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Orbital Vigilance: The Need for Enhanced Space-Based Missile Warning and Tracking

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Key Points

China and Russia are deploying next-generation long-range missiles capable of flying non-ballistic, maneuvering trajectories at hypersonic speeds that cannot be tracked by the U.S. military's current ballistic missile warning architecture.

China and Russia are also deploying multiple anti-satellite (ASAT) weapons and other systems that can hold at risk current U.S. space-based missile warning sensors, which are undefended and locked into highly predictable orbits.

DOD must shift its missile warning architecture to a new multi-orbit force design that can defeat these threats.

A new U.S. space-based missile warning architecture must provide persistent warning and precise tracking for non-ballistic, hypersonic missile defense and include defensive measures, such as onboard defensive weapons or enhanced maneuver and decoys.

DOD should also deploy offensive space weapons systems that can hold Chinese and Russian targets at risk. This will enhance deterrence and enable greater survivability against present and future threats.

Abstract

Space-based ballistic missile warning systems developed by the Department of Defense (DOD) have served our nation well for more than 50 years. Without question, the current architecture, called the Space Based Infrared System (SBIRS), is the most advanced ballistic missile warning capability in the world. Looking forward, however, SBIRS alone will not provide adequate warning of missile attacks by peer adversaries on the United States and its forward-deployed military forces. The future lies with a diversified approach.

Today, both China and Russia are fielding a new generation of hypersonic, low-flying missiles that U.S. ground-based radars are unable to track in the time needed to provide warning and cue defenses. They are also fielding anti-satellite (ASAT) weapons to degrade or destroy existing U.S. space-based missile warning sensors. U.S. systems currently lack sufficient defenses against these threats and are locked into predictable orbital regimes that leave them vulnerable. In combination, these capabilities give China and Russia a decisive advantage in a major conflict with the United States.

DOD must create a more survivable, multi-orbit sensor architecture that can track salvos of these hypersonic weapons and other maneuvering, non-ballistic missiles, then cue defenses against them in real-time. The DOD should also enhance the resilience of this missile warning architecture by fielding satellites capable of enhanced maneuver, deploying decoys in different orbital regimes, and developing its own kinetic and non-kinetic counterspace capabilities to counter enemy ASAT and other counterspace threats. DOD now has the technology to create such a multi-orbit system of systems; realizing it must be a priority to avoid ceding the U.S. national security advantage in space that will be critical to the success of U.S. forces in all domains in a future peer conflict.

Understanding the Challenge

DOD began fielding the first of a series of space-based missile warning systems designed to provide early warning of attacks by Soviet intercontinental ballistic missiles (ICBMs), which flew predictable trajectories, during the Cold War. SBIRS added the functionality to detect shorter-range "theater" ballistic missiles. While SBIRS is an advanced infrared (IR) sensor-based system, both China and Russia have developed multiple long-range missiles designed to evade detection by SBIRS and other U.S. legacy missile warning sensors. These new weapons range from low-flying supersonic cruise missiles to Mach 5-plus hypersonic missiles that fly depressed trajectories in the atmosphere and maneuver. Hypersonic "boost-glide" weapons consist of rocket boosters that launch unpowered glide vehicles into depressed trajectories. SBIRS cannot detect or track these hypersonic glide vehicles since they have very low IR signatures after separating from their boosters.[1] While cruise missiles are typically powered, they also have low IR signatures that cannot be detected by current overhead systems. Moreover, both cruise missiles and hypersonic weapons can maneuver to create unpredictable flight paths that make them difficult for surface radars to locate and track. Very-low-flying weapons can also take advantage of the curvature of the Earth to avoid detection by surface radars. A combination of low-altitude flight and high speeds can greatly diminish the time available for U.S. radars to detect incoming missile threats, predict their impact points, cue defensive systems, and launch countermeasures.

China and Russia are also fielding anti-satellite (ASAT) weapons to degrade or destroy U.S. space-based missile warning sensors, which lack sufficient defenses and are locked into predictable orbital regimes. In combination, these capabilities will give China and Russia the means to negate much of DOD's current ability to detect large-scale missile attacks, track them, and relay fire control information to U.S. air and missile defenses. These missile attacks could cause large-scale attrition of U.S. forces and damage to theater bases, which would give China or Russia a decisive advantage in a major conflict with the United States.

There is an answer to these challenges. DOD now has the technology to create a multi-orbit system of systems that can detect non-ballistic missiles from launch to their designated target areas. The most effective approach would be to develop a multi-

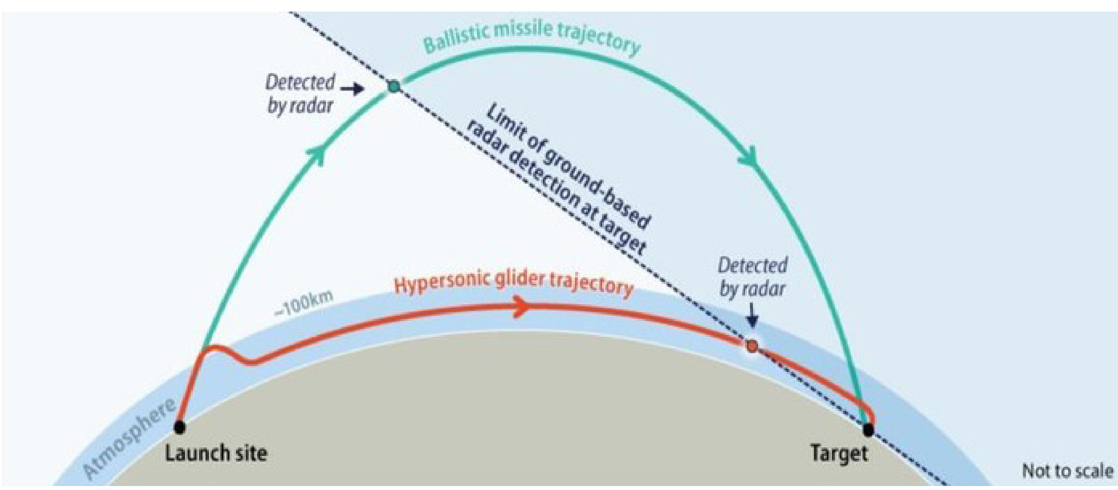


Figure 1: Ground Based Radar Detection of Ballistic vs Hypersonic Glide Weapons

Credit: Congressional Research Center

layered, space-based architecture of sensors across all orbital regimes—Low Earth Orbits (LEO), Medium Earth Orbits (MEO), Geosynchronous Earth Orbits (GEO), and Polar orbits. This multi-orbit architecture must be capable of detecting missile launches, tracking maneuvering missiles at all altitudes, and then providing fire control information directly to appropriate air and missile defenses in near-real-time. The DOD should enhance this missile warning architecture's resilience by fielding satellites capable of enhanced maneuver to avoid or otherwise negate ASATs; deploying systems such as decoys at LEO, MEO, and GEO to complicate an adversary's attacks; and developing its own kinetic and non-kinetic counterspace capabilities to defeat enemy ASAT and other counterspace threats directly.

