Discoverer II:
A Space Architecture for Information Dominance

G. D. Duchak
SAGE Solutions Group, Incorporated
6229 Martins Brandon Way, Suite B200
Centreville, VA 20120-3942
703-627-1227
george@sage-solutions.com

Abstract[1]—Discoverer II is a space-based SAR, GMTI and DTED[2] demonstration expected to launch in mid FY04. It is a risk reduction effort on the path to a global constellation of similar radar surveillance satellites that will provide near instantaneous access to and constant surveillance of Areas of Interest almost anywhere on the globe. Like the ubiquitous surveillance camera at the local Quickmart, always monitoring the store and its occupants, a system such as Discoverer II can constantly monitor fixed and moving objects of interest in all weather, anytime and anyplace. The omnipresence of such a capability has the fundamental capacity to change how our adversaries behave and to fundamentally alter how the US will react to threats to our national security.

On the battlefield, the information provided by this omnipresent God's eye view will enable precision maneuver and strike. Constant surveillance allows the battlefield commander to understand an adversary's intentions and neutralize them before they place US forces in harm's way. The precision strike that a Discoverer II system brings to the battlefield enables smaller and more mobile forces with an accompanying reduction in logistics. The information dominance it provides embodies the tenets of Joint Vision 2010 and helps make it a reality. Knowledge is power.

Nam et ipsa scientia potestas est.
--- Francis Bacon

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1. Introduction

Throughout history, gathering, exploiting, and protecting information has been critical... While the friction and the fog of war can never be eliminated, new technology promises to mitigate their impact.

--- Joint Vision 2010

In July of 1996, the Chairman of the Joint Chiefs of Staff issued a conceptual framework to the armed forces for leveraging technological opportunity to increase effectiveness in joint warfare. This framework is known as Joint Vision 2010 and has become the defining document for our military's evolution of warfare. The precept that knowledge is power is as old a man and our founding fathers clearly recognized the importance of what we now call "information dominance." What has changed however, is the technology that allows access and distribution of information as it occurs.

The foundation of Joint Vision 2010 rests firmly on technological innovation, the very core of which is technologies that enable information superiority. That is, technologies which promote the ability to collect, process, and disseminate information while denying the enemy the ability to do likewise. Discoverer II is the embodiment of Joint Vision 2010. The operational concepts of dominate maneuver, precision engagement, full-dimension protection, and focused logistics, are enabled and advanced by a Discoverer II constellation.

Our national military objectives, in the most fundamental sense, are to promote stability and to thwart aggression. To do so, we must understand an adversary's capacity to act as well as their will to act. We must understand what we are observing and then act decisively based on this information. To decisively thwart aggression when it affects our national military objectives requires dominant battlefield knowledge. Discoverer II will be the purveyor of Dominate Battlespace Knowledge (DBK) permitting the U.S. military the unparalleled ability to get well inside any adversary's

[2] Synthetic Aperture Radar, Ground Moving Target Indicator, and Digital Terrain Elevation Data.

OODA Loop[3] and ultimately enable victory on our terms. Discoverer II is on the path to making Joint Vision 2010 a reality.

2. Background

The Task Force believes the objectives of [Discoverer II] are an appropriate basis for substantial investment. We believe that future military operations will need the combination of day, night, and all-weather access, the rapid revisit of imagery and broad-area, moving target surveillance represented by the [Discoverer II] proposal.

---Defense Science Board Task Force on Satellite Reconnaissance, January 1998

In March 1998, the Defense Science Board (DSB) recommendation was incarnated as a joint initiative among the Air Force, Defense Advanced Research Projects Agency (DARPA), and National Reconnaissance Office (NRO) known as Discoverer II (DII).

Discoverer II will develop and demonstrate an affordable space-based radar (SBR) with High Range Resolution Ground Moving Target Indication (HRR-GMTI), Synthetic Aperture Radar (SAR) imaging capabilities and Digitized Terrain Mapping Elevation Data (DTED) that will revolutionize reconnaissance, surveillance and precision geo-location support to the tactical warfighter.

3. Why Now?

It is a doctrine of war not to assume the enemy will not come, but rather to rely on one's readiness to meet him; not to presume that he will not attack, but rather to make one's self invincible.

--- Sun Tzu
The Art of War

Conceptually, Discoverer II is at the confluence of many ripening and corrigible technologies. It is on the cusp of the Military Technical Revolution[4] (MTR). Current views no longer see MTR of and by itself the catalyst for warfighting change. This concept has evolved into the Revolution in Military Affairs (RMA) which is more holistic in its ideology, embodying changes in operational concepts and organizational changes. Nevertheless, the "revolution" is very heavily shaped by the technology available or foreseeable. Throughout history advances in technology have fundamentally changed the way war is waged. Tactics and technology form the Yin and Yang of warfare. One of the most difficult aspects of the adoption of new technologies is the development of appropriate tactics, techniques, procedures and doctrine that maximizes the use of the technology. In the modern era, imagine warfare (tactics and doctrine) before and after the advent of the capital inventions such as the tank, the submarine and the aircraft[5]. What confluence of technologies resulted in these revolutionary weapons systems?

