February 2004

Ground Moving Target Indicator Radar

And the Transformation of U.S. Warfighting

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NORTHROP GRUMMAN

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Executive Summary

Introduction: Ground Moving Target Indicator Radar and Transformation (p. 5) *Among the technological advantages U.S. forces have enjoyed in recent conflicts, information superiority stands out as the capability that truly differentiates U.S. forces from all other militaries. The purpose of this paper is to examine one of the key technologies contributing to U.S. information superiority—**Ground Moving Target Indicator (GMTI) radar**—and its implications for the transformation of the way the United States fights its wars.*

GMTI can help transform Intelligence, Surveillance, and Reconnaissance (ISR), a mission area essential to the U.S. battlefield information advantage, because it can depict vehicular movement of enemy forces in near-real time throughout a large area, regardless of weather. This unprecedented capability reduces uncertainty, clearing the Clausewitzian "fog of war" that has hung over land battles for centuries, thereby multiplying the capability of the combined force and transforming the execution of air-land operations.

GMTI Radar Technology (p. 7)

The asymmetrical advantage modern GMTI technology provides U.S. forces results from its unique ability to distinguish targets moving on land or water from surface clutter over a large area. This is possible even in bad weather and darkness by virtue of the Doppler radar return of the moving targets. The GMTI picture shows moving vehicles as dots overlaid on a digital map.

The History of GMTI (p. 11)

Cold War Military Requirements

The propelling force behind development of the capability to track moving forces in near-real time was Cold War military necessity. After the 1973 Arab-Israeli War, senior U.S. Army leaders realized that to defeat the Soviets under the highly lethal conditions of modern warfare, field commanders would have to know the enemy's situation beyond the front lines.

GMTI Technology Development

Modern GMTI radar technology evolved from the U.S. Army's Stand-Off Target Acquisition System (SOTAS) and the U.S. Air Force/Defense Advanced Research Projects Agency (DARPA) Assault Breaker/Pave Mover programs developed in the 1970s. When it became clear that neither the Office of the Secretary of Defense (OSD) nor Congress would fund separate GMTI programs for the two services, Army and Air Force leaders agreed to a single program, Joint STARS (Surveillance and Target Attack Radar System), that would provide battle management of strike aircraft for the Air Force and wide area surveillance for the Army.

Post-Cold War Employment of GMTI

When the end of the Cold War eliminated the Soviet threat, some defense experts suspected that Joint STARS was no longer needed. However, GMTI platforms have played key roles in almost all subsequent conflicts.

The Gulf War — Two developmental Joint STARS aircraft supported Coalition forces engaged in Operation *Desert Storm*. Early in the War, during the Battle of Al Khafji, they located advancing Iraqi ground forces that had attacked at night in an effort to avoid detection. When Iraqi forces began withdrawing from Kuwait, GMTI was again the source of timely, reliable information that enabled air attacks to disrupt the Iraqi retreat.

Kosovo — Despite the magnitude of its contribution in the Gulf War, GMTI was not fully exploited in planning for Operation *Allied Force* in Kosovo. However, operational experience with GMTI soon led commanders, their staffs, and aircrews to appreciate its capabilities—recognizing, for example, that its ability to detect, locate, and track vehicular movement reduces the need for inefficient visual searches. When the Kosovo Liberation Army (KLA) began its offensive, Joint STARS' GMTI helped create a dilemma for Serb forces. If the Serbs attempted to maneuver, the movement made their forces visible to GMTI and thus vulnerable to NATO air attack. If the Serbs did not move, they handicapped their ability to achieve the force ratios and position needed to defeat the lighter KLA forces.

Afghanistan — Joint STARS operations during Operation *Enduring Freedom* in Afghanistan had many similarities to previous conflicts. As in Kuwait and Kosovo, Joint STARS was not deployed in sufficient numbers for persistent coverage. Like Kosovo, the presence of civilians required positive target identification by an unmanned aerial vehicle (UAV) or manned aircraft. However, Joint STARS enhanced other surveillance assets by cueing UAVs with high-resolution but restricted field-of-view sensors. Northern Alliance units supported by U.S. Special Operations Forces (SOF) threatened Taliban and al Qaeda forces sufficiently to cause them to move in vehicles, allowing GMTI to detect, locate, and track them.

Iraq — U.S. and British forces in Operation *Iraqi Freedom* benefited from the Joint STARS lessons learned from previous conflicts. For the first time, sufficient aircraft were deployed to meet the GMTI requirement for a major portion of the operational area. Because GMTI was capable of detecting vehicular movement, Iraqi commanders and their forces faced the same

operational and tactical dilemma the Serbs faced in Kosovo. If they moved, they were seen by GMTI and attacked by air or artillery. If they dispersed and remained camouflaged and dug in, they were either bypassed or defeated in detail by ground forces.

Trends from Recent Conflicts (p. 19)

Positive Trends

By revealing battlefield movement in near-real time regardless of weather or light conditions, GMTI has begun to transform U.S. ISR capabilities, contributing to a "new American way of war" in which information and precision reduce the amount of time and mass required, significantly speeding up military operations. Near-real time, dynamic GMTI targeting information coupled with weather-independent precision guided munitions, such as JDAMs, has also redefined both close air support and battlefield air interdiction by allowing these tasks to be performed effectively by high-altitude bombers.

Because it has continuous wide-area coverage, GMTI provides a battlefield picture that can be used for airborne command and control, to provide near-real time situational awareness to commanders, and to cue other ISR systems. By focusing the efforts of other ISR elements, GMTI has increased the effectiveness and efficiency of the entire ISR network.

Because it provides an identical "ground truth" picture to air and ground users alike, GMTI helps joint, air, and ground commanders share a common understanding of the battlefield, its dangers, and opportunities for exploitation.

Negative Trends

In the first three conflicts GMTI capability was insufficient to provide the desired 24/7 coverage of all major operational areas. Planners have been slow to incorporate GMTI or deploy it early enough in a conflict to take advantage of its capabilities. Terrain, foliage and opportunities for enemy ground forces to disperse or avoid maneuver can hinder detection and tracking by GMTI. GMTI lessons also have had to be relearned from conflict to conflict, indicating that both doctrinal and organizational development have yet to capitalize on GMTI's capabilities.

Trend Implications

The superior situational awareness provided in part by GMTI approached its transformational potential only in the latest Iraq conflict. Here, the most transformational characteristic of Operation *Iraqi Freedom* was that its concept of operations appeared to depend upon the overwhelming information superiority that ISR systems, including GMTI, afforded the Coalition. In a sense, General Tommy Franks' operational concept substituted information, precision, and speed for mass and firepower. However, it remains to be seen if this will become the norm in U.S. operational concepts.

Future GMTI Capabilities (p. 21)

New technological advances are now being incorporated into a second-generation GMTI system known as the Multi-Platform Radar Technology Insertion Program, or MP-RTIP, to be deployed on more advanced manned and unmanned aircraft. The improved range, resolution, and accuracy of this new active electronically scanned array radar, combined with automatic target recognition software, add the capability to classify targets by types, to tag them with a unique target designator, and to track them much more precisely.

Because space, the "ultimate high ground," logically provides the best location for obtaining the greatest coverage from a GMTI system, the Air Force is currently investigating orbiting versions of GMTI. However, space systems also require significantly longer range, which in turn requires significantly greater power and antenna size.

Operational Implications of GMTI's Potential (p. 23)

The unprecedented level of situational awareness that U.S. forces supported by GMTI enjoy today has the potential to significantly enhance both maneuver and fires. In coordination with other advanced ISR systems, GMTI can enable a new,

more effective approach to warfighting where situational awareness and precision weaponry reduce both the time and mass required to execute operational tasks. This allows:

Faster Maneuver

The more uncertainty a commander faces, the greater the mass of units he needs to hedge against surprise. Conversely, the more information he has about the situation, the less mass he needs. Thus, the battlespace situational awareness enabled in large measure by GMTI allows faster maneuver by reducing uncertainty.

More Effective Fires

Enhanced situational awareness can also help to substitute for mass in air and ground delivered fires. For example, with GMTI-provided information, strike aircraft search less and are able to engage more targets per sortie.

Faster and Better Decision Making

The more uncertain a commander is about the enemy, the slower and more cautious his decision-making must be to avoid stumbling into disaster. The opposite is also true—the more information he has and the greater its precision, the faster he can make good decisions.

Faster, Lower-level Joint Integration

GMTI gives both air and ground users an identical "ground truth" picture, helping them share a common understanding of the battlefield, its dangers, and opportunities. This same common picture is shared not only among joint headquarters and the service components but also down the different echelons of command, thereby creating not only a horizontal but also a vertical common understanding of the battlefield and enhancing the ability to conduct integrated joint operations at lower levels more quickly and more effectively.

Conclusion: GMTI and the Transformation of U.S. Warfighting (p. 27)

Only time will tell if GMTI and its related ISR technologies will permanently transform the way the U.S. military fights. To paraphrase Secretary Rumsfeld, all the GMTI systems in the world will not transform our forces unless we first transform the way we think about warfighting. While GMTI generally was not used to its full potential in recent conflicts, the 2003 campaign in Iraq showed promising signs that U.S. forces have accepted GMTI as a key technology for modern warfare.

I. Introduction

The fortunes of war have always favored those commanders having better and more timely information on what was happening on the battlefield, even if on the other side of the hill. This has certainly been true of our most recent conflicts, where the accomplishments of U.S. forces have been truly remarkable and unprecedented.