A Primer on U.S. Space-based Missile Warning

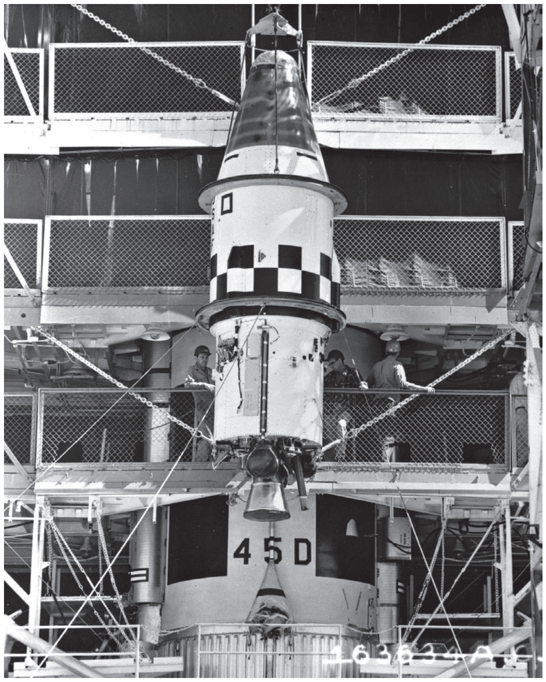
Capabilities to monitor and provide early warning of missile attacks have long been vital to the defense of the United States and the effectiveness of its military operations at home and abroad. In the past, adversaries who lacked the technologies needed to develop long-range bombers relied on ballistic missiles to strike over long distances. In a sense, ballistic missiles have served as a "poor man's air force." Today, medium-range weapons that can be launched by China, Russia, North Korea, and Iran threaten America's forces and the bases they rely upon to project power globally. Salvos of guided missiles numbering in the hundreds have the potential to devastate our military's ability to defend U.S. allies and partners in nearly every region of the world. Missiles with intercontinental range and air- or sea-launched cruise missiles also threaten the U.S. homeland, especially "dual-capable" variants that can carry nuclear or conventional warheads.

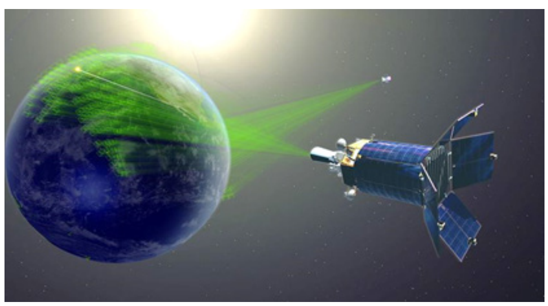
Similar to countering other threats, defeating large-scale missile attacks depends on "seeing" them first, then providing warning in time to cue countermeasures. In response to the Soviet Union's development of nuclear-tipped intercontinental ballistic missiles (ICBMs) early in the Cold War, the United States developed a network of space-based infrared (IR) and terrestrial long-range sensors to warn of attacks on the U.S. homeland. As ballistic missile technologies began to proliferate globally during the latter part of the Cold War, the DOD adapted its missile warning systems to detect and track shorter-range "theater" ballistic missiles. By the mid-1990s, the mission of the U.S. space-based missile warning architecture had expanded from nuclear deterrence and defense to also providing warning of theater ballistic missile attacks. This threat has only grown over the past three decades, and, just in a recent example, the massive January 2020 Iranian strike into northern Iraq still sent U.S. troops in the area "rushing for shelter."[2]

Early U.S. space-based ballistic missile warning systems

Detecting and tracking nuclear strikes on the United States has been a primary requirement for DOD's space-based missile warning systems since the Soviet Union first developed operational ICBMs in the 1950s. The first such architecture, called the Missile Defense Alarm System (MIDAS), was a 12-satellite constellation designed to provide U.S. leaders with enough advanced notice of a Soviet ICBM attack to direct a response before DOD's nuclear forces could be destroyed.[3]

A more advanced follow-on system called the Defense Support Program (DSP) operated in various configurations from the 1970s until the early 2000s, when it was subsumed into the larger SBIRS program. DSP systems were deployed into GEO orbits with supplementary sensors operating





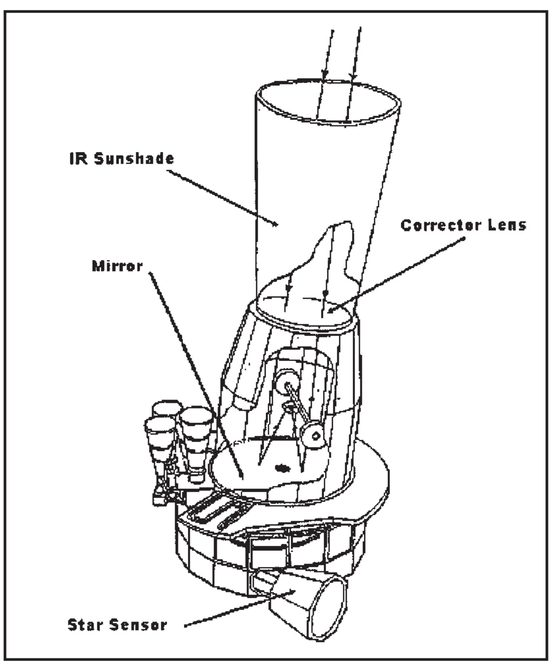


Figure 2: (Top) MIDAS Vehicle
Credit: U.S. Air Force Photo
Figure 3: (MIddle) DSP Satellite
Credit: courtesy of Northrup Grumman
Figure 4: (Bottom) DSP Sensor Array
Credit: Air University Space Primer

in Highly Elliptical Orbit (HEO) to provide uninterrupted global early warning coverage of ballistic missile strikes.