[3] Observation-Orientation-Decision-Action loop first proposed by Col. J.R. Boyd, USAF in *A Discourse on Winning and Losing*, August 1987.

[4] The Center for Strategic and International Studies defines Military Technical Revolution (MTR) as a fundamental advance in technology, doctrine or organization that renders existing methods of conducting war obsolete. This concept was first advanced in 1993.

[5] The tank was developed to penetrate the barbed-wire entanglements that guarded the enemy machine guns. Machine guns had the force multiplier effect of producing the equivalent firepower of several squads of soldiers, and devastating the opposing infantry. The joining together the internal combustion engine, armor, rolling tracks, and light artillery resulted in the tank, and changed fighting tactics and doctrine. The battlespace was extended with the longer range, mobile cannons and new tactics were devised to counter this revolutionary mechanized vehicle, the tank.

The submarine was originally developed by the Confederate States of America in an attempt to break the Union blockade. CSS Hunley was the first submarine to sink an enemy ship, the *USS Housatonic* off Charleson Harbor in 1864. The magnetic compass and the mercury depth gauge developed then were essentially the same as used in the submarines of WW I and II. The technological confluence of diesel-electric propulsion, batteries, torpedoes, improved magnetic compasses, and improved structures for the pressure vessel resulted in a capability that sank an average of 800,000 tons of allied merchant shipping each month during WW II. So successful was the submarine that, although they accounted for only 2% of total naval personnel, they sank 95% of the Japanese merchant fleet. The battlespace was further extended and stealth and surprise had a profound psychological impact. Tactics such as the "wolf pack" were invented for this new technology, and new weapons such as depth charges were developed in response to this threat. A completely new type of warfare, anti-submarine warfare, came into being. Eventually, these stealthy platforms embraced advances in aerospace and nuclear technologies and the result was a virtually undetectable and unlocatable platform that carried long range nuclear weapons that bore a destructive capability greater than all the bombs dropped in every war that preceded it. The doctrine of nuclear deterrence resulted.

The aircraft was quickly adapted to military use. Less than seven years after the Wright brothers' first flight, the Navy was modifying a ship to conduct experiments invoking the launching of an aircraft from a naval vessel. The Army stood-up the Army Air Corps to adopt this technology for a warfighting advantage. The concept of strategic bombing of an enemy's means of production further extended the battlespace. Fighther aircraft were developed to attack these bombers as well as to protect them. The Norden bomb scope ushered in the era of "precision" bombing. Radar, invented in 1935, was used to detect aircraft at ranges far beyond visual range. Warfare took on a third dimension, altitude.

Aircraft also served as reconnaissance and surveillance platforms. They were used as spotters over land and sea to locate enemy forces. As we moved into the cold war, America needed a means to observe the Soviet activities and in particular, their nuclear and weapons deployment efforts. The U2 effort began in 1954 and took the first reconnaissance photographs over the Soviet Union in 1956. It was only a matter of time before technology could be used by the Soviets to shoot down the U2. Corona, our first reconnaissance satellite, was launched in 1959 and allowed viewing of the interior of sovereign nations without their consent and without fear of being shot down.

A defining characteristic of the current RMA is the political and popular insistence of limiting the number of casualties and the amount of collateral damage in any confrontation. Precision information becomes the dominant theme. This means getting the right weapon, on the right target, at the right time; no more and no less. This is a fundamental change in our warfare of attrition and a return to what Clausewitz called the decisive victory (coups de main or great battlefield victory)[6]. The ongoing defense drawdown (or euphemistic, right-sizing) will make overwhelming force much harder and costly to field.

4. What Does the Warfighter Need to Accomplish This?

The Task Force recommends that the Department of Defense undertake a program to create a Military Space Radar Surveillance Program targeted to achieve broad-area, all-weather and near continuos radar access for integration with military operations.

--- Defense Science Board Task Force on Satellite Reconnaissance, January 1998

Staring, staring, staring. Always looking and observing. Long-dwell, near-continuous, all-weather surveillance of the adversary allows our military constant synoptic and integrative knowledge rather than discrete inferential assumptive reconnaissance. The Orwellian nature of continuous surveillance means that an adversary will not be able to hide force movement and disposition unless extreme measures are taken. Those extreme measures will no doubt be costly and time consuming. Our current optical systems give us aperiodic reconnaissance snapshots when the weather permits. Our airborne optical systems suffer from the same limitations however; they may provide more continuous viewing of an area of interest if there is no anti-air threat. Airborne radar (SAR and MTI) is constrained by geometry and does not give the deep look unless there is no anti-aircraft capability. Only space-based radar can offer the ability to safely broach national borders to view the situation below. A large constellation of space-based radars affords the long-dwell near-continuous all-weather surveillance capability to deny an adversary unfettered hostile intent or actions. A large constellation further permits our forces to act at any time without the Keplerian coordination constraints imposed by the use of a single or small number of space assets.