- *Operation* Desert Storm *in Kuwait, our first major conventional war against an armored/mechanized enemy since World War II, defeated the world's fifth-largest armed forces with a 38-day devastating air campaign followed by a 100-hour air-ground offensive.*
- *Operation* Allied Force *in Kosovo was the first-ever use of air power in isolation to defeat an enemy field army.*
- *Operation* Enduring Freedom *in Afghanistan used precision airpower and U.S. SOF supporting an indigenous ally over a few weeks to collapse an enemy in remote Central Asia far from established U.S. bases.*
- *Operation* Iraqi Freedom *saw a regime that controlled a country of 23 million people defeated in 21 days by massive, precise, and responsive airpower and a smaller ground force that attacked over unprecedented distances with previously unseen speed.*

Many factors, such as high quality personnel, innovative leadership, well-trained units, and advanced technology, have provided the tremendous jump in U.S. military capabilities evidenced by these conflicts. In the technological dimension one factor truly differentiates U.S. forces from all others: information superiority. The purpose of this paper is to examine one of the key technologies providing our forces this information superiority—Ground Moving Target Indicator (GMTI) Radar—*and its implications for the transformation of the way the United States fights its wars.*

Ground Moving Target Indicator Radar and Transformation

Fed by the unblinking eyes of GMTI radars on Joint STARS[1], the computer screens filling Coalition command posts during Operation *Iraqi Freedom* provided a "God's eye view" of moving vehicles throughout the area of operations, despite the dark of night, the smoke of oil fires, or the dust of sandstorms. What was seen could also be destroyed with responsive, highly accurate, and lethal munitions.

The ability to precisely and accurately strike enemy forces from the air—sometimes when in close contact with friendly forces in near-zero visibility—is certainly impressive, but the GMTI radars provided much more than rapid and precise targeting data. U.S. commanders and staff officers in command posts from tactical ground units to theater levels only had to glance at their computer screens to observe the fluid movement of the land battle throughout most of the operational area.

This ability to see moving vehicles in near-real time contributed significantly to the decisive U.S. battlefield information advantage. Properly exploited, advantages of such magnitude can

[1] Joint Surveillance Target Attack Radar System. The E-8C Joint Surveillance Target Attack Radar System (Joint STARS) is an airborne battle management and command and control (C^2) platform. This system uses advanced Ground Moving Target Indicator radar to conduct ground surveillance, enabling commanders to develop an understanding of the enemy situation, and to support attack operations and targeting. From a standoff position, the aircraft—a modified Boeing 707/300 series commercial aircraft—detects, locates, classifies, tracks and targets hostile ground movements, communicating near-real time information through secure data links with U.S. Air Force and U.S. Army command posts.

sometimes lead to a major shift—a transformation—in the conduct of warfare. Such a transformation is one of the top goals of the Department of Defense (DoD), which defines transformation as:

> a process that shapes the changing nature of military competition and cooperation through new combinations of concepts, capabilities, people and organizations that exploit our nation's advantages and protect against our asymmetric vulnerabilities... Shaping the nature of military competition ultimately means redefining standards for military success by accomplishing *military missions that were previously unimaginable or impossible* [emphasis added] except at prohibitive risk and cost.[2]

GMTI can help transform Intelligence, Surveillance, and Reconnaissance (ISR), a mission area essential to the U.S. battlefield information advantage, because it can detect movement of enemy (and friendly) forces in near-real time—a previously impossible capability. Historically, commanders had to assume that information on opposing mobile forces "on the other side of the hill" (beyond direct line of sight) of friendly forces would be unreliable, often dangerously so, because of the many constraints on their ability to collect, process, exploit, and disseminate information. Available sensors in the form of human eyesight and, later, cameras not only had very constrained fields-of-view but were limited to daylight and good visibility. The persistence of the coverage most sensors provided was also limited by human fatigue, weather, smoke, and light conditions.

Even as technology increased sensors' capabilities, information available to warfighters remained limited because of the extensive time that could pass between data collection and information dissemination. Enemy movement occurring during this time made information increasingly unreliable.[3] Therefore, commanders could use movement to create the advantages of superior force ratios, favorable position, and surprise. Napoleon put it best when he proclaimed, "Aptitude for war is aptitude for movement…."[4]

As a result, commanders were often forced to rely on having friendly troops in contact with enemy forces to know enemy locations. This reliance does much to explain why the close battle long dominated the organizational and employment concepts for land warfare. However, the introduction of GMTI renders obsolete the underlying assumption that accurate information on enemy mobile forces depends on military contact. For forces equipped with such radars, the Clausewitzian "fog of war"[5] that had hung over land battles for centuries lifts as they enjoy a tremendous advantage in situational awareness.

GMTI radars provide a foundation for Information Age warfare. The near-real time, precise data they collect on ground operations across the full sweep of an operationally significant area, together with the ability to link that information to multiple air and ground force elements throughout the entire theater, can multiply the capability of the combined force and transform the execution of air-land operations.

GMTI radar technology can provide the type of knowledge-based transformational capability that DoD envisions exploiting to execute new and more effective operational concepts. Therefore, analysis of the history of GMTI radar development, its contributions to the past several conflicts, and its future potential is useful in several ways. This paper tells the history of GMTI technology and, with that history, traces the development of an essential element in the transformation of the U.S. military. As a case study of a transformational technology, it describes the evolution of GMTI, explains the impact of the technology on modern warfighting and suggests the transformation GMTI represents for the future.

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[2] Department of Defense, *Transformation Planning Guidance*, April 2003, pp. 3-4.

[3] Theoretically, when unconstrained by geography, friendly uncertainty of an enemy unit's location increases in proportion to the square of the time that has passed since the last sighting. If a military unit can move distance "r" in a given time, then it can be anywhere in a circular area "A" equal to πr^2 in that time.

[4] Le Comte de Dervieu, quoted in JFC Fuller, *The Conduct of War, 1789-1961* (New York: Minerva Press, 1968), p. 50.

[5] "Like most useful military concepts, 'fog of war' normally is attributed to [Carl von] Clausewitz, who receives the credit for the alliterative "fog and friction"— friction referring to a physical impediment to military action, fog to the commander's lack of clear information." Eugenia C. Kiesling, "On War Without the Fog," *Military Review*, Sept./Oct. 2001, page 85.

II. GMTI Radar Technology

It is helpful to begin an analysis of GMTI with an understanding of the radar technologies involved and how they operate.

The asymmetrical advantage modern GMTI technology provides U.S. forces results from its unique ability to distinguish targets moving on land or water from surface clutter over a large area, even in bad weather and darkness, by virtue of the Doppler[6] return of the moving targets. The "picture" GMTI provides is similar to Doppler radar pictures of weather features, such as thunderstorms, familiar to viewers of television weather programs. Rather than the moving green masses on weather radar, the GMTI picture shows moving vehicles as moving dots overlaid on a digital map.

These dynamic GMTI vehicle "tracks" display vehicle locations in real time and can correlate well with imagery and signals intelligence data to provide a real-time Common Operating Picture (COP) of the dynamic battlefield. By its very nature GMTI provides a true picture of enemy, friendly, and civilian movement. Because of its relatively low data rate requirements, this GMTI picture can be transmitted to ground stations over a wide area.

There are two types of GMTI radars: static (or snapshot) radars and dynamic (or continual observation) radars. Static radar provides a momentary picture of what was moving at a point in time with infrequent updates depicting moving target density. The Army OV-1 Mohawk's[7] radar was an example of a static or snapshot GMTI radar. Developing radars capable of continual observation was key to the immense operational value of GMTI information. The E-8C Joint STARS' radar is an example of a dynamic GMTI radar system that provides periodic updates and allows precise tracking of a moving target.

A radar system's ability to provide detailed, near-real time information on vehicular movement depends on its ability to reliably detect, accurately locate, and precisely track slow moving ground targets. GMTI can provide target information, such as vehicle length and the order of specific vehicles within a convoy, essential to ensuring track accuracy, even when terrain screening or aircraft turns temporarily interrupt radar returns.

To provide precise, near-real time information on vehicles moving within a given area, a GMTI system must be able to generate and maintain numerous automatic tracks. The ability to do this depends on the system's performance in terms of the following metrics:

- *Probability of Detection (Pd)* — the probability of detecting a given target at a given range any time the radar beam scans across it
- *Target Location Accuracy* — a function of platform self-location performance, radar-pointing accuracy, azimuth resolution, and range resolution
- *Minimum Detectable Velocity (MDV)* — the rate of movement determining whether the majority of military traffic, which often moves very slowly especially when traveling off-road, will be detected
- *Target Range Resolution* — the fidelity determining whether two or more targets

[6] Doppler [Effect]: a change in the frequency with which waves (as sound or light) from a given source reach an observer when the source and the observer are in motion with respect to each other so that the frequency increases or decreases according to the speed at which the distance is decreasing or increasing.

[7] First produced in 1959, this U.S. Army observation and reconnaissance aircraft served widely in every conflict (especially Vietnam) and operation until it was retired in 1996.

moving in close proximity will be detected as individual targets

- *Stand-off Distance* — the distance separating a radar system from the area it is covering
- *Coverage Area Size* — the area the system can keep under continuous surveillance from a specific orbit. [See Figure 1 below.]. The earth's curvature and screening from terrain, foliage, and buildings cause system altitude to be a key factor determining coverage area—the higher the altitude, the greater the coverage.
- *Coverage Area Revisit Rate* — the frequency with which the radar beam passes over a given area

If performance in even one of these GMTI metrics is degraded, the system will lose tracking performance and compromise the accuracy and timeliness of the ground picture.[8]

The ability of GMTI radar technology to integrate these performance metrics and track slow-moving vehicles precisely provides the detailed, near-real time information needed for high quality intelligence and pinpoint targeting. Tracking vehicular movement defeats many of the camouflage, concealment, and deception measures effective against other collection methods. GMTI coverage makes using decoys difficult because the decoys must be able to move, and orchestrating decoy movement on a large scale, such as for an army battalion, can quickly become cost prohibitive, if not dangerous. This is not to say that GMTI cannot be spoofed. In fact, the Opposing Force at the Army's National Training Center claims significant success in deceiving Joint STARS radar by dragging concertina wire behind vehicles.[10] However, such deception operations become more difficult on a large scale and can be countered by cross-cueing UAVs to provide positive target identification and by better radar operator training.