A DSP satellite consisted of a photoelectric cell detector and a vehicle, also referred to as a "bus," which carried a sensor array that could detect infrared radiation using a combined telescopic optical system. An enemy-launched ballistic missile's rocket would emit IR energy that entered the opening in the sensor array's IR sunshade, passed through a corrector lens, traveled past the photoelectric cell detector array, reflected off a mirror, and then focused onto the detector array.[4] A DSP sensor array included thousands of individual detector cells that could rapidly scan the Earth's surface for potential missile IR sources. In its fourth generation, DSP satellites increased the number of infrared cells each carried from 2,000 to 6,000, further enhancing their ability to rapidly scan for IR sources and discriminate between separate launch events. After a DSP sensor detected a candidate source, the satellite processed possible threat information before transmitting it through a downlink to ground stations. While global coverage was possible using three DSP satellites, the constellation maintained additional satellite vehicles to provide dual or triple coverage to increase the system's launch detection accuracy and reduce time required to provide warning of an attack.[5]

SBIRS, DOD's current space-based missile warning system

After DSP successfully detected several Iraqi short-range "SCUD" theater ballistic missile launches during the 1991 Gulf War, DOD determined there was a need to provide its warfighters with better information on theater ballistic missile strikes. To meet this expanded mission requirement, DOD developed its SBIRS constellation to detect shorter-range, non-maneuvering ballistic missile launches and increase the accuracy of the missiles' predicted impact points.

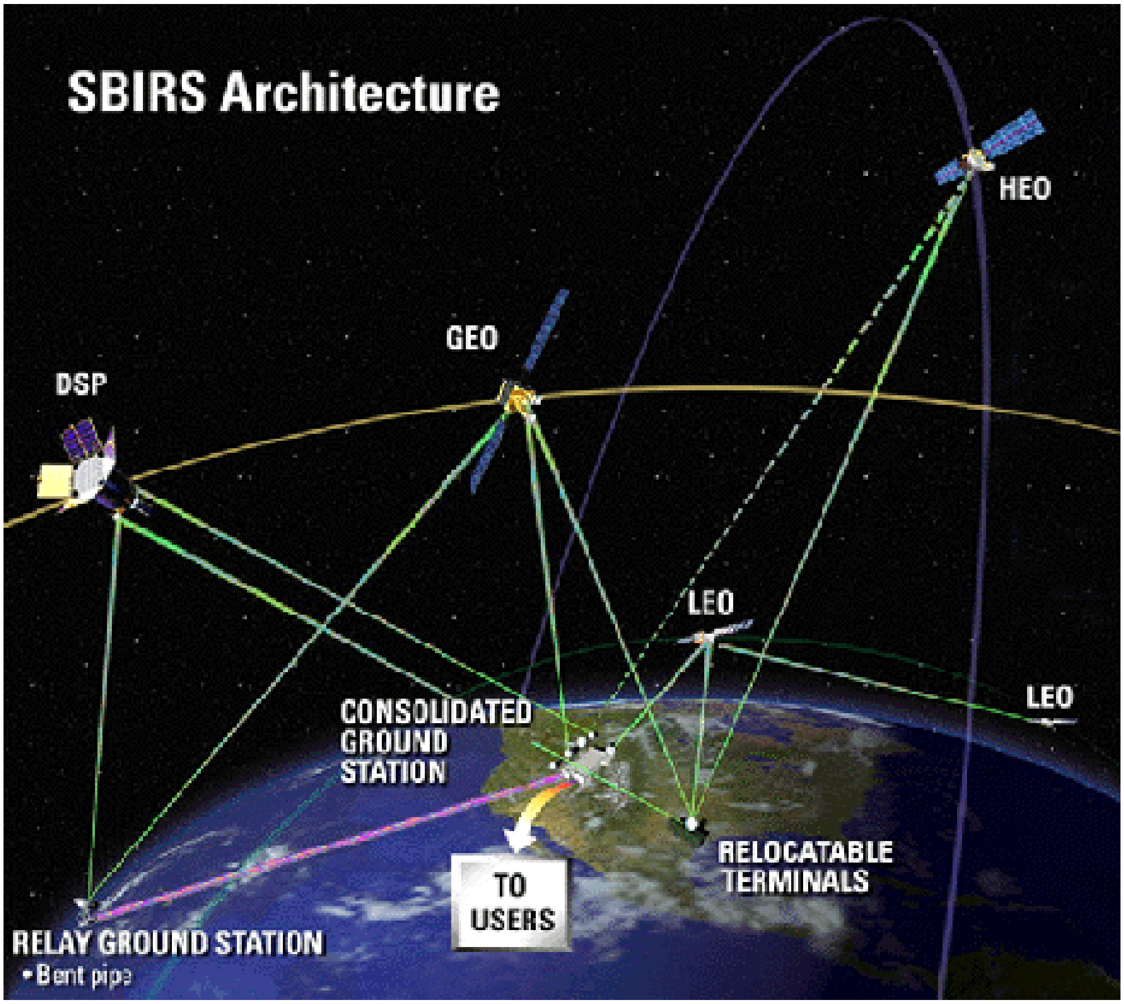


Figure 5: Space Based Infrared System Architecture

Credit: U.S. Air Force

SBIRS consists of five dedicated satellites operating in Geosynchronous Earth Orbit and sensors carried by two host satellites in Highly Elliptical Orbit. A SBIRS GEO spacecraft consists of a bus with a radiation-hardened shell and five separate mission downlinks that enhance their survivability and endurability. Unlike DSP, SBIRS has more advanced sensors that can see a wider range of the infrared spectrum. This improves SBIRS ability over older systems to accurately determine where ballistic missiles are originating and better predict where they may go. Without this added capability, deployed U.S. and allied forces could not receive the warning they would need to shelter and effectively defend against an attack. A SBIRS array has a scanner sensor and a separate step-starer sensor.[6] The scanner provides a persistent 24 hours/7 days a week "stare" over large geographic areas to detect ballistic missile launches and support other intelligence missions. The step-staring sensor has a much improved agile and accurate pointing and control system with a faster revisit rate and higher sensitivity to IR targets to detect theater ballistic missile events. SBIRS GEO and HEO sensors both send processed and unprocessed data on missile launch events to ground stations.

Exploiting Gaps in DOD's Missile Warning Architecture

The current U.S. space-based missile warning architecture was optimized to detect traditional ballistic missile launches that followed relatively predictable flight paths from their launch to their impact points and could be detected and tracked early enough in flight to aid ground-based radars to cue defensive systems. While this architecture has significant advantages over its predecessors, it lacks the capabilities needed to address Russian and Chinese missile systems that have been designed specifically to fly at lower altitudes and hypersonic speeds to avoid legacy missile warning radars. Understanding the advantages and disadvantages of SBIRS and other U.S. contemporary missile warning systems is an integral step toward determining the attributes of a system of systems that should augment or replace them.