[6] This point is argued by Jeffrey Cooper in his chapter "Dominate Battlespace Awareness and Future Warfare" in the National Defense University publication Dominate Battlespace Knowledge, edited by Johnson and Libicki.

Improvements in understanding combat dynamics and the piercing of the fog of war in real time become the temporal and spatial entering arguments for tactical actions. Who knows better and needs the information more than the on-scene Joint Tactical Commander. Surveillance that can be directed in real time as the phases of engagement dictate allow our forces the expedience necessary to get well within the adversary's OODA Loop. Actions can be timed for maximum effectiveness, and Battle Damage Assessment (BDA) can be performed in real time to determine if success was achieved while denying an adversary any time to recover or regroup. An adversary must now be wary of a threat from any direction. Precision surveillance and targeting from omni-directions render the concept of a battle front or battle line obsolete. If the adversary moves, it is noted by GMTI. If the adversary remains fixed, it is noted by SAR. Direct theater control for the tasking and dissemination of the Discoverer II sensor enables getting the right data to the right user at the right time. Timeliness of information is a critical combat advantage.

Improvement in geo-location will be critical for precision targeting. Under traditional assumption, accuracy will decrease as distance increases. Discoverer II Digital Terrain Elevation Data (DTED) will enable the "benchmarking" of the adversary's geographic positions which will allow very precise delivery of weapons to that location. Long range weapons with very precise targeting deny the enemy the acumen of knowing where an attack will come from. Because an attack could come from any direction at any time, the adversary is squarely on the defensive.

The continuous all weather surveillance and precision location which enable precision munitions results in a smaller, lighter and more mobile force that can concentrate actions with surgical accuracy. The amount of ordnance required is then greatly reduced. This results in an amplified reduction in logistics tail. Some estimates show that logistics, people and munitions can be reduced 10 to 40 times by the use of precision munitions.

Wrapped around all of the above is cost; both the initial acquisition cost and the life cycle cost. If the systems are unaffordable then the above attributes will never be realized by the warfighter. Cost is the fulcrum for balancing mission needs and projected resources.

The table 1 summary of warfighter needs points to the necessity for a space-based radar constellation of sufficient size to provide near continuous coverage on a global scale.

Table 1. Warfighter Needs Summary.

Warfighter Needs:	Potential Solutions
Day/night, all-weather surveillance	Radar: Essentially immune to cloud cover and darkness unlike EO systems
Deep, theater-wide, assured access	Space-Based: Territorial sovereignty is not violated; large field of regard for viewing but dependent on altitude
"Birth-to-death"	Near-Continuous Dwell: A dense constellation

tracking to counter "shoot-and-scoot"	of Low Earth Orbit satellites allows areas of interest to be under constant surveillance while at the same time have the requisite power aperture that are small and light enough to remain affordable
The right information, at the right time, disseminated to the right user	Theater Control: The warfigher will need near instantaneous access to the information and data garnered from the surveillance
Elevation accurate to ~1 meter for visualization and precision guided (level 4-5) munitions targeting	Digital Terrain Elevation Data (DTED): Newer precision weapons are enhanced greatly with improved geo-location accuracy and digital elevation models
Affordability	Above all, the system must be affordable: Small, relatively simple satellites will generally be low cost. Best commercial manufacturing practices must be employed System must leverage and maximize existing TPED[7] infrastructure: Manning requirements must be minimized

5. Discoverer II: A Notional Concept

In order to meet the warfighter needs of all weather, day/night, deep look, and instant access continuous surveillance with near real time receipt of the information, a fairly dense constellation of radar satellites is required. Notionally, the objective Discoverer II constellation is postulated to have 24 satellites (eight plans of three satellites each) in a Low Earth Orbit (LEO) at an inclination of approximately 54 degrees. Figure 2 depicts the notional instantaneous global coverage from a 24 satellite LEO constellation.

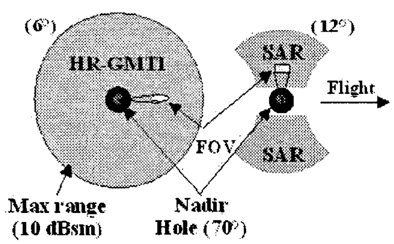


Figure 1.
SAR & GMTI Footprints

Figure 1 illustrates the instantaneous access area footprints for a single satellite. The larger circular footprints represent the GMTI coverage area whereas the smaller "butterfly" shaped footprints represent the SAR coverage area. The SAR footprints do not have the range extent that the GMTI footprints do because they are limited to a 12 degree grazing angle[8] whereas the GMTI footprint can go out to a 6 degree grazing angle.

