantaneous worldwide access to current and forecast weather conditions for a given point or area in time and space.

21st Century Weather Support Architecture examines options in accessing integrated weather information in 2020 and proposes an architecture to provide user friendly weather data and forecast products directly to the military and civilian end users via the information superhighway.

Space operations are in constant jeopardy of mission degradation or failure because of space weather. Capability to provide space weather forecasts and hazard alert warnings will become increasingly important as space use increases. Space-Based Solar Monitoring and Alert Systems proposes a satellite monitoring and alert system orbiting in deep space that will continuously observe the solar atmosphere and monitor solar plasma emissions

(solar wind). The system consists of multispectral sensors with on-board analysis capability to provide near real time space radiation hazard warnings and forecasts of radiation impact to an operations center on earth or in space for protection of satellite resources and space operations.

Communication and interconnectivity of C3I-S assets will be critical to providing the infosphere of the 2020 warfighter. Ionospheric variability (space weather) caused by solar radiation significantly impacts ground and space based communications. Space Weather Support for Communications proposes enhanced ionospheric sensing capabilities to predict and provide warning of potential communications, radar and navigation disruption or complete blackout. The concept envisions deploying ionospheric sensing devices on GPS and possibly IRIDIUM commercial satellite constellations to obtain daily, world-wide mapping of the ionosphere.

The final paper in this section, Holograms from Space, examines the prospect of projecting holograms from space using various types of lasers. It explores applications for Special Operations Forces missions including developing deception scenarios, supporting psychological operations and visual communication throughout the spectrum of war. Other potential applications include holograms to increase aircraft survivability by generating decoys or deceiving enemy reconnaissance by "painting" false images over targets.

1. Sun Tzu Wu, The Art of War: The Oldest Military Treatise in the World, trans. Lionel Giles (Harrisburg PA: Military Service Publishing Co., 1944, p51.)

WHITE PAPER

GPS FOLLOW-ON SYSTEMS
(NAVIGATION AND C³I FOR THE 21st CENTURY)

C.A.T. TEAM C³I

Date: 17 Mar 94

Is this a continuation of a previous White Paper Template? No

- I. Subject and Problem Statement
- II. The Capability and its Relevance
- III. Potential Technologies
- IV. Near Term Technologies and Operational Exploitation Opportunities

Concept papers embedded: C³I group paper

Technology abstracts: Integrated GPS - recon 0014, Autonomous Space Navigation 0147

I. Subject and Problem Statement

In the midst of an information Military Technological Revolution (MTR) the GPS system is an important key to linking multiple disjointed military capabilities together. While current stand alone, and follow-on increasingly capable "GPS" navigation systems will be important, their importance will be multiplied by the amount they have been integrated with other sensors. The navigation systems of the future will link multiple independent systems serving different masters for different purposes to a truly integrated system providing real time navigation. This future real time 3D navigation will include and targeting information melded with state of the art sensor data from a variety of sources and be provided to a variety of military and civilian users by a truly revolutionary C³I system controlled through a military system guaranteeing users access even in time of war. The importance of GPS (navigation) to these types of systems and the continued

guaranteed military access to this information for effective control and integration can not be understated.

GPS and spin-off technologies have evolved at a rapid pace despite the fact the system was only recently declared "operational." More than any recent technological development, GPS daily proves the ability to affect many facets of commercial as well as military operations. While rapid development in GPS technologies show great promise as a point of departure for future navigation possibilities, they also promise to develop into conflict between commercial and military users of GPS and controversy over who will control GPS and its future. A Super GPS of the future (S-GPS) will have the ability to display positions on the order of centimeters, anywhere in the world. Coupled with communication and sensor satellite capabilities, real time obstacle (threat) avoidance navigation overlaid on 3D maps (or target information) of all scales are possible. Fusion of assets initially gives ever increasing capabilities to users desiring real time 3D navigation capabilities, while follow on efforts lead to full integration of S-GPS data into a real time C3I battle field management tool available to all levels of combatants.

While GPS is only now becoming operational, efforts by civilian agencies are already in full swing to gain control over this important capability. The reason for the friction is due to the nature of overlap in civilian and military usage of global positioning. Immediate action is required in this area in setting an important precedent regarding use and control of important national security assets. This opportunity is not only critical to national security but also the future nature of civil/military shared use of space. Where large sums of national wealth are spent to develop important systems such as GPS, the civilian users must expect to pay a fair non-profit price to access the system just as military users pay for civilian capabilities. In the case of GPS, there are several reasons why the time is right to go forward with development of control programs. First, while many civilian users already depend somewhat on GPS, uses for its capability are still being developed and issues such as control of the system are just now coming to a head. Second, systems like differential GPS (DGPS) offer increased accuracy capabilities which could be selectively offered and controlled by the current GPS system. As an S-GPS system becomes

available, future competitive systems such as radio determination satellite service (RDSS), terrestrial radio frequency (TRF), and other GPS/dead reckoning systems will be eclipsed by S-GPS ability to fuse with and include geographic information, road maps, special address navigation and threat displays/obstacle avoidance. Overall, the accuracy and future integration capabilities of S-GPS will make it critical to civilian as well as military personnel. The ability to control access to this information on a continual bases to civilian users, and to service various levels of joint military customers will be critical to national defense well into the 21st century.

II. The Capability and its Relevance

The capabilities of S-GPS provide evolutionary as well as revolutionary possibilities. Evolutionary in the case of developing increased accuracy's, autonomous satellite capabilities, fusion with other resources and the ability to respond to specific requests with real time information. The revolutionary capability will be in a totally fused, real time, 3D navigation and targeting device providing both military and civilian services in both terrestrial and space environments.

Current efforts underway by the Army are aimed at developing a network which is capable of processing gigabits of information at rapid rates and fusing combat ID, position fixing and navigation technologies together in one system. This computer control network makes important steps in harnessing technology by utilizing available digital, computing and signal capabilities. The future work to supply modern battlefield demands are focused around high-speed digital communications and high-speed switch capabilities based on evolving asynchronous transmission mode (ATM) and synchronous optical network (SONET) standards. These capabilities give the Army the ability to provide tactical information to the soldier in the battlefield, regardless of his location and all at real time speeds. Expanded data capabilities and high speed switches allow data such as image-based video and photographs/graphics to be utilized.

The current computer-controlled, digital communications network for Army use on the battlefield is the enhanced position location reporting system (EPLRS). The system provides good capability to provide communication, identification and navigation services to the war fighter on the move. The future of such systems is to provide multi-service linkage, fuse with other sensor data and utilize low power, broad band capability to provide identification - the all service joint S-GPS of the future.

The ability to link with other services is going to be essential in the future. Systems that track Army units today without providing the information to other service systems waste valuable information that could save lives on the battlefield. While individual requirements and desires continue to be a current driver of system acquisition - the future is in information integration and fusion with the maximum number of other resources. The information control paradigm must change for the 21st century.

GPS itself provides good capability for one specific portion of the infosphere available to the war fighter. S-GPS will not only increase current GPS capability and refine its accuracy, but effectively fuse it with other sensor assets, providing on orbit processing leading to real time information availability, and on demand information delivery. As the infosphere available to the war fighter increases the ability to control the data, who gets access, who controls access, which geographic locations and at which command levels not only become complex command and control questions but important 21st century technology involving the ability to support effective transmission of large amounts of data to a variety of users.

One way that S-GPS could control civilian access, guarantee some navigation capability even during war and provide a complex systems information access network to multiple levels of customers is through coded signals. Current GPS signal capability could include "pay per view" type codes and keys which could control access to civilian users as well as provide a first step in solving information distribution problems for the battlefield for a C3I system. While charging civilian users for current capability may not be viable, the increased accuracy's and data fusion with other sensors could be very useful to many different markets. The idea is to offer the civilian

community a capability it can not live without, at a cost it can not afford to pass up. This capability must exceed that of "poor mans" terrestrial based systems such as DGPS, RDSS and TRF.

III. Potential Technologies

The ability to fuse all sensor, position, geographical and weather information into a real time product available on request to the warrior will be absolutely essential in the future. When one examines SUN TZU in light of present capabilities, you would see a trend to have many different service components knowing something about their enemies capability, but very few having access to the entire picture or all the critical pieces they individually need to "know the enemy" as they know themselves. Often, this is not a problem of the information failing to exist but one of widely scattered resources under the control of parochial groups. The roadblocks need to come down so the information can be fused and made available to those in need.

GPS IIa is currently in place and operational. GPS IIr will begin launch in March of 1996 and include some on orbit data processing capability to assist with autonomous constellation operations. Currently GPS plans through 2013-2018 do not include fusion of navigation information with other systems. Phasing to incorporate fusion of navigation and sensor assets could include:

Phase one:

GPS becomes position and time reference for inter-platform integration in such systems as JTIDS, AWACS, JSTARS and space sensors. Early groundwork laid for future capability to fuse asset information.

Phase two:

GPS develops "pay per use" access codes (like pay per view technology)

Develop capability

Civilianize the concept

Phase three:

New S-GPS develops basic on orbit processing capability and autonomous navigation capabilities for the constellation. Further refinement of "pay per use" codes and key serves old systems and makes available enhanced capability (accuracy) for new S-GPS receiver units. S-GPS units should utilize modular construction for further refinements of autonomous navigation capabilities, on orbit processing and first generation active positioning (serving requests of multiple customers).

First fusion products available with navigation, geographic, spectral imaging and weather information available on coded signal. Highly accurate signals available to both space and terrestrial users.

Technologies required for the advancement of fused S-GPS information:

Phase one and two:

Update capability of current command center battle picture aids. Increase ability of current AWACS, JSTARS, and other sensors/links to report to a shared "net" and update the battle picture every 10 seconds. Develop ability to transmit up to and interact with on orbit S-GPS processor.

Expand current "p code" capability to carry different S-GPS service signals to a variety of users.

Develop encryption and key algorithms for a code scheme to secure transmissions.

Phase three:

Modular construction should be used in all assets to allow fusion of future sensors as the overall S-GPS C³I system becomes more robust. Initial phases build on current capabilities to integrate many sensors into an orbiting satellite that constantly broadcast "info bits" to users using low power, spread spectrum technology. Increased computing capability will enable this service to be near real time. This scheme processes data on earth, and beams it to orbiting servers in coded "info bits". Future enhancements would involve real time on-orbit data gathering and processing, with data available to specific user request.

IV. Near Term Technologies and Operational Exploitation Opportunities

The S-GPS should enhance both civilian and military systems. In order to pay for the S-GPS system, related maintenance and operating cost, and future enhancements, we recommend an innovative "pay per view" finance scheme similar to satellite TV be used. This finance scheme is basic for commercial corporations, i.e., those who use, pay. In other words, the system would be paid for by those who use it, instead of all taxpayers, and this coded "pay per view" concept could begin today. The users who require the greatest precision pay the additional incremental cost for this service. In addition to a monthly service charge, an excise tax on equipment would provide funds for upgrades and maintenance.

Currently, individuals whom own satellite TV receivers must pay a monthly charge for specific programming like HBO, Show Time, etc. When they wish to obtain this programming, their equipment unique code is switched on at the satellite, and they are able to receive the service. To apply this scheme to S-GPS, the required precision code or "p" code on L1 and L2 band signals, which provide different levels of navigation accuracy, should also include an equipment unique controlled access code. This controlled access code, when activated, would provide the authorization for a specific level of precision. The four level system recommended below (fig 1) would provide for graduated capabilities based on need, precision required, and cost of service.

S-GPS • SERVICE LEVELS

Military	- Highest precision	- encrypt	- N/A
Commercial air	- Point specific high precision	- commercial encrypt	- monthly charge
Commercial	- moderately high precision	- commercial encrypt	- monthly charge
Consumer	-basic	-none	-equipment tax

fig 1

An illustrative representation of the S-GPS operating levels is shown in fig 2.

SUPER GLOBAL POSITIONING SYSTEM (S-GPS) SERVICE LEVELS

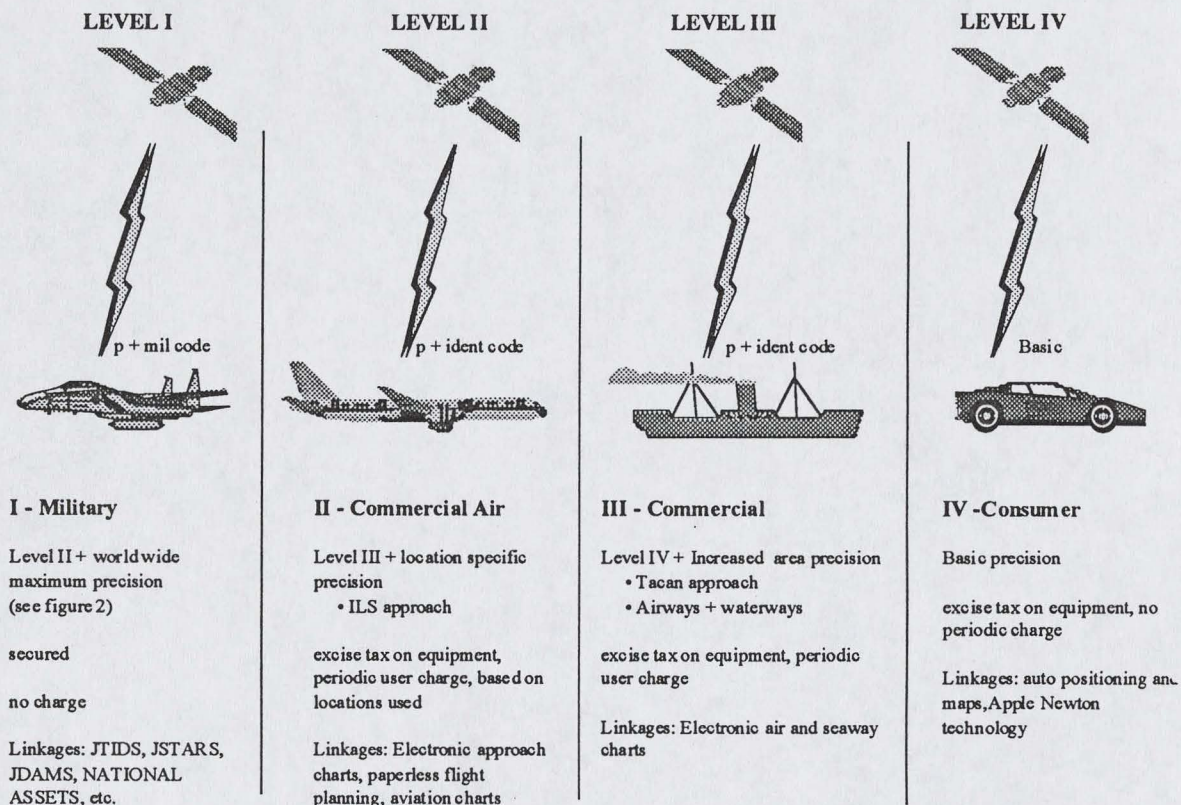


fig 2

As the S-GPS system evolves, it would be desirable to provide point accuracy on a "pay per view" bases. Not only would this allow the capability to control access to certain levels of information but would allow broadcast of information codes specific to the needs of a particular geographical areas or customers. This system of codes signals would use encryption and keys for access and would alleviate the problems civilian users would have with the current possibility of a system shutdown in case of a national emergency. S-GPS must improve accuracy, reliability, modularity, future expandability, and multi-sensor platform integration capability, in addition to

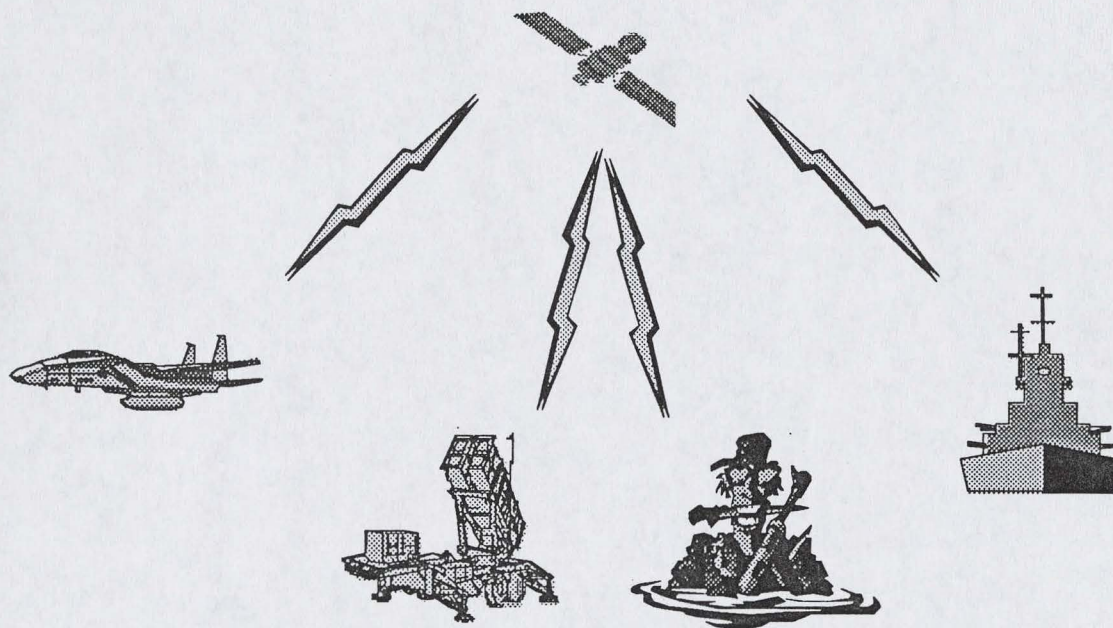
autonomous position keeping a new funding scheme designed to be paid for by its users.

Continuing the phased growth of the fused S-GPS system:

Phase Four:

Increase code complexity and further fusion of sensors to provide real time C³I tool. Civilian applications could include personal vehicle navigation systems capable of going coast to coast while avoiding obstacles automatically. This phase continues to use continuous broad band transmissions broken by codes tailored by individual users. An illustrative representation of the S-GPS tailoring to individual military users at various operating levels is shown in fig 3.

SUPER GLOBAL POSITIONING SYSTEM (S-GPS)
SERVICE LEVEL I - MILITARY



Coded "Info Bits" available to different users, different levels at different places.

fig 3

Phase Five:

Genesis of information packages available on demand. This phase requires advancement in our current S-GPS transmission/code scheme. S-GPS could continue to operate in a low power, broad band mode, but development of increased computing power, on orbit capability and use of low noise spread spectrum two way communication will be required.

WHITE PAPER
ON
SPACE TRAFFIC CONTROL

Command, Control, Communications, Intelligence, and Surveillance Team

Date: 23 Mar 94

Is this a continuation of a previous WPT second draft? NO

White Paper Templates consolidated in this submission: NONE

I. Subject And Problem Statement

In the span of time from 1958 to 1994, computers advanced from room-sized machines to hand-held personal digital assistants, fighter aircraft from the F-100 to the F-22, and arcade entertainment went from pinball to virtual reality. In the same period of time, however, US space system operations made about as much progress as the B-52 -- missions changed dramatically, technology charged ahead, but the same old shell, power plant and control systems are still in place. The B-52 is still a good bomb truck, and the US method of performing space operations still (arguably) gets the job done, but both have outlived their design lifetimes.

Military space operations are systemically inefficient and hence provide products that do not fully support the warfighter. The US space "culture" developed in such a way that the result is inconsistent, unfocused doctrine and policy combined with needlessly compartmentalized, "stovepiped" satellite development efforts. This in turn results in extraordinarily expensive space systems that, although the best in the world, have not taken full advantage of the unique aspects of the space environment. These systemic problems, if not addressed or allowed to evolve in the proper direction, threaten to strangle US space operations as budget pressures increase and technology improves.

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With those thoughts in mind, if we leap forward to some of the worlds envisioned in the SPACECAST 2020 Alternative Futures section, the use of space in 2020 could involve significantly greater numbers of spacecraft competing for limited range arcs and pieces of the electromagnetic spectrum. Motorola's Iridium concept and Bill Gates' recently announced vision of over 800 communications satellites demonstrate that space could become a very crowded place. As space becomes packed with expensive nuggets of technology, the downside risks of impacts with other spacecraft or orbiting debris become an increasing concern. We already lead the world in our ability to track space objects, but that system is a very costly, archaic one that doesn't hold the potential for the kind of situational awareness we will require in the future. Our answer is to develop a space traffic control system that we call SPATRACS, for Space Traffic Control System. As this paper articulates, SPATRACS is not merely a "system of systems" that integrates sensors, collision avoidance, and deconflicted flight planning, but comprises a whole way of thinking about modern space operations that enables significant US space leverage in the coming generation. Given the current state of space operations and a general vision of the future space environment outlined above, this paper now ties it all together in order to broaden and more sharply define the SPATRACS concept.

Current budgetary pressure is creating an atmosphere that is exposing how little clothing the US space emperor is wearing. An active, focused effort is needed now, and into the next century, to allow the United States to fully realize the benefits that are possible through the control and exploitation of space. This effort needs to be focused in two primary areas: 1) the development of a new space doctrine that will allow the more effective development and operation of space systems, and 2) fundamental changes in the way we design, build, and operate (e.g., task, monitor, control) space systems to take better advantage of new technologies and new ways of doing business. The effective integration of these two efforts (as embodied by SPATRACS) would create many

benefits, both direct and indirect, one of those being the creation of an environment where operations in space, and someday even transit through space, becomes much more routine, realistic, and affordable.

This begins with a new space operations doctrine. That doctrine implies radical changes in the way space systems are designed and built, provides for a more efficient and effective means of operating space systems, greatly increases our awareness of and ability to respond to changing situations in space, and ties all these things together within the umbrella concept of SPATRACS. Such changes make sense: even at the existing level of space operations, savings of billions of dollars per year are possible. Equally important, the changes are necessary to make space systems truly integrated with and responsive to the warfighter. Finally, the changes proposed in this paper will be a necessary part of any great expansion in the use of space. If we maintain the systemic status quo, the US faces one of three possibilities: 1) the rigidity and cost of current space operations concepts will be so great as to prevent any significant increase in the use of space; 2) of necessity, the US will be forced to implement changes on an ad hoc basis when space uses expand for other reasons (national emergency, breakthrough in lift costs, or some other driving factor), with resulting confusion, excessive cost, waste and duplication of effort, or 3) the US will simply cede leadership in future space operations (military, civil and commercial) to another power (Japan?, China?, a resurgent Russia?, Bill Gates?) that has a greater vision and a more cohesive, focused plan for the use of space.

In the sections that follow, we will outline the primary elements of a new space operations concept. First, it will describe a vision for the future of military operations in space. This is followed by a discussion of the doctrine and policy changes needed to eliminate stovepiped systems in favor of systems that can be unique but still conform to certain interface standards. Then it will describe how space system design should be changed to support this doctrine, and the implications these design changes would have

for space operations. A key theme is increased satellite autonomy (to include at least navigation and housekeeping functions); which implies the need to think about an entirely new philosophy (or paradigm) for keeping track of and controlling systems in space (and that transit space) -- in other words, a SPACE TRAFFIC CONTROL SYSTEM. An enabling capability for such a system is an improved space surveillance, tracking and identification (SSTI) architecture. This paper will also outline such a capability. Any of these changes and improvements alone has the potential for cost savings and increased operational effectiveness; but when combined, this paper's concepts constitute a revolutionary new approach to space operations.

II. The Capability and Its Relevance

In the year 2020, an ever-increasing number of satellites will be orbiting the globe. These satellites will probably be smaller and either will last much longer than the satellites of today or will be deliberately designed for short life or replacement to take advantage of emerging technology. The performance of space systems under the SPATRACS aegis will also be significantly superior to any system we have today. Because of the natural advantages that accrue from being a part of SPATRACS, insurance would be diminished and other space actors would make SPATRACS-compatibility a design standard. Access to space will be, due to the economic demands of the commercial sector, much more affordable and responsive. Satellite constellations will be integrated via crosslinks allowing many satellites on-orbit to share information. Nearly every satellite deployed after 2010 will carry internal navigation and housekeeping packages, and perform routine station-keeping maneuvers on their own. Only anomalous conditions (e.g., health and status problems, collision threats, etc.) would be reported to small, satellite-specific ground crews. Slightly larger crews (still small by today's standards) would man centralized SPATRACS ground stations. These ground stations (primary and backup) would be responsible for handling anomalous situations, coordinating collision avoidance

maneuvers with satellite owners, authorizing corrective maneuvers, and coordinating space object identification (particularly threat identification). The space segment of SPATRACS would consist of a few (<20) small, simple satellites composed of passive sensors and on-board processing responsible for tracking all objects in space (or transiting space). SPATRACS would be the "glue" that holds the system together and enables a sea change in satellite operations. It would also provide the detailed, timely information on space activities that would allow the US to fully understand and begin to control the environment of space. SPATRACS would eliminate or downsize many of the current satellite control ground stations as well as the current ground based space surveillance system. Savings of billions of dollars per year are possible (given the current level of operations). More importantly, this system would enable a vast expansion in space operations with very little marginal cost. It will be inherently more flexible and responsive than the current system. When overarching requirements are developed for a new use of space, including standardization of spacecraft bus and support functions and interfaces, the development effort can focus almost totally on the payload -- the "pointy end of the spear" that is focused on supporting the war fighter.

Integration of atmospheric flight with SPATRACS will be a natural outgrowth when the learning curve with space operations merges with advanced sensor systems and trans-atmospheric flight. Even though much of the technology exists today for making space traffic control more robust and cost-effective, integrating maximum atmospheric situational awareness, to include flight planning, conflict avoidance, and sensing of anything transiting the air is far off but well within a conceivable evolutionary chain. The computing and information handling ability required to take inputs from the wide variety of sensors and make accurate decisions increases dramatically when atmospheric flight is introduced. As an example, the personal jet pilot in 2020 would have a navigation system that checked and filed his flight plan, offered more conflict-free or fuel saving tracks,

offered constant in-flight collision avoidance, and stacked him into busy airports with voice or heads-up display. Transcontinental flight would be free of "hand-offs" and air traffic controllers with accents. The only stealthy aircraft would be those with feathers. This vision for seamless, user-intimate, total air-space awareness is a natural stepping stone to even more brilliant information synthesizers as envisioned in "Surveillance and Reconnaissance in 2020" (WPT #36).

The full potential of these, or similar, ideas by the year 2020 won't be realized by stating their desirability or dreaming about what could be. Just as every brilliant idea eventually degrades into plain old hard work, so every complex human endeavor hinges on unity of effort gained through plain old leadership. We must first define a vision for fully integrated space operations and build a consensus for its creation. This cannot be done without addressing the critical issue of space doctrine and policy. It must be changed or little of this vision is possible in the next twenty-five years.

SPACE OPERATIONS DOCTRINE AND POLICY. The operator of every satellite system, be they a military or a civil/commercial user, defines certain interfaces satellite designers must meet to support ground operations. These ground operations are also defined by the satellite owners. Historically, there has been very little commonality in any of the system developments. The result is a series of stovepiped satellite operations where no two systems are exactly alike. An operator trained to support one satellite system must be retrained before crossing over to another system. The development of a standard doctrine for space operations would eliminate these inefficiencies and would create savings, not only in operations, but also in satellite development.

INTERFACES. Mandatory interfaces concerning satellite navigation, housekeeping, and telemetry, tracking, and control (TT&C) must be defined (see "Standardized Space Systems Design" below). Since interfaces have to be defined for system designers

anyway, and if standardization is recognized as a goal that would result in tremendous savings, standard interfaces could be defined that would also support a vision for space traffic control. Satellite design requirements must include on-board processing to accomplish many of these functions currently performed on the ground. Such standard interfaces (hardware, software, data, etc.) would have to be phased in over the coming years as technology, particularly improved on-board processing, becomes available. An aggressive technology program should be pursued while a joint working group of civil/commercial/military satellite operators work at the development of a roadmap to implement standards for integrated operations. As these standards are worked out, the next logical step is to begin to apply them in practice, namely in improving standardization in the design of new space systems.

STANDARDIZED SPACE SYSTEM DESIGN. A truly effective military space capability must be responsive, resilient, flexible and cost-effective. Current stovepiped, manpower-intensive systems have none of these characteristics. This has already been outlined, but now there are some more specific actions that will narrow our aim toward a more efficient mode of space operations that will support aerospace traffic control.

What must change? Virtually all aspects of space system design, including:

1. Launch concepts
2. Orbital insertion and checkout
3. Spacecraft "housekeeping"
4. Navigation
5. Telemetry, tracking and control (TT&C)
6. Mission payload management
7. Space system ground segments

How should the US redesign our space systems, and what effect will this have? The first element of the redesign is to get away from detailed system design specifications and concentrate on interface specifications. This means not only the on-board hardware interfaces (physical, electrical, thermal) but even more critically the data interfaces for the payload to communications system, inputs and outputs for spacecraft housekeeping, navigation and control functions, and ground segment hardware. This idea specifically addresses the problem of stovepiped systems -- rather than a unique design of everything from the launch vehicle interface to the mission data ground workstation, a focus on interface specification allows an increased degree of commonality among space systems, both in hardware and software, and has the potential to greatly reduce training and operations costs. This interface requirement is analogous to the personal computer video bus standard (e.g., VESA), which enormously improves system integration, but allows for competing systems to forge their way to market when other system capabilities outpace bus limitations. The key is that you maintain innovation within systems and can upgrade to new integration standards if technology drives the equation, as it inevitably will.

For launch systems, an improved space operations concept absolutely requires that payloads be less complex, fragile, unique, and dependent on specific expertise. Given an inexpensive, rapid, flexible, and reliable way to get to space as proposed in SPACECAST 2020 White Paper #1, payloads can be designed either to fit whatever space is available, or to be assembled on orbit from segments that fit the launcher envelope. Again, interfaces from the satellite to the launch platform should be standardized so that whatever on-orbit capability is required can be launched on demand.

Satellite designers should take full advantage of miniaturization, modularity, and standardization to design systems that can be rapidly upgraded and/or tailored to a particular mission and delivered for launch with minimal test and check-out. Where on-orbit upgrading is desirable, maximum use should be made of designs that allow software

upgrading to improve performance. Design philosophies must be driven to emphasize rapid, flexible design and manufacturing of satellites, even if they come at the expense of satellite endurance. Given the right launch system, it is economically and militarily preferred to possess surge capability with capable spacecraft than to orbit a few exquisitely capable but irreplaceable "battlestars."

Moving to the area of on-orbit operations, spacecraft must be designed to allow more rapid check-out and activation. It does no good to put a satellite on orbit within hours of a request if it takes days or weeks to make it fully operational. Modularity, standardization of interfaces, and a reduction in complexity of individual satellites will help reach the doctrinal design goal. There is the possibility of on-orbit servicing and design.

Once a spacecraft is operational, an inordinate amount of manpower and contact time is currently devoted to routine functions such as housekeeping and navigation. The current system is archaic and should be replaced with a three-tiered approach: - On-board systems would perform routine housekeeping and navigation chores (this is well within current technology) and update the ground segment periodically. These on-board systems would have sufficient intelligence to alert ground operators if any parameter was diverging unacceptably from nominal values. - The second tier would be an austere ground segment manned with expert system support to handle most-likely satellite emergencies. ® Finally, there would be an available technical troubleshooting staff if a problem required expertise beyond that built into expert systems (this staff would constantly update the expert systems). The work of these troubleshooters would be diminished significantly by the increased commonality in space system design. One group could conceivably perform depot-like support for all space systems. Costly technical staffs are currently employed for each system. This environment would greatly reduce training requirements, and as a result, greatly reduced numbers of spacecraft "operators" would be able to move from system to system with minimal difficulty.

With spacecraft functions and interfaces standardized, the only real specialization among satellite systems would be in mission payloads. Here also, interface specification and careful satellite design will reduce or even eliminate differences in routine operations among systems. In terms of the ground segment, only the mission element (tasking system, data displays, analytical support) will be different from system to system, and this element will not even have to be collocated with the spacecraft control element. This would allow mission terminals (of relatively small size and weight) to be deployed in support of theater or other warfighters, while the routine operations functions are kept separate and at the most convenient location.

The above improvements will greatly reduce the need for current TT&C practices. Satellites will be able to handle many functions on their own; for example, knowing their own position, monitoring their own health and status, discharging and recharging batteries as necessary, and even carrying out theater CINC mission tasking autonomously (i.e., the mission payload ground segment would task a satellite to perform certain functions -- with the aid of software to ensure these functions were possible -- and the satellite would be able to carry them out on its own, pointing, tracking, and perhaps even maneuvering as necessary). A central control site would monitor regular reports from the satellite, be able to allocate priorities to various users of the system and could intervene in an emergency. Under normal conditions, however, the system would require little direct control. Power, weight, bandwidth, and ground segment assets currently used for TT&C could be allocated to more mission oriented tasks.

The combination of technologies, design practices and procedures mentioned above will have the effect of reducing the frequency and duration of contacts a satellite (or an entire constellation) must make with the ground. This will not only reduce the number of personnel required, but will greatly reduce space system vulnerability through decreased dependence on ground sites to include elimination of overseas ground sites via data

crosslinking. Not only is the system less vulnerable because the ground sites are removed as targets, but spacecraft are less dependent on ground contact in general, and can operate autonomously if there is a communications outage, destruction or degradation of CSTC or CSOC, or other conceivable degraded conditions.

A further step in the "operationalizing" of space is an improvement in our space surveillance, tracking and identification (SSTI) capabilities. Since the spacecraft described above will be more autonomous, the concept of a space traffic control system (SPATRACS) begins to not only make sense, but also more closely approximate air traffic control. Eventually, the two systems could even overlap if and when true aerospace vehicles come on line.

SPACE TRAFFIC CONTROL SYSTEM (SPATRACS). The environment of space is becoming more and more crowded (accumulation of satellites, debris, etc.). It is hazardous today, and will be even more hazardous as the year 2020 approaches, to fly in space without having an "approved" flight plan, particularly in low earth orbit (LEO). The space shuttle, for instance, occasionally makes unplanned course corrections to avoid debris damage. High earth orbits with limitations on "slots," deconflictions, spacing, RF interference, and frequency allocation also present unique problems that are only forecast to get worse in the next century. As more international actors utilize space, it will be advantageous for the United States, as a nation, to aggressively pursue an integrated Space Traffic Control System (SPATRACS). Similarly, as the boundaries between space and atmospheric travel become less distinct (e.g., trans-atmospheric vehicles), this system could conceivably integrate all airborne and spaceborne assets into a seamless, global, integrated system. The surveillance, infrastructure, and information integration requirements are substantial and require technical, operational, and financial capabilities that currently exist only in this country. Since the US has the best current space tracking system, it is an area of competitive advantage that could be a point of leverage in future

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space operations. The idea is to have a system that it improves our own space operations while being so advantageous that other space-fairing nations will also be encouraged to use SPATRACS. Such cooperation would not only foster cooperation among nations, but deter possible development of aggressive space systems.

As mentioned, the creation of an integrated space traffic control system -- if done correctly -- would benefit the United States by providing more situational awareness in air and space and more efficient space operations. The risks to both new and existing space assets are increasing. The inability to meet current military requirements for space surveillance creates minor impacts on military space operations now, but will create major impacts as other nations begin to rely more on space systems and products. Also, as mentioned previously, the current method of space operations is extremely inefficient and costly.

OPERATIONS UNDER SPATRACS. Space operators in the future would have a system where they could enter a flight plan and automatically receive preliminary deconflicted clearance. In addition, ongoing, in-flight deconfliction would also be available without operator manipulation. It could integrate information from even more sophisticated sensors of the future, such as electro-magnetic, chemical, visible, and omni-spectral. "Hand-offs" from one sector to another would occur, but only in the on-orbit SPATRACS brain, which is transparent to the operator. It provides a vision of a next generation, smart system that integrates volumes of information into a format that gives the operators just what they need to know on a timely basis. Having said that, a more in-depth discussion of how to get there from here is required.

For the most part, sensors for this system will be space-based. Due to the elimination of atmospheric interference, these sensors will be able to detect and track very dim targets. Although they will mainly be passive sensors, given sufficient numbers and on-board

processing and crosslinking of data, they will be able to generate accurate orbital elements for the objects being tracked. Low to medium resolution visible spectrum sensors will conduct the bulk of the space surveillance. These will be augmented by similar resolution IR sensors to track high priority targets in earth's shadow, to detect new launches, and to track maneuvering targets. Space object identification will be conducted through one or more of the following methods: spectral signature analysis using low resolution sensors, deployment of higher resolution sensors, or use of medium resolution sensors to produce interferometric images. All the data gathered can be augmented by ground site data collected from CONUS bases, but the system could also be design to work on its own.

Having generated track files, tentative object identification and catalog updates on orbit, the system would then downlink the information to a central facility that would provide fusion with other data (e.g., from ground based sensors which are arguably advantageous for tracking atmospheric traffic), validation, and additional analysis. In addition, the facility will develop tasking for the space surveillance network (which will have capacity for specific observations beyond orbital catalog maintenance, e.g., to focus efforts in anticipation of the launch of a new threat country space asset). This facility will be directly linked to the main satellite control facility, so that collision warnings would be immediately available for action, and to all national and other customers interested in space object track data.

INTEGRATION. The long-term integration of SPATRACS with all satellites operating in space could be planned for later in the 21st century. The initial SPATRACS as described above could perform the bulk of its mission using its own sensor information. SPATRACS satellites, should, however, be designed to allow for the incorporation of off-board information available from other satellites. As other satellites become increasingly autonomous, ever increasing accuracy could be obtained from SPATRACS. Satellites after the year 2010 should all be designed to effective interface with SPATRACS.

ATMOSPHERIC TRAFFIC CONTROL. If space travel or space transit (using a trans-atmospheric vehicle) ever becomes routine, a system like this is essential. Although such travel may not be routine in 2020, a fully capable "aero"space traffic control system, seamlessly integrated with the air traffic control system, would allow for conflict-free transit of multiple simultaneous events.

ADVANTAGES. If the United States was able to provide a space traffic control system that the rest of the world was interested in using, many advantages are possible:

1. Financial. If the US adopts the proposed new vision for space operations, the savings over time would be phenomenal. Much of these savings would be realized through the elimination of stovepiping and over-reliance on manned ground systems. The information could be sold to foreign interests, helping pay for the acquisition and maintenance of a system in a time of declining budgets. It would need to be available at a price low enough to encourage its use, but not so expensive that other nations would be encouraged to buy their own. A national, long-term strategy to underwrite entry into the business may be required to provide this kind of early, low cost service and would lead to substantial downstream saving.

2. Space Operations Streamlined. Our dominance of the entire space realm would remain intact precisely because we moved quickly to a more consistent, efficient approach to space operations to insure competitive advantage. This vision sees space operations as more regular and affordable, expanding the bounds of what is doable from space. Because the US has this advantage, they will necessarily interface with space operators from other countries and entities. Our exposure to other systems would give us a "clearinghouse advantage." Just as trade route intersections developed into major, thriving communities due to their access to diverse points of view, an aerospace traffic control system would bring diverse space technology to our attention. The relationships started and built as a

result of being a planning consideration for space systems from any source would insert us fully into an advantageous information crossflow. This kind of space operations also better matches the direction being pursued by the commercial and civil sectors in the US. Such common ground could provide even greater economies of scale for all the parties involved.

3. Space Control. If the United States had a system that could provide current, accurate (precision) information on satellite position and movement, it then becomes feasible to deny it to potential enemies -- and use it for our advantage. Such information is required for intelligence as well as for space control purposes in time of conflict. By possessing dominance in this area, the US would be able to deny potential adversaries many space control options. It also comprises a platform for developing space tracking and detection that would be a force multiplier in a future that might include space to space force employment.

DISADVANTAGES. This paragraph addresses, in shotgun style, some downside potentials with a system like SPATRACS. Some problems include the international agreements that would have to be hammered out to get this system to be world-wide in scope. Given a world where there are enough actors to make it feasible, aerospace traffic control becomes a security issue for satellite owners and a significant source of leverage for the controller. In the history of international agreements, where the subject of discussion is of relatively minor interest (e.g., the Antarctica treaty), the agreement enjoys success. Once vital national interests come into play, there is both trouble achieving agreement and more trouble enforcing compliance. Another problem is that the US would in some senses become a space insurance agency, thereby incurring some liability. If a space operator is told that their planned or current track is debris-free, and they take a lethal or debilitating impact from space junk, is the US responsible? If it happens to an unfriendly (from a US point of view) international actor, did we set them up for failure on

purpose, and what would be the international implications of that incident? A more practical concern is our ability to even get to that position of control because of the failure to forge a coherent national space policy. This assumes a Japan-like strategic vision and execution in order to maneuver high-cost systems into a position of competitive advantage. We clearly have some kind of advantage already, but could be easily eclipsed by others given our national lack of space vision. There is also a technical vulnerability issue when you start talking about standard systems that must be addressed. There is the chance for introduction of a "Trojan Horse" that could disable all your systems, and since that chance exists, how should we counter it? Is there a requirement for multi-level security when you have certain users that only need certain information? None of these are easy questions.

SUMMARY. This paper discussed the many problems that currently exist in the way we operate space systems. It also articulates a recommended series of solutions that, if implemented even in part, would significantly improve this nation's ability to control and exploit space. An integrated effort to adjust US space doctrine and policy combined with the creation of a new methodology for designing and operating satellites would clearly, however, have the highest payoff. If such an effort is undertaken, it is feasible that by the year 2020, all on-orbit systems could be integrated and controlled by a new Space Traffic Control System (SPATRACS) that not only would significantly improve US operational military capability, but would also yield tremendous savings in the cost of space system design and development. Such a system would also provide a competitive advantage for our civil and commercial space programs in the world market. SPATRACS is more than an interesting mission in space. It defines a future for US space operations that is in line with our traditional aerospace leadership role and avoids a quagmire where institutional inertia becomes the blindfold we can't remove in time to see the brass ring flying by. The

benefits that could be derived through the focused integration of doctrine, policy, and operational systems is nearly limitless -- and should be pursued.

III. Potential Technologies

This section will describe a complete "roadmap" for integrating near-term and far-term efforts and changes in technologies and doctrine necessary to fully meet the vision of space operations in 2020 described in this paper. Section IV (Near-term Technologies and Operational Exploitation Opportunities) will reiterate some of the critical near term activities that are recommended for immediate action or continuation. Overlap between these two sections is intended.

Most of the technologies needed for implementing the new space operations, monitoring, and traffic control architecture described above are either already available or are rapidly emerging. Practically speaking, wholesale changes cannot and will not happen overnight. Risk aversion, institutional inertia, already programmed acquisitions, and funding limitations will all encourage a gradual pace of change. What is needed in the near term are measures to lay the doctrinal foundations, prove key technologies in operationally realistic environments, reduce system-level risks, and demonstrate operational and cost advantages. All of these, in aggregate, will sow the seeds for future generations of space systems that achieve our vision for space operations

DOCTRINE. To some extent, this is already showing glimmers of change as documents like HQ USSPACECOM documents titled "Space Logistics Master Plan" and "Sustaining Space Systems for Strategic and Theater Operations" show. Senior military space leaders are calling for new satellite systems to incorporate modularity, standardized interfaces, and ground segments requiring less manpower. There is general recognition of the need for more flexible, responsive and cost-effective operations. We recommend the Air Force and other services turn the attention of their doctrinal development

organizations to assessing the impact of emerging technologies as described in this paper, with the goal of building a joint doctrine that will drive space system development instead of merely adapting to the limits of current systems.

TECHNOLOGIES.

Launch systems: Reducing launch costs and making access to space more reliable and flexible is essential to any efforts at improving space operations. SPACECAST 2020 WPT #1 addresses this problem in more detail.

Autonomous navigation: GPS receivers that can provide navigational inputs for spacecraft are currently available. One is being flown on the Technology for Autonomous Operational Survivability (TAOS) experimental spacecraft that was recently launched. TAOS also incorporates on-board sensors and a flight computer that provide a truly autonomous (as opposed to a GPS-based system, which naturally depends on GPS signals) navigation capability. TAOS incorporates other features desirable for autonomous operations, including a new electronic architecture with the first use of a MIL-STD 1553B data bus connecting the various subsystems. Perhaps most importantly, it's planned experiments will provide the first chance for space system operators to become familiar with a satellite with some autonomous capability. Many other experimental satellite proposals in recent years proposed including autonomous navigation capabilities, but most of these proposals foundered for lack of money. The key next step is to begin tying autonomous navigation to other elements of autonomy, such as housekeeping, on-board mission data processing, expert systems in both the space and ground segments, and to put these all together with mission-oriented experiments (e.g., surveillance) to convincingly demonstrate the positive cost and operational impacts to warfighting CINCs and space system operators. The Space Surveillance, Tracking and Autonomous Repositioning (SSTAR) demonstration incorporates several of these elements with a space-based space surveillance mission payload.

One of the weaknesses in these two experiments is that they are single event experiments. For the first attempt at implementing new technologies, this is understandable. However, follow-on experiments to TAOS and SSTAR should be planned with a system architecture (like described above) as the focus. These follow-on experiments are even more crucial than initial attempts because they will begin to integrate concepts into ideas that operators can use. It is essential that TAOS and SSTAR be continued with further, more detailed efforts.

Standardization and interfaces: TAOS is also an important first step in this area, with its use of the Space Test Experiments Platform (STEP) spacecraft bus and the 1553B data bus mentioned above. A more significant program, since it addresses on-board interface standardization and the ability to design spacecraft modularity to a greater extent that STEP can, is the ARPA-sponsored Advanced Technology Standard Satellite Bus (ATSSB) program, which has been suffering from funding cutbacks. Although the contractor proposals received for this system indicate a high degree of confidence in industry that we can begin to design and build multi-mission, modular spacecraft buses, a full-up demonstration is almost certainly an essential risk-reduction element before the governments begins specifying features for operational satellite systems.

Modularity: TAOS and ATSSB, mentioned above, both incorporate key elements in proving the concept of modularity; the next step is to prove the flexibility of the basic spacecraft design by flying different missions using the same basic platform. In addition, there are few technological obstacles to design of a satellite for remote (as opposed to human, which has already been proven with the Hubble space telescope) on-orbit servicing, repair, and upgrading. The key obstacles are the cost of getting to orbit combined with the penalties of designing a system for servicing. In the past, this made servicing unattractive compared to replacement. With new technologies available, however, it is probably worth revisiting this concept either as a hedge against increasingly

expensive large booster costs or to take advantage in a breakthrough that dramatically lowers launch costs for small payloads. A further application of modularity would be the design of systems for assembly on orbit, which has similar advantages.

Expert systems. There should be no great obstacle to concurrent design of an on-board, rule-based "expert system" for a spacecraft incorporating the design techniques mentioned above. For experimental (initially) and operational (later) purposes, the satellite would have sufficient on-board processing power, memory and a suitable operating system to run such software, then the "expert system" can be developed over time from ground operations and regularly updated and uploaded to the spacecraft. This system will eventually be able to take over routine housekeeping functions, subsequently expanding its capabilities to deal with minor anomalies, and perhaps eventually (again assuming appropriate satellite design) progress to handling emergency situations (non-fatal impact, subsystem failure) and even perform self repair (e.g., by reconfiguring subsystems to compensate for some kind of failure). The design can be flexible enough to allow for gradual testing and implementation as the expert system gets smarter and the human operators gain confidence in it.

Operating system software: there currently is no DOS (or even UNIX) for spacecraft. Each of our systems is custom designed and coded, with corresponding extra cost and incompatibility. We strongly support initiatives such as Phillips Lab's Reusable Operating System Software (ROSS) that will attempt to correct this deficiency.

Electronics: The primary elements that the new space operations concept depends on are sufficiently powerful (but not power-hungry) processors and on-board memory. For processors, a thorough study of design choices is needed. Should we continue with customized MIL SPEC designs such as the Advanced Spaceborne Computer Module (ASCM), which, though offering impressive radiation hardness and other design capabilities is already generationally obsolete, or can we now accept some system design

compromises (shielding, redundancy) in order to make use of the latest commercial technology in satellite design? For on-board storage, we support aggressive pursuit of solid-state memory devices to replace tape recorders as standard mass storage on board spacecraft.

Communications: Both greater satellite constellation independence of ground stations and an improved space surveillance capability depend on high capacity, secure crosslinks. Because of size and weight considerations, we believe that LASER CROSSLINKS are preferable to radio frequency systems. Although the laser crosslink program for the DSP system has a checkered history, alternative approaches (such as Phillips Lab/MIT Lincoln Lab's LITE program) may be ready to provide the required capability. Up and down link requirements will be reduced by performing more routine functions in space (e.g., it will be simpler to downlink orbital elements from the space-based space surveillance system than to dump all the raw observation data to the ground), but this will require some confidence building demonstrations before it can become widely used.

Ground segment: In parallel with satellite design and development, the ground segment must be completely restructured. There is no technical reason why a satellite or even a constellation that incorporates a degree of autonomy cannot be controlled by a very small number of personnel using software-reconfigurable workstations. As with most of the other issues here, this is not a matter of new technology as much as it is of smart design and a change in operational philosophy. This particularly includes the concept of separating satellite/constellation control functions from payload tasking and mission data receipt, analysis, and dissemination. With suitable demonstrations and testing, the concept of a warfighting CINC's staff directly tasking and receiving data from a mission payload without compromising centralized control of the satellite itself could be realized.

SPACE-BASED SPACE SURVEILLANCE.

Sensors/detectors: For the most part, detector technology is sufficiently advanced to build the kind of capability that is required. We fully expect, that by the year 2020, sensor technology will be advanced far beyond the requirements for the system we have described, to include the first glimmers of next-generation atmospheric transit sensors.

Optics: light weight and thermal compatibility (with detectors and host satellites) are the primary features needed here. New approaches, like silicon carbide optical elements, may be preferable to traditional multi-metal telescope designs. The Phillips Lab SSTAR experiment has proposed demonstrating such a device.

Position determination: a space-based system must be able to accurately determine its own and its target's position. Current position can be gained from GPS or other autonomous navigation techniques, while accurate determination of target position will require correlation of data from more than one passive sensor (a single passive sensor suffers from an inability to get unambiguous range data, even against fairly deterministic targets such as satellites).

Brains/software: new algorithms and data handling routines will be needed to incorporate space-based data into the space surveillance system. Some of this work has already been done for the Space-Based Visible (SBV) experiment on board the BMDO MSX satellite.

Deployment: the sensor/position determination/brains/communications package can be deployed on light, dedicated satellites, but it can probably also be deployed as a piggyback package on satellites with other primary missions. A modular design would greatly aid in this, as the SPATRACS system could be easily distributed on the host.

Tasking and analysis: ground segment capabilities and requirements should be developed in conjunction with the demonstration of space-based space surveillance hardware and software. The purpose of this is to take full advantage of new capabilities

and maintain parity with advances in other space systems in the areas of flexibility, modularity, reduced manning requirements, etc.

System-level demonstration: THIS IS VITAL TO ACCEPTANCE OF THE SPACE-BASED SPACE SURVEILLANCE CONCEPT. SBV will be a first step in this direction. The SSTAR demonstration will be significantly more comprehensive and allow for true operational utility demonstrations.

IV. Near Term Technologies and Operational Exploitation Opportunities

(Including Commercial Opportunities)

ESSENTIAL: As mentioned in Section III, the services should focus the attention of their doctrinal development organizations to assessing the impact of emerging technologies (as described in this paper), with the goal of building a joint doctrine that will drive space system development instead of merely adapting to the limits of current systems. This is a "two in the bush" issue that is harder to deal with than the "bird in the hand" of the current system paradigm. It can only happen through the force of a visionary leader who seizes the opportunity and takes a sledgehammer to institutional inertia.

IMPORTANT: The Technology for Autonomous Operational Survivability (TAOS) experimental spacecraft is essential for demonstrating many of the critical technologies needed to fulfill the vision for 2020 described above. Its planned experiments will provide the first chance for space system operators to become familiar with a satellite with some autonomous capability.

IMPORTANT: The ARPA-sponsored Advanced Technology Standard Satellite Bus (ATSSB) program has been suffering from funding cutbacks. Such a system is essential to meeting the desire for standard satellite modules in the future. If the ATSSB is not pursued, another effort will need to take its place. The commercial sector (e.g.,

Motorola's Iridium) is also pursuing standard buses. A joint government/commercial effort could be beneficial in this area.

Phillips Lab's Reusable Operating System Software (ROSS) is an important critical program that should be continued. It is also a program that could be worked jointly with commercial industry. Bill Gates, founder of Microsoft and father of DOS, recently announced plans to build an 840 communication satellite constellation. If DOS and Windows are any indication, he will clearly be developing a standard operating system. Joining forces early could be a tremendous advantage.

Laser crosslink is an essential capability that is not being aggressively pursued. We recommend increased effort in this area. This will free SPATRACS compatible satellites from the complications of RF spectrum squabbles (a major problem) and provide information control.

In the Ballistic Missile Defense Office programs, the Space Based Visible (SBV) experiment is an important demonstration of many critical technologies. We recommend its continued support.

Also, the Air Force's Brilliant Eyes program begins to implement many of the same concepts this paper proposes. We are not able to evaluate the specific technical merits of this program versus others (e.g., DSP), but we do recognize Brilliant Eyes as being the type of satellite that will dominate the heavens in the next century.

Continuing to address the commercial sector, the development of expert systems along with powerful computer processors with large on-board memory lies in an area where both the government and the commercial sector will have continuing interest. In these areas we expect the commercial sector will proceed faster than the government. Therefore, in these two areas, the government should closely monitor the commercial sector and take advantage of their efforts. Large government programs are not required,

but small efforts should be continued to ensure that any military unique requirements are adequately addressed.

That is SPATRACS. Notionally, it's a design for space traffic control, but when you lift the covers, it is a whole way of thinking about and doing space operations. It is a true 2020 system that can evolve into and be the bridge for a "Spock mind-meld" cognizance of the aerospace dimension in follow-on, fused, hyper-intelligent systems. In order to head down the path toward that level of omniscience in future space operations, however, we need take-charge leadership now. US aviators' ability to cognitively "slip the surly bonds of earth" and see the air dimension as more than a land support arm paved the way for a legacy of air superiority that we enjoy today -- but only after senior leadership did the gut-level work of transforming vision into reality. That same opportunity exists today in the "final frontier," and SPATRACS is our attempt to bring a new legacy-building vision into sharper focus.



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White Paper (#51)

On

21st Century Weather Support Architecture

(Weather)

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I. Subject and Problem Statement

The 21st century battlefield will be a highly lethal, cyberwar-oriented, four-dimensional regime with the dimension of time being the most critical. For the war fighter to succeed, he or she must have immediate access to key information to make quick and accurate decisions faster than his or her enemy's OODA (Observe, Orient, Decide, Act) loop capability. In similar manner, the civilian and commercial world will see a fast-paced, computer-oriented regime where decision-making may be highly time sensitive and requiring vast amounts of information. One critical set of information required by both the war fighter and his or her counterpart in the commercial and civilian world, is weather conditions affecting the mission to be accomplished. The weather information user, whether he or she is on the ground, at sea, or in the air, will need near instantaneous, global access to worldwide weather information data bases that will provide key weather data and forecast information for a given point, a path, or an area in time and space anywhere in the world. Weather information in these data bases must be accurate,

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universally available in a timely manner, and packaged so that it is easily usable by people who may or may not be weather-trained and easily inserted into software applications.

To provide the type of information needed in the 21st century, technological improvements and/or changes in operational support paradigms will probably be necessary in the four major aspects of our current national weather support architecture: data collection; data base fusion and dissemination; analysis and forecast product development; and weather product/information dissemination. The extensive cost of developing new capabilities and of changing current operational weather support paradigms is expected to require a consolidated, joint-use effort among DoD, civilian, and commercial weather information producers.

II. The Capability and Its Relevance

This paper proposes the development of a national (DoD and civilian) weather support system that will have the necessary architecture to provide to the weather information user (military, civilian, and commercial) near real-time, worldwide access to weather data and forecast products through the use of integrated weather information data bases residing on the information superhighway. These data bases would include as a minimum: (1) Current single location and gridded surface and upper level worldwide weather data; (2) Global cloud imagery; (3) Area specific Doppler radar and lightening strike information; (4) Worldwide ionospheric/radio wave propagation forecasts; (5) Area specific environmental surface (ground, sea state) conditions; (6) Single point forecasts and warnings for worldwide critical points of interest; (7) Worldwide climatology information; and (8) Worldwide gridded forecast fields for specified time periods, both at the surface and standard upper levels.

The weather support architecture must allow the weather information user direct access to the integrated weather information data bases residing on the information

superhighway. This access would be obtained through interactive ports connected to the information superhighway via hardwire (fiber optic cables, home/office telephone line connections) or direct satellite broadcast. Interactive ports would include such devices as large mainframe computer connections, small personal computers, and hand-held or vehicle-mounted (cockpit/tank/ship/ground) micro-processor receivers, capable of receiving direct satellite broadcast from the information superhighway. The ultimate goal is for the weather information user to quickly obtain the information desired through a "push of a button or a flip of a switch, with or without hard-line connection."

It is envisioned that the weather information user could use the information superhighway to obtain pre-ordered tailored products from a forecast or data processing center. He or she could also take the residing data bases off of the superhighway and generate his or her own weather products using on-location software. For the war fighters, hand-held or vehicle-mounted direct broadcast receiving devices could contain microprocessors that could take the weather information and insert it into pre-programmed decision aids that would, within seconds, determine weather impacts for a proposed mission. Information provided from the microprocessor could be the actual weather data, to include direct broadcast of cloud imagery and vertical sounding data, or a tailored product for direct input into a course of action decision process. Civilian and commercial applications would be similar; possible users would include truck drivers, commercial airlines, farmers, and private car owners.

III. Potential Technologies

The weather systems support architecture to meet the weather information data base development needs is envisioned to consist of the following, in general terms: A consolidated and technologically integrated (National Oceanographic and Atmospheric Administration (NOAA), National Aeronautics and Space Administration (NASA), and

DoD) meteorological and remote multispectral sensing polar orbiting satellite system, consisting of a constellation of four to six satellites, evenly separated by nodal time; a high resolution multispectral US geostationary satellite constellation; a quick launch capability to put LightSat weather satellites in geostationary or high elliptical orbit to support theater military commanders during war or major regional contingencies; continued world cooperative access to foreign geostationary satellite data and surface-based weather observations and upper air soundings; a centralized, high capacity, high speed data processing center(s) that would down link satellite data, ingest ground observations and upper air soundings, and fuse the entire realm of continuously updating data into gridded information data bases to be sent over the information superhighway; centralized national weather support forecast center(s) that would take the gridded information data bases off of the information superhighway and produce worldwide gridded weather forecast, point forecasts, etc. as well as tailored forecasts for special commercial, military, and civilian needs, all of which could be inserted back into the information superhighway. End-use of the information, as discussed earlier, would be obtained through interactive ports and micro-processors with programs tailored to take the weather information and convert it to mission impact information for use in a decision making process, if needed.

The following technological hurdles will need to be overcome to successfully build the architecture: Database fusion of multispectral data from both polar orbiting and geostationary satellites with surface data and vertical soundings; new-generation, high speed, high capacity satellite down link and processing capability, development of micro-processors with built-in decision-aids designed for specific needs, integrated satellite bus, development of high resolution geostationary satellite systems, computer systems architecture that can process trillions of data bytes every hour, and forecast model development to take into account the high-dimensional non linearity of the atmosphere.

IV. Near Term Technologies and Operational Exploitation Opportunities

(Including Commercial Opportunities)

The proposed weather support architecture will require the following exploitation of near term technologies and operational opportunities:

First and foremost, it is envisioned that by the year 2020, with declining federal budgets and the rapidly increasing computer hardware and software technologies, the military and governmental civilian (National Weather Service) centralized weather support structures will probably consolidate--a major shift from current operational paradigm. The resulting national weather support structure would need to be able to process, develop and disseminate weather information data and provide tailored product support to military, civilian, and commercial weather information users. It is envisioned that a single, centralized data ingest and processing center to produce the worldwide weather information observation and cloud imagery data bases to go over the information superhighway will be needed. However, to produce the forecast data bases and specially tailored products, a distributed network of governmental forecast centers that could pull the basic weather information off of the information superhighway could be used. Need and budgetary concerns will dictate the distributed network development. Commercial weather support companies, who currently obtain weather data and cloud imagery through agreements and purchase requests from the government, will continue to operate as long as they produce a profitable product.

If consolidation does occur between DoD and National Weather Service, it is envisioned that the weather support personnel, at least for CONUS locations, would be governmental civilian employees, in a paramilitary-status, supporting the military mission as a civilian during peacetime, becoming active duty military personnel during war, contingency, national emergency, or possibly exercise. This type of weather support structure already exists for many of our NATO allies; Great Britain and Germany are prime examples. Benefits from this consolidated paramilitary structure are expected to be

reduced manpower, operating, and facility costs, enhanced technological performance, and a more focused and rigorous technological development program. Permanently assigned active duty weather personnel, however, will probably still be needed to support forward deployed forces.