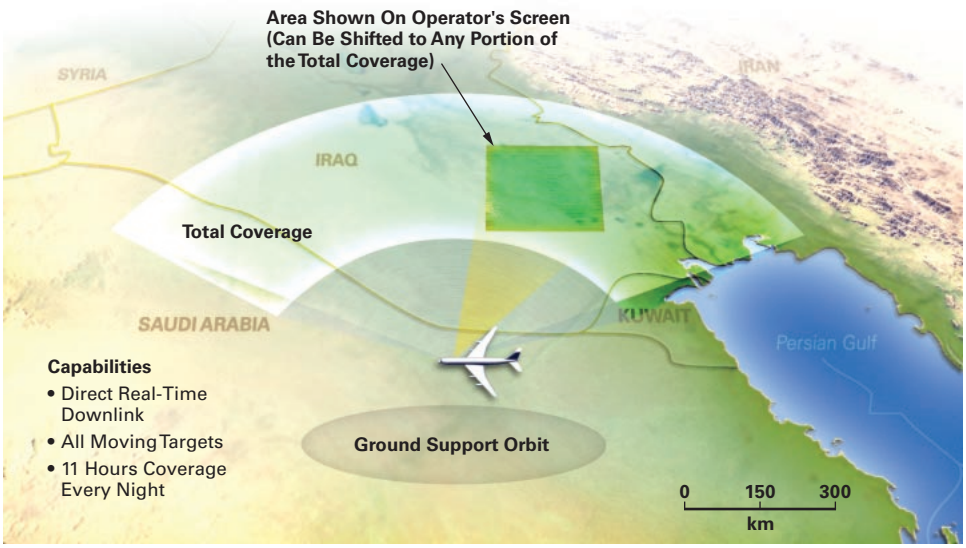

Figure 1. Joint STARS Coverage In Operation Desert Storm[9]

The GMTI system's ability to concurrently collect high-resolution, photo-like Synthetic Aperture Radar (SAR)[11] still images is also vital to reliably tracking mobile forces. Collection of SAR images with associated GMTI information is essential for quickly locating vehicles that have stopped moving. Most GMTI radar systems can collect either GMTI or SAR information

[8] For technical descriptions of each of these metrics, see the GMTI Performance Metrics Appendix.

[9] Brigadier General Robert H. Scales, Jr., *Certain Victory: The United States Army in the Gulf War* (Washington, DC: Office of the Chief of Staff, United States Army, 1993), p. 169.

[10] Briefing by Colonel John D. Rosenberger, U.S. Army, "The Inherent Vulnerabilities of Technology: Insights from the National Training Center's Opposing Force."

[11] Synthetic Aperture Radar (SAR) is a coherent radar system that generates high-resolution remote sensing imagery that can be photo-like in appearance and resolution. Signal processing uses magnitude and phase of the received signals over successive pulses from elements of a synthetic aperture to create an image. As the line-of-sight direction changes along the radar platform trajectory, signal processing having the effect of lengthening the antenna produces a synthetic aperture.

but not both simultaneously.[12] Since collecting a single SAR image for a small area takes several seconds, collecting numerous SAR images quickly leads to frequent interruptions in GMTI operation. However, the concurrent collection of SAR images with GMTI information means there is no mission compromise when both forms of imagery are needed. The radar can also make Inverse SAR[13] images which use a moving vehicle's motion to speed collection of a high-resolution image. Coupled with high-resolution SAR pictures, these allow target characterization by Automatic Target Recognition[14] (ATR) algorithms.

GMTI radar with a high revisit rate and high-resolution vehicle feature information is significantly different from pixel-based imagery like photographs or SAR images. Finding stationary enemy targets in large areas with high-resolution pixel imagery can be an overwhelming task requiring large numbers of highly trained human image analysts and significant computer processing power. On the other hand, automatic analysis of GMTI-derived moving target information is significantly easier and faster because it includes data on movement as well as an image. As every hunter knows, a moving target attracts the eye and it is easier to separate moving objects from their backgrounds.

[12] Several different aircraft are capable of both GMTI and SAR: Joint STARS, U-2s, and Global Hawk. The Global Hawk, manufactured by Northrop Grumman, is a high-altitude UAV used for collecting imagery. The U-2, manufactured by Lockheed Martin, has been the Air Force's primary, acknowledged, high-altitude intelligence gathering platform for more than 40 years and can simultaneously collect signals intelligence and imagery. U-2s and Global Hawk are currently optimized for high resolution SAR, but their GMTI capability is more rudimentary. Joint STARS has an excellent GMTI capability, but its SAR resolution is more limited.

[13] Inverse SAR (ISAR) is a SAR system that uses the target's motion to achieve the equivalent of a large synthetic aperture. The ISAR signature of a stationary radar imaging a rotating target is mathematically equivalent to the SAR signature of a moving radar imaging a stationary target.

[14] Automatic Target Recognition (ATR) uses a computer to analyze individual target features to allow recognition of the target.

III. The History of GMTI

GMTI makes it possible for the first time to track moving forces in near-real time. Development of these capabilities required technological breakthroughs in radars, processing capabilities, and software, advances all impressive in their own right. However, the propelling force behind their development was not transformation. It was Cold War military necessity.

Cold War Military Requirements

When U.S. Army fact-finding teams visited the battlefields of the 1973 Arab-Israeli War, they grimly noted that, in the course of the six-day conflict, Arab and Israeli forces collectively had lost more tanks and other major combat equipment than the U.S. had deployed in Europe at that time. General William DePuy, then commanding the Army's Training and Doctrine Command (TRADOC), understood what this new battlefield lethality meant to the NATO defense of Europe against the Warsaw Pact. In developing new operational concepts to win under these highly lethal conditions, he recognized that "field commanders would have to know the enemy's situation beyond the front lines, to include his successive echelons, artillery, support troops, headquarters, and possible course of action."[15]

Taking over TRADOC from General DePuy in 1982, General Donn Starry expanded these operational concepts to include attacking Soviet second-echelon forces through the concept of "deep battle" as part of the Army's new AirLand Battle Doctrine. This doctrine recognized the need to synchronize ground and air power at the operational (campaign) level. This necessary unity brought the Army and Air Force to agreement and enhanced the close working relationship between Army TRADOC and Air Force Tactical Air Command (TAC), the agencies responsible for developing the two services' future warfighting concepts. This led to a 1983 agreement between Army Chief of Staff General John Wickham and Air Force Chief of Staff General Charles Gabriel to explore 31 specific initiatives supporting air-ground operations. Development of a surveillance target and attack radar system (Joint STARS) was among them.[16]

GMTI Technology Development

Modern GMTI radar technology is the result of the Army's Stand-Off Target Acquisition System (SOTAS) and the Air Force/Defense Advanced Research Projects Agency (DARPA) Assault Breaker/Pave Mover programs developed in the 1970s. The evolution of digital-based radars with much greater processing capability than analog radars made these programs technically practical. With the added development of clutter-rejection algorithms, these radars allowed operators to detect even slow moving targets against heavy clutter backgrounds.

Demonstrations of the helicopter-mounted SOTAS technology led to growing Army support for the program as commanders became aware of the value of seeing opposing forces' movement. With this information, Army division commanders believed they would have the capability needed to defeat the numerically superior Warsaw Pact. However, a major cost overrun and the transition to a new administration in 1980 led to the program's cancellation despite strong support from the Army's field commanders and senior leaders.[17]

[15] Paul H. Herbert, *Deciding What Has to Be Done: General William E. DePuy and the 1976 Edition of FM 100-5, Operations*. Leavenworth Papers Number 16 (Fort Leavenworth, KS: Combat Studies Institute, 1988), pp. 30-31.

[16] Richard G. Davis, Office of Air Force History, *The 31 Initiatives: A Study in Air Force-Army Cooperation* (Honolulu, HI: University Press of the Pacific, 2002), p. 114.

[17] Charles A. Fowler, "The Standoff Observation of Enemy Ground Forces—From Project PEEK to Joint STARS," *IEEE Aerospace and Electronics System Magazine*, June 1997, pp. 7-9.

While the Army was working on SOTAS, the Air Force sponsored MIT Lincoln Laboratory's development of advanced radar capabilities, including those needed to permit GMTI operation on a fast-moving fixed wing aircraft—a key requirement for the DARPA/Air Force Pave Mover system.[18] Another relevant effort, started in 1975, was the Grumman/Norden development of a Radar Guided Weapon system (RGWS) that eventually led to a GMTI radar.

A 1976 Defense Science Board Summer Study, also examining the challenge of countering a Warsaw Pact offensive, proposed a system to locate and attack the Warsaw Pact's second and third echelon attacking forces. The system would use GMTI radars to detect and locate vehicles in these echelons that would then be attacked with air- and ground-launched missiles delivering smart, terminally guided submunitions. DARPA adopted this idea and sponsored a program known as Assault Breaker.[19] In support of this mission, Grumman/Norden changed RGWS' emphasis to a side-looking GMTI radar, giving them a head start in meeting Pave Mover and subsequently Joint STARS requirements.

Early studies of the radar required for Assault Breaker led to the DARPA/Air Force Pave Mover target acquisition and weapon delivery system, which used an electronically scanned radar mounted on an F-111 aircraft. The Pave Mover radar could shift between GMTI and Synthetic Aperture Radar (SAR) mode, allowing high-resolution imaging of areas of interest, including those where vehicles had stopped. Pave Mover tests in 1981-83 successfully demonstrated all the required modes, including the ability to locate targets over long distances and guide weapons against those targets.[20]

Having realized the revolutionary potential of GMTI, the Army searched for a replacement for SOTAS. However, when it became clear that neither the Office of the Secretary of Defense (OSD) nor Congress would fund separate GMTI programs for the two services, Army and Air Force leaders were forced to meld their divergent requirements into a single program. Selecting one system to meet both the Army's desire for surveillance of the entire operational area and the Air Force's requirement for battle management of strike aircraft created tensions that required resolution. Joint STARS was conceived as a theater asset, like Pave Mover, providing both GMTI and SAR information for attacking the second and third echelons while also, like SOTAS, providing the Army with moving target information on closer forces. Because the Air Force would operate Joint STARS and given the intrinsic conflict in the two service missions, the Army was concerned that the close battle might be neglected as the program developed. However, a Memorandum of Agreement signed by the service chiefs laid out an equitable plan for prioritizing Joint STARS missions and assuaged the Army's concerns.[21] In 1985 the contract for the Joint STARS system was awarded to Grumman/Norden with Motorola winning a separate contract for the Army's ground support module. Initial planning called for a 10 aircraft program with four development aircraft.[22]

In sum, GMTI was very much a child of Cold War requirements, conceived from the need to locate and attack the Warsaw Pact's armored follow-on forces before they could break through NATO's defenses. Insightful leaders in both the Army and Air Force understood the potential of new technology to meet this requirement by providing superior battlefield situational awareness. This would allow their forces to fight smarter and faster and operate inside the decision cycle of their more massive but less situationally aware enemies.