Advantages and disadvantages of the current SBIRS architecture

DOD's SBIRS architecture provides persistent global warning of ballistic missile launches. SBIRS satellites in GEO and HEO can scan the entire surface of the Earth (with the exception being the Antarctic region) to detect the IR signatures of missiles in their boost phase of flight after launch. Unlike DSP, SBIRS has a distinct advantage: the ability to continuously scan and provide early warning while simultaneously dwelling over theater areas of interest. However, SBIRS also shares a critical limitation with its predecessors; it was never designed to continuously track ballistic, non-ballistic, maneuvering, and very-low-altitude hypersonic warheads after separation from their launch boosters. To a significant extent, this limitation is tied to the high altitudes of SBIRS orbits. While GEO and HEO are great for achieving global sensor coverage, they are not ideal for systems that must also provide continuous, high-fidelity tracking of low-flying, maneuverable warheads that do not produce as intense of an IR signature as their launching booster.

China and Russia recognize these limitations with our current radars and space-based missile warning systems. Both have developed low-flying, hypersonic glide vehicles (HGVs) and other weapons that are capable of maneuvering—for last-minute corrections or added precision targeting—while in flight.[7] In general, there are now five basic categories of threats a future U.S. missile warning architecture must be capable of tracking:

1. Traditional long-range ballistic missiles with no post-boost payload maneuverability
2. Missiles on ballistic trajectories with the ability to perform very small, exo-atmospheric trajectory corrections via multiple large propulsive burns that deploy multiple independently targetable (MIRV) warheads on independent trajectories with impact points several kilometers apart
3. Missile systems with post-boost weapons, flying ballistic trajectories capable of very small maneuvers during the terminal portions of the trajectory inside the atmosphere, known as MaRVs
4. Boost-glide missiles that fly non-ballistic, depressed trajectories at hypersonic speeds in the upper atmosphere that can maneuver en route to their target and in the terminal phase
5. Missiles that can sustain long-range flight in the atmosphere and maneuver after launch, such as cruise missiles[8]

In order to determine requirements for a system of systems that should augment or replace SBIRS, it is important to understand the dynamic flight characteristics of hypersonic and other modern missile threats and how they can complicate efforts to track them over their entire flight profiles.

Addressing the Challenges of Tracking Hypersonic Weapons

In addition to the missiles capable of flying "depressed" trajectories they have already developed, in 2019 China and Russia announced they were also developing hypersonic weapons, including weapons that may have the capacity to carry nuclear warheads.[9] These announcements, along with Russia's claimed use of hypersonic weapons against Ukraine, highlight the urgent need for DOD to reassess the effectiveness of its missile warning systems and how their inability to track these threats affects deterrence and operations to counter them. While DOD acknowledges maneuverable missile systems are a threat, it still lacks a coherent strategy for creating a space-based missile warning system capable of continuous chain-of-custody tracking—not just providing initial warning—of these weapons from their launch points to target areas.

Multiple launch options and unpredictable flight paths

The current U.S. missile warning architecture was simply not designed to address the challenges hypersonic weapons present, given their unique attributes. For example, hypersonic weapons can be launched from a variety of platforms such as airborne aircraft, ships deployed at sea, and land-based mobile launchers that are distributed over very large areas. Long-range air-launched hypersonic missiles with scramjet engines could, for example, be launched by an enemy's bombers from under cover of air defenses in their own airspace. Also, such weapons could be deployed as part of a fractional orbital bombardment system. The variety of and within launch options means hypersonic weapons that have separated from their initial booster rockets might not create an IR signature intense enough, despite the incredible heating of atmospheric friction, to be detected

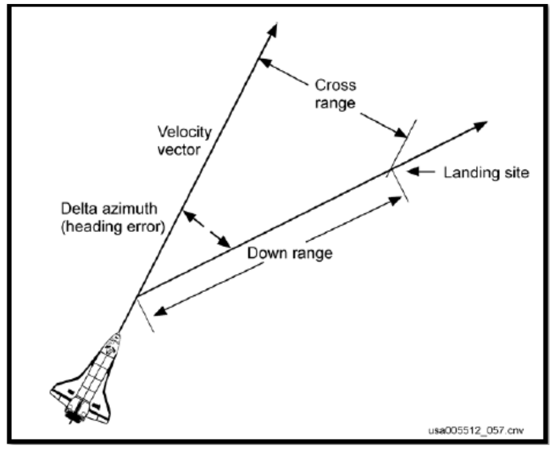


Figure 6: Example of Cross Range from Space to a Targeted Landing with Space Shuttle
Credit: United Space Alliance

by current U.S. ground-based phased array radars and satellite sensors in GEO and HEO. The potential these weapons have for cross range capability, that is, the ability to maneuver vast distances to hit multiple targets, likewise creates a challenge in determining the targets at risk. An example of this is the space shuttle. The space shuttle is essentially a hypersonic boost-glide vehicle. It was designed with a cross range capability of landing at any point 2,000 km off its orbital path.

A second challenging attribute is that these new hypersonic missile systems can fly at much lower altitudes—called depressed trajectories—than ICBMs. Long-range ballistic missiles typically have flight trajectories that take them over 300 km into space before they reenter the atmosphere. The highly predictable flight paths and high altitudes of non-maneuvering ballistic missiles make them much easier to detect by current ground and space-based sensors. In contrast, some hypersonic missiles can fly 30 to 50 km above the Earth's surface or even lower, which means that, because of the curvature of the Earth, they may be below areas that are effectively covered by today's radar warning architecture. Indeed, it is impossible for current radars and space-based IR sensor systems to maintain flight tracking of low-flying, hypersonic weapons that are capable of maneuvering after their boosters burn out. The ability to maintain continuous "custody" of a missile threat, post-boost phase, is critical to providing target cues to air-, land-, and sea-based missile defenses. So, even if current space-based systems detect the initial launch of a hypersonic weapon, it is unlikely they could track them over their entire flight path, much less provide accurate cues for air and missile defenses to intercept them.

Finally, speed itself affects the ability of current U.S. systems to warn and defend against maneuvering hypersonic weapons. In general, the faster a weapon's speed, the less time is available for a defender to detect an attack, determine its probable targets, and then decide on appropriate countermeasures. With the current ground- and space-based missile warning system, any tracking that is achieved would be too little, too late to provide adequate warning time for U.S. and allied personnel.