If you visualize the satellites in figure 2 orbiting, it is apparent that space-based radar offers much more angle diversity over a given area of interest. A recent analysis of the amount of terrain that can be masked from radar energy due to terrain obscuration, reveals that in an area of central Europe, airborne reconnaissance assets can see about 27% of the area. Seventy-three percent is obscured due to terrain blockage. That same area is 99% visible with a notional Discoverer II constellation. Only one percent of the terrain is masked.

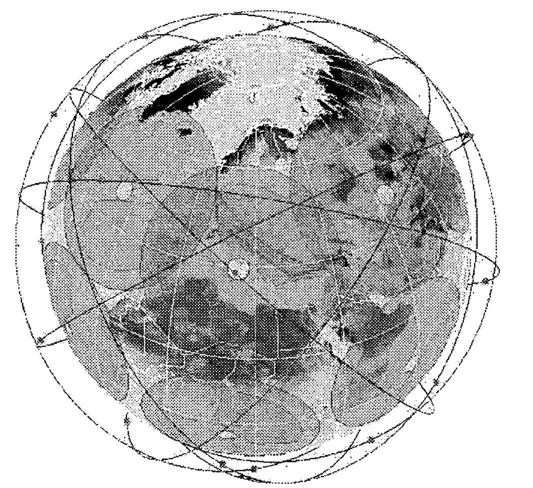


Figure 2.
View of Notional 24 Space Vehicle Constellation

At higher altitudes, signal losses from simply the physics of propagation require higher radiated power in order to get enough energy on the target of interest to reflect back to the space vehicle. This higher required power can be achieved by either more antenna aperture to focus the beam or by putting more power into the driven elements of the array. Both of these solutions will generally add weight and complexity to the space vehicle and thereby also adds cost.

Figure 3 illustrates several curves for access time as a function of the number of satellites in the constellation for particular latitude. Since the GMTI footprint is larger (shallower grazing angle) the access is better than for SAR. To achieve greater than 90% access to areas of interest at 30 to 40 degrees latitude, a constellation of 24 satellites is needed.

[7] Tasking, Processing, Exploitation, and Dissemination.

[8] Grazing angle is the angle between a plane tangent to the earth's surface at the point where the radar beam intersects the earth and the radar satellite.

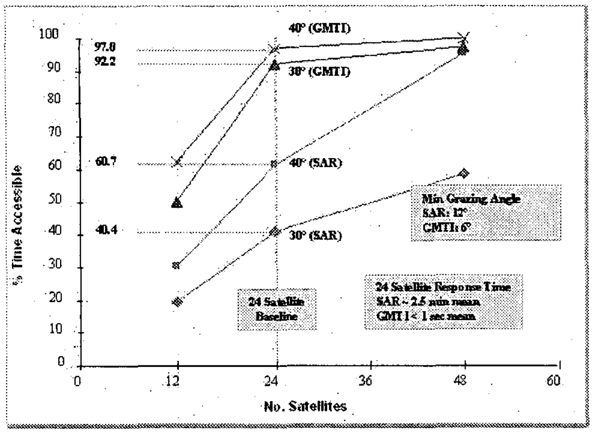


Figure 3.
Trade space for access time and constellation density.

Table 2 lists many of the notional system characteristics for a system such as Discoverer II. The constellation will have to be dense enough to provide the assured access to areas of interest. The radar will operate in an approved band. There will need to be a significant amount of onboard processing in order to have reasonable communication downlink rates. The bus must be low mass and agile in order to steer beams throughout the access area in reasonable times.

Table 2. Objective System Notional Characteristics

Space Segment	
Orbit	24 space vehicles, Walker orbit, 770 km circular , 54 degree inclination
Radar	Multi-mode Electronic 40 m^2 2D Scaned Array (Az & El) X-band (10 GHz) Power (peak), TBA Power (average), TBA -23 dB ILS 12 minutes radar operation per revolution Duty Cycle, <20% Space-Time Adaptive Processing (STAP)
Satellite Bus	Low Mass; <1000 kg (w/o ESA) Agile (roll/yaw response and settling) Existing design or close derivative to an existing design
On Board Processing	1200 GOPS
Ground Segment	
	Compatible with existing airborne reconnaissance infrastructure 2-meter ground antenna Direct Downlink/Direct Tasking Collection and management planning Use exploitation tools such as MTE & SAIP

Getting to a system that can image an area of interest and track a ground moving target while itself moving at over 7 km/sec presents a number of technical challenges in addition to being constrained by the bounds of affordability. But how to you get there from here? What are the technical risks that must be retired before full objective constellation of radar satellites is fielded? The approach is multi-faceted. Several concurrent risk reduction efforts are underway in parallel to the main effort of designing and building a two-space vehicle demonstration.