[18] Fowler, p. 9.

[19] John N. Entzminger, Jr., Charles A. Fowler, and William J. Kenneally, "Joint STARS and GMTI: Past, Present and Future," *IEEE Transactions on Aerospace and Electronics Systems*, April 1999, pp. 752-753. For additional relevant background information see Fowler, reference 17, pp. 9-10.

[20] Entzminger *et al.*, p. 753. Also see Fowler, reference 17, pp. 9-10.

[21] Davis, p. 78.

[22] Congress subsequently reduced the number of development aircraft to two. "Joint USAF/Army JSTARS System Set for Airborne Test in 1988," *Aviation Week & Space Technology*, December 9, 1985, pp. 91-99. William H. Gregory, "U.S. Army, Air Force Continue Development of Joint STARS," *Aviation Week & Space Technology*, May 5, 1986, pp. 113-116.

Joint STARS, the first operational system providing wide-area, high performance GMTI, was also a product of the bureaucratic process of the U.S. Department of Defense and the services. Despite its significant promise, the Army was never able to bring SOTAS to fruition, and funding constraints would not allow the Air Force to move forward independently with Pave Mover. Consequently, the services agreed to a single, joint program to meet their requirements.

Post-Cold War Employment of GMTI

When the end of the Cold War eliminated the threat posed by a massive, multi-echelon Warsaw Pact land offensive, some defense experts suspected that Joint STARS was no longer needed. However, as the following brief histories of GMTI employment in post-Cold War conflicts show, GMTI platforms have played key, if not transformational, roles in all of them.

The Gulf War

Occurring shortly after the fall of the Berlin Wall, Iraq's invasion of Kuwait in 1990 provided an early opportunity to test GMTI's value. Army Lieutenant General Fred Franks, whose VII Corps deployed from Europe to Saudi Arabia in November of 1990, had been tremendously impressed by the Joint STARS prototype aircraft's performance in tests in Europe the previous September. He convinced the Army senior leadership to insist on deploying both prototype aircraft to the Persian Gulf over the objections of the Air Force, whose leaders were concerned about risking and supporting the developmental aircraft in theater.[23] However, a special CENTCOM-sponsored Defense Science Board Task Force strongly supported the Army position[24] and on January 12, 1991, two developmental Joint STARS aircraft arrived in Saudi Arabia to support Coalition forces engaged in Operation *Desert Storm*. Since the system was still in development when the Iraqi invasion of Kuwait occurred, the Coalition leadership's lack of Joint STARS knowledge was a serious handicap. The Gulf War air commander, General Chuck Horner, later noted, "…we who were responsible for planning and orchestrating air operations had little appreciation of the system's capabilities and limitations."[25]

Lack of familiarity extended to the Joint STARS crews, which had to be formed and then trained. In a somewhat unprecedented move, these crews included civilian systems experts from Grumman Corporation to assist in aircrew training while the systems were en route to the theater. Even the system's concept of operation had not been fully developed. But thanks to significant "on-the-job" training on the system's abilities, the Coalition quickly began to exploit GMTI's ground surveillance and targeting capabilities.

Early in the Gulf War, during the Battle of Al Khafji, Joint STARS' GMTI information made it possible to locate advancing Iraqi ground forces that had attacked at night in an effort to avoid detection. The Coalition's air forces used GMTI cues to locate, target, and destroy these forces before the majority of them could close with Coalition land forces. Besides significantly enhancing the effectiveness and efficiency of air attacks against Iraqi forces, GMTI provided Coalition leaders valuable threat information by assuring them that the Al Khafji attack was not a deception supporting a major Iraqi attack elsewhere.[26]

Later, during the Coalition's ground offensive, which took place during the worst weather of the war, Joint STARS surveillance revealed Iraqi efforts to reposition their forces, providing advancing Coalition forces with the information they needed to defeat the maneuver. When Iraqi forces began withdrawing from Kuwait, GMTI was again the source of timely, reliable information that enabled air attacks to disrupt the Iraqi retreat.[27]

[23] Scales, p. 167.

[24] Fowler, p. 11.

[25] General Chuck Horner (Retired), "An Information Superiority Lesson: Airborne Ground Surveillance Offers an Effective New Way of Fighting Enemy Ground Forces," *The ISR Journal*, 2002/Issue 1, p. 17.

[26] Lt. Col Price Bingham, USAF (Retired), *The Battle of Al Khafji and the Future of Surveillance Precision Strike*, (Arlington, VA: Aerospace Education Foundation, undated), p. 9.

[27] Scales, pp. 237, 248, 275, 277, 315, and 320.

Joint STARS contributed significantly to the Gulf War's victorious outcome by supporting the defeat of Iraqi land forces despite numerous major handicaps. Deploying just two aircraft meant that it was not possible to provide persistent GMTI coverage. For extended operations, three aircraft are required to maintain a single, continuous orbit because of the need for crew rest, aircraft maintenance, etc. Persistence was further reduced because Coalition commanders had many urgent requirements for using the system. Commanders would often task the one airborne Joint STARS to conduct surveillance during a single mission extending from the far western portion of Iraq to the coastal area of Kuwait.

After the war many U.S. military leaders recognized the magnitude of the contribution GMTI and Joint STARS had made. Brigadier General John Stewart, the Army's senior theater intelligence officer, stated that, "Joint STARS was the single most valuable intelligence and targeting system in *Desert Storm*."[28] General Merrill McPeak, Air Force Chief of Staff, told a symposium, "Never again will we want to go to war without some kind of Joint STARS capability."[29] Years later during a conference on the war, General Walter E. Boomer, Commanding General, 1st Marine Expeditionary Force, noted that during the war, "Intelligence began to improve with information that came from JSTARS.… As JSTARS information was coming to me, we could see that the Iraqis were indeed escaping from Kuwait. From that point, we pushed as fast as I believed possible."[30] In *Desert Storm* GMTI had hinted at its ability to change the conduct of warfare.

Despite Joint STARS' success during the Gulf War, the DoD acquisition system did not treat it kindly thereafter. After performing well in combat, Joint STARS was returned to the Operational Testing and Evaluation (OT&E) process to prove it could do in testing what it had already done in combat.[31] Nor did the system fare well in the post-Gulf War resource battles. The 1997 Quadrennial Defense Review (QDR) reduced the size of the fleet from 19 to 13[32] (it has since increased to 17), despite early studies that projected a need for 32 aircraft, while contradicting the QDR's own premise that "modernization of our forces depends on a strong C4ISR backbone."[33]

Kosovo

Despite the magnitude of its contribution in the Gulf War, there was little appreciation shown for the value of GMTI in U.S. planning for Operation *Allied Force* in Kosovo. To some extent the failure to fully exploit the system's targeting capabilities from the very beginning of hostilities could be explained by major differences between the two conflicts. Unlike Kuwait and Iraq, Kosovo's rugged terrain and foliage increased the amount of radar screening, making it more difficult for Joint STARS' GMTI surveillance to detect, locate, and track mobile forces.

Initially, another key difference was the lack of friendly ground troops to threaten Serb units. This allowed the Serbs to disperse and limit their movement to avoid providing the large number of moving targets that Joint STARS had been able to detect in the Gulf War. Serb use of civilians as "human shields" and commingling of units with civilian traffic required NATO air forces to visually identify targets, thereby limiting the value of GMTI.[34]

Basing also had an impact on Joint STARS employment. Limited near-by basing and the refusal of the Swiss and Austrian governments to permit overflight made it necessary for Joint

[28] Brigadier General (Promotable) John F. Stewart, Jr., U.S. Army, G-2, 3rd U.S. Army, *Operation Desert Storm The Military Intelligence Story: A View from the G-2*, April 1991, p. 31.

[29] USAF Tactical Air Command Symposium, Orlando, Florida, January 31, 1991.

[30] General Walter E. Boomer, USMC (Ret.), Lieutenant General John J. Yeosock, USA (Ret.), Admiral Stanley R. Arthur, USN (Ret.), General Charles A. Horner, USAF (Ret.) "Ten Years After," *Proceedings*, January 2001, p. 62.

[31] Fowler, pp. 13-14.

[32] U.S. Department of Defense, *Report of the 1997 Quadrennial Defense Review*, Section 7.

[33] Robert P. Haffa and Barry D. Watts, "Brittle Swords: Low-Density, High-Demand Assets," *Strategic Review*, Fall 2000, p. 47.

[34] Benjamin S. Lambeth, *NATO's Air War for Kosovo: A Strategic and Operational Assessment* (Santa Monica, CA: RAND, 2001), pp. 139, 205, and 213.

STARS aircraft to fly to their operating orbits from their base in Germany, reducing on-station time.

As in the Gulf War, the paucity of available aircraft also limited Joint STARS' initial contribution to Operation *Allied Force*. Even though Joint STARS was no longer a prototype, the fleet at that time consisted of only four operational systems; for most of the operation, only two systems were in theater. Even with a high sortie rate,[35] the limited number of aircraft and the distance they had to fly from their base to their orbit again combined to prevent Joint STARS from providing 24-hour coverage. The lack of persistent GMTI coverage gave Serb forces valuable opportunities to move without the risk of being detected, located, or tracked.