Other challenges created by the capability to maneuver

During the early years of the Cold War, ballistic missiles capable of delivering one or more warheads to their targets were the pacing challenge that shaped the development of U.S. missile tracking systems. Ballistic missile payload vehicles lacked the ability to maneuver after separation from their boosters, which made it easier to predict their flight path as well as probable target areas. Today, most of China and Russia's deployed long-range missiles can carry one or more weapons that can maneuver in space, in the atmosphere, or both.

Ballistic missiles with limited exo-atmospheric post-boost weapons maneuverability. One type of maneuvering weapon has payload-carrying vehicles equipped with post-boost propulsion system engines that can deploy multiple warheads on independent trajectories while above the atmosphere. ICBMs with Multiple Independently Targetable Re-Entry Vehicles (MIRVs) are one example of this type of weapon. A MIRV ballistic missile carries multiple reentry vehicles on top of its main rocket booster. These vehicles separate from the missile after its boost phase of flight and have a small propulsion module or kick motor that can make small trajectory adjustments and velocity changes to place their warheads onto separate reentry flight paths to strike separate targets. Some of these reentry vehicles could be configured as unarmed decoys to complicate an opponent's missile defense operations. Discriminating between "live" weaponized reentry vehicles and decoys can be a major challenge for tracking sensors. Most Russian ICBMs and all Russian SLBMs can carry MIRV payloads. Chinese missiles of this type

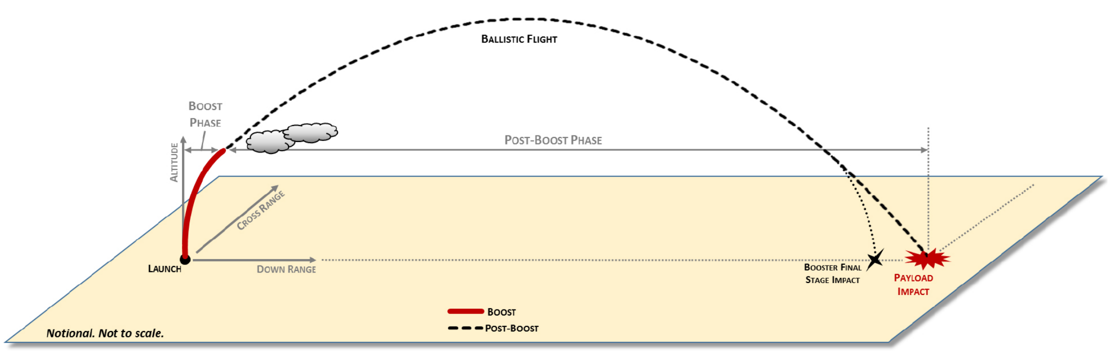


Figure 7: Traditional Non-maneuvering Ballistic Missile Flight Path

Credit: The Missile Threat: A Taxonomy for Moving Beyond Ballistic, Aerospace Corporation, 2020.

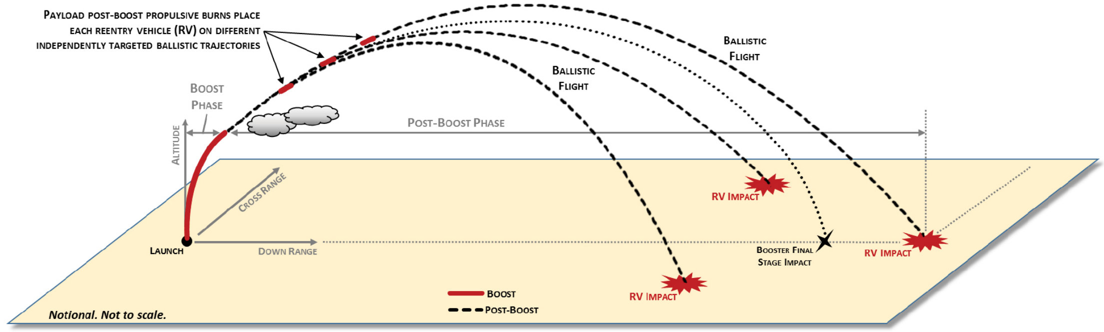


Figure 8: Ballistic Missile with Multiple Independently Targetable Re-Entry Vehicle

Credit: The Missile Threat: A Taxonomy for Moving Beyond Ballistic, Aerospace Corporation, 2020.

include the very long-range DF-41 ICBM, which is also road-mobile and therefore more difficult for space-based and airborne sensors to find, fix, and track since they can be launched from multiple unknown locations after their launchers deploy from their garrisons.[10]

Missiles with warheads capable of minor post-boost, aerodynamic maneuvers in the atmosphere. These weapons are another type of maneuvering threat with external control surfaces that can be moved to direct a warhead to its target with greater accuracy than is typical of weapons that can only fly gravity-assisted, spin-stabilized ballistic flight paths. Maneuverable Re-entry Vehicles (MaRVs) are aerodynamically capable weapons that can alter their flight paths within the atmosphere to establish glide profiles that can extend their range. Hypersonic Boost-Glide Vehicles (HGVs) can also aerodynamically maneuver, but they have the capability to glide at hypersonic speeds for most of their flight in the atmosphere after booster separation. HGV weapons are typically accelerated by booster rockets to reach speeds above Mach 5 and high altitudes between 25 and 60 miles to give them their long ranges.[11]