6. TECHNICAL CHALLENGES

You see things; and say "Why?" But I dream of things that never were; and I say; "Why not?"

--- George Bernard Shaw
Back to Methuselah, part 1, act 1

What are the technologies that will enable a system such as Discoverer II to become a reality? Low cost production, low cost and light weight phased array antennas, high speed signal processing, lightweight space structures, efficient energy storage systems and solar cells, and high data rate communications are the most significant.

Table 3. Risk Reduction Activities and Results to Date

Risk Reduction Activity	Results to Date
Radar	
Develop a generic ESA (TR module and brassboard Develop GMTI & SAR Algorithms Produce subscale articles Develop tracing algorithms	♦ Initial thinned T/R module designs complete ♦ Signal processor architecture design complete ♦ 0.25um line spacing chip demonstrated ♦ 25 Gops/Watt demonstrated ♦ Algorithms tested using airborne asset ♦ Airborne collections to refine SAR and GMTI algorithms
Communications	
Frequency allocation for radar and communications links High data rate downlink Encryption	♦ Frequency allocation request (stage II) submitted ♦ Data compression ♦ Waveform improvement investigations
Small, Agile Satellite Bus	
Mass and power are the highest risk Subsystem requirements are based on radar payload requirements and system capabilities	♦ Existing technology risk have been evaluated
High-Resolution Terrain Mapping	
System level collection rate at various DTED levels Determine space vehicle requirements to support DTED level 4 and 5	♦ Collection and processing methods identified
Tactical Ground Segment	
GMTI image formation IFSAR and STAP ground processing determination	♦ Identify interface requirements for high data rate

Low Cost Production.

The commercial communications satellite industry has undergone a fundamental philosophical shift in how satellites are produced. Although still greatly labor intensive, the coming large LEO constellations require a production line approach to satellite construction if these satellites are to be produced cheaply enough to support the business case analysis for the commercial market. This evolving view of satellite production results largely from the concept that mass production leads to economies of scale[9]. Figure 4 notionally illustrates that if "large" numbers are going to be produced, it makes economic sense to design in producibility. Designing in producibility adds additional non-recurring costs to the design, so if the number produced is low, then economically, it does not make sense to do so. Designing-in producibility produces a flatter cost curve. Figure 4 also illustrates that the greater the number of units produced, the greater the allocation base for the non-recurring costs and thereby reducing the total average unit cost.

Designing-in producibility means that every aspect of the manufacturing process and design are reexamined. Assembly workflow, use of COTS parts, interchangeability of hardware and connector, standardized components and configurations, and lastly testing. The entire concept of testing at each stage to very high levels is replaced by testing to verify design and process adequacy and once verified, test only for assembly verification. Environmental testing is not done on every unit, saving cost and time.

Only because of the advanced LEO communications concepts (288 Teledesic, 66 Iridium, and the like) have the low volume, custom, satellite production model changed. We are grateful to systems such as Iridium that have shifted the space vehicle-manufacturing paradigm.

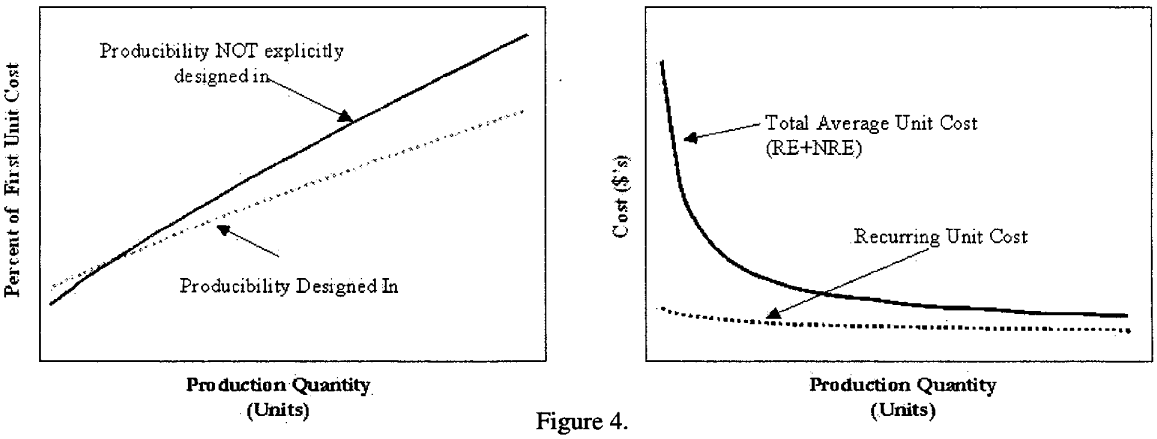


Figure 4.
Economies of Scale

Spaceborne Active Electronic Scan Array (ESA).