But Joint STARS might have been used more effectively in Kosovo had its capabilities and limitations been more fully understood by U.S. European Command (USEUCOM) personnel when it was first deployed. This lack of familiarity may help explain why USEUCOM did not request the system's deployment early in the crisis when it could have revealed the magnitude of the Serb movement into Kosovo. Once the system was deployed, it was placed in an orbit that did little to minimize screening. This also caused Joint STARS to be used, initially, only for surveillance and not to support targeting. Further, the command did not request the right equipment to exploit GMTI information. All of these shortcomings improved once the Joint STARS wing sent liaison officers and the proper equipment to the EUCOM command and control nodes requiring live Joint STARS data.[36]

Just as in the Gulf War, operational experience with GMTI eventually generated a greater appreciation for its capabilities among commanders, their staffs, and aircrews. With this knowledge came a growing understanding that GMTI could make a valuable contribution to the effectiveness of NATO air operations. Fighter pilots came to recognize that the system "changes the rules" because its ability to detect, locate, and track vehicular movement reduces the need for an inefficient visual search that decoys and camouflage can easily overcome.[37] Soon Joint STARS assumed the role of an airborne command and control asset, providing crucial data that helped direct the air war and cueing airborne forward air controllers and UAVs on locations where movement was occurring. This allowed such assets to be much more effective and efficient at finding, identifying, and targeting Serb forces.

Later in the conflict, when the weather began improving and the Kosovo Liberation Army (KLA) began its offensive, Joint STARS' GMTI demonstrated its contribution to joint air-ground operations by allowing NATO to create a dilemma for Serb forces. If the Serbs attempted to maneuver in response to the KLA's offensive, the movement made their forces visible to GMTI and thus vulnerable to NATO air attack. But if the Serbs did not move for fear of being detected and attacked, they handicapped their ability to achieve the force ratios and position needed to defeat the lighter KLA forces.

Afghanistan

Joint STARS operations during Operation *Enduring Freedom* in Afghanistan again saw less than optimal use of GMTI. However, there were encouraging signs that its capability was increasingly valued. As in Kuwait and Kosovo, Joint STARS was not deployed in sufficient numbers for persistent coverage. The presence of civilians on the battlefield was also similar to Kosovo, making positive target identification a key requirement.[38]

Afghanistan's rugged terrain also made screening a problem. In Afghanistan, however, the rugged

[35] 93rd Air Control Wing Briefing, Robins AFB, Georgia, July 18,1999. As in the Gulf War, the Joint STARS Team excelled in generating effective sorties, flying 83 effective sorties between February 22 and June 28, 1999, for a total of 730.7 on-station hours.

[36] E-mail Interview with Marc Lindsley, Director, Northrop Grumman Washington Office Operations for Air Combat Systems. During Operation *Allied Force* he served as commander of the 93rd Air Control Wing that provided Joint STARS support.

[37] "Allied Force pilots say improved training key to strike operations," *Inside the Air Force*, October 13, 2000, p. 8.

[38] Elaine M. Grossman, "Key Command Banned Nearly All Attacks on Afghan Roads, Bridges," *Inside the Pentagon*, January 9, 2003, p. 1.

terrain that screened Joint STARS' radar also restricted the Taliban's mobility. Here, Joint STARS' radar surveillance was more effective when the terrain channeled vehicular movement, particularly when orbits were well planned and other surveillance capabilities, such as UAVs, U-2s, and SOF complemented GMTI.[39]

As previously seen in Operation *Allied Force*, Joint STARS' GMTI information was used to cue UAVs. This enhanced the capabilities of Joint STARS as well as the UAVs with their high-resolution but restricted "soda straw" field-of-view sensors. Although Joint Stars was highly reliable,[40] the distance Joint STARS had to fly to reach an orbit and the impact of altitude on terrain screening reduced on-station time and increased refueling requirements as in Kosovo.

As in the Gulf War and during the final days of operations in Kosovo when the KLA offensive occurred, Joint STARS operations in Afghanistan were enhanced by the presence of friendly ground forces. Northern Alliance units supported by U.S. SOF threatened Taliban and al Qaeda forces sufficiently to cause them to move and concentrate. Because the enemy relied upon vehicles to provide their forces with mobility, heavy firepower, and armored protection, GMTI could often detect, locate, and track them. By waiting until they moved out of populated areas before attacking them, CENTCOM reduced collateral damage.

Joint STARS deployment to Afghanistan was delayed and the system did not arrive in theater until after combat operations had been under way for weeks. This may have been due to a failure during planning to recognize GMTI's ability to support the types of operations planned for Afghanistan.[41] By the time the system was available, much of the vehicular movement that had initially characterized Taliban and al Qaeda operations was no longer occurring, and many of the lucrative targeting opportunities that could have been exploited with GMTI no longer existed.

Despite this oversight, Operation *Enduring Freedom* provided GMTI an opportunity to demonstrate what it could contribute to combat operations, even in the remote reaches of Central Asia against an unanticipated enemy in a dynamic combat environment. As Chairman of the Joint Chiefs of Staff Air Force General Richard Meyers explained, "I think one of the most innovative ways we have used our assets can be seen in the Joint STARS. That was designed during the Cold War for a very linear battlefield with the bad guys on one side and the good guys on another. Here it was being used to cue Global Hawk, which in turn could cue other systems."[42]

Iraq

U.S. and British forces in Operation *Iraqi Freedom* benefited from the lessons learned from Joint STARS deployments in previous conflicts. For the first time, nine aircraft were deployed, providing coverage for three orbits (one continuous), essentially meeting the GMTI requirement for a major portion of the operational area. Additionally, these aircraft were deployed into the theater early enough to collect baseline data on Iraqi forces before the conflict began. Early deployment also helped ensure that combatant commanders and their staffs were familiar enough with GMTI technology to employ it effectively when combat operations commenced.

During the major combat phase of the war, the primary mission of Joint STARS was to support air and ground forces directly engaged in combat operations by providing them near-real time information on enemy (and sometimes friendly) movement throughout the theater. At times these surveillance missions were combined with attack support missions.

[39] Price T. Bingham, "Targeting Systems Are Critical in Mountain Ops," *Proceedings*, April 2002, pp. 91-3.

[40] Northrop Grumman, *Enduring Freedom* Metrics. Between November 7, 2001, and April 27, 2002, Joint STARS flew 249 missions, 100% of those scheduled. Of these, 245 missions were effective, for a 98.4% effectiveness rate. Of the final 189 missions, 188 were effective for a 99.5% effectiveness rate.

[41] Amy Butler, "Roche Backs Boeing's 767, Wants to Boost JSTARS Requirement," *Inside the Air Force*, October 22, 2001, p. 1

[42] Hunter Keeter, "Lessons Learned in Afghanistan May Shape Military Transformation," *Defense Daily International*, December 14, 2001.

Because GMTI was capable of detecting vehicular movement, Iraqi commanders and their forces faced the same operational and tactical dilemma the Serbs faced in Kosovo. If they moved, they were seen by GMTI and attacked by air or artillery. If they dispersed and remained camouflaged and dug in, they were either bypassed or defeated in detail by ground forces. In many cases entire units (including Republican Guard units) abandoned their tanks and armored vehicles rather than face almost certain detection and destruction from the air.[43]

GMTI information was key to the rapid maneuver of Coalition ground forces. It not only allowed direct targeting of Iraqi forces based on precise knowledge of their locations but also provided the "protective overwatch" that allowed commanders to maneuver with confidence even though their flanks and supply lines were unprotected. Although Coalition situational awareness was imperfect along the supply lines where convoys were attacked by dismounted Iraqi forces and others mounted in civilian vehicles, the Coalition was able to respond effectively to Iraqi threats of any significant size. Wide area surveillance detected developing Iraqi threats to vulnerable areas early enough for decisive Coalition response, including repositioning of forces or air/artillery attack. Although Iraqi ground forces greatly outnumbered those of the Coalition, they were unable to achieve surprise or to mask their movements, even by moving under cover of a massive sandstorm. Consequently, Coalition forces consistently operated so much faster than the Iraqis could track them and respond that an Iraqi general enroute to work blindly ran into some of the first U.S. forces to enter Baghdad.[44]

Joint STARS also played a significant role in time-sensitive targeting (TST). Using precise, near-real time radar location data, the immediately available on-board battle management capability directed strike aircraft onto quick-reaction targets. Because their fields of view are both very broad and persistent, Joint STARS systems often cued UAVs and other sensors to time-sensitive targets as well.

[43] Terry McCarthy, "What Ever Happened to the Republican Guard?: A Time investigation suggests most of the elite Iraqi forces survived the U.S. bombardment," *Time Magazine*, May 12, 2003, pp. 38-43.

[44] Michael R. Gordon, "U.S. flexes muscle in capital: U.S. Tests Baghdad's defenses—Armoured column on three-hour raid," *The Toronto Star*, April 6, 2003, p. AO1.

IV. Trends from Recent Conflicts

Analysis of the two Iraq wars and operations in Kosovo and Afghanistan reveals both positive and negative trends related to GMTI technology and the U.S. ability to employ it effectively.

Positive Trends

Operational Advantage — GMTI technology has delivered on its promise. After each conflict, senior leaders identified GMTI as one of their most important ISR capabilities. GMTI in combination with the other sensor systems it often cued has provided U.S. forces an immeasurable information advantage. The U.S. military is able to analyze the data collected and produce a near-real time, virtually complete picture of the battlefield for distribution to air and ground users throughout the theater. Stripping away much of the "fog of war" and uncertainty that surrounds combat operations has allowed U.S. commanders to be much faster and more precise in their application of both air and ground combat power. By revealing battlefield movement in near-real time, GMTI has helped begin a transformation of U.S. ISR capabilities. GMTI and other advanced ISR systems can enable a "new American way of war" in which information and precision reduce the amount of time and mass required, significantly speeding up military operations.