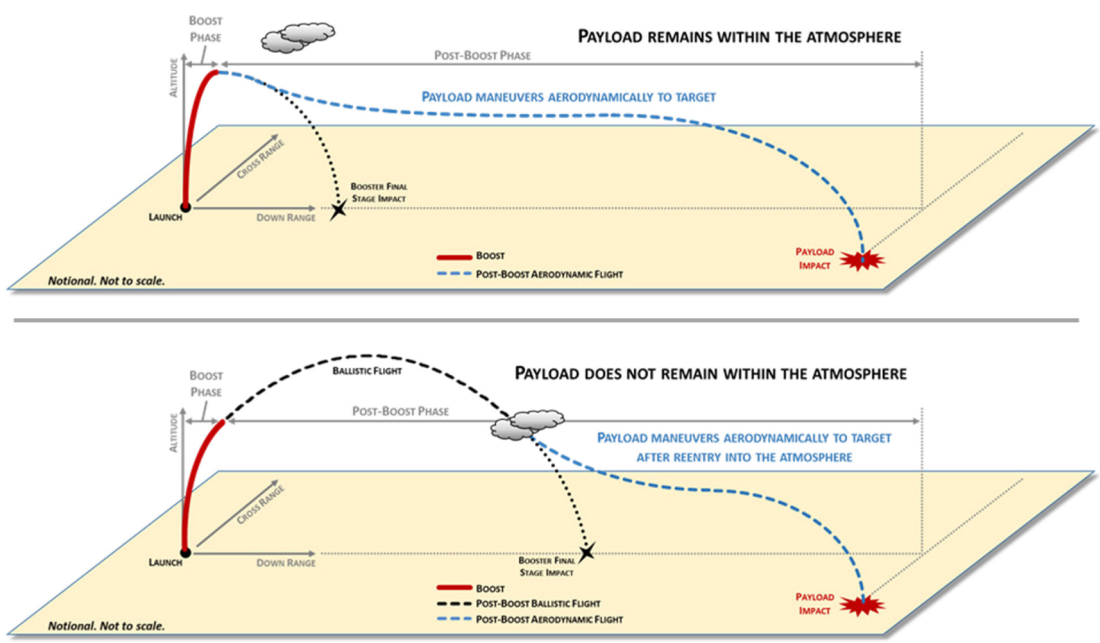


Figure 9: Missiles with Maneuverable Re-Entry Vehicle (bottom image) and Hypersonic Glide Vehicles (HGV) (upper image)

Credit: The Missile Threat: A Taxonomy for Moving Beyond Ballistic, Aerospace Corporation, 2020.

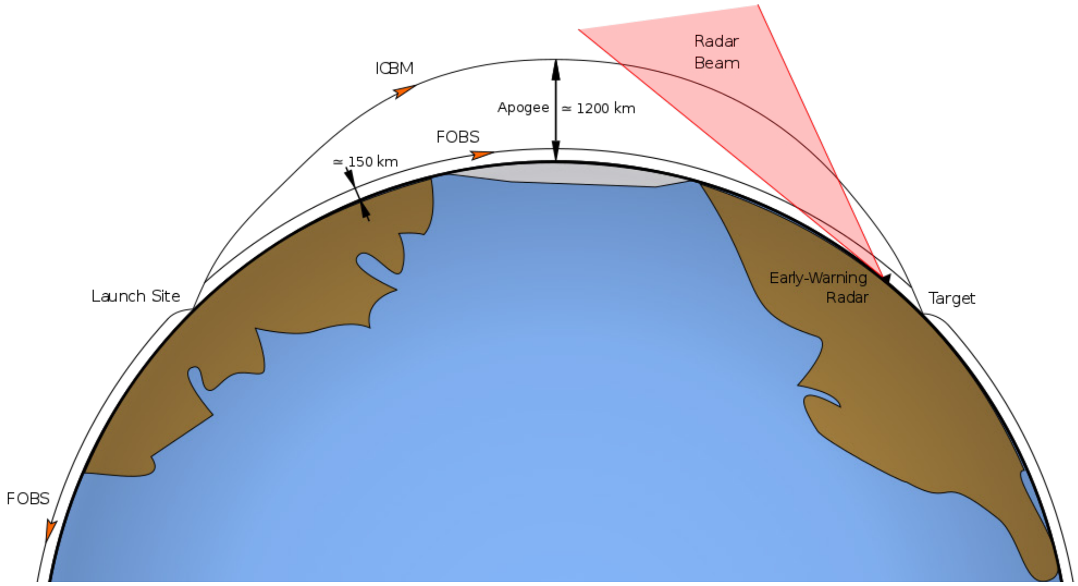


Figure 10: ICBM vs. Fractional Orbital Bombardment System Flight Paths Credit: Creative Commons.

HGVs can also be boosted into fractional orbits (part of an orbit around the Earth) or full orbital flight paths and then deorbit to strike a target. While Fractional/Orbital Bombardment Systems (F/OBS) fly most of their flight profiles in space, they can also operate at much lower altitudes than typical ICBMs. This can make them more difficult to track by space-based and ground-based sensors. F/OBS were demonstrated by the Russians during the Cold War and by China in August 2021.[12]

Missile systems that combine both post-boost propulsion and aerodynamic surfaces. These attributes further extend the range and maneuverability of a warhead's flight to its target. Examples include the medium-range DF-21D "carrier killer" anti-ship missile, which China has operationally deployed since 2010. The DF-21D has a ballistic missile booster with a payload that separates and maneuvers to a designated target. The missile system has a dual anti-ship and land-attack role; its design includes a post-boost propulsion system and flight surfaces that give its warhead the ability to change targets or modify its flight path to correct for moving targets—like ships at sea.[13]

Cruise missiles. Finally, cruise missiles are weapons that combine aerodynamic control surfaces and jet propulsion engines to extend their ranges or atmospheric flight times. Cruise missiles can be highly maneuverable, which can increase the number of directions from which a cruise missile can attack a target. This multi-vector attack capability can greatly complicate an opponent's ability to find, fix, track, and direct an intercept against these weapons.

Most Cold War-era cruise missiles flew at subsonic speeds to achieve fuel efficiencies that extended their ranges. More modern variants can spend part or most of their time of flight at supersonic or even hypersonic speeds. China has already deployed a DF-100 missile that combines a booster rocket and a ramjet engine to enable it to fly at sustained supersonic, and possibly hypersonic, speeds for part of its flight profile. Higher missile speeds can have the effect of reducing time available for a defender to detect an attack, decide on an appropriate countermeasure, and then execute it before an incoming weapon reaches its target. At present, the United States lacks the ability to track cruise

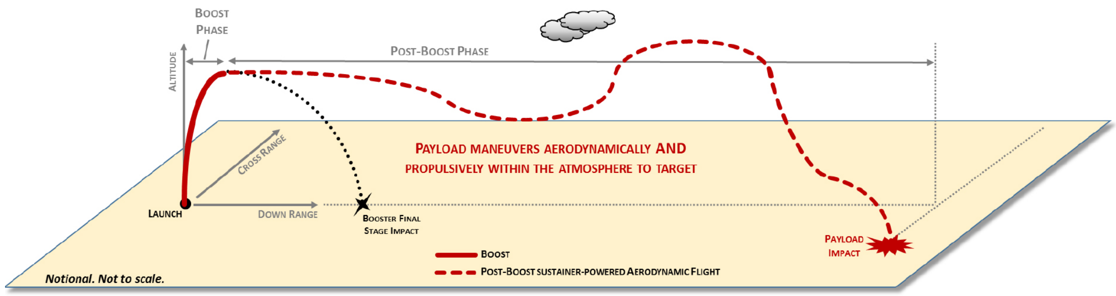


Figure 11: Maneuvering Cruise Missile Trajectories

Credit: The Missile Threat: A Taxonomy for Moving Beyond Ballistic, Aerospace Corporation, 2020.

missiles from space. However, some future space-based sensor proposals recognize that countering these cruise missile threats is one of their critical mission design requirements—on top of tracking hypersonic missile requirements.[14]

Summarizing future missile threats

We have lived in a world where attacks on our overseas bases or the homeland were only a remote possibility. Our defensive aperture is designed with that underlying assumption in mind. Our adversaries know this and have invested tremendous sums to field highly lethal, precise strike options. These weapons could neutralize the forward operating bases that we depend on to deter aggression. Whether going after military targets or broader aimpoints connected to our civilian infrastructure, the damage inflicted could be severe. Addressing these steps begins with actionable situational awareness to find, fix, track, and defeat these assets. We need a space sensor enterprise up to that task.

Looking ahead, the U.S. military must be ready to defend against a mix of missile threats that are very different from what it has organized, trained, and equipped to counter in the past. Instead of ballistic missiles that fly highly predictable flight paths and are detectable by ground-based radars in time to defeat them, missiles of all types will be increasingly maneuverable, fly at lower altitudes, and fly at speeds that can vary from subsonic to hypersonic—even in a single mission. China, Russia, and increasingly other adversaries are exploiting these missile technologies to take advantage of the limitations of the U.S. military's space-based and surface-based missile warning systems. DOD's future space-based missile defense architecture must be capable of providing early warning of these threats as well as highly accurate target cueing information to its air and missile defenses at home and abroad.

Challenges of Operating in a Contested Space Domain

DOD's space-based missile warning constellations and supporting ground segments are critical to the defense of the United States, its allies, and its friends. The loss of these and other space-based capabilities would open the door for an enemy to launch attacks nearly at-will against the U.S. homeland, its global forces, and its military bases. As such, America's space-based assets will remain a center of gravity that adversaries will seek to disrupt, degrade, and destroy. This includes the SBIRS constellation, which is becoming a single point of failure for U.S. missile warning operations; it has only a limited number of GEO and HEO satellites and lacks defenses against many types of counterspace threats. Ground-based missile warning sensors alone are similarly inadequate to provide early warning of missile attacks since their radars have limited ranges that are restricted by the curvature of the Earth.