Essential to the success of Discoverer II will be the ability to develop and place on orbit a lightweight, "low"-cost phased array antenna. The goal is an array and structure weighing less than 500 kg with approximately 40 m^2 of aperture. Magnetron power tubes and Klystron power amplifiers have given way to solid state T/R[10] modules that can be fabricated and assembled in lightweight panels. The dimensions of this panel (i.e. arrangement of the T/R modules) will determine the amount of beam steering in azimuth and elevation. The amount of beam and antenna steer will influence the number of spatially diverse targets that can be observed. Actuators, reaction wheel assemblies and control moment gyros are necessary if the antenna is to be mechanically slewed. This has an impact on the bus design to support the array. Electronic steering or scanning will reduce the amount of mechanical steering. There is a trade between adding additional electronic scan to the array in terms of cost, weight and complexity, and the cost, weight and complexity of adding mechanical agility to enhance the electronic scan. Performance is wrapped around this trade space. Target scan and schedule optimization will be important to maximize the number of targets that can be observed.

Any reduction in the size of the ESA has a multiplicative effect on the space vehicle weight. A smaller array will require less power so solar panels and batteries can be down sized. Additionally, reaction wheels or control mass gyro necessary for spacecraft agility can also be downsized.

Processing Power.

Computer processing power, obeying Moore's Law has greatly reduced the size, weight, and power required to perform a given number of operations. Very sophisticated on orbit processing is foreseeable at a reasonable SWAP[11]

9 Economies of scale can also be referred to as increasing returns to scale. It is simply a notion that output increases more than in proportion to input.

10 Transmit and receive modules.

11 Size, Weight, and Power.

and cost. In particular, the number operations for a given power consumption and weight continues to increase. This "light weight, low power, dense processing" enables the use of onboard space-time adaptive processing (STAP) and reduces the data downlink required from the satellite. The trade space for onboard processing includes size, weight and power of course, but also the amount of buffering in terms of onboard memory, improved communications capability, or reduced performance.

The processing power necessary is related to the amount of instantaneous rf bandwidth that is being processed. The instantaneous bandwidth determines the resolution that is achievable. Reducing the instantaneous bandwidth will allow a wider selection of rf and digital components which can reduce costs. Additionally, reducing the instantaneous bandwidth will directly translate into a reduced downlink requirements

Lightweight Structure.

There is a direct relationship between space vehicle weight and launch cost. Launch cost is a significant fraction of total life system cost. The more space vehicles that can be launched on a given launch vehicle, the lower the constellation cost. Significant weight reduction must occur in order to get multiple Discoverer II space vehicles on a single launch platform such as a Delta II. A Delta II has a lift capacity of 3475 kg. In order to launch two Discoverer II satellites, each one can weigh 1738 kg. The radar antenna array is estimated to be 500 kg therefore 1,238 kg remains for everything else. Between 1991 and 1995, structure as a percentage of space vehicle weight has gone from 9% down to 6%, a 33% reduction. As a reference point, structure as a percentage of space vehicle weight was about 18% in 1981. Clearly the power subsystem must also show significant weight reductions since structure alone cannot make the satellite "light weight". Power is estimated to account for over 60% of the bus mass fraction and the payload is estimated at 25% to 30% of the mass fraction. Trades to reduce power may include reducing the radar array power. The resulting Power-Aperture product may precipitate changes to the array (more aperture) and affect the size and weight by more than what is saved by reducing power. Other options to reduce power may include modifying the demonstration concept of operations to only image every other orbit or decrease the imagining time per revolution. As always, performance may be modified to fit within the trade space.

Energy Storage Systems.

Currently, nickel hydrogen, NiH_2, batteries are employed on a LEO communications constellation. It uses a packaging technology known as Single Pressure Vessel, SPV. SPV is a single point of failure since it cannot employ individual bypass circuits should a failure or anomaly occur. Projections are that this technology may improve to allow high rates and depth of discharge within the next decade. If so, battery mass may be reduced by up to 30%. Lithium Ion and Sodium Sulfur batteries are under investigation as candidates for weight savings should acceptable discharge rates and depth of discharge improve. Flywheels show promise; however, being a mechanical device, reliability issues need to be addressed and demonstrated in a space environment. In any case, the trade space between bus and array power required and the size and weight available for energy storage will have to occur. The amount of imaging (array radiation) per orbit may be reduced which could call for increased constellation density to maintain the origin baseline for view time. This trade also manifests itself in the ability of the tracking algorithm to establish and maintain track during shorter viewing times with larger gaps between coverage (handovers).

High Data Rate Communications.

The amount of onboard processing will greatly influence the communications data rate. Once the data rate has been determined, how to get the data to the user must be resolved.