In that context it should also be noted that near-real time, dynamic GMTI targeting information coupled with weather-independent precision guided munitions, such as JDAMs, have redefined both close air support and battlefield air interdiction, air power's two major ground support roles. By allowing these functions to be performed very effectively (regardless of weather and visibility conditions) by high-altitude, long duration, survivable air platforms with large weapons inventories, GMTI and JDAMs open up major opportunities to rewrite the book on integrating aerial fires with ground maneuver.

GMTI as an "ISR Quarterback" — Joint STARS GMTI capability has allowed it to assume a command and control role. Because it has continuous wide area coverage, it provides a broad and complete battlefield picture to component commanders. GMTI can also cue other ISR systems to provide a more detailed picture of specific areas of interest. By focusing the efforts of other ISR elements, GMTI has significantly increased the effectiveness and efficiency of the entire ISR network.

Increasing Jointness — GMTI capability has done much to enhance joint warfighting. Because it provides an identical "ground truth" picture to air and ground users alike, it helps joint, air, and ground commanders share a common understanding of the battlefield, its dangers, and opportunities that can be exploited through integrated and synchronized application of air and ground combat power.

For example, these wars demonstrated that GMTI's unique capability to detect moving vehicles could place an enemy ground commander in a deadly dilemma. If he keeps his ground combat systems dispersed, camouflaged, and static to avoid detection and destruction from the air, attacking ground forces can destroy his forces piecemeal. If he maneuvers and concentrates his forces to respond to ground attack, GMTI can detect his forces and air power can destroy them.

Because air and ground commanders can share a common real-time battlefield picture showing movement of friendly, enemy, and civilian vehicles, GMTI can also help to avoid fratricide or the inadvertent attack of innocent civilians. This ability will be enhanced by the future improvements in GMTI (described in the following section) that can provide greater target categorization.

Negative Trends

Insufficient GMTI Coverage — In the first three conflicts GMTI capability was insufficient to provide the desired 24/7 coverage of all major operational areas. In Kosovo and Afghanistan the Joint STARS aircraft had to fly extensive distances to reach their operational orbits, compounding the limitations imposed by the small number of available systems. Only in Operation *Iraqi Freedom* were enough GMTI systems deployed to provide coverage of most operationally significant areas.

GMTI Lessons Had to be Relearned from Conflict to Conflict — While it is understandable that *Desert Storm* commanders and staffs would have to learn the system's capabilities and limitations from the ground up, U.S. forces should have been able to do better during the subsequent conflicts. However, in both Kosovo and Afghanistan, Joint STARS was brought into theater late. In Kosovo, Afghanistan, and Iraq many of the lessons identified in *Desert Storm* regarding orbits, command and control functions, UAV cueing, etc, had to be rediscovered. This indicates that both doctrinal and organizational development have yet to fully reflect and capitalize on GMTI's capabilities.

Another reason for relearning past lessons is the lack of joint training exercises employing GMTI assets. Although the Army does a good job of representing GMTI collection capability in its formal command post exercises at division and corps level, field exercises normally focus at battalion level and below; and Joint STARS and other systems are rarely, if ever, involved in joint field exercises. Consequently, field training opportunities for both crews and GMTI information users as part of the larger air-ground combat operations team are insufficient to develop and maintain top proficiency in GMTI employment. However, recent Army initiatives to make Army Combat Training Center field training exercises fully reflective of joint capabilities would do well to include either actual GMTI platforms, if available, or a surrogate representation of GMTI capability through distributed simulation systems.

Trend Implications

In each of the four major post-Cold War conflicts, GMTI contributed to the unprecedented near-real time, wide area situational awareness enjoyed by the U.S. and its allies. Despite the sometimes conflicting requirements of the Army for broad area surveillance and Air Force for battle management, the shortage of Joint STARS, and the pre-conflict lack of familiarity with GMTI capabilities, U.S. forces appear to be improving their ability to exploit the advantages it provides. In particular, GMTI capabilities have enhanced U.S. ability to conduct joint operations because of the common operational picture they provide to both air and ground forces. However, the superior situational awareness that GMTI helped provide approached its transformational potential only in the latest Iraq conflict.

From the GMTI perspective the most transformational characteristic of Operation *Iraqi Freedom* was that its concept of operations appeared to depend upon the overwhelming information superiority that GMTI and the full set of ISR systems afforded the Coalition. This allowed ground commanders to accept risk and conduct rapid operations with smaller, fast, but lethal forces that relied upon their information advantage and speed to outmaneuver the enemy. Coalition ground forces were supported by precisely targeted, highly responsive precision air-delivered munitions that often reduced Iraqi forces to "combat ineffective" levels. In a sense, General Tommy Franks' operational concept substituted information, precision, and speed for mass and firepower. It remains to be seen if this becomes the norm in U.S. operational concepts.

V. Future GMTI Capabilities

As noted in The History of GMTI section, the technologies that combined to provide the transformational GMTI capabilities debuted by Joint STARS in Operation *Desert Storm* in 1991 were initially developed in the 1970s and 80s. Since then radar and computer technologies have advanced significantly, and some have been integrated into existing platforms. In particular, older computers are being replaced with new, commercial-off-the-shelf processors that will significantly improve on-board computational capacity.[45]

Other technological advances are now being incorporated into a second-generation GMTI system known as the Multi-Platform Radar Technology Insertion Program, or MP-RTIP, that was initially intended to be a product improvement to Joint STARS but will now be deployed on more advanced manned and unmanned aircraft. The improved range, update rate, resolution, and accuracy of this new active electronically scanned array radar, combined with automatic target recognition software, will add the capability to classify targets by length and (in some cases) types (e.g., tanks, missile launchers, civilian buses), to tag them with a unique target designator, and to track them much more precisely. This, plus its higher range resolution, will allow better target recognition and track maintenance, speeding the targeting of time critical targets. MP-RTIP will also have the potential to track low-flying cruise missiles. This may be expanded in future development to include a full air moving target indicator (AMTI) capability. The new radar will be both modular and scalable, meaning that it can be deployed in different configurations on different aircraft.[46]

Rather than just slowly updating moving dots, advanced GMTI radar systems will be able to provide high revisit rate moving target detection along with individual moving target recognition features. This will provide significantly more information about the nature and dynamics of thousands of moving targets over large areas. Such information would generate a dynamic picture compiled from vehicle characteristics, speed, vehicle origin and destination, and the number of vehicles moving in specified areas. Vehicle features, coupled with high location updates, would provide much higher tracking reliability as well as significant information concerning types of military units and their activities.

While most of the enhanced GMTI capabilities of MP-RTIP radar represent major performance improvements over existing systems, it is the capability to classify and tag targets that is new and transformational. Today's systems can only tell that a vehicle (tracked or wheeled) is moving along a particular path in a given location. With its greater resolution, MP-RTIP could provide much more specific information on targets, further classifying them into potential enemy, friendly, or civilian sets. This might reduce the numbers of targets of interest that require cross-cueing of other sensors for positive identification, further speeding the prosecution of time-sensitive targets.

With its impressive performance in all four of our most recent conflicts and demonstrated potential to transform the way the U.S. fights wars, GMTI should have a prominent place in future concepts of operations and force structure. However,

[45] Honorable James G. Roche, Testimony before the Senate Committee on Armed Services, Tuesday, February 12, 2002, p. 29.

[46] Jonathan Bernhardt, "Multi-Platform Radar Technology Insertion Program," Northrop Grumman Integrated Systems Briefing, August 28, 2003. Also see Sandra I. Erwin, "Air Force To Run Wars From Sensor-Packed Jets," *National Defense Magazine*, July 2003, and Department of the Air Force, Fiscal Years 2004/2003 Biennial Budget Estimates, Research, Development, Test and Evaluation Descriptive Summaries, Volume III, Budget Activity 7, February 2003, p.2.

current programs only provide for completing the 17 authorized Joint STARS aircraft (15 have already been delivered). Eventually, the Air Force hopes to deploy MP-RTIP radar in the new Multi-sensor Command and Control Aircraft (MC2A) where, as Secretary of the Air Force James G. Roche testified, it would "provide five to ten times the air to ground surveillance capability of current JSTARS."[47] However, even optimistic estimates place initial deliveries of these aircraft in the 2010-2012 timeframe.[48]

For the future, efforts to capture GMTI's full transformational advantage in advanced systems continue. Recognizing GMTI's potential, the Air Force plans to incorporate a highly sophisticated version in the fourth (and final) development spiral of the Global Hawk ISR UAV. Scheduled to begin flying around 2009, the 12 aircraft of this spiral will have an appropriately scaled version of the MP-RTIP radar.[49] Combining the ISR potential of MP-RTIP with the Global Hawk's range and flight endurance promises to open new, unprecedented opportunities to exploit GMTI's capabilities.

As noted earlier, the earth's curvature and screening by terrain, foliage, and buildings make GMTI system altitude a key factor in determining depth of coverage. Therefore, space, the "ultimate high ground," logically provides the best location for obtaining the greatest coverage from a GMTI system. However, orbiting GMTI systems also require significantly longer range, which in turn requires significantly greater power and antenna size. The Air Force is currently conducting a DoD-directed Analysis of Alternatives that addresses the complementary roles for air and space-based radar systems in meeting national needs for GMTI, SAR, and High Resolution Terrain Information (HRTI).[50] Interim results support the Space-Based Radar (SBR) requirement, and current baseline funding could lead to a 2012 initial launch capability.[51] The SBR program has recently been approved to move into the concept definition stage.[52] Even if eventually fielded in the 2012 timeframe, SBR alone will not be able to satisfy the ISR requirements of operational commanders; a cost-effective combination of space-based and airborne systems will therefore be required for purposes of ubiquity, timeliness and resolution.

[47] Roche, p.31.