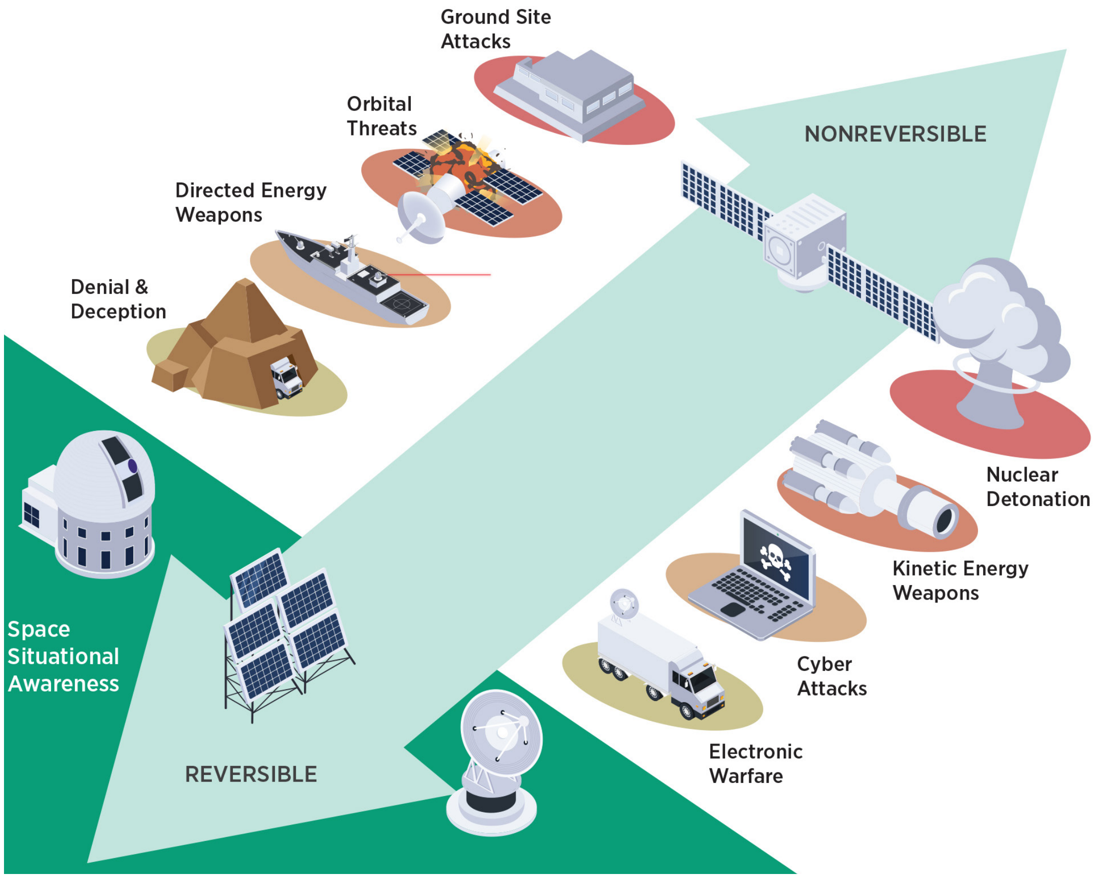


Figure 12: Counterspace Threat Continuum

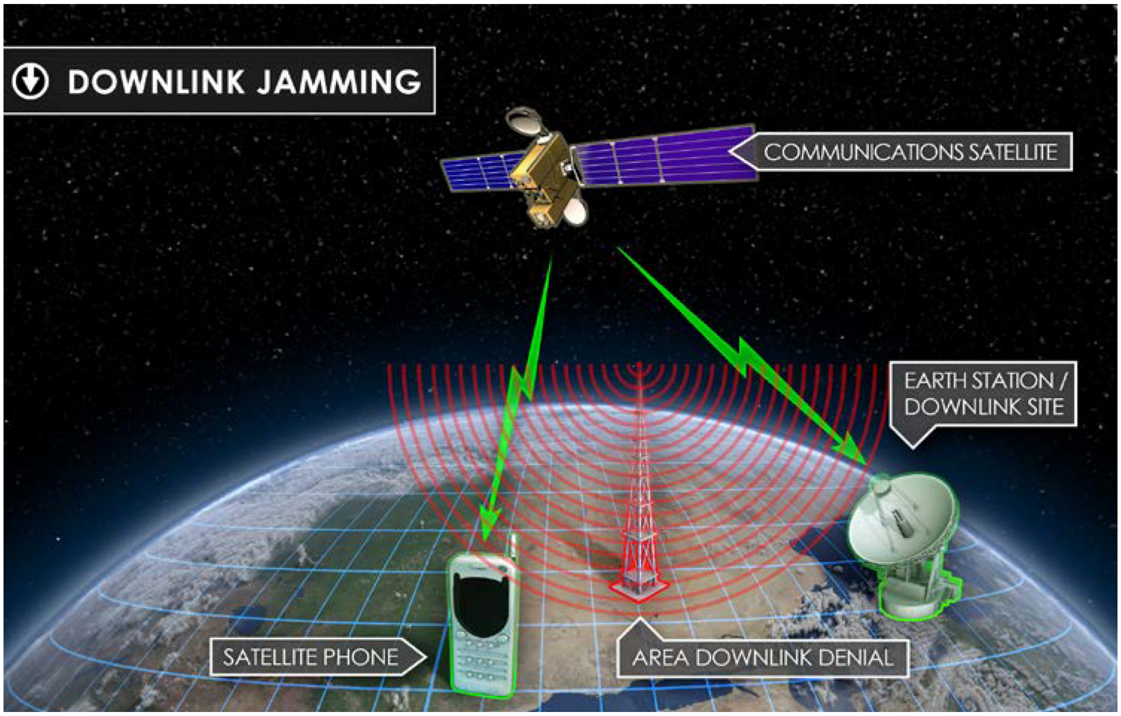
Credit: Defense Intelligence Agency illustration

While it may have been the case, as some have suggested, that the Soviet Union and the U.S. Government agreed to avoid targeting each other's space-based missile warning assets during the Cold War, DOD should not assume this will hold true in a future peer conflict. Both China and Russia now consider U.S. space-based assets as high-value targets that can be threatened to coerce the United States in a crisis or attacked to achieve space superiority in a conflict. They have developed kinetic ASATs and other space weapons to hold these "difficult to defend, easy to attack" targets at risk. These realities point to the need to ensure that DOD's future missile warning architecture and other space systems are designed and deployed in modes that will help them survive and operate in this contested environment.

China's counterspace forces

China has developed and deployed what it refers to as a "multi-layered attack architecture" with weapons systems that span the counterspace threat continuum. In combination, these weapons systems can degrade, deny, or destroy U.S. space systems in all orbital regimes in ways that are reversible or nonreversible.

On the non-kinetic side of this threat continuum, China has operational ground-based jamming systems that are capable of disrupting satellite communications, GPS navigation signals, synthetic aperture radars, missile warning, and other satellite systems. Jamming can prevent users from using satellite communication (SATCOM) networks, degrade or prevent transmissions of vital missile warning data from space-based sensors to warfighters, and disrupt uplinks and downlinks needed to command and control spacecraft.[15]



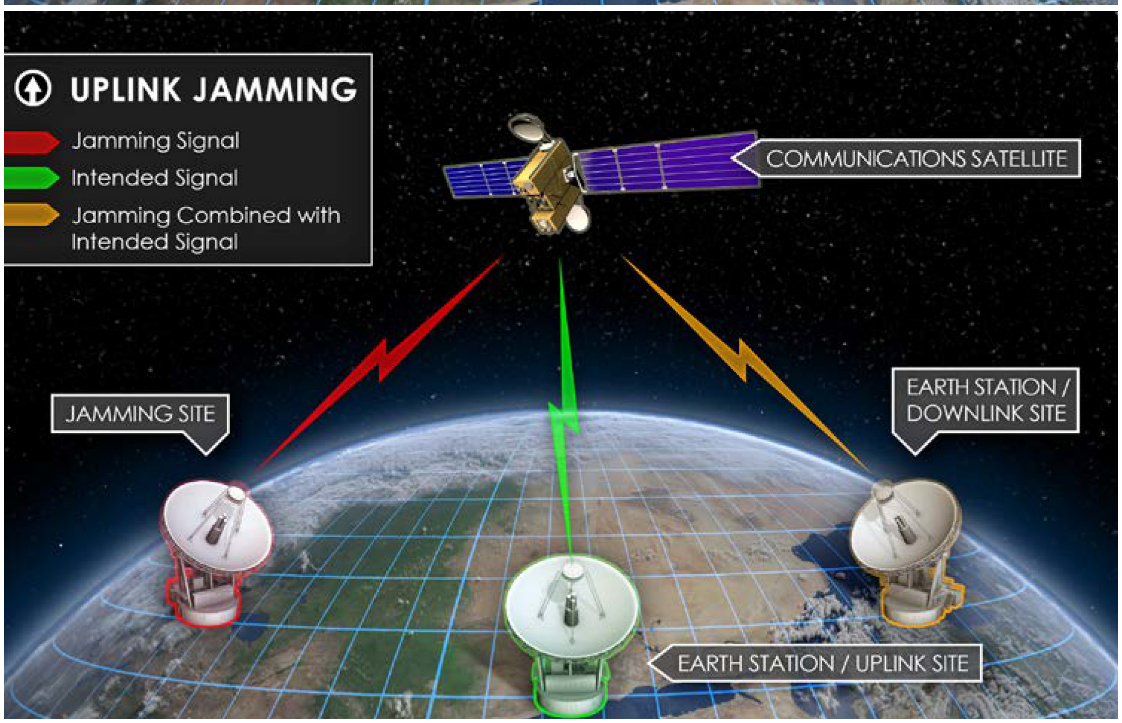


Figure 13: (Top) Downlink Jamming

Credit: National Air and Space Intelligence Center illustrations

Figure 14: (Bottom) Uplink Jamming

On the kinetic side of the threat continuum, Chinese forces have deployed ground-launched ASAT missile systems that can attack assets in LEO. China has also demonstrated capabilities to reach targets in MEO and GEO, as well as its ability to maneuver co-orbital anti-satellite spacecraft close to high-value U.S. space systems. Some of these orbital systems