Small (< 2 meter) in-theater antennas constrain options for link closure. More on orbit antenna gain or EIRP can be added to close the link but this costs in terms of weight (structure, solar arrays, batteries, etc). The data rate may be "throttled" to that supported by the link. If so, onboard storage will have to be added, increasing the space vehicle weight, or the area coverage rate (radar coverage) will have to be reduced to fit within the data rate supported by the link.

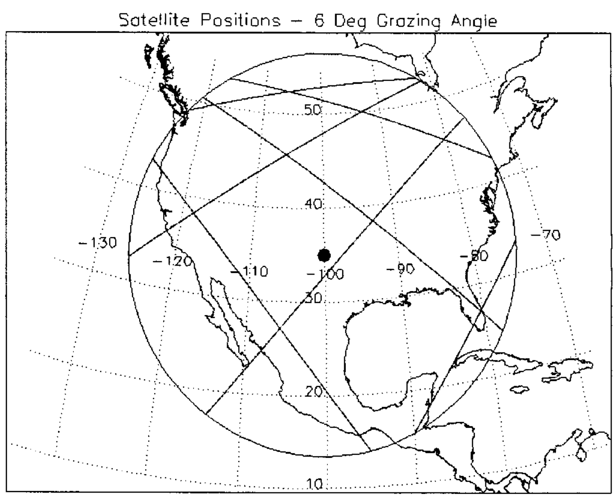


Figure 5.
Typical Pass Length for a Notional Satellite over a Central US Ground Station

Figure 5 illustrates the number and duration of notional satellite passes in a 24-hours period over a mythical ground station in the center of the United States. The average duration of a pass (6 degrees to 6 degrees) is approximately 10 minutes. The total time in view for a 24-hour period is approximately 69 minutes. The distribution of these passes is lumpy. They occur in an 11-hour window. There are no passes for the next 13 hours. Clearly, for the two-space vehicle demonstration, communications can become a binding constraint on the amount of data that can be direct downlinked to a ground station.

For the given aperture of 40 m^2, data is collected by the array and processed to a point where the estimated rate is 6,900 Mbps for GMTI and 1725 Mbps for SAR. If the problem is constrained to a direct downlink, the data produced on the satellite will have to be buffered and trickled down to the ground station. For a 10 minute imagining window, approximately 1 to 4 terabytes of data may be collected. To get the data to the ground at a respectable 500 Mbps, it will take between 0.5 hrs and 2.2 hrs. At the high end, it will take almost three days work for average passes in order to link the data to the ground.

Higher communications frequencies offer higher data rates for a given modulation (bits per Hertz), but suffer from limitations due to physics of absorption and make the link availability lower for a given power compared to a lower frequency. Additional power can be added but this adds weight and the state of maturation of transmitters at Ka bands lags the more commercially mature C, X, and Ku bands. The ground terminal elevation angle will greatly affect the link budget. Higher elevation angles are better but without a relay of some sort (cross links or uplinks to a MEO or GEO), the connectivity time is greatly reduced and the constellation density has to increase to give the same amount of communications access time as would have been available at lower elevation angles. Relays or crosslinks can be added, but that will add additional weight, cost and complexity to the space vehicle and constellation.

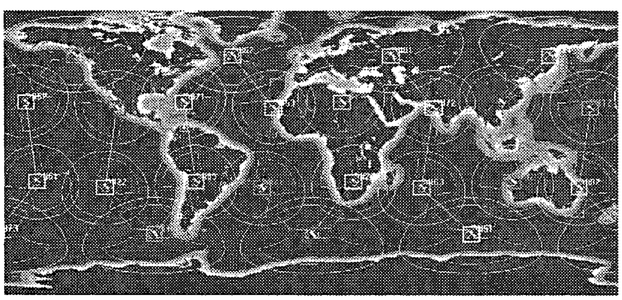


Figure 6.
Crosslinked 24 Satellite Notional Constellation

In the notional objective system constellation of 24 satellites, a continuous link between satellites is formed that circle the globe as illustrated in figure 6. The satellite crosslinks increase the utility of the objective system by allowing tasking and routing of data anywhere within the constellation. A noteworthy by-product is that this allows very high data bandwidth global connectivity between any points in view of a Discoverer II objective system satellite. The Discoverer II sensor constellation can function as a high data rate global communications backbone. If multi gigabit optical crosslinks are employed, Discoverer II becomes an on-orbit transport mechanism for global connectivity. An astonishing fact is that a single optical crosslink has a data capacity that exceeds the entire current milsatcom aggregate throughput.

Software Development

A significant development, but often overlooked in favor of perceived higher risk hardware technology, is the software that will hold this system together. It is pervasive in every aspect of the program from tasking the system to collect an image or track a target to the processing & exploitation of the collected data and subsequent dissemination. This is a significant but understated portion of the program.

Fundamentally the software development is divided into space (flight) and ground segments. For the space segment, software will be necessary to fly the vehicle, control the payload, and process the data (to some degree) onboard the space vehicle. For the ground segment, the software will be developed for TT&C[12], tasking & mission planning, and data production.

It is expected that the flight software development will follow the build-test spiral. This development effort is well understood and is expected to be similar to NASA missions such as EOS, Coriolis, HESSI, Deepspace 1, MightySat, Mar 98 and Stardust. With this heritage, extensive reuse (>50%) is anticipated. The maturity of understanding for this portion of the software development lends itself well to automatic code generation tools coupled with closed loop simulation for the ACS[13].

During flight software development it is expected that the hardware and software will be incrementally built and then integrated together. Testing and verification are expected to be accomplished incrementally at the unit level and then the subsystem level. The program office estimates that the flight software will be in excess of 30 KSLOC.

The payload control software will have to be tightly coupled to the flight software. This software will set up and operate the radar payload including the steering of the ESA. Very conceivably, a payload command will result in a flight command for the vehicle. While there is potential for some reuse, this code is expected to be predominantly new development. It is estimated that about half of this code will have a real-time run requirement. The payload software development effort is considered to be moderately complex and is estimated to take approximately 40 KSLOC.

Probably the most complex software development for the space segment will be the onboard processing software. The baseline model estimates that it will take over a teraflop for

12 Tracking, Telemetry, and Control
13 Attitude Control System

full onboard processing. The extent to which this can be implemented in the demonstration timeframe remains to be seen. The amount of onboard processing is symbiotic with the communications downlink requirement. The more processed the data, the lower the data rate requirement becomes for the downlink. This is an ongoing trade. It is estimated that over 70% of this code will be real time. The magnitude of this software development (KSLOC) is directly related to the amount of onboard processing implemented.

The entering assumption for this system is that it should be interoperable with the existing airborne reconnaissance infrastructure. Ground segment software that is unique to planning, tasking and controlling a space vehicle payload will need to be developed. Data will be downlinked to a fixed CONUS[14] site and a tactical government furnished component as well.

It is expected that the program will be able to leverage tasking, mission planning and TT&C software developed for a similar space demonstration. If done correctly, the objective system may be able to heavily reuse this software developed for the demonstration. Overall, it is estimated that approximately 50% of the total code developed for the ground segment will be new.

7. Summary

The side that understands it enemy better, is better prepared for conflict.
--- Sun Tzu

Discoverer II stands in the vanguard of the Revolution in Military Affairs and the Military Technical Revolution in as much as it provides the God's eye view of almost any area almost all the time. It provides the information dominance necessary for our forces and government to maintain a competitive advantage to win the fight by applying the right force, to the right location, at the right time. Discoverer II enables information dominance, by bringing the tactical theater commander:

- Long dwell SAR Imagery and GMTI unbound by national borders – Surveillance and Reconnaissance any time and any place
- Indications and Warnings
- Terrorist activities
- Weapons of mass destruction monitoring
- Deter or prevent crisis from occurring
- Intelligent Preparation of the Battlefield
- SAR/MTI symbiosis and cross-queuing of other platforms
- Precision Engagement- Long range precision strike from any direction
- Reduced logistics tail
- Enable smaller, lighter, faster and more mobile forces
- Reduction in casualties and collateral damage
- Battle Damage Assessment in real time

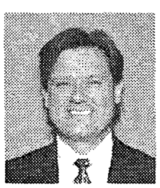
In a time where the enemy is less well-defined and certainly not confined to any single geographic area, the need for a global sensor that provides tactical and strategic utility cannot be overstated. The time and technology are right to build the system that will make Joint Vision 2010 a reality.

8. Final Remarks.

Change almost always comes as a surprise because things don't happen in straight lines. Connections are made by accident. Second-guessing the result of an occurrence is difficult, because when people or things or ideas come together in new ways, the rules of arithmetic are changed so that one plus one suddenly makes three. This is the fundamental mechanism of innovation, and when it happens the result is always more than the sum of the parts

--- James Burke

In closing, I hope that this introduction to a new military space mission and capability has enlightened the reader. Discoverer II has the potential to enable a new generation of improved military capabilities and equipment with improved responsiveness and effectiveness. As was the case when the Global Positioning System (GPS) was at its infancy, we cannot begin to imagine what changes in hardware, military doctrine and tactics, will be a direct result or enabled by this revolutionary capability.



***George Duchak** is an Associate at SAGE Solutions Group, Incorporated. He provides day to day Scientific, Engineering and Technical Assistance to the Discoverer II Joint Program Office. He has a BSME from the United States Naval Academy, MSAE and AeE from the Naval Postgraduate School and an MBA from The Ohio State University. He has over 22 years of government and private sector technical and managerial experience working on numerous space, communications, and sensor programs related to intelligence, surveillance, and reconnaissance efforts.*

[14] Continental United States