[48] At this writing, the future of the E-10A MC2A appears to be somewhat uncertain. According to current U.S. Air Force plans, it would be the ultimate airborne GMTI ISR system and will also be equipped with the MP-RTIP radar. Employing a Boeing 767 airframe with space for up to 60 operators, the E-10A has been envisioned as a "flying air operations center" serving as the "hub" of a "constellation of manned and unmanned aircraft and satellites conducting ISR missions and providing command and control." Global Security.org, "E-767-Multi-Mission Command and Control Aircraft (MC2A)," Jan 8, 2003. Amy Butler, "Sources Question Need to Fly Large BMC2 Staff on Aircraft," *Inside the Air Force*, May 16, 2003.

[49] Amy Butler, "Aldridge Approves Next Two Global Hawk Development Spirals," *Inside the Air Force*, January 6, 2003, p. 1.

[50] High Resolution Terrain Information (HRTI) can have postings as dense as one meter, absolute accuracy on the order of a few meters and relative accuracy in the sub-meter range. National Geospatial Intelligence Agency website, [**www.nima.mil/cda/article2/0,2421,3104_10573_128077,00.html**].

[51] Lt. Col. Alan Davis, "Space Based Radar Update to General Officer Steering Group," Headquarters U.S. Air Force Briefing, January 9, 2003.

[52] Thomas Duffy, "Industry Briefing Marks Next Step for Space-Based Radar Program," *Inside the Air Force*, August 15, 2003, p. 1.

VI. Operational Implications of GMTI's Potential

Looking at GMTI's contribution in the past four conflicts and extrapolating to account for the enhanced and new capabilities of the next generation of GMTI systems suggests GMTI's potential impact on future military operations. In each conflict GMTI has demonstrated its ability to generate near-real time, highly accurate, broad area pictures of most moving vehicles throughout a large area of operations, even in darkness and bad weather. This information has been exploitable for intelligence, battle management, and targeting at multiple levels of command. It has also been used extensively to cue UAVs and other elements of the ISR constellation with more limited fields of view. Such cross cueing enhances effectiveness of the entire ISR system by getting other sensors onto targets of interest faster and by providing positive identification of GMTI targets.

GMTI has also shown its unique ability to provide critical battlefield information to multiple echelons of command without a requirement for fusion. A GMTI sensor platform provides a near-real time, detailed (targeting level of resolution), single distributable picture of an entire operationally significant area without the need to integrate inputs from multiple, smaller-scale sensors. For example, Joint STARS data can be distributed through links to common ground stations and presented on a "zoom in/out" map overlay simultaneously available to all users. This provides joint, air, and ground commanders and staffs at multiple echelons a common, near-real time understanding of what is occurring on the battlefield.

This common operational picture contributes in large measure to the unprecedented level of situational awareness that U.S. forces supported by GMTI enjoy today. Such a high level of situational awareness (one that will increase considerably when future GMTI systems are fielded) has the potential to significantly enhance both maneuver and fires and enable a new, more effective approach to warfighting where situational awareness and precision weaponry reduce both the time and mass required to execute operational tasks. Such reductions can increase the pace of operations, allowing U.S. forces to attack and collapse enemy centers of gravity before they can respond effectively. Specifically, GMTI-enhanced situational awareness can enable faster maneuver, more effective fires, faster and better decision-making and lower-level joint integration. Taken together, these enhanced capabilities make it possible to conduct decisive operations faster with smaller forces.

Faster Maneuver

One of the most influential forces in warfare is uncertainty, Clausewitz's famous "fog of war." Uncertainty results from a lack of information or unclear information about such critical battlefield factors as the location, number, and capability of the enemy. To avoid being surprised by the enemy, commanders must take precautions to deal with uncertainty. These can include maintaining a continuous front against the enemy, assigning units to protect flanks, keeping a portion of the force in reserve, maintaining favorable force ratios, and building "iron mountains" of supplies in case they are needed. Additionally, every combat unit committed to an operation requires even more support units to provide supplies (e.g., fuel and ammunition) and services (e.g., medical and maintenance support). All this can require a large amount of mass, and mass is both slow to deploy and slow to employ, given

finite land, sea, and air transportation resources and infrastructure.

The more uncertainty a commander faces, the greater the mass of units he needs to hedge against surprise. Conversely, the more information he has about the situation, the less mass he needs and the faster he can move. Thus, the battlespace situational awareness enabled in large measure by GMTI allows faster maneuver by reducing uncertainty.

The U.S. Army's advance on Baghdad during Operation *Iraqi Freedom* shows how reduced uncertainty can shrink the amount of mass required for decisive operations. Traditionally, ground commanders arrayed their forces to present a continuous front to the enemy. This protected vulnerable flanks and supply lines from surprise enemy attack. During its dash to Baghdad, the U.S. Army's 3rd Infantry Division advanced directly on the city with no ground forces on either flank, leaving its flanks and supply lines exposed for hundreds of miles. The Army commanders apparently felt they could accept this risk in part because they were confident GMTI and other ISR assets could immediately detect any significant Iraqi attempt to maneuver, allowing a timely counter blow by strike aircraft, attack helicopters, or ground maneuver forces if necessary.[53] This allowed a single division to advance on a narrow front by itself against a much larger enemy force.

This is not to suggest that GMTI-supported ISR can substitute for ground forces. It does suggest, however, that enhanced situational awareness allows more effective and efficient use of ground forces.

More Effective Fires

The enhanced situational awareness provided in large part by GMTI can also allow precise command and control at the individual combat system level of resolution to achieve precise effects at the desired time and place. This can significantly improve effectiveness of fires in the battle space, including precision fires. While some have cited the revolution in precision fires over the past several decades as a quantum improvement in warfighting capability, they forget that precision fires must be enabled by precision information that shows what targets are where and when they should be engaged. Without precise information, precision fires only represent an improvement in weapons accuracy—not a transformation in warfighting.

Enhanced situational awareness can also help to substitute for mass in air and ground delivered fires. For example, during Operation *Desert Storm*, Joint STARS significantly increased the effectiveness of the strike aircraft it controlled by reducing the amount of time spent searching for targets.[54] With GMTI-provided information, these strike aircraft were able to engage more targets per sortie.

Following Operation *Desert Storm*, during Operations *Allied Force* and *Enduring Freedom*, GMTI platforms were also used to direct strike aircraft and other sensors to targets. However, on several occasions in *Iraqi Freedom*, GMTI and SAR-derived target coordinates were passed directly to strike aircraft and loaded into the JDAMs they were carrying. By logical extension, this could eventually allow airborne battle management to use targeting data derived from a GMTI platform to direct a weapon launched

[53] This confidence was proven on several occasions. In once instance, the Iraqi Republican Guard Medina Division virtually surrounded the 3rd Infantry Division's cavalry squadron, which was leading the advance through a major sandstorm. However, radar and other ISR assets impervious to weather detected this Iraqi maneuver and provided precise targeting information for air attacks that reduced the Medina Division to an estimated 20% combat effectiveness. William M. Arkin, "Fliers Rose to Occasion; In Iraq, a pause refreshed ground troops and let planes inflict major damage," *Los Angeles Times*, June 1, 2003, Opinion; Part M, p. 1.

[54] Joint STARS controlled strike aircraft typically had a 90-percent success rate in finding and engaging assigned targets on their first pass. Consequently, they consistently ran out of munitions before they ran out of fuel. Thus they were significantly more effective than aircraft that were not controlled by Joint STARS. David A. Fulghum, "Desert Storm Success Renews USAF Interest in Specialty Weapons," *Aviation Week and Space Technology*, May 13, 1991, p. 85.

from another platform, enabling net-centric air-delivered fires.[55]

Faster and Better Decision Making

The more uncertain a commander is about the enemy, the slower and more cautious his decision-making must be to avoid stumbling into disaster. The opposite is also true—the more information he has and the greater its precision, the faster he can make sound decisions.

GMTI provides air and ground commanders and staffs not only the ability to see enemy and friendly forces moving in near-real time but also the ability to recognize and comprehend the implications of that movement. Joint STARS' debut during Iraq's attempted counterattack at Al Khafji during the 1991 Gulf War is an excellent illustration of this effect. Writing about the battle after the war, General Horner (the Air Component Commander) stated,

> …Joint STARS told me where and when the enemy was moving... you could make the case that my information superiority and my increased capacity to analyze and decide what that information meant gave me the means to thwart an attack before I even knew I was being attacked.[56]

Faster, Lower-level Joint Integration

GMTI gives both air and ground users an identical "ground truth" picture, helping joint, air, and ground commanders share a common understanding of the battlefield, its dangers, and opportunities that can be exploited through integrated and synchronized application of air and ground combat power. This same common picture is shared not only among joint headquarters and the service components but also down the different echelons of command, thereby creating not only a horizontal but also a vertical common understanding of the battlefield and enhancing the ability to conduct integrated joint operations at lower levels more quickly and more effectively.

In the past, information had to flow from a sensor to a decision-maker to a strike unit to a strike platform. In joint operations the information often had to flow across different service components, adding hours (if not days) to the sensor-to-shooter time. However, shared, near-real time situational awareness at lower echelons allows lower-level joint forces to operate more autonomously within the context of the joint commander's intent, essentially achieving "dynamic self coordination"[57] without depending upon the time-consuming flow of information from higher echelons.

A good example of this occurred during Operation *Iraqi Freedom*, when a Joint STARS aircraft passed critical enemy information to an air controller with an Army cavalry troop that was about to be overrun by massing Iraqi forces. The air controller used the Joint STARS targeting data to direct JDAMs onto the approaching Iraqis, destroying dozens of vehicles and killing hundreds of enemy troops—in the midst of a blinding sandstorm.[58] This was a joint operation

[55] In fact, DARPA's precision, all-weather Affordable Moving Surface Target Engagement (AMSTE) project has already shown that GMTI information makes it possible to engage moving targets precisely from stand-off ranges in all-weather conditions using seekerless weapons. On September 30, 2002, AMSTE technology passed GMTI target information triangulated from two GMTI sensors to a Joint Standoff Weapon (JSOW) launched from an F/A-18 at 30,000 feet, hitting a tank moving at 15 miles per hour some 35 miles from the weapon release point. That same day AMSTE technology successfully guided two JDAMs launched from a F-14 at 20,000 feet against two different moving targets within a convoy. Press Release, "DARPA Demonstrates Affordable Moving Surface Target Engagement Using Both JDAM and JSOW Weapons," [http://www.darpa.mil/body/NewsItems/pdf/AMSTE1002.pdf] October 9, 2002, p. 1.