To improve observations of the atmosphere and earth and to help build timely worldwide weather observation and information data bases, high resolution, multispectral meteorological satellite coverage is needed. Currently, the DoD develops and operates the high resolution, Defense Meteorological Satellite Program (DMSP) which normally maintains two satellites in polar, sun-synchronous orbits at low altitude. NOAA develops and manages both the low orbit, sun-synchronous (POES-Polar Orbiting Environmental Satellite) and the geostationary orbit (GOES-Geostationary Orbiting Environmental Satellite) programs. NASA operates the polar orbiting LANDSAT remote multispectral sensing satellite. The DMSP and NOAA polar orbiters fly to support respective missions many of which require similar data. DMSP is driven by strategic taskings while NOAA launches to support forecast model production needs. Unfortunately, DMSP and NOAA often have nodal times fairly close to each other; thus timing of satellite coverage around the world is uneven and often leaves gaps of several hours which lessens tactical use of the data and forecast accuracy. LANDSAT is in a different orbit and generally measures the earth's surface at tasked locations, usually which are not in aligned with the weather satellite orbits. LANDSAT, though a civilian satellite, has the capability to provide wide-area surveillance surface data to support theater commanders.

Consolidation of the polar orbiters would reduce costs, enhance technological performance and capability, and provide more frequent measurement of the atmosphere and the earth's surface. Integrating the polar orbiter missions onto one satellite bus and maintaining 4-6 satellites in uniformly spaced orbits (i.e. nodal times 6 hours apart or 4-hours apart, respectively) would provide significant benefit to forecast accuracy and weather support to both civilian and military users. Currently, the atmosphere is vertically

sounded from the surface twice a day. Remote sensing from DMSP and NOAA POES satellite systems generally can occur twice a day over a particular region, if tasked. Integrated capability of four-to-six satellites could provide an average of four soundings for a given location a day, if needed.

The development and launch of higher resolution, enhanced multispectral geostationary satellites and the incorporation of the 30 minute geostationary satellite images into the polar orbiter data base would greatly enhance the weather support architecture. Currently, the US and other major countries maintain geostationary environmental satellites on orbit. These satellites provide timely cloud cover images (every 30 minutes) that have proven highly beneficial to near-term forecasting applications, both military and civilian. Disadvantages of these satellite images are the decrease in imagery resolution as one progresses away from the subpoint of the satellite, the overall lower resolution of the image, the earth limb distortion of the imagery, and the difficulty in fusing the data into data bases containing polar-orbiter weather data. In the 21st century, geostationary satellites should be designed to take higher resolution imagery, provide an expanded multispectral sensing capability, and configured to produce a data flow that is easily fused into a gridded data field for use on the information superhighway.

In addition to the primary geostationary weather satellite system just discussed, LightSat weather satellites, placed in geostationary or high elliptical orbits should be a commonly available asset for theater military commanders to quick-launch in support of a war or major regional contingency. Even during peace time, availability of foreign geostationary weather satellite data for a region may not exist. Currently, India refuses to allow any nation real-time access to their geostationary INSAT weather satellite data. This data would have greatly benefited war time weather support during Operations DESERT SHIELD/DESERT STORM. The European Space Agency moved one of their METEOSAT weather satellites further eastward to provide better coverage of the Southwest Asia area to support the Gulf War effort. This move significantly helped the

weather support effort, but the imagery still contained significant distortion due to its closeness to the limb of the satellite's viewing access. A CINC-directed, quick-launch geostationary weather satellite would have greatly supported the Kuwait Theater of Operations.

Significant capability enhancement, or possibly new technological design, of satellite down link capability as well as data ingestion, fusion, and processing capability will be needed. High speed, high capacity computers will be needed to process the trillions of data bytes coming through the funnel every hour. Process will need to convert the data into a synthesized gridded fields containing several variables that can be sent through the pipeline into the information superhighway for further use.

New forecast models and specially tailored products, for both military and civilian use, would have to be devised to ingest the gridded data and produce a usable product. With increased frequency and coverage of data, the accuracy of forecast models should increase. Expansion of current spectral forecast model capability would be possible due to the availability of more data and faster computers. New modeling techniques and product production is also anticipated, especially those involving high-dimensional nonlinear iterative methods, designed to handle the non-linearity of the atmosphere.

A worldwide ground-based observation and atmospheric sounding network is already in place and overseen by the World Meteorological Organization (UN), but needs to be upgraded in technical quality and made less manpower intensive. The Air Force maintains the Automated Weather Network which is a worldwide high speed data network used to collect worldwide weather data and disseminate weather information out to DoD users. Upgrade in capability or potentially redesign of the Awn into the information superhighway architecture will be needed to meet the fast-paced weather data requirements of the 21st century.

During war time, access to portions of the world weather data may be denied. Surface and upper air observations are critical to military operations, thus, a capability to

obtain data from denied areas is needed. One suggestion is to insert by air, by missile, or by hand, micro-miniaturized surface weather sensors that can measure surface conditions continuously and transmit data back to a communications relay satellite for collection and dissemination by direct broadcast back to the theater weather information users or insertion into the information superhighway. These sensors would also provide ground truth for satellite vertical soundings in the area. A polar orbiting weather satellite or possibly a LightSat geostationary weather satellite, could be designed to receive the ground sensor transmission and upon receipt generate a vertical profile of the atmosphere. The sounding could be directly broadcasted back to the theater or sent into the weather data collection network residing on the information superhighway.

In addition, worldwide access to special observation systems, such as the Doppler radar and lightning detection systems, should be obtained and/or expanded. Information gathered would greatly benefit weather information users who must quickly make decisions in situations where severe storms and lightning occurrences endanger operations. Airplane pilots, munitions and fuel supply areas, and community safety concerns are just some potential users who would benefit from access to this type of information residing on the information superhighway.

Currently, three data distribution systems exist that are forerunners of a portion of the future capability envisioned in this paper. These systems are the Air Force's Automated Weather Distribution System (AWDS), the Navy's Naval Oceanographic Data Distribution System (NODDS) and the Air Force Global Weather Center's (AFGWC) Dial-In System (AFDIS). The AWDS is a new generation computer/communications system with a dedicated communications and switching network that directly connects AFGWC with Air Force Base Weather Stations around the world. AFGWC can flow distributed gridded data bases of current and forecast weather information to the Base Weather Stations for in-house analysis and display over a computer terminal. The NODDS and AFDIS systems utilizes telephone line connections between a user's small computer

and the mainframes of the military centralized facilities the Fleet Numerical Oceanographic Center (FNOC) and AFGWC. Already processed gridded data fields, tailored graphic displays of weather information, and satellite cloud imagery from the Satellite Global Data Base (developed by AFGWC and shared with FNOC) can be sent from the centralized facilities to the requester. This capability greatly enhances weather support during operations where access to worldwide weather data is limited to nonexistent. NODDS proved itself during Operations DESERT SHIELD/DESERT STORM. AFDIS is currently undergoing initial employment in the field. AWDS, NODDS, and AFDIS products are the kinds of products that could be suitable as integrated weather information data bases on the information superhighway, especially if they can be obtained through direct satellite broadcast anywhere in the world using small microprocessors and receivers.

With access to the information superhighway, the need for a hands-on local meteorologist to provide the forecast may diminish. Nothing will ever replace the human intuition in forecasting or the public, personalized service, but as we move into the 21st century, interactive graphic and data access to the information superhighway coupled with one's own decision-aid micro-processor, weather support will become more direct, timely, automatic, and user-friendly.

Concept Paper Numbers embedded: C121U, C050U, C094U, C012U

Technology Abstract Paper Numbers embedded: A0214, A164, A008

White Paper (#52)

On

Space-Based Solar Monitoring and Alert System

[Space Weather]

C.A.T. Team name: C3I-S, Weather: Lt Col Tamzy J. House

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Is this a continuation of a previous WPT second draft? Refinement after Executive Board review, 15 mar 94

White Paper Templates consolidated in this submission: NONE

I. Subject and Problem Statement

Spacecraft operations, both manned and unmanned, are in constant jeopardy of mission degradation or failure due to the impacts of space weather (i.e., variability of the near-earth and interplanetary space environment). More specifically, space weather can cause spacecraft charging, orbital drag variations and hazardous radiation effects on spacecraft and astronauts. For example, the Jupiter Pioneer spacecraft encountered severe space weather in the Jovian radiation belts which nearly destroyed many on-board systems. Closer to home, the geostationary earth orbiting ATS-6 satellites, launched in 1974, recorded static surface potentials as high as 20,000 volts due to severe space weather. Satellite orbits can rapidly decay due to space weather causing higher atmospheric density, and thus, increased satellite drag. Narrow-beam tracking radars can temporarily lose fixes on the spacecraft due to these unexpected orbital changes. Often times the drag is degrading enough to require orbital adjustments to keep the satellite in a usable orbit. The main space weather hazard to life in space is found in the ionizing radiation resulting from exposure to high energy particles ejected by the sun during a solar

flare. These particles, which produce ionizing radiation when they hit shielding and human tissue, can be responsible for a thousand fold increase in the radiation dose over short periods.

Space weather, in general, is caused by galactic cosmic radiation from distant stars and galaxies and the sun's varying emission of electromagnetic radiation and solar wind plasma (i.e., an ionized gas consisting of protons, electrons, and other heavy, energetic particles ejected from the sun's corona at a mean velocity of 400-500 km/sec with a mean density of 5 particles per cubic centimeter). Near-earth space weather is primarily the resultant of the sun's electromagnetic radiation and plasma interactions with the earth's intrinsic geomagnetic field. The variability of space weather is closely tied to the 27 day rotation period of the sun and the sun's approximate 11-year sunspot cycle. During solar maximum, the magnitude of the variability can become quite large, producing extremely hazardous space environmental conditions.

Our current capability to provide space weather observations, accurate forecasts, and timely hazard alert warnings is greatly limited by our solar observational access, our space weather sensor technology, and our overall scientific understanding of the physics involved. Current forecast accuracy for predicting geomagnetic storms, for example, which result from the magnetospheric influx of solar plasma and electromagnetic radiation produced by a solar flare, is in the range of 20 to 40%. Geomagnetic storms can severely degrade the radiowave propagation characteristics of the ionosphere, resulting in black-out of communications, radar, and navigation. Forecast accuracy for geomagnetic storm prediction could reach the 80 to 100% range with more accurate and timely observations of space weather conditions. To meet the space weather support challenges in the years 2020 and beyond, significant improvement must occur in our solar observation capability, in our measurement of earth-bound solar electromagnetic radiation and plasma, and in our ability to rapidly process, analyze, and provide alerts and accurate forecasts of space weather impacts to near-earth and interplanetary space operations.

II The Capability and Its Relevance

To achieve the needed improvement in our capability to provide responsive, high quality space weather support in the 21st Century, a space-based, solar monitoring and alert satellite system is proposed. The satellite system, consisting of one, maybe up to three satellites, placed in a deep space earth orbit ahead of the earth's magnetosphere bow shock, possibly near the earth-sun libration point, would provide direct and continuous optical observation of the sun as well as continuous measurement of the sun's emitted electromagnetic radiation and solar wind plasma. Key functions and data collection by the satellite would include the following: multispectral electro-optical images of the sun, sunspot mapping and analysis, solar interplanetary magnetic field mapping, solar flare monitoring/alert capability to include solar disk location and magnitude of mass and radiation ejection, plasma particle measurements, and direct measurement of the sun's electromagnetic energy emitted towards earth to include a direct measurement of the full disk flux in the extreme ultraviolet (EUV).

The proposed solar monitoring and alert satellite system could provide a warning lead time of up to three days for solar plasma ejections that will hit the earth. As stated earlier, these solar plasma ejections can be lethal to manned space operations; magnitude of impact is dependent on the operating orbit, the interplanetary space travel and site location, and the physical protection available to the operators in space. The atmosphere protects the inhabitants of earth from the lethal aspects of the incoming plasma; however, inhabitants are affected by the space weather generated when the plasma interacts with the earth's magnetosphere and ionosphere.

Measurement of EUV radiation is critical to near-earth space weather forecasts since it is this form of short-wave radiation that photoionizes atomic oxygen above 100 km in the earth's upper atmosphere, producing charged particles called ions, and, thus, the atmospheric region known as the ionosphere. The energy released by the ionization

process produces the temperatures of the thermosphere. Essentially, this flux drives the ionospheric and thermospheric conditions that allow radio wave propagation to occur; it also affects atmospheric density, and thus, satellite drag. EUV radiation can not be measured directly from earth; its energy is mostly released in the upper atmosphere and what remains in the lower EUV wavelengths is absorbed by the earth's ozone layer--a fortunate occurrence, since EUV radiation is lethal to man and many other life forms. Currently, EUV flux estimate is only inferred from a known, but not perfect, correlation with the 2800 MHz solar radio flux (F10.7 cm flux).

The satellite payload is envisioned to consist of a multispectral optical telescope that would continuously monitor the sun's photosphere, chromosphere, and corona, as a minimum, for explosive solar flare occurrences, for mass injections into the solar wind caused by disappearing filaments, for sunspot activity, and for coronal hole locations from which the solar wind plasma is spirally ejected outward into space along interplanetary magnetic field lines. A bank of sensors would be on-board to measure the energy content of the solar radiation emitted throughout the electromagnetic spectrum. Besides visible wavelengths (optical), the solar radiation measured would predominately include X-rays, infrared, near ultraviolet, extreme ultraviolet and radio waves. Plasma particle counters would also be part of the payload to determine the magnitude of the solar mass being ejected towards earth.

The satellite would have on-board data processing capability. It is envisioned that the on-board computer could analyze the optical images for critical solar features and through the use of artificial intelligence schemes provide high probability forecasts, to include timing and regional location, for solar flare eruptions as well as other solar mass ejection occurrences, such as disappearing filaments. Multispectral electro-optical digitized pictures of the sun as well as the on-board analysis would be sent back to an operations command center either on earth or in space. The radiation and plasma information would be analyzed on-board for alert warning thresholds. Immediate

warnings as well as raw data would be broadcasted back to an operations command center on earth or in space for hazardous increases in flux levels of electromagnetic radiation and plasma. With the on-board capability to monitor coronal holes, to measure the solar interplanetary magnetic field, and to determine probable areas and timing of solar flares, forecasts of solar plasma wind conditions and radiation flux affecting near-earth space environment as well as interplanetary space over the next 24 hours, possibly even out to 72 hours, could be generated by on-board computer models with the results broadcasted back to an operations center on earth or in space. The operations center would have the flexibility to task the satellite to transmit various combinations of data packages back to the center. Analysis and forecast capability would exist as a redundant capability at the operations center in case of satellite problems.

The proposed satellite configuration and orbital location was chosen to provide optimum, continuous support to interplanetary space operations as well as near-earth space environment. As described, the envisioned satellite system would be a direct broadcast beacon for space weather data, advisories, and forecasts. Space weather information would be available to all those in-range of the beacon and who have the capability to access the transmission. Putting the satellite system in geostationary or low earth orbit would require more satellites to provide continuous coverage of the sun and would deny the total measurement of the radiation and plasma interacting with the earth's magnetosphere and ionosphere. Furthermore, solar imaging telescopes in low earth and geostationary orbits would have to overcome more severe background brightness problems due to the earth's albedo (reflectance) and aurorae than they would in a deep space earth orbit.

Fielding the proposed satellite system would eventually provide monetary benefit by negating the need for the earth-based network of solar observatory monitoring and alert facilities that currently exists; it would also provide space weather alert protection (a potential lead time of up to three days for solar plasma bombardment) for space station

occupants, interplanetary and near-earth space operators, and earth-based users of space. Beyond 2020, maybe by 2050, this envisioned system would be the space weather equivalent to today's Weather Radio Alert System managed by The National Weather Service. Humans in space would use the warnings to take protective shelter. Special temporary shielding may be employed on the spacecraft or satellite to minimize impact of energetic particles. In the 21st century, magnetic force field generation might be possible to protect spacecraft by directing the plasma bombardment away from the spacecraft along outwardly radiating magnetic field lines. Increased space weather warning lead-time could provide space operators and users an opportunity to do alternate communication contingency planning, such as changing ray paths, reverting to different systems less affected, or selectively shutting down systems to avoid electronic damage.

III. Potential Technologies

The development of a satellite-based multispectral sensor package to include a telescopic optical capability (Hydrogen-alpha, K-line of ionized Calcium, etc.) would be required; in addition, new communications, computer hardware, and software architectures would be needed to process the data, to analyze the data, to identify and provide direct broadcast notification of hazardous conditions, and to develop and provide forecasts of solar flare occurrences and solar wind plasma conditions. Satellite system protective devices would have to be specially designed to harden the satellite against the effects of the tremendous electromagnetic radiation and solar plasma bombardment it is trying to measure and analyze.

Technological hurdles to overcome include the following: (1) The development of a small, high resolution optical telescope suitable for satellite use with the capability of sending electro-optical, digitized pictures of the sun's atmosphere back to a command center (current solar telescopes are large--tens of feet long); (2) The development of a

satellite-based, accurate model or artificial intelligence scheme to predict the timing and location of solar flare occurrences; and (3) The development of an on-board capability to optically analyze the solar photosphere, chromosphere, and corona for structural features that could be used in solar flare and solar wind prediction models.

The envisioned space-based solar monitoring and alert system could be achieved through a phased period of development and employment. During the first phase, the basic satellite data collection system, consisting of a multispectral optical telescope, electromagnetic sensors, and solar wind plasma monitors, would be developed and launched into the deep space orbit. The data collected would be transmitted, without any on-board analysis, back to an earth-based operations center, such as the current AF Space Forecast Center. Space weather forecasts and advisories would be sent to supported space operators and users from the earth-based operations center. Phase Two of the satellite system evolution would concentrate on the development of the on-board analysis and forecast model capabilities. Development of solar flare and solar wind forecast models as well as schemes to analyze solar atmospheric features (sunspots, flares, plages, disappearing filaments, coronal holes, etc.) are envisioned to use artificial intelligence schemes coupled with solar physics. These models and schemes will require substantial development effort and experimentation using the data acquired from Phase I of the program to ensure a useful level of accuracy can be obtained. Computer miniaturization and increased speed and capacity will be key assets in hardware development to support the on-board analysis and forecast capability. Phase Three of the program would be the launch of the entire space-base solar monitoring and alert system, as envisioned.

IV. Near Term Technologies and Operational Exploitation Opportunities

(Including Commercial Opportunities)

Currently, solar observations are obtained from a network of earth-based, solar observatory monitoring and alert facilities. The United States Air Force maintains a worldwide alert network of five solar optical observatories and four solar radio telescope observatories to provide continuous monitoring of the sun for solar flare occurrences. Solar monitoring information is also obtained from several civilian observatories around the world. Solar observations are fed into the Air Force Space Forecast Center at Falcon AFB CO for analysis and issuance of space weather advisories and forecasts to military space operators and users. The same solar observation information is also sent to the US-civilian, Space Environmental Services Center in Boulder CO who provide similar space weather support to US civilian and commercial space operators, users, and non-space users impacted by space weather (i.e., power companies, pipeline companies, etc.).

Earth-based solar observatories experience decreased observational effectiveness due to cloud cover and to atmospheric attenuation and absorption of the electromagnetic radiation which limits the spectral monitoring capability to two primary optical spectral lines (Hydrogen-alpha and K-line of ionized Calcium) and a few solar radio wave frequencies. The solar observatory effectiveness is also degraded by local radio wave interference, by the observatory's geographic location, especially latitude, and by international politics. For example, the Air Force's Mideast Solar Observatory, now located at San Vito AS IT, has a tumultuous history due to international politics. When located in Tehran, Iran, during the fall of the Shah, the solar observatory was taken over by the Revolutionary Guard and the commander thrown into prison for a week; before capture, the commander was able to hide the Hydrogen-alpha filter, thus disabling the optical telescope, and smuggle the filter out-of-country upon his release. The solar observatory was later reestablished in Athens, Greece, but terrorist threats frequently closed the observatory. The current location of the Mideast Solar Observatory has been operational since 1986.

Current space-based solar observational capability is limited to a few geostationary satellites, such as the United States' Geostationary Operational Environmental Satellite (GOES), carrying sensors to monitor X-ray emissions generated by solar flares, charged particle flux, and the magnetic field surrounding the spacecraft. The Defense Meteorological Satellite Program (DMSP) does not carry sensors to monitor the sun; it does, however, have a suite of sensors to monitor space weather conditions in the earth's ionosphere. A few solar monitoring satellites have been launched in the past, such as NASA's Orbiting Solar Observatories (OSO) in the 1960's and early 70's, but they were limited in their mission duration and in their electromagnetic spectrum capability, and were designed for scientific exploration and not continuous solar radiation hazardous alert monitoring.

Promising solar imaging technology for possible use on the envisioned solar monitoring and alert satellite system is underdevelopment at the Phillips Laboratory Space Physics Division Solar Research Branch, located at Sacramento Peak Solar Observatory in Sunspot NM. The technology involves a new sensor package, called the Solar Mass Ejection Imager, that could actually image the plasma ejection from the sun, trace it through interplanetary space, and provide accurate forecast of arrival at earth in real time. This information coupled with direct EUV and plasma particle measurements would significantly increase the accuracy of space weather forecasts, for both interplanetary and near-earth space environments.

Countermeasures for this concept are expected to be negligible, especially if the satellite system is located in a deep space earth orbit; but if they do occur, they would include jamming, input of deceptive information, or satellite destruction. This concept is not viewed as a threat that would currently warrant enemy military action; action would be more likely once man had a large permanent residence in the near-earth space environment. World-wide agreements are already in-place and have been for years, through the United Nations, to share environmental data. Present day collection of solar

data by the civilian and military-owned observatories are routinely made available for world community use. During times of war, the solar environmental data could be reported through secure channels, if needed.

Space weather is important to all space users. As we exploit space and establish a continuous civilized presence in space, the importance of knowing the space weather will be critical to human and hardware survival; this cannot be over-emphasized. Incoming plasma particles ejected into interplanetary space by a solar flare, the most hazardous space weather for mankind, could be as dangerous to one's health and property in outer space as tornadoes are in the Midwest. As stated earlier, warning lead-time can be achieved for this type of space weather since it does take several hours for the energetic particles to reach the near-earth space environment. Solar electromagnetic radiation, however, would be essentially sensed at the same time it affects the near-earth space environment since it travels at the speed of light. The tremendous solar data collection capability of the space-based solar monitoring and alert system will substantially increase the space weather support capability far into the 21st century.

Concept Paper Numbers embedded: C116U

Technology Abstract Paper Numbers Embedded: A0057, A0341

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White Paper (#53)
On
Space Weather Support for Communications
[Space Weather]

C.A.T. Team name: C3I-S, Weather: Lt Col Tamzy J. House

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Is this a continuation of a previous WPT second draft? Refinement after Executive
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I. Subject and Problem Statement

Ionospheric variability (space weather) significantly impacts ground and space-based communications. In essence, the electrically charged particles of the ionosphere (i.e., the ionized portion of the atmosphere starting at about 80 km above the earth's surface) can attenuate, totally absorb, reflect, change direction of propagation, and/or change the phase and amplitude of radio waves. The magnitude of the impact is dependent on ionospheric space weather conditions resulting from the variability of the solar radiation entering the upper atmosphere (primarily extreme ultraviolet (EUV)), the solar plasma entering the earth's magnetic field, the gravitational atmospheric tides produced by the Sun and the Moon, and the vertical swelling of the atmosphere due to the daytime heating of the Sun.

Space weather in the ionosphere becomes more intense and hazardous during solar flare activity. Sudden ionospheric disturbances (SID), ionospheric storms, polar-cap absorption (PCA), and geomagnetically induced storms are forms of space weather resulting from solar flare activity. During these conditions, enhanced levels of energetic

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particles and EUV enter the ionosphere, increasing atmospheric neutral and electron density through particle injection and photoionization. Depending on the intensity of the variability induced, the resulting space weather could significantly impact radiowave propagation, causing intermittent or a complete blackout of communications, radar, and navigation, primarily in the polar regions and high-to-middle latitudes.

Ionospheric space weather can also be induced by the tilt of the earth's geomagnetic field. This tilt produces anomalous regions in the South Atlantic and over Southeast Asia where energetic particle interactions are occurring with neutral particles at a much lower altitude resulting in increased radio propagation effects.

Ionospheric scintillation, another form of space weather, can cause fluctuations in the phase and amplitude of radio wave propagation. This space weather phenomena causes havoc on satellite-to-ground or satellite-to-aircraft transmissions, especially in the equatorial regions. FTSATCOM, AFSATCOM, and GPS are vulnerable to this form of space weather.

Our current capability to provide ionospheric space weather observations, accurate forecasts of space weather conditions, and timely hazard alert warnings is limited by our ionospheric sensing capability, by the density and frequency of ionospheric observations available, by the sophistication and accuracy of the ionospheric models, and by our overall scientific understanding of the physics of the ionosphere-thermosphere-magnetosphere coupling mechanisms. To improve our ionospheric space weather support capability, especially to tactical and satellite communications, our ability to measure the ionosphere in the vertical must be enhanced to a daily, consistent in time and space, worldwide mapping capability. The frequently replenished observational data, to include electron density profiles, ultraviolet imaging of auroral zone and airglow spectra, in-situ particle counters, kinetic temperature measurements of ions and electrons, and plasma irregularities, would provide critical space weather alert indications. Study of the data could bring new insight into the space weather physics, leading to improvement in ionospheric and thermospheric

models, and thus, space weather forecasts for satellite operators and users for use in improving efficiency of their systems.

II. The Capability and Its Relevance

To achieve the daily global mapping of the ionosphere, it is proposed that ionospheric sounders and other sensing devices be placed on the Air Force-developed Navstar Global Positioning System (GPS) and the future IRIDIUM system, commercially being developed by Motorola. The GPS constellation consists of 24 satellites in circular orbits just under 11,000 NM above the earth's surface. There are four satellites in each of six orbital planes, each plane inclined 55 degrees to the equatorial plane and separated by 60 degrees in Right Ascension. The replenishment requirements for the GPS constellation with the resultant periodic launches would provide the opportunity to include an ionospheric measurement capability on future production satellites. The IRIDIUM system, designed to provide worldwide cellular phone access, is still under production; initial launch is expected within the next two or three years. The constellation is projected to contain ⁶⁶76 LightSats (i.e., small, light-weight satellites). Attaching ionospheric sounding devices on this system would greatly enhance ionospheric mapping capability.

Forecast reports for diurnal, worldwide, terrestrial propagation characteristics of electromagnetic energy in the 3 MHz to 300 MHz frequency range would be a key product produced from the daily worldwide mapping of ionospheric data. Forecasting radio frequency propagation is similar to weather forecasting in that large volumes of fresh data, collected over vast territorial expanses, are needed daily to provide condition estimates that are reasonably accurate and sufficiently detailed. The daily worldwide data would also be useful in enhancing the accuracy of radio direction finding activities. This data would be a significant aid in accurately determining the location of tactical communications sources utilizing the communication frequency ranges where the signals

are readily refracted by the ionosphere. The ability to routinely and accurately locate and track platforms using tactical radio intercepts would significantly improve order of battle assessments. Error ellipses are expected to improve by an order of magnitude through the use of the daily worldwide data.

To enhance the overall global ionospheric mapping and to significantly improve our ability to understand, predict, and exploit equatorial ionospheric scintillation, additional remote sensing of the equatorial ionosphere is needed. Certain regions in the equatorial ionosphere are significantly disturbed to cause electromagnetic amplitude and phase fluctuations (scintillation) on satellite-to-ground or satellite-to-aircraft transmissions. The disturbed regions, called equatorial plasma depletions or bubbles, develop after sunset, drift to the east, and persist well past midnight, resulting in a six to eight hour period of potential intermittent SATCOM and GPS outages. To obtain the necessary data, an ionospheric remote sensing satellite, in addition to the GPS or IRIDIUM constellation, is proposed to be flown in a circular orbit between 20 degrees latitude north and south at an altitude of about 700 km; however, a remote sensing package could be flown as an add-on sensor on another satellite if a similar orbit is being used.

Information obtained from the equatorial ionospheric sounding satellite or package would be used to forecast the existence and movement of equatorial scintillation regions. With the real-time, daily measurements of ionospheric parameters, such as temperatures, densities, and plasma irregularities, combined with new scientific insight and model development, highly accurate forecasts of future outage locations can be expected. This predictive capability for equatorial ionospheric disturbance regions would improve the reliability of communications within this region through the use of alternate raypaths or relay to non-disturbed regions. Operational users would finally have the ability to uniquely distinguish ionospheric outages from hardware problems or jamming.

III. Potential Technologies

Ionospheric modeling would be significantly enhanced with the availability of daily worldwide data. Ionospheric structure would be more readily apparent which could lead to advances in scientific understanding of coupling mechanisms within the ionosphere, thermosphere, and the magnetosphere. The inclusion of directly measured daily total EUV flux in the ionospheric models would also significantly improve the models' accuracy. (See White Paper on Space-Based Solar Monitoring and Alert System.) Potential technologies are essentially seen as a significant advancement in current modeling capability.

The scientific challenge in understanding ionospheric scintillation is to determine the exact geophysical conditions which lead to the onset of plasma depletions at a particular location and time. This challenge relates directly to a major operational SATCOM requirement to issue accurate outage forecasts to operational satellite users dispersed worldwide and operating over a wide range of frequencies. The ability to forecast these C3I outages would overcome a long standing limitation of reliable SATCOM in the equatorial region.

A potential exploitation technology could be developed in the 21st century once ionospheric variability is understood, globally measured on a daily basis, and made predictable with a good degree of accuracy. This technology would involve temporarily modifying the ionosphere through insertion of chemicals at certain altitudes and locations to increase the neutral and electron density of a given region. This effect could be enhanced by using a high energy laser, microwave, or particle beam to photoionize the chemical insertion to increase the electron density and particle interactions. Result would have a jamming effect on the enemy's radio wave propagation capability due to absorption of the wave energy by the charged particles in the enhanced ionosphere. The danger is that your own communications could be affected as well.

IV. Near Term Technologies and Operational Exploitation Opportunities (Including Commercial Opportunities)

Currently, earth-based ionospheric sounders (recorders) can measure and produce excellent vertical profiles of electron density through the lower half of the ionosphere. The upper half of the ionosphere, unfortunately, can not be measured by the sounder because the signal is either reflected back by the level below the maximum electron concentration or not at all. To measure the upper half of the ionosphere, satellite-based ionospheric sounders and other sensing devices must be used.

Satellite remote sensing of the ionosphere exists today as a capability, but it is limited in coverage, frequency, type of data collected, and timeliness. Some low-earth orbiting satellites, such as the Defense Meteorological Satellite Program (DMSP) (currently two on-orbit), carry ionospheric sensing devices. In the case of the sun-synchronous, polar-orbiting DMSP, a suite of four sensors, known as the Ionospheric Plasma Drift and Scintillation Monitor (SSIES), measures plasma parameters such as ion and electron temperatures, densities, and plasma irregularities. The DMSP also carries a Precipitating Electron/Proton Spectrometer (SSJ/4) that detects and analyzes electrons and ions precipitating into the ionosphere producing enhanced auroral displays. This information provides critical knowledge of the state of the polar ionosphere for communications, surveillance, and detection systems such as the Over-The-Horizon radar that propagates energy off, or through the ionosphere.

New upper atmospheric models are under development at various universities and laboratories around the world. As these models develop, they will eventually be incorporated into global circulation models that will have the goal of specifying worldwide ionospheric and thermospheric conditions. The US Air Force's Phillips Laboratory is currently developing a new ionospheric model, known as PRISM, which will eventually

be used operationally by the Air Force Space Forecast Center at Falcon AFB CO to forecast ionospheric space weather. The accuracy of this and other models would be significantly enhanced with daily worldwide mapping data of the upper and lower ionosphere, achieved through space-based ionospheric soundings coupled with earth-based ionospheric sounder data. The ultimate goal of these models would be to provide more accurately, for example, current and forecasted electron density profiles, atmospheric densities, and auroral disturbance locations. Space operators of communications, radar, and navigation systems as well as operators concerned with predicting satellite orbit already use current and predicted space weather information to more efficiently use their assets; however, the estimated accuracy of the space weather information is about +/- 25%. Daily, worldwide mapping of ionospheric data could reduce modelling error significantly.

The Space Forecast Center provides operational space weather support to DoD space operators and users in the form of bulletins/alerts and forecasts of space weather conditions of the near-earth space environment. Ionospheric sensing is critical to their capability to provide support. Accuracy of products is degraded due to the lack of near real-time data and worldwide coverage for a given time in space. With a worldwide data base, frequently replenished throughout the day, accuracy of ionospheric space weather products should significantly increase, possibly by an order of magnitude. To take advantage of the increased data availability, from all sources, the Space Forecast Center will need faster and more accurate forecast models (e.g., ionospheric, magnetospheric, thermospheric, solar, satellite drag, etc.) coupled with a high speed, high capacity data processing and product development capability.

The proposed use of the GPS and/or IRIDIUM constellations as well as the launching of an equatorial ionospheric sensor are considered to be a joint-use/dual-use venture among civilian, DoD, and commercial interests. All share similar communication concerns, and oftentimes communications systems are jointly used, thus, all need the same

type of information to efficiently use their respective systems. Data collected is expected to be made available for worldwide use unless threat dictates encryption or some type of control.

Concept Papers Numbers embedded: C163U

Technology Abstract Paper Numbers embedded: A015, A152

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HOLOGRAMS FROM SPACE

SPECIAL OPERATIONS (C3I) -- TEAM 8

Date: 25 March 1994

Lt Col Rich Davenport

I. Subject and Problem Statement

SPACECAST 2020 proposes that holograms be projected from space onto the ground, in the sky and on the oceans. Holograms are envisioned to develop deception scenarios to support operations, pysops and visual communication throughout the spectrum of war for all military services. Space systems with hologram generation capability are forward deployed and can support large and small units at any time and in any theater virtually without notice.

Holograms are uniquely different from photographs or movie projections and hologram images are three-dimensional projections which are incredibly life-like. Scientists and engineers have been generating holograms in the labs and some commercial applications have already been marketed. Emblems on credit cards are simple holograms which change shape as the card is rotated in the light. A more elaborate hologram used lasers to generate warning signs which appeared in the middle of the highway -- these were clearly visible but driving "through" the hologram signs caused more distracted motorists and accidents and the program was terminated. Holograms are being embedded into transparent materials (glass, plastic, Mylar) which exactly duplicate invaluable jewels and art treasures which in strong light (sunlight or fluorescent light) appear indistinguishable from the real "McCoy" [Conversation Jim Trolinger, 21 March].

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Holograms were invented in 1948 but to date military application has not been exploited from space. This paper briefly outlines how Special Operations and the military services would be dramatically impacted by Holograms in Space by 2020.

II. The Capability and Its Relevance

SPECIAL OPERATIONS

Special Operations emphasize small units employing speed and stealth to insert into tense situations and get out without detection. Success is a premium for Special Operations and balancing risk against the potential for securing National interests is a fine line as clearly illustrated during DESERT 1. Holograms from space can minimize risk and increases the likelihood for success and these space systems will be a tremendous asset in the future.

Special Operations include hostage extraction, recce, and small unit operations. Imagine the scenario -- a Special Operations (SO) unit is under cover at night waiting for the culminating point to "snatch" the hostages. The SO commander directs the spacecraft to generate hologram images into the forest to distract the guards. A variety of images could be very effective against the guards -- holograms could generate light flickering on the trees or simulate an explosion to get their attention and in most cases the guards would investigate. If the special operation were conducted in an open terrain with complex mission objectives, more sophisticated holograms could be required for deception. Holograms could generate helicopters either simulating a feint or model a SAR operation; again, just need a few minutes is all that is required to distract the enemy and make the difference for Special Ops to secure success.

During Desert Storm, leaflets were dropped by C-130s on the Republican Guards to influence many to surrender and communicated US intentions to promote action against Hussein. While the C-130s pysop mission was effective, the Special Ops units were at risk {loss of the C-130s in Desert Storm and more recently off the coast of Africa) and the mission could be accomplished from space without risk to US forces. Space holograms "messages in the sky" could be seen by thousands on the ground to disseminate information quicker and with more impact -- this message cannot be thrown away or disregarded and will dramatically improve the probability for a pysop mission. To reinforce the message, the spacecraft can project holograms on buildings or billboards to graphically depict the US intent whenever and wherever directed by the Special Ops.

The advantage of using holograms is that there is no attribution because there are no "evidence" after the mission is complete -- when the mission is complete, the spacecraft stops generating the holograms and there is no trace is left. A magician can repeat an illusion many times and the audience can continually be fooled but just like any illusion it is best to reduce the amount of exposure. Long use of holograms may reduce the impact of the deception scenarios; this is normally not a problem for Special Operations because the mission plan requires the use of holograms for normally just a few minutes at a time.

OTHER UNITS

All services rely on speed and surprise for small and large units but is not constrained by clandestine operations. Holograms could be used to increase survivability by generating air decoys or simulations to keep the enemy confused about aircraft positions and numbers. Holograms could be used to deny data from enemy forces by "painting" images over targets. For example, BDA sorties could use holograms to show targets as "destroyed" or known targets could be made to appear such as abandoned warehouses. Offensive counter-air or interdiction missions could employ holograms to illumine targets either with light or IR at night missions.

For close air support missions would be enhanced by having, for instance, A-10s to appear as an enemy aircraft -- delaying response by soldiers on the ground buys time for the A-10 and increases its effectiveness. Prior to any air interdiction or bombing could be enhanced by "creating" a hologram raid -- any response by the enemy would be targeted for SEAD. During the air to air missions it would be quite different if US planes were made by holograms to look differently than what the enemy expected (i.e. F-16 vice an F-15). This scenario could be further complicated so that an enemy planes could be made to look like, for instance, F-15s while US pilots could wear special lenses to distinguish the "good guys" from the "bad guys". Once again, this gives US forces an advantage and that means better military results.

Naval and Army units should be able to employ holograms from space using the same kind of deception techniques described for the Air Force. Operations in the 2020 time frame will include using holograms to mask ships and tanks to appear non-combatants to allow closer engagements and increase effectiveness. Specifically, Navy would clearly benefit utilizing spacecraft to generate images simulating floating mines in the harbors and periscopes in the open seas by forcing reaction by the enemy. Army units would be able to take advantage of space holograms to improve camouflage opportunities -- buildings and foliage could be generated as required for cover, helicopters could be masked behind clouds to support airborne operations and ground forces could be become invisible from air. Visual communication would be particularly useful for small Army and Naval units; holograms from space could provide a detailed accurate picture of the changing battlefield projected directly to isolated units (including SEALs operating underwater) -- valuable information becomes the lifeline for the warriors.

Should the spectrum of conflict expand beyond pysop and small unit operations, holograms would still have an impact in limited war. During DESERT STORM, Centcom employed a large Western sweep to flank the Iraqi positions after the front was fixed with a large amphibious demonstration and several frontal feints. These feints could be simulated with several

satellites and a large number of holograms. Again, the advantage to the CINC is that maneuver operations could be accomplished with holograms without risking troops to support deception.

SPACECRAFT DEPLOYMENT

The proposed architecture for holograms from space includes geosynchronous and medium altitude satellites. Three geosynchronous satellites in a 5-10 degree inclination nominally cover the world interest regions (i.e. Europe/Middle East/Africa, Americas, Far East/Russia). The concept of operations is that two of the geosats would be centered in the Eastern and Western hemispheres with the capability to maneuver quickly to cover any region directed by the NCA. The third geosat would act as the backup and support surge as required for multiple conflicts. If the architecture is fiscally constrained, actually a single geosynchronous satellite could support the hologram from space mission given the following assumptions: two major conflicts could not be simultaneous; a minimum of 10 days is required for warning to allow repositioning of the satellite; and unlimited gas is available for refueling the spacecraft. Small packages would be included on selected GPS follow-on satellites to support world-wide coverage for tactical hologram projections.

The geosynchronous satellites would be large based on the estimates required for the optics necessary to generate holograms to project on buildings, ships, planes etc. Dishes should be a minimum of 50 feet to collect sunlight which is focused onto a large Mylar screen which contains the hologram information for projection to the ground. This application requires a large amount of energy to project large holograms over long distances. Holograms could be generated by powerful lasers but utilizing radiant energy keeps the spacecraft size manageable. Another advantage is that generating images using sunlight requires less maintenance than on-orbit lasers - this is a must for geosynchronous satellites.

Thousands of Army, Navy and Air Force images can be built graphically by Crays and stored one on top of each other on the Mylar screen. Images of deception scenes are indexed and

the on-board computer electronically directs sunlight onto the Mylar region (hologram is defined by the screen depth and longitudinally) to reconstruct the proper Hologram. If a unit requires a Hologram image which had not been stored, Crays can build another hologram in near-real time and the information is then transmitted to the satellite. The on-board computer directs that the data is stored onto the Mylar screen and small hologram disks.

The high altitude system will be tied to the GPS hologram packages. The GPS packages provide the laser illumination while the projection source is generated by the geosynchronous satellite. GPS packages should weigh no more than 100 pounds which includes three high-power color lasers to generate "white" light holograms. Lasers are positioned in lower altitude to increase hologram resolution for small, detailed images (i.e. for projections of close-up views of people). Rather than generating the image from the satellite, the laser illumines a remote hologram which is much closer to the ground -- again, this will increase the resolution. Remote holograms can be carried simply by RPVs which deploy Mylar screens at whatever altitude required. Another approach is to have the geosat drop the appropriate disks (like Brilliant Pebbles) into the right position and then the laser illumines disks which generates the hologram -- this may be the right answer for clandestine operations.

The easiest counter to space holograms is to generate smoke clouds which prevent viewing of holograms. Any device which disturbs the air around an object could interfere with the projection of holograms -- this might be a countermeasure against deceptions which mask aircraft, ships and tanks.

III. Potential Technologies

Laser technology is advancing but is still far from generating effective holograms from space. Phillips is looking at using large optics for generating holograms to increase resolution and help penetrating clouds. Research labs has looked into generating holograms at higher frequencies (IR, X-ray etc.) to penetrate clouds and work the problem of how to effectively enlarge holograms -- to date noone has worked this successfully. MIT has used a Cray to generate a graphic description of a hologram image in 1992. More work in this area would support near-real time generation of holograms in the future. Visual encryption of holograms is possible using lenses.

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White Paper

on

Force Application (U)

(U) The US Air Force must be able to reach out and touch ANYBODY, ANYWHERE, ANYTIME

- Phillips Laboratory,
Force Application Study

(U) Subject and Problem Statement

(U) Force application brings space power to bear directly against surface targets. This role includes those missions that apply combat power against surface targets exclusive of missions whose objective is space control.¹ Example of targets include armor formations, carrier task forces, aircraft, submarines and hardened bunkers.

(U) This paper presents conceptual capabilities. No particular application doctrine or strategy is implied. This paper proposes a family of force application concepts to provide an increased capability for prompt, intense, lethal and non-lethal, parallel attack against terrestrial (land, sea, and air) targets with minimum risk to allied personnel and minimum collateral damage. The concepts presented in this paper exclude information warfare (including electronic warfare) which is covered in a separate white paper. The family of concepts are not all space only architectures and result from combinations of earth- and space-based C4I systems for surveillance, acquisition,

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targeting and attack assessment (SATKA) and real-time command, control and communications and battle management (C3BM) (decision making); earth-based (landborne, seaborne, airborne, and spaceborne) and space-based weapons delivery platforms; and weapons (munitions). Many of the combinations either exist today or are possible. What does not exist today are space-based shooters (space-based weapon systems).

(U) A force application architecture responds to the world the SPACECAST team envisioned in the early 21st century, and to the space assumptions and imperatives derived therefrom. Specifically, we did our part in responding to the Chief's direction to envision capabilities and identify high-leverage space technologies² that will support the US national security interests 25 years or so from now. SPACECAST 2020 envisioned a future world which armed conflict will still exist due to geopolitics, economic competition, desired access to limited natural resources, social fragmentation, and existence of non-state actors. In a world of anticipated future conflict, a technologically superior capability to apply force is essential to deterrence, and if deterrence fails, the US's ability to fight and win. Warfare media has moved progressively from land to sea to air to aerospace. Space is the next logical step, and US national security demands we maintain freedom of action there as well. In a SAF/AQ briefing given to SPACECAST 2020 entitled "A Framework for Dealing with Uncertainty", a futures-to-strategies-

to-task model leads to functional force structure building blocks--survey, assess, command, control, generate, and engage--which form the foundation upon which to make future investment decisions. This paper focuses on the engagement block. Mr

Lowell Wood of Lawrence Livermore National Laboratories clearly sees a requirement for the future USAF to block large-scale attacks launched in inconvenient locations with only hours notice with large quantities of compact, ultra-precision munitions.³

One can postulate that future force postures will continue to move away from large fixed overseas bases and the accompanying logistics support. Future US forces will be more and more expeditionary in nature and will have to respond upon short notice where a premium will be placed on early show of force in an attempt to diffuse crises.⁴ Space force application can do that.

(U) These capabilities could be applied at the strategic, operational, and tactical levels of war as well as across the spectrum of conflict. They can be used to deter, defend and defeat. Force application could be applied singularly as a show of force or independent flexible deterrent options, or easily integrated into an air campaign or combined arms operation.

(U) Much of modern civilization lives close to borders, being thus vulnerable to swift, no-notice attack. Many nations important to US national security, like South Korea, lack strategic depth. An aggressor could quickly seize mass hostages

or threaten infrastructure such that counterattack would leave an undesirable war termination end state. Thus, speed of response is critical--in some cases, aggression must be stopped before more than a few kilometers advance. This requires initial counterstrike within an hour of sovereignty violation and these counterstrikes must be extensive to be effective--10,000 equivalent sorties per day intensity is a representative requirement.⁵ For comparison purposes, in Desert Storm, coalition forces flew, on average, 1600 combat (shooter) sorties a day.⁶ (U) Furthermore, space-based weapon systems could potentially introduce a particularly strong psychological aspect to deterrence and defense. The ability to service 2,000 aim points in 30-40 minutes could induce strategic paralysis. Rapid, precision strikes from space may be the ultimate shock weapon. Just demonstrating such a capability, even in a test, may have a significant deterrent ability.⁷

(U) Space-based (including spaceborne) weapon systems bring some unique capabilities to warfighting. It is the ultimate in global reach and global power. Space-based weapon systems can provide global access and presence without the concomitant increase in theater footprint required by terrestrial forces. Only space systems have the potential to be available everywhere in the globe that US forces may have to operate.⁸ Deorbited hypervelocity kinetic energy weapons (KEW) can provide energy in the megaton range depending on the mass on the reentry vehicle

(RV). The time to target for KEWs can be less than 15 minutes. Directed energy weapons (DEWs) and radio frequency (RF) weapons travel at the speed of light. Space-based weapons require no basing or overflight rights. No forced entry is required for their employment. No soldiers, sailors, or airmen are put directly in harm's way when space-based weapons attack terrestrial targets. We also better not rest on our laurels of enabling technology from the Gulf War. Many experts predict stealth has a short half-life.⁹ Precision strike in enemy territory will eventually require new penetrating capabilities--space weapons can do that!

(U) Space-based weapon systems also have disadvantages. Placing weapons on-orbit requires significant lift. They would be high value counterspace targets for our adversaries. They might be hard to maintain and keep modern (i.e kept from obsolescence) unless cheap, routine spacelift is available. Furthermore, orbits are predictable and a space order of battle that does not provide 24 hour per day global coverage could be exploited by an enemy.

(U) Orbit architectures will depend on mission and survivability requirements. Sensors could be in LEO and MEO. Numbers of satellites/platforms could range from 10s to 1000s. Communication could be in GEO and require only 3 satellites, except over the poles. "Shooters" could be orbited anywhere, but promptness would decrease with a smaller number of

satellites/platforms in higher orbit and will require tradeoffs among cost (number of satellites), promptness (for KEWs) and survivability. Technologies considered are kinetic energy, directed energy, NBC, conventional (high explosive and submunitions).

(U) Today, US laboratories are pursuing the technologies which enable at least a rudimentary force application space power projection capability . In fact, AFMC's Space and Missile Systems Center feels the real challenges are political and economic, and that both will change in the next 10 years.¹⁰

(U) The Capability and Its Relevance

(U) Integrated Architecture

(U) The total force application architecture (e.g. SATKA (sensors), C3BM (communication and decision making), WDP, and weapons) could be integrated onto one space-based platform or it could be distributed across several space-based platforms. Also, the capability could be made up of a mixture of space- and earth-based components. Communication will most likely be located on-orbit. Decision-making will most likely be located on earth-based platforms (land, sea, air, etc.) unless the space-based platform is manned. Weapons could be space- or earth-based as could be sensors. The most likely initial systems could be sensors and communication in space and decision-making and weapons earth-based. Multiple permutations can be envisioned by random combinations of the four basic elements from table 1.

SENSORS	COMMUNICATION/DECISIONMAKING	PLATFORMS	WEAPONS
<u>Land-Based</u> - SOF - Soldier - Field Systems <u>Sea-Based</u> - Ship -- Cobra Judy -- Space Track -- Aegis - Submarine <u>Airborne</u> - Fixed Wing --AOA - Rotary Wing <u>Spaceborne</u> - Shuttle -- SAR-A - NASP - TAV - MAV - WDV <u>Space-Traversing</u> - <u>Space-Based</u> - Satellites - Platforms - Space Station	<u>Land-Based</u> <u>Sea-Based</u> <u>Airborne</u> - NEACP - ALCC - ARIA <u>Spaceborne</u> - Shuttle - NASP - TAV - MAV - WDV - Space Cruiser <u>Space-traversing</u> - MEECN <u>Space-based</u> - Satellite - Platform - Space station	<u>Land-based</u> - GBL - WLW -- ERIS - Light gas gun - EM gun - ET gun <u>Sea-Based</u> - WLW - EM gun - Et gun <u>Airborne</u> - F-15/MHV <u>Spaceborne</u> - Shuttle - NASP - TAV - MAV - WDV - Space Cruiser <u>Space-traversing</u> - CICBM - CSLBM - Light Gas - EM/ET Gun <u>Space-based</u> - Satellite - Platform - Space station	Rocket-propelled impactor TRIM Space-base laser X-ray laser Neutral particle beam HP microware Reentry vehicles BP ETC

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(U) SATKA/C3BM

(U) These are enabling capabilities for any force application capability. These capabilities are categorized as force enhancement and addressed in other white papers. In general, though, surveillance must provide the ability to detect, identify, and track any type of terrestrial and airborne target. This surveillance capability must be robust enough to prevent fratricide. Target data must be available from weapons release until weapon impact (if provided independent of the weapon). Kill assessment must be unambiguous to avoid restriking killed targets, and to assess reattacking of targets with remaining operational capability. C3BM must provide for centralized control and decentralized execution, contain significant decision aids, and allow rapid transfer of weapon operation control.

(U) An alternative to space-based sensors is developing a sensor projectile, package or munitions which is co-deployed or fired first as the terminal controller of follow up weapons. This round could disperse submunition-like sensors which are networked together or could some how loiter over the target area while providing designation of desired targets.

(U) The desired trend is toward ultrasmart (brilliant) autonomous weapons which could do their own target acquisition in the terminal phase without outside assistance. Surveillance and reconnaissance could be done by outside systems, but once target data has been passed and the weapon released, the weapon is stand

alone.

(U) Weapons Delivery Platforms (WDP)

(U) Force application weapons delivery platforms could be space-based (permanently on-orbit), earth-based intercontinental strike weapons (non-nuclear ICBMs and SLBMS, light gas guns, and electromagnetic (EM) rail guns), or spaceborne (manned or unmanned reusable aerospace vehicles).

(U) Space-based platforms provide the most responsiveness. These platforms could be located in any orbits including the moon's. The most likely orbits are low ones. On-orbit platforms should be proliferated, provide 24-hour-per-day global coverage, and be serviceable by telepresence or a manned aerospace vehicle. Proliferation compounds the enemy's counterspace problem and ensures a robust force structure remains after a limited ASAT attack. Global, full-time coverage ensures the ability to conduct prompt and sustained combat operations to eliminate an enemy sanctuary provided by predictable outages. Twenty-four hour-per-day coverage denies the enemy breathing room, maximizes CINC options, and allows maximum shock effect.

(U) Intercontinental strike weapons (ICSW) consist of CONUS-based non-nuclear ICBMs, submarine-based non-nuclear SLBMs, light gas guns, and electromagnetic (EM) and electrothermal rail guns. ICSW platforms are less vulnerable and can be easily retrofitted with the latest technology. However, they are not as responsive as on-orbit platforms and require more infrastructure.

Vulnerability is assessed as less due to assumed reluctance on an adversary's part to attack U.S. homeland. Future space system survivability techniques may, however, swap these relative vulnerabilities. Non-nuclear ballistic missiles also have the disadvantage of being confused with nuclear ICBMs. Some sort of international inspection may be needed to solve this problem. Light gas guns and EM rail guns can propel projectiles to intercontinental ranges. Light gas guns are theorized to propel 400 pound projectiles into LEO or intercontinental distances.¹¹

(U) Many of the advantages previously cited for space-based platforms can be duplicated with manned or unmanned, reusable spaceborne platforms. Additional advantages are recoverability, unpredictability of launch trajectory, and maintainability. They can also defend themselves using active and passive measures. Like ICSW, spaceborne platforms are less vulnerable due to their CONUS basing. Again, this may change if an adversary determines it is easier to strike the US than to attack something on-orbit. Also, like ICSW, their earth-basing allows easier maintenance and upgrade. A separate white paper makes the case for a specialized space weapons delivery vehicle.

(U) Weapons

(U) Space force application weapons ^{could} include:

- Reentry Weapons
 - Nuclear, biological or chemical¹²
 - High explosive
 - Submunitions dispersal

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- Rods, flechettes, non-lethal munitions
- Kinetic energy
 - Rods, rocks, pellets, flechettes
- Directed Energy Weapons
 - Lasers
 - Focused sunlight
 - Neutral particle beams
 - High energy microwaves
 - EMP weapons
 - Plasma weapons (e.g. compact toroids)
- Command and Control Warfare Weapons (covered in a separate white paper)
 - Psychological
 - Visual projections
 - Propaganda broadcast
 - Broadcast jamming
 - Decision-making
 - Virus introduction
 - Communication link break in
 - Data corruption
 - GPS time/position modification
 - Electronic warfare
 - Jamming
- Other
 - Weather modification (covered in a separate white paper)

(U) These proposed weapons can generally be classed as precision guided (or aimed) weapons. They will require self- or externally provided (via satellite) guidance, hypervelocity flight control, smart fuzing, small powerful computers, and high-g hardening. Other enabling technologies include nose tips, lethality mechanism and payload deployment.¹³

(U) Other advances in weapon design will include explosively dispersed carbon fibers (toxic to certain types of electronics), super-hard ceramic pellets traveling at hyper-velocity speeds, miniature shaped-charge explosives, and compact energy sources capable of generating directed-energy beams.¹⁴ Other concepts

include compact microprojectiles, about the size of a soda bottle, employing a variety of kill mechanisms such as anti-material chemical and motor-stopping ceramic shards.¹⁵

(U) Target Considerations

(U) For any given target, certain subsystems could be attacked, such as structures, electronics, software and computer data, information, people, and energy sources. Target location and mobility are critical. Mission objectives could include disruption, delay, denial, or destruction. The mixture of target characteristics and desired outcome drive method of attack.

(U) Fixed land targets will required sophisticated surveillance and targeting capabilities. For example, the ability to image, process, communicate, sort, store, retrieve, and further process target data to 0.1 meter resolution confers a potential to attack targets at submeter accuracy given fresh data and tight control loop logic.¹⁶ Mobile (see figure 1) and moving targets require even more sophisticated capabilities.¹⁷ If a space-based weapon was used when two opposing forces were in contact, a credible identification friend or foe (IFF) capability is required. Any of the recommended delivery vehicles apply. Reentry/DE weapons could be very effective against land targets.

FIGURE 1 GOES HERE

(U) Naval surface targets (figure 2) require the same level of surveillance and reconnaissance with some differences due to the difference in signal to noise from water versus land. IFF is

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an important capability for forces in contact.

FIGURE 2 GOES HERE

(U) Targeting of air targets (figure 3) will be more difficult than mobile land and naval surface targets due to the increased velocities involved. IFF will be critical if force application weapons are use during air-to-air engagements.

FIGURE 3 GOES HERE

(U) Subsurface targets (figure 4) will be challenging targets since the detection and targeting through water may still evade us. Also, the dispersive effect of water on RVs may make their use less effective.

FIGURE 4 GOES HERE

(U) Subterranean targets (figure 5) are similar to fixed land targets, except for different targeting signatures and vulnerabilities.

FIGURE 5 GOES HERE

(U) Potential Technologies

(U) SATKA/C3BM

(U) See section III of Surveillance and Reconnaissance and Integrated C3I white papers.

(U) Weapons Delivery Platforms

(U) See section III of Reusable Delivery Vehicle white paper.

(U) **Space-based platforms.** The U.S. has demonstrated the dispensing of RVs from space-based platforms since the Discoverer

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program in 1959 ¹⁸ ICBM/RV separation is well understood. Peacekeeper RV bus has demonstrated release and back away capabilities required for space-based platforms. Space-based weapon delivery vehicle technology seems fairly low risk.

(U) **Intercontinental Strike Weapons.** Recent articles have discussed the conversing ICBMs and SLBMs from nuclear to conventional capability.¹⁹ ICBMs, currently enjoying great accuracy, could be used to carry non-nuclear weapons payloads.²⁰ Greg Caravan of LLNL proposes arming ICBMs with GPS-guided impact munitions to provide a hard target kill capability employable in a matter of minutes.²¹

(U) Light Gas Guns To be further researched.

(U) EM/ET Guns To be further researched.

(U) Electromagnetic implosions of cylindrical or quasi-spherical solid liners, driven by axial current discharges in the 10 to 100 megamp range, can be used to compress an internal fluid to drive a hypervelocity projectile in an axial gun barrel with high uniformity and shocklessly. This fluid is, ideally, hot hydrogen previously injected by a coaxial plasma gun. The proper discharge of a projectile in space is critical to LEO hypervelocity weapon deployment concepts.²²

(U) **Spaceborne Platforms.** Over the years, numerous spaceborne platforms have been proposed (NASP, MAV, TAV, WDV). The technology challenges have been well documented by the

current NASP program. Other ideas have include hypersonic orbital vehicles (HOVs). Prepositioned HOVs placed at strategic points in earth orbit could respond to local conflicts. The HOVs could be armed and/or carry other military equipment and would allow rapid response. Autonomous navigation, plasma communication, end game targeting, vehicle controllability, and the long term storage of liquid hydrogen fuel are some of the technical risk areas.²³

(U) Weapons

(U) Reentry Weapons. A variety of reentry weapons types are envisioned to include hydrodynamic penetrators, kinetic energy penetrators, pyrophoric enhancement rods, impactor coupled enhancement weapons, explosive warheads, EMP warheads, and conventional submunitions. Hydrodynamic penetrators which have a hard target kill capability, are weapons with 8 kfps minimum impact velocity and employ multiple maneuver RVs. Kinetic energy penetrators (KEP) have both a hard and soft target kill ability and 3 kfps minimum impact velocity. They use a single RV and multiple KEPS. Pyrophoric enhancement weapons can greatly enhance lethality, through rod ignition, using candidate metals such as tantalum and depleted uranium.²⁴ Impactor coupled enhancement, a LLNL paper concept, proposes penetrating rods carrying a secondary warhead into a target for enhanced lethality.²⁵ Electromagnetic pulse weapons theoretically can provide defense suppression. Conventional submunitions could be

dispersed from a maneuvering reentry vehicle.²⁶ Hypervelocity projectiles can be tailored to the targets class. For example, area targets could be attacked with 1000-10000 rodlets of 10-100 grams mass each for tank tops, artillery, supply dumps, airfields and ordinary structures. Point targets such as armed aircraft revetments, capital combatant ships, and missile silos could be successfully killed by 10-100 rods of 0.1-1 kg each with a combined CEP of not greater than 10 m. Finally, deep underground or underwater targets could be attacked using a linear driven string of 100-1000 of these connected rods.²⁷ A high precision micromunition with tank of artillery kill capability would require packaged for delivery and dispensing a mass of about 5 kg. The throwweight of the ex-Soviet ICBM force, for example, could thus deliver about a million of these micromunitions. ²⁸

(U) Guidance technology areas which need to be investigated include miniature GPS receivers, miniature inertial measurement units (IMU), digital processor units and data buses, and adaptable interface units.²⁹

(U) Research and development has been conducted on RV structures. Technologies areas include hypersonic glide vehicles, maneuverable reentry vehicle (MARV), tactical reentry impacting munitions (TRIM), global precision response capability (GPRC), and Sandia winged energetic reentry vehicle experiment (SWERVE).³⁰ Maneuvering RVs could use GPS for guidance and terminal seekers. Maneuverability provides significantly

increased cross range capability.

(U) The science appears mature--what is required are research programs to demonstrate weapons system stability and RV deployment, RVs themselves, fuzing, penetrator design, controllability, lethality mechanisms, non-fratricide, closed loop guidance and control, transonic submunition deployment, multi-warhead deployment, and high Mach nose tips (reentry survival).³¹ It appears miniaturization would have utility as well, especially for actuators for control surfaces and terminal guidance systems.³²

(U) Directed Energy Weapons.

a. (U) Tracking and pointing. Technologies in this area are common for all space based weapon and discrimination applications. The fundamental requirement is to directly engage the target at long ranges in a time-line driven by the limited battle space. The goal is to develop fire control decision function technologies to establish feasibility of meeting performance requirements for accuracy and timeline constraints in dynamic engagements.³³

b. (U) Beam control/optics. Research still required.

c. (U) Laser generation. High energy technologies need further development.³⁴ However, significant progress towards the demonstration of a short wavelength chemical laser (SWCL) has been made during the past few years. With the demonstration of an efficient and scalable SWCL device, the technology will be

available for a kilowatt class laser.³⁵

(U) With the availability of watt-class semiconductor lasers, Phillips Laboratory is spinning off the technology into prototype laser systems for many applications. The Laboratory is working closely with various operational commands in the Air Force as well as other DOD and federal agencies. One example is a portable medical laser, battery-operated 10-watt system that weighs six pounds.³⁶ A variety of high energy lasers have been tested and developed. Ground experiments have been conducted on HF freerunning and fundamental (Alpha) lasers. A scalable laser has been demonstrated in the MW class. Line selected HF, HF overtone, DF and coil lasers have been undergone some ground experiments in the sub MW class. FEL, EDL and High Power solid state lasers have been demonstrated at 100 W in the NIR, 10-100 kW, and 1 kW in the NIR, respectively.³⁷

(U) Fission-Activated Laser Concepts (FALCON) directed by DOE investigates the feasibility of large laser systems which derive their energy from direct nuclear excitation. These reactor pumped lasers might deliver extremely high energy pulses or be operated steady state at multi-megawatt power levels. Wavelengths could be selected in the IR, UV or visible ranges, with nearly 100% transmission through the atmosphere. System designs have demonstrated small size compared to other high-power laser concepts, with excitation power density in the range of 10s of MW/m³.³⁸

d. (U) Plasma weapons. Compact toroids are magnetized plasma rings which can be compressed and accelerated without fluid instability growth. Applications include intense x-ray sources, fusion and plasma projectiles. The stored electrical energy requirement is approximately 10 to 30 megajoules. One megajoule, 9x compression experiments have already yielded about 10 kilojoules of KeV range x-rays.³⁹

e. (U) High Power Microwave. Technology is available, but on-orbit powers are limited.⁴⁰

f. (U) Neutral Particle Beam. Could be used for BMD and to disrupt avionics computers, structures and so forth. The BEAR experiment was not at the weapons level. Power must be increased.⁴¹ More research to be conducted.

**(U) Near Term Technologies and
Operational Exploitation Opportunities**

(U) Certain delivery vehicle/weapons mixes could be demonstrated in the near term. ICBMs with KE weapons could be demonstrated with little development in the short term. Non-nuclear RVs could be launched and reentered from the shuttle or some experimental satellite like STEP. Next, rocket-assisted non-nuclear RVs could be reentered from satellites or the shuttle. Air launched, rocket-assisted hypervelocity weapons could be demonstrated using existing ASAT control infrastructure and ASAT configured F-15s. Commercial spin-ons are not foreseen.

Notes

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White Paper (Fourth Draft)

on

Preparing for Planetary Defense

CAT Name: Planetary Defense

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I. Subject and Problem Statement: Recent years have witnessed an explosion in the discovery and research of objects from space that have the potential for striking the Earth. Amateur and professional astronomers alike have uncovered hitherto unknown objects in the asteroid and comet families. New and more refined Earth-based observing techniques have shed additional light upon the size and nature of these objects. And fast electronic computer systems have enabled orbital calculations to reach a much higher standard of precision.

This new data has resulted in much evidence that the Earth is not only at risk from, but also repeatedly being struck by, objects from space. The strikes appear to occur randomly, and the objects vary in size from a few hundred centimeters to 10 to 20 kilometers across. Larger objects strike less often than smaller ones, but do more damage. Sixty-five million years ago, for example, evidence suggests the age of dinosaurs was brought to an end by the impact of an asteroid that is thought to measure approximately 20 kilometers across. And in 1908, a 50 meter asteroid is thought to have devastated an area covering over a thousand square kilometers when it exploded in the air above the Tunguska river in Siberia. Had this latter asteroid impacted only a few hours later, it would have meant catastrophe for the populated city of Moscow. Impacts such as the Tunguska incident are thought to occur every few hundred years, while craters on the surface of the Moon, Earth, and other planets suggest smaller impacts occur continuously.

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Once we recognize that collisions with objects larger than a few hundred meters in diameter could threaten global civilization, means for mitigating them seem clearly worth considering. We develop this theme by first defining the threat and looking at some of the technologies and methods for acquiring, identifying, tracking, and cataloguing potential impactors. We then focus on issues associated with interception and deflection or destruction efforts. And finally, we look at the benefits of a DoD role in an international effort and make specific recommendations as to how we might best become actively involved in the effort to protect the Earth from catastrophic impacts of planetary debris.

II. The Capability and Its Relevance: The reader's initial reaction to this problem statement, contained in a document of such vision for future capabilities of the Defense Department, may be something like "You can't be serious!". We admit that usually when we first mention this issue to the unaware, we often hear them laugh out loud or at least see them try to stifle a grin. It does have a "Chicken Little" connotation about it. However, though this subject still suffers from a high "giggle factor", we assure you that we are very serious about the requirement for measures to counter this naturally occurring threat. Most of humanity is oblivious to the prospect, but this hazard from space is a subject of deadly concern to the entire population of the planet.

Work by several nationally recognized scientists who have been investigating this issue for a number of years, some for decades, has brought them to the awareness that the risk may be just as great for the average citizen of the United States to die as a result of an asteroid impacting the Earth as to die in an aircraft accident!¹ Incredible, you say! Many people die every year as a result of airplane crashes but there has been no recorded death due to impact of rocks from space, albeit there have been some relatively close calls with small meteorites striking cars and houses.² However examination of the estimated probability numbers, though they still be very round, bears out this seemingly dubious

supposition and lead to congressionally directed studies in 1991 and 1992 managed by NASA.

Almost everyone, perhaps in youthful days, has looked up at the sky on a clear night to glimpse a meteor, commonly called a falling star, streak across the heavens. Certainly everyone has seen the craters on the Moon, perhaps even through binoculars or a small telescope. What we were seeing are remnants, and perhaps warning signs, of this very real threat. So why isn't the magnitude of this danger commonly held knowledge? Simply put, we are dealing with events, time scales and forces which are well outside our human experience.

The Earth's atmosphere protects us from many dangers in the harshness of planetary space, from intense solar radiation to the most common variety of planetary debris, meteoroids of tens of meters or less in size. The heat from friction created by the force of their entry into the atmosphere, at 10 to 30 kilometers per second, causes meteoroids of this size to completely burn up or explode before they reach the ground, referred to then as meteors or bolides if they explode. However, almost every literate person has also read of, and some personally seen, meteors of sufficient size for a remnant to reach the ground, then called a meteorite and frequently of an iron-metallic composition. These events are common, occurring several times a year around the world.

What is less commonly known is the force with which these objects can enter and explode or impact the Earth (See Figure 1). A stony meteoroid of 10 meters in diameter, once it hits a resistance greater than its own mass (in this case a column of air which builds up in front of it), will explode with a force of about 20 kilotons TNT.³ The exact yield of course depends on the speed of entry into the atmosphere and the meteoroid's specific composition, but this is greater than the force of the device which destroyed Hiroshima. Such "airbursts" are regularly detected by Defense Support Program (DSP) satellites, according to data recently released by the Air Force to scientists studying this phenomena. At least 136 such events of greater than 1 kiloton have occurred around the world since

Figure 1: Asteroid Diameter vs Equivalent Yield

1975⁴ with the latest "big one", at about 100 kilotons TNT, having been detected just this February.⁵ But as impressive as this is, keep in mind that these are just the ones that weren't big enough to make it to the ground!

So how big does a rock from space need to be to strike the solid Earth and, just as important, how often does this happen? Scientists calculate that it would take a stony object of greater than 50 meters in diameter to survive penetration of the atmosphere.⁶ (Planetary debris of this size and larger, up to several hundred kilometers, are generally referred to as asteroids.) Based on calculations derived from surveys of the age and density of impact craters on the Moon, this probably occurs at least once a century. But before we breathe a sigh of relief, it is also calculated that such an object would impact with a force of 10 megatons (Mtons)!⁷ (See Figure 2.)

We believe an event of this magnitude last occurred 30 June, 1908, in Tunguska, Central Siberia. Although this object did not quite make it all the way to the ground, it is calculated to have exploded with a force of ~12 Mtons at an altitude of 5 to 10 kilometers. Even so, it devastated forests over a 1,000 square kilometer area and ignited large fires over thousands of acres near ground zero. Had the event occurred just 3 hours later, a mere microsecond of geologic time, it would have been catastrophic for the citizens of the Russian city of Moscow.⁸ There is also evidence that a similar event occurred over New Zealand's South Island about 800 years ago.⁹ As populated areas continue to spread across the Earth's surface the probability will increase of a strike in a population center, ruining the day for a lot of people.

But a 50 meter object is probably the least of our worries given the relatively localized effects. Meteor Crater near Winslow, Arizona, is an evident example of such a comparatively small impact. But, we can see every clear night that the Moon has been struck many times by much larger objects and so has the Earth, although it has taken observations by satellites to get us to realize just how often and how big. Geologists guided by observations from orbit have begun to detect more and more features on the

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Figure 2: Impact Interval vs Equivalent Yield

Earth's surface which are actually remnants of impact sites. Some are quite large such as the Manicouagan Crater in Canada at over 65 km in diameter. Almost all have been partially obscured by the Earth's dynamic weather and vegetation, making them difficult to detect while on the ground. And anyone who reads the popular press or listens to the media in recent years could not have missed the many articles and discussions about the asteroid (or asteroids) which probably killed off the dinosaurs.

A theory first advanced by the father-son physicist-geologist team of Luis and Walter Alvarez in 1980, it is now widely accepted by geologists and paleontologists alike that an impact by one or more relatively large asteroids occurred approximately 65 million years ago. This cataclysmic event is believed to have wiped out the dinosaurs, and many other species on the Earth as well, by the immediate and more long term effects of the impact(s).¹⁰ Scientists now believe the most likely site of at least one large impact from that time is in the Gulf of Mexico, off the northern coast of the Yucatan Peninsula.

Readily visible evidence of the impact has long since been obscured by the Earth's dynamic surface changes but the subsurface rock still bears wounds from this catastrophic event.¹¹

Estimated to be greater than 10 kilometers in diameter, the suspect asteroid would have struck with a force of about 100,000,000 Mtons TNT, or 10,000 times the total of all the world's current nuclear arsenal.¹² Not only would this ring the Earth's bell, but it also would have thrown trillions of tons of material into its atmosphere and started a global firestorm which would have added more smoke and soot to the layers of dust already in the stratosphere. The global winter resulting from blockage of the Sun's heat reaching the surface might have lasted for more than a decade, accounting for the extinction of at least half of the different species of life on the Earth at that time.¹³ The settling of this dust to the surface created what geologists refer to as the "Cretaceous/Tertiary (K/T) Boundary", which is a physical demarcation in Earth's geologic record (i.e. rock layers) between these two ages and lead to the Alvarez's theory. Furthermore, paleontologists have discovered

several other points of mass extinction (See Figures 3 and 4) in the geologic record with the speculation being they may have been caused by the same type of event.¹⁴

But it doesn't take a "planet buster" of 10 km in diameter to wreak global havoc. Scientists estimate that the effect from an impact by an asteroid even as small as 0.5 km could cause climate changes sufficient to dramatically reduce crop yields for one or more years due to killing frosts in the mid-latitudes in the middle of summer. Impacts by objects 1 to 2 km in size could therefore lead to mass starvation by a significant portion of the world's population as few countries store as much as even one year's required amount of food. The death toll from direct impact effects, blast and firestorm, as well as the climatic effects could be as much as 25% of the world's human population.¹⁵

This would be a natural disaster totally outside our realm of comprehension and leads many people to suspend their belief that anything like this could ever happen despite what the many recent studies by the scientists are telling us. It is similar to our individual egotism that a fatal accident will never happen to us, only on a much grander, entire species level scale. Like the danger of a large earthquake in Southern California, people do not accept the risks involved has having any relation to their daily lives. But the threat which we discuss here gives new definition to "The Big One"!

Some might argue that asteroids of this size have all already been swept clear by the planets over the millennium. Not so! Astronomers have already catalogued over 120 asteroids of 0.5 km or larger that are in orbits around the Sun that also cross the Earth's orbital path.¹⁶ (See tables on Earth Crossing Asteroids, or ECAs.) The work to detect the Near Earth Objects (NEOs) has been going on for a couple of decades and new techniques and technology has increased the rate in which they are being discovered. On average, two or three NEOs of a few tens of meters or more in size are currently being found every month.

And just for timely proof that such cosmic events do still occur, a comet named Shoemaker-Levy, after its coincident discoverers (one of whom, Dr. Eugene Shoemaker, is

Figures 3 and 4: Mass Extinction Diagram and Curve



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very prominent in the planetary debris detection business), is predicted to impact the planet Jupiter in July of this year! This is certainly not an every day occurrence and this is the first time we have known about such a spectacular event in advance, giving us a chance to observe it happen. This will be an event of unprecedented interest to all space scientists and astronomers, as it should be for all solar system inhabitants as a demonstration of what cataclysms can occur in our natural environment.

Astronomers believe they may only have found about 5% of the total number of asteroids greater than 0.5 km in size. Based on estimated asteroid population densities, astronomers believe there are well over 2,000 such asteroids in Earth crossing orbits. However, at the current rate of progress it will take over 100 years to insure they have catalogued at least 90% of them. A proposed global detection system might reduce this to 25 years, but even so, new members of this ominous population are continuously being created by the interaction of the planetary gravitation fields on the main asteroid belt between Mars and Jupiter and the comets which enter the inner solar system from deep space.¹⁷

So how does all this boil down to the rather significant risk of death by asteroid mentioned earlier? In round numbers, scientists estimate that there will be an impact on the Earth of an asteroid large enough to have global consequences every 500,000 years. So the probability of a strike in any one year is 1 in 500,000 assuming they are completely at random. Since 25% of the world's population could die as a consequence, the risk of death for any one individual if such a strike occurred would be one in four as a worldwide average. Therefore the risk of death in any one year for an individual is 1 in 2,000,000. Over a seventy-five year lifetime the risk would then be about 1 in 25,000. This is within the ball park of the before mentioned risk of death of a US citizen in an aircraft accident or any number of other yearly accidents or natural disasters such as hurricanes, earthquakes and floods (See Table 1), all for which this nation spends tens of millions of dollars each year to both warn people of their approach or to mitigate their effects.¹⁸

Figure 5: Effect -- Number Killed Per Event vs. Probability

Figure 6: Average Annual Fatalities and Average Fatalities vs Asteroid Diameter

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Please don't misinterpret what we are saying here. We are not running around yelling "The Sky is Falling!" We are not advocating a crash program costing billions of dollars to build a asteroid deflector. No specific asteroid threatening to impact the Earth has yet been identified and many years may pass (hopefully) before one is. However, the probability is finite. Indeed, one day it will be exactly equal to 1. Even if one does find the risks of death due to a asteroid outlined above hard to swallow, we do know that the Earth has been impacted by large objects in the past and that someday the planet will be faced with the prospect of another such catastrophe. Currently we have no idea when that day will come, hence a modest but prudent ECA detection program is warranted. A few million dollars judiciously spent may buy us a lot of peace of mind. However it may also alert us to the prospect that our day of reckoning is closer at hand than we realize.

Therefore, it is also prudent that some effort, mainly mental, be spent to examine what capabilities we currently have versus what capabilities we may need to counter such a threat. Once these are identified, we can then formulate some contingency plans to have on the self if the time comes, and develop a coherent path to get ourselves to a more comfortable position by encouraging the development of technologies which will not only help us deal with this problem but have many other benefits in the exploitation of space or "spin-offs" for commercial applications as well.

Which brings us around to why we believe the Department of Defense should take an active interest in this issue. Of course should such a disaster actually occur, at least four compelling reasons come immediately to mind:

1. *The Resulting Need for Humanitarian Relief:* The DoD would certainly be involved in any humanitarian relief effort after such a disaster. Humanitarian relief efforts have rightfully become a constant mission for our forces, with many examples during the last few years, not only in the US with relief efforts for victims of Hurricane Andrew in 1992 and the Midwest Floods in 1993, but also wherever it might be needed in the world. But these examples would be relatively minor efforts compared to what might be needed

Table 1: Relative Probability of Death by Asteroid



in response to even a relatively small impactor if it occurred in a populated area. This might require a concerted effort from many nations and place a severe strain on the resources of the international community even if everyone was cooperative.

2. *The Destabilization of the International Community:* A natural disaster of this magnitude could put tremendous pressure on the nations involved, both friend and foe, destabilizing not only their economic but social fabric. Indeed, such a calamity would affect the entire world community. Governments have lost stability to lesser disasters when they found their resources lacking to adequately respond to the needs of its victims. Many times it has only been the infusion of external aid that has prevented more severe outcomes. What will be the result when a significant portion, such as 25%, of the world's population is in need of aid, particularly when it is not known how long the effects may last?

3. *The Threat to National Security:* Given such an event, the effects could very well threaten the national security of the United States even if it were not physically impacted. We would be dealing with scenarios in which the world has almost literally been turned upside down. We're talking post-global-nuclear war holocaust stuff lacking only (maybe) the lethal radiation effects.

4. *The Call for Action:* Were an impactor to be detected in advance, the nation and perhaps the entire planet would quite naturally look to the DoD for the fortitude, technical expertise and leadership, not to mention the required force in the form of nuclear devices, to counter such a threat to its citizen's lives and well being. Although other organizations and agencies certainly will be involved, NASA and DOE for instance, and there would most likely be an international effort, few organizations other the United States Department of Defense have the experience and wherewithal to even attempt such an effort. Our Russian counterparts are probably the only other team in town, but such an project could indeed take a consolidated effort. Suffice it to say that the DoD would form the core around which the rest could organize.

All these potential effects from an asteroid impacts are currently within the DoD charter of responsibilities for any number of more commonly occurring events. Just because it may only happen once in 500,000 years doesn't absolve us of responsibility if it does occur on our watch, particularly if we could have the ability to prevent or at least mitigate it. And perhaps for the first time in not only human history, but the battered history of the planet, we, the inhabitants of Earth, are on the verge of having such capability.

For many natural disasters such as earthquakes, hurricanes and tornadoes we don't know any viable technique for preventing them. Some we cannot even give adequate warning against. Such is not the case with asteroids. We certainly have the technology, with a relatively modest investment, that would allow us to provide warning of an impending catastrophe maybe years and perhaps decades in advance. In most cases for objects with sub-global consequences more than enough warning time could be given to allow at least evacuation of affected areas once an adequate detection system were in operation for several years and their orbits precisely known enough for reliable predictions. We also have the technical understanding of the forces required (orbital mechanics and nuclear explosions) to prevent such disasters, at least up to the 10 km size asteroid and given enough warning time.

III. Potential Technologies to Counter the Threat: Work is needed in two broad areas: capabilities to detect and characterize the potential threat and capabilities to mitigate it once a specific threat is identified.

A threat is defined as a planetary debris object (asteroid or comet) of sufficient size and composition to do significant harm to Earth's inhabitants either by direct impact effects or damage to the ecosystem should it strike the planets surface or explode in its atmosphere. The analysis we examined earlier showed this to be, at most, all objects greater than 50 meters in size because those are the ones with the potential of surviving their entry into Earth's atmosphere. However, one could argue that objects smaller than 500 meters

Figure 7: Tunguska Blast

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should not be of concern since their effects would be relatively localized and most probably, at least for another century or so, would fall in unpopulated areas. This fortunately was the case for the Tunguska event (which was not even an impact), but had it occurred over a populated area the loss of life would have been consequential (See Figure 7). And as the human population spreads, the probability for great loss of life due to any sizable impact anywhere on a land goes up.

Even ocean impacts of these smaller objects are of some concern because of the potential for tsunamis being created by even an object as small as 100 meters. A fifty foot ocean wave could do significant damage to surrounding coastal areas, actually increasing the destructive potential above that from a same sized object's land impact. This is a hypothesized phenomena not yet well understood. Also, some might even consider the loss of florae and fauna in even unpopulated areas to be of significant enough concern to be worth some amount of effort. So drawing the line somewhere above the 50 meter size invites some debate.

However, for the remaining duration of this paper we will concentrate on objects greater the 0.5 km, up to about 10 kms, with the understanding that anything larger is an exceedingly rare event, even by our standards, and that capabilities against our chosen class, defined as smaller than ($<$) 10 km but larger than ($>$) 0.5 km, would give us significant capability against anything smaller, with the notable exception probably being distant detection of the object.

Surveillance - Detection, Tracking and Characterization: Scientists who have worked with this issue for a number of years have put much thought into the surveillance issue. Some prototyping of potential systems has already been done, a notable example being the Spacewatch System at Kitt Peak, Arizona, organized by Dr. Tom Gehrels of the University of Arizona who has worked on this issue for over three decades. There are already some specific ideas and programs which could be quickly initiated using dedicated ground based sensor networks based on current technology. Unfortunately, lack of any

significant funding has kept even a modest program from being initiated. Until this year, the Spacewatch System was run on a shoestring through private donations.

In the report of the NASA study commissioned by the US. Congress, resulting in three Near Earth Object Detection Workshop sessions held during 1991, the scientists propose an internationally supported detection system they call the "Spaceguard Survey Network", after a system conjectured by Arthur C. Clarke in his science fiction novel *Rendezvous with Rama*. This system would provide detection of objects as small as 1 km diameter within a suitably large volume of space using a network of six globally dispersed 2.5 meter aperture, f/2 prime focus reflecting telescopes, each with four 2048X2048 pixel charge-coupled device (CCD) detectors in the focal plane. Automated signal processing and detection computer systems would recognize asteroids and comets from their motion against the background of stars. All technology for this system has already been demonstrated in the prototype at Kitt Peak. Acquisition costs for such a system could be as low as \$50M and the annual operations and maintenance costs would be in the \$10M range. This system could be in operation in less than 5 years after funding was made available.¹⁹

This system sounds remarkably like the Ground-based Electro-Optical Deep Space Surveillance System, or GEODSSS, albeit with smaller 1 meter telescopes and CCDs, but built at four sites a decade ago and currently operated by the Air Force to track manmade geosynchronous satellites. However, this Space Command surveillance asset does not do wide area searches needed for asteroid detection, but rather searches for manmade objects based on their predicted position and rejects the detection of any object which moves as fast as an asteroid, providing it where close enough to be seen. In a way, GEODSSS, does the converse of what Spaceguard sites would need to do. However, it could probably be upgraded to do asteroid detection if it weren't already heavily tasked with its current mission.

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But there are many parallel techniques between what the Spaceguard Network would be required to do and what is currently done by U. S. Space Command's network for "space surveillance" of manmade objects. The Spaceguard Report also speaks to the need for a "survey clearinghouse and coordination center" to catalog newly discovered objects, coordinate observations by other sites to verify existence of each object and collection of addition sightings to determine their orbits. This center would also project the orbit of each object, both for "recovery" (sighting of the object on the next orbital pass) and to determine if any pose a threat to Earth. All this is currently done for asteroids and comets by the International Astronomical Union's Central Bureau for Astronomical Telegrams and Minor Planet Center in Cambridge Massachusetts, but at a rate far less than would be needed for the Spaceguard Network. However, such an activity could benefit greatly from the experience and automation used for similar tasks done for manmade objects in Earth orbit by the Air Force's Space Surveillance Center (SSC) at Cheyenne Mountain AFB, Colorado. This is not to say that this existing network could easily take on this additional task (it couldn't), but it is to say that the Air Force has significant experience in a closely related area which could be applied to the problem.

However, the Air Force's current space surveillance mission could also benefit from systems developed for asteroid surveillance. Optical systems developed to detect and track these relatively dim objects (down to 22nd magnitude) might also find application against the tracking problem presented by manmade orbital debris. Precise tracking of asteroids can also be greatly enhanced with augmentation by powerful deep space radar systems. Currently there are only two such system available, at Arecibo, Puerto Rico, and Goldstone, California, and even their performance is limited in relation to this task. Research and development on more capable radar systems would probably be of benefit to the traditional space surveillance mission as well, not to mention other defense related areas. Work on sensors, both active and passive (microwave, multi-spectral and hyper-spectral) could also be of mutual benefit. In the software and modeling arena, both

missions would benefit from development of more precise and comprehensive, as well as rapid, orbit prediction models. This might also lead us further into use of parallel processing techniques for space surveillance that we are just starting to investigate. Bottom line is that we see great potential for cross flow of technology, equipment and techniques between these two space surveillance missions which in itself would warrant interest by the Air Force.

So far we have only talked about ground based technologies. It is always advantageous when dealing with dim celestial objects to get up above the atmosphere to eliminate its interference with the object's signature and the diurnal constraints imposed by the Earth's rotation. The asteroid detection and tracking mission by itself may not warrant space based capabilities, but coupled with other more traditional Air Force missions a mutual benefit would be gained. More distant, and therefore earlier, detection of both asteroids and comets would be possible from space based systems. It would also give us greater capability against a class of asteroids, called the Atens, which are defined by their orbits about the Sun being inside of Earth's but reaching out far enough to cross the Earth's orbit (See orbit diagrams, Figure 8-11). Because we would almost always be looking toward the Sun to see objects in this class, they are difficult to detect from ground based observatories. Although less than 15 objects in this class have so far been discovered, it is speculated that this class may be at least as common as the Apollo class, asteroids in orbits more similar to Earth's and the class to which the majority of known ECAs (over 100) belong. Astronomers point out that Mercury, the planet closest to the Sun, has more craters than any other object in the solar system.²⁰ Therefore a space based surveillance system, perhaps even Moon based or better yet, at a stable Earth - Sun Lagrangian point (L2 or L5??), would have distinct advantages in covering certain classes of objects.

Finally, in discussion of the surveillance mission, we come to "characterization" of the asteroids and comets. Although we have known of their existence for almost two hundred

Figure 8: ATEN Asteroids

Figure 9: APOLLO Asteroids

Figure 10: AMOR Asteroids and Short-Period Comets

Figure 11: Long-Period Comets

years, we still know little about their composition, or even if it is common for them to be the typical solid, large rock-like body we usually think of. There is some speculation that many of them may actually be more like orbiting rubble piles. Little more is known about comets although they are typically thought of as "dirty snowballs".

Many things can certainly be learned from concerted remote sensing program but before we could have full confidence about what effects certain mitigation techniques might have, we would want to do a closer in survey, especially given enough warning about a specifically identified threat to impact. Hence asteroid and comet rendezvous missions are of great importance to the surveillance of this potential threat to ensure we learn as much as possible about these possible adversaries. Because of the communities interest, close approaches to main belt asteroids were added to the Galileo Jupiter mission. It passed within 1600 km of the asteroid Gaspra in October 1991, and to within 3200 km of the asteroid Ida in August of 1992. NASA Space Sciences Office is also planning a Near Earth Asteroid Rendezvous (NEAR) spacecraft to co-orbit for at least one year with an Apollo asteroid later this decade. These are examples of the kind of missions that can be done with current technology. The currently ongoing BMDO/NASA sponsored Clementine mission to the Moon with a subsequent close approach to the asteroid Geographos to test SDI developed sensors is an example of the kind of mission with mutual benefits which can be conducted. History may well look back on the Clementine mission as the Defense Department's first foray into this new mission area!

Threat Mitigation: Mitigation of earth-threatening asteroids and comets, to include both deflection and fragmentation options, has received substantial attention over the last three years. In particular, the NASA-sponsored Near-Earth-Object Interception Workshop investigated the subject in-depth and made this conclusion: "... chemical or nuclear rockets with nuclear explosives are the only present or near-term technology options available that have significant probability of success without significant research

and development activities." ²¹ More succinctly, the Chairman of the workshop indicated to Congress that "... technologies currently exist that could be integrated into systems capable of protecting the earth from most any NEO impacts." ²² In short, news from the mitigation front is good.

As both background and support for the conclusions above, this section addresses mitigation strategy and intercept scenarios, reviews the NEO threat with respect to the intercept scenarios, and then discusses to first-order a selection of mitigation options. Finally, this section addresses the sensitive implications of using nuclear explosives in an earth-defending role. As an aside, the key source of information for this section is the record for the Congressional hearing on "The Threat of Large Earth-Orbit Crossing Asteroids". ²³

Mitigation Strategy: The previous section introduced a curve of "annual average fatalities" as a function of asteroid size (Figure #6) This "fatality curve" rises sharply and peaks with asteroids one-to-two kilometers in diameter, the threshold size for global effect as previously discussed. Very simply, one should first develop mitigation options for those objects correlating to the peak in the curve, and secondly those larger. Intuitively, options which accommodate the large asteroids should also accommodate the small ones, but there may also be less-complex, less-costly, and thus more appropriate options for dispatching the small assailants. Such is the proposed mitigation strategy. Now before considering options, intercept scenarios and a re-look of the threat are presented below.

Intercept Scenarios: There are two intercept scenarios, distant and close-in, as summarized in Table #2 below. ²⁴

Distant intercept, which implies distance in both space (interception at the sun, i.e. NEO perihelion) and time (interception at two or more orbits prior to predicted final approach), is the scenario of choice. It is desired since at a distance relatively small deflections suffice to avoid earth impact while allowing use of the full range of propulsion and deflection technology options available. Importantly, it allows for a "deflect-look-

deflect" style of operation which is prudently conservative in nature. And finally, if inadvertent fragmentation were to occur, the resulting debris would have time to disperse before reaching earth. By way of calibration, deflection velocities for the distant intercept scenario are on the order of centimeters per second.^{25,26}

Table # 2: Intercept Scenarios ²⁷

1) Distant Intercept ... the simpler case

- Small deflections suffice
- Allows full range of options
- Opportunity for deflect-look-deflect

2) Close-In Intercept ... the tougher case

- Large deflections
- Limited to high energy options
- One or two shots

The close-in scenario is the tougher case and involves interception of an object on final orbital approach. This would likely occur a few tenths of an AU from Earth (AU, Astronomical Unit = 150 million kilometers) and require deflections on order of a thousand times larger than the distant intercept case.²⁸ The need for larger deflections would limit propulsion and deflection technologies to those providing high energy and, accordingly, have increased potential for inadvertent fragmentation. And finally, time may only allow for one or two attempts at deflection. It is now helpful to review the threat in light of these two intercept scenarios.

Threat Categories: Following the lead of the Interception Workshop, there are four threat categories as identified in Table #3 below. The first two categories are clear candidates for distant intercept while the second two would likely require close-in deflection. And in each category, warning time is the obvious key figure of merit.

Table # 3: NEO Threat Categories²⁹

- 1) Well Defined Orbits
 - Earth-Crossing Asteroids (ECAs)
 - Warning Time: Decades
- 2) Uncertain Orbits
 - Newly Discovered ECAs; Short-Period Comets
 - Warning Time: Years
- 3) Immediate Threat
 - Long-Period Comets; Small ECAs
 - Warning Time: 1-12 Months
- 4) No Warning
 - Long-Period Comets; Unknown ECAs
 - Warning Time: 0-30 Days

The first category includes objects whose orbits can be well-determined, specifically the earth-crossing asteroids (ECAs). Once discovered and catalogued, subsequent optical measurements of these objects, perhaps coupled with radar tracking, can yield orbital predictions with tight position errors (on the order of the Earth's radius) well into the future, thus giving decades of warning time.

The second category also includes ECAs, but newly discovered ones for which the orbits have not been well-determined due to limited tracking opportunities. Some asteroids may also display "chaotic variations" in orbital eccentricity which further confound prediction (Figure # 12).³⁰ This category also includes short-period comets (periods less than 20 years) which, due to outgassing while near the sun (seen as their characteristic tail), have non-gravitational components to their orbits which make them hard to predict. The coma surrounding, and hence obscuring, a comet also contributes error. Orbital uncertainties for both of these objects, then, limit warning times to years.

Figure 12: Chaotic variations of asteroid orbit

The third category includes long-period comets (periods greater than 200 years) and newly discovered ECAs. The comets could come from any inclination and be a first time visitor, making their early detection difficult but critical. Earliest feasible discovery of a long-period comet on "final approach" would yield at best several months warning time. Newly discovered ECAs, perhaps succumbing to Chaos Theory, or ones simply missed during survey, may also yield limited warning times.

The final category is the "horror scenario" and includes objects which simply arrive on the scene with little or no warning. Ironically, this is the most likely case since most asteroids and comets remain undiscovered.³¹

Having defined intercept scenarios and the threat, we may now consider mitigation.

Mitigation Options: To first order, current technologies can mitigate threatening earth-orbit crossing asteroids and comets. There are basically two technology areas to consider: those related to propulsion, and those related to deflection/fragmentation as summarized in Table #4. We submit, given the notional rigor of this paper, that all the technologies discussed could accommodate either distant or close-in intercepts as a function of NEO size. System sizing and sensitivity analyses are beyond the scope of this effort.

For propulsion design, we desire a system with high specific impulse. This property would give an interceptor high in-route velocity, thus increasing the chance for distant intercept. It would also give high terminal velocities, and hence kinetic energy, which could broaden deflection/fragmentation options. And as a function of system design, high specific impulse could allow for relatively large payloads. Nuclear propulsion offers the best near-term advance in specific impulse over current technology, specifically by a factor of two or three over chemical propulsion designs.³² Both the United States and Russia have developed nuclear propulsion systems but none has yet been tested on orbit, and what is more, "no current or near term DoD lift requirements

mandate nuclear capabilities."³³ Planetary defense could mandate such a design. Other propulsion options, clever but highly speculative and not likely to be available by 2020, include mass driver reaction engines located in situ, hypervelocity systems employing nuclear explosions to impart momentum, and antimatter devices.³⁴ Chemical and nuclear propulsion systems now in development offer the best options for planetary defense.

Table #4: Propulsion and Deflection Technology Options³⁵

1) Propulsion

- Chemical	... Current Technology
- Nuclear, Mass Drivers	... Next Two Decades
- Hypervelocity, Antimatter	... Several Decades

2) Deflection / Fragmentation

- Nuclear, Kinetic Energy	... Current Technology
- Lasers, Ultra-High Kinetic Energy	... Next Two Decades
- Antimatter, in situ Mass Drivers, Solar Sails, Asteroid Eaters	... Several Decades

Deflection/fragmentation options constitute the second technology area. Kinetic energy projectiles and nuclear devices offer current solutions. By way of calibration, a 200 kg projectile with 12 km/s closing speed (within the capability of chemical systems) could successfully deflect a 100 meter asteroid in a distant intercept scenario.³⁶ Similarly, a 100 Kton nuclear device could accommodate a 1 km asteroid while a 10 Mton device could accommodate a 10 km asteroid.³⁷ The "best" nuclear device for the purpose of NEO deflection would be an enhanced radiation design, one which provides a large flux of high energy neutrons. These are necessary to cause material blow-off from the object after irradiation from an explosion in a "stand-off" mode.³⁸ The use of a nuclear device in a stand-off mode represents the "gentle nudge" of all the options available. Though

technically much more difficult, nuclear devices exploded on or beneath the object's surface impart ten or more times the impulse of a stand-off explosion.³⁹ This approach would require detailed knowledge of the object's composition and propensity for fragmentation, however, and may also have larger payload requirements, thus offsetting any advantage. Relative to kinetic energy options, nuclear options appear "to be favored for NEOs over about 100m diameter."⁴⁰

Other near-term options relative to the year 2020 include the use of ground or space-based lasers to induce material blowoff, and ultra-high kinetic energy devices requiring nuclear propulsion.⁴¹ And far in the future, options include the use of antimatter,⁴² large solar sails,⁴³ and man-tended mass drivers or reaction engines located *in situ*.⁴⁴ Finally, there could come a time for "Asteroid Eaters". In this scheme we would infest the object with a few devices whose purpose is to replicate themselves using "desk-top manufacturing" technology and the asteroid itself as raw material. Over the period of several months or a few years, these devices, recreating themselves into an army of thousands, could completely "mine" the asteroid away, or at least reduce it to a size that is no longer a threat or is more easily maneuvered by rocket technology. A variation on this would be to have these devices also mine the asteroid for fuel that rockets could use to move the object into a benign orbit. Technology advances are required in "Desk-top" Manufacturing, Artificial Intelligence, Materials "Permutation" (molecular breakdown and alteration), Robotics & Micro Machines. Advances in these areas could lead to many "spin-offs" in other defense or commercial applications.

In short, there are many promising options for deflecting or fragmenting earth-threatening asteroids and comets. The apparent best option today includes nuclear devices and perhaps nuclear propulsion. These, however, carry political ramifications which must be addressed.

Nuclear Solution / Political Fallout: The good news is nuclear devices can protect the earth from threatening NEOs; the bad news is they carry heavy political

baggage. Ironically, these devices "... could be notably straightforward to create and safe to maintain because they derive from vast research and development expenditures and experience accumulated during the forty-five years of the Cold War."⁴⁵ These devices could not be used as weapons without an appropriate re-entry vehicle. And, in any event, international protocols and controls could be established to minimize potential for misuse.

The debate will certainly continue, as evidenced by the "Deflection Dilemma": "... the potential for misuse of a system built in advance of an explicit need may in the long run expose us to a greater risk than the added protection it offers." ⁴⁶

IV. Near -Term Technologies and Operational Exploitation Opportunities: We have discussed what we believe to be some more creative approaches, many of which we think are valuable in that the technology involved will have application in other high technology and space oriented endeavors. We believe that a wealth of progress in man's conquest of space can be gained by the capture of an ECA into Earth orbit. Besides just the experience in large space operations such an endeavor would give us, great benefits could be gained through mining of the asteroids natural resources (including its orbital energy) or use of the asteroid as a space platform for large systems used in surveillance of the Earth or near-Earth environment. An asteroid parked in an orbit slightly higher than geosynchronous might be an ideal base of operations to maintain and salvage geosynchronous communication and surveillance satellites. Its orbit would naturally provide periodic revisit to all geosynchronous stations. A captured asteroid could also be used for large space based manufacturing or even as a "space dock" for buildup of interplanetary missions, eliminating the need to launch large structures from the bottom of Earth's gravity well. In summary, we see use of these asteroids as "stepping stones" for man's future in space.

Recommendation: The longest journey begins with one small step. The current efforts by a few extremely dedicated individuals are commendable, but lack the national

level focus and impetus to achieve the necessary results. A few foresighted predecessors led us into the true control and exploitation of the air, we believe the Air Force should now begin this inevitable journey into true control and exploitation of space. It should establish a project office to provide the leadership and advocacy necessary to achieve progress in this new but critical mission area.

Initially this project office will be responsible for examining and fostering capabilities to detect, track, characterize and mitigate planetary debris of sufficient size to cause significant destruction of human lives and property should it impact the Earth. To do this it will:

- a. Coordinate with existing efforts within DoD (if any), NASA, DOE, and Academia. It will coordinate resource support for these efforts where needed and consolidation of efforts where warranted.
- b. Seek cooperation with and support for similar efforts in the international community and lead the efforts of the United States team in the international arena.
- c. Advocate before Congress and international bodies the funding and fielding of an internationally supported surveillance system similar to that already proposed to Congress.
- d. Seek the set aside of existing resources determined to be surplus which may aid in the surveillance and mitigation of the planetary debris threat. Specifically, applicable space lift capable missiles and nuclear devices.
- e. Support the development and cross feed of applicable technology efforts.
- f. Plan and program for potential future efforts to include:
 - 1) Contingency planning for anticipated mitigation efforts.
 - 2) Requirement definition for technology needs, emphasizing multi-use potential.
 - 3) NEO rendezvous, characterization and deflection test missions.

For decades we as a species have lived in fear of our own destruction by the space delivery systems and nuclear warheads we have designed to employ against our own kind. We find it somewhat ironic, but perhaps a sure indication of a divine sense of humor, that as we rush to discard these dreadful weapons we find we should now work together in learning to employ these same systems as the tools to deliver our planet from naturally occurring devastation.

We must now prepare for planetary defense!

NOTES

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