[56] Tom Clancy with General Chuck Horner (Retired), *Every Man a Tiger: The Gulf War Air Campaign* (New York, NY: Berkley Books, 2000), pp. 348-349.

[57] Dynamic self-coordination–increased freedom of low-level forces to operate near-autonomously and re-task themselves through exploitation of shared awareness and commander's intent. Department of Defense, *Transformation Planning Guidance*, p. 31.

[58] An e-mail sent from Baghdad International Airport dated April 17, 2003 by an Air Force tactical air controller supporting Army forces of the 3rd Squadron 7th Cavalry graphically described the consequences of combining the near-real time, precise targeting information provided by GMTI with the ability to quickly act upon the information at low levels:

> JSTARS saved our ass a couple of times! At one point we had a troop of the Cav with a 1C4 [Tactical Air Controller] holding an intersection near An Najaf. It was during the horrible sandstorm and you couldn't see 50 yards in daylight let alone anything at night. The crunchies [Iraqis] kept trying to drive fuel trucks into the intersection trying to blow up the Bradleys [Army tracked Infantry Fighting Vehicles]. JSTARS was able to pick the vehicles up, relay that to the 1C4 we had at the intersection and he was able to call in JDAMs [Joint Direct Attack Munitions] on all the roads and vehicles leading to their position. Middle of the night in a blinding sandstorm and we still nailed them with CAS [Close Air Support].

conducted at the lowest level as quickly as possible.

Result: Transformed, High Tempo Operations

The aforementioned enhanced capabilities of a GMTI-supported force are a direct consequence of increased situational awareness that is diffused horizontally and vertically throughout the force. Taken together they have the potential to increase the tempo of friendly operations, a phenomenon noted several years ago during the U.S. Army's series of advanced *Army After Next* Wargames. This series discovered that when the information advantage between two adversaries increased by a factor of four or better,

> the velocities of maneuver increased arithmetically, and formations began to spread out and disperse to the point where familiar linear battlefield geometry disappeared. Freed from the need to fight in lines, the game players consistently swept tactical units across vast distances without regard to fronts or flanks. As a consequence, the tempo of battle accelerated considerably. Engagements that normally took days to culminate were over in hours. As time compressed, the size of the battlefield expanded—in some cases as much as an order of magnitude or more over conventional mechanized warfare.[59]

The recent Iraq campaign provided convincing proof for this theory. Enjoying an information advantage of the magnitude posited in the wargames, Coalition forces moved an unprecedented 358 miles from Kuwait to Baghdad and decisively defeated Iraq's armed forces in 21 days. The tempo of their decisive operations overwhelmed Iraq's attempts to respond.

[59] Major General Robert H. Scales, Jr. (U.S. Army, Retired), *Yellow Smoke: The Future of Land Warfare for America's Military* (New York, NY: Rowman & Littlefield, 2003), p. 11.

VII. Conclusion: GMTI and the Transformation of U.S. Warfighting

GMTI provides the capability to comprehend in near-real time what is happening throughout the depth and breadth of the battlespace and to exert precise command and control to achieve precise effects at the desired time and place. These are truly transformational capabilities that potentially can raise the tempo of U.S. combat operations to new, previously unachievable levels well above an enemy's ability to respond. Is the U.S. military ready to realize this potential—to go beyond *employing* GMTI to using it to *transform* the way it fights? Do our forces recognize the transformational potential of GMTI?

Writing in Foreign Affairs, Secretary of Defense Donald Rumsfeld noted that "we must change not only the capabilities at our disposal, but also how we think about war. …All the high-tech weapons in the world won't transform the U.S. armed forces unless we also transform the way we think, train, exercise, and fight."[60]

In the most recent four conflicts U.S. forces have made good use of GMTI—but in the first three the systems were brought in late and in all four their full potential was not recognized until the conflict was well underway. The fact that leaders and staffs have experienced significant learning curves in employing GMTI in each conflict is a strong indication that our thinking has not yet been transformed to incorporate the full implications of GMTI technology. That said, CENTCOM's Iraq campaign and the substitution of information, precision, and speed for mass may indicate a broadening understanding of GMTI's potential. Only time will tell if the U.S. military will be able to leverage GMTI and its related ISR technologies to permanently transform the way it fights. To paraphrase Secretary Rumsfeld, all the GMTI systems in the world will not transform our forces unless we first transform the way we think about warfighting.

[60] Donald H. Rumsfeld, "Transforming the Military," *Foreign Affairs*, Vol. 18 No. 3, May/June 2002, p. 29.

VIII. GMTI Performance Metrics Appendix

The following factors determine the performance levels of GMTI radar systems:

- *Probability of Detection (Pd)* — The probability of detecting a given target at a given range any time the radar beam scans across it, Pd is determined by factors that include the size of the antenna and the amount of power it radiates. A large antenna radiating at high power provides the best performance. For high quality information on moving targets the Pd must be very high.

- *Target Location Accuracy* — Location accuracy is a function of platform self-location performance, radar-pointing accuracy, azimuth resolution, and range resolution. A long antenna or very short wave length can provide fine azimuth resolution. Short antennas tend to have a larger azimuth error, an error that increases with range to the target because signal-to-noise ratio varies inversely with range. Location accuracy is vital to tracking performance because it prevents track corruption when there are multiple targets and makes it possible to determine which road a vehicle is on if it is moving in an area with many roads.

- *Minimum Detectable Velocity (MDV)* — MDV determines whether the majority of military traffic, which often moves very slowly, especially when traveling off-road, will be detected. A GMTI radar must distinguish a moving target from ground clutter by using the target's Doppler signature to detect the radial component (see Figure A-1 below) of the target's velocity vector (i.e., by measuring the component of the target's movement directly along the radar-target line). To capture most of this traffic, even when it is moving almost tangentially to the radar (i.e., perpendicular to the radar-target line), a system must have the ability to detect very slow radial velocities. As the radial component of a target's velocity approaches zero, the target will fall into the clutter or "blind zone."

- *Target Range Resolution (High Range Resolution or HRR)* — Target range resolution determines whether two or more targets moving in close proximity will be detected as individual targets. With higher performance radars, target range resolution—known as High Range Resolution (HRR)—can be so precise that it may be possible to recognize a specific target (i.e., one that has been seen before) and to place it in a specific class (e.g., "a T-80 tank"). This would allow more reliable tracking of specific vehicles or groups of vehicles, even when they are moving in dense traffic or "disappear" for a period due to screening.

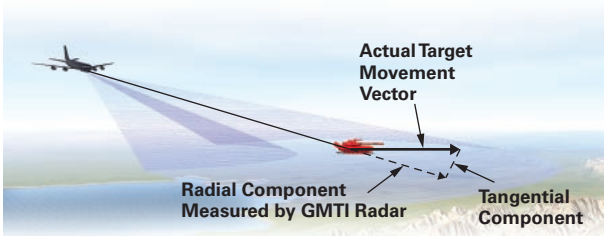

Figure A-1. Target Movement Vector Components

- *Stand-off Distance* — Stand-off distance is the distance separating a radar system from the area it is covering (see Figure A-2 below).
- *Coverage Area Size (breadth and depth)* — Coverage area size is the area that the system can keep under continuous surveillance from a specific orbit (see Figure A-2 below). Well-known design principles cause a radar's maximum detection range to depend on the size of its antenna (radar aperture), the amount of power radiated from the antenna, and the effectiveness of its clutter cancellation mechanism. The earth's curvature and screening from terrain, foliage, and buildings cause system altitude to be another key factor determining depth of coverage. The ability to cover an area the size of an army corps commander's area of interest[61] from a safe stand-off distance is the hallmark of an effective, advanced GMTI system.
- *Coverage Area Revisit Rate* — This equates to the frequency with which the radar beam passes over a given area. Frequent revisits are very important to the radar's ability to achieve track continuity and contribute to an increased probability of target detection by lessening the chance of obscuration from screening by trees, buildings, or other objects. A fast revisit rate becomes critical to providing an uncorrupted track when a target moves in dense traffic or is temporarily obscured, if only by trees along a road.

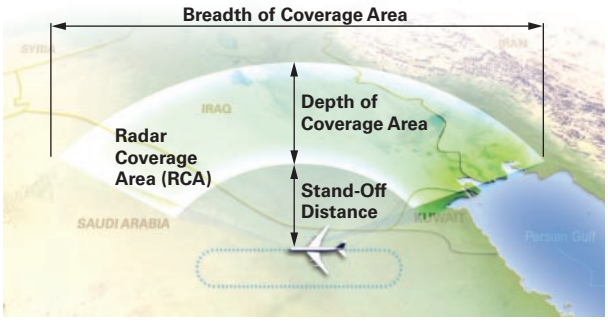

Figure A-2. Stand-off Distance and Radar Coverage Area

[61] "Area of interest" is a geographical area from which the commander requires information and intelligence in order to execute successful tactical operations and to plan for future operations. This varies based upon several operational factors but may be several hundred kilometers deep by several hundred kilometers wide for a U.S. Army corps.

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Acknowledgements

The authors deeply appreciate the contributions of many in the Washington defense community, members of the armed services, public policy organizations, and government agencies who offered valuable insights when this paper was being developed. In particular we would like to thank John Entzminger, one of the true "fathers" of GMTI, for reviewing the paper and providing substantial comments for inclusion. We would also like to thank Barry Watts, Jim Carafano, and General (Retired) George Joulwan for providing detailed and helpful comments on our draft. Within the Analysis Center, Mary Hubbell, Laura Barrett-Oliver, and Adam Cushing provided essential research, editing, and proofreading. Thanks also to our external editor, Kimberly Burger Capozzi, for her efforts in making our somewhat tortured prose less painful for the reader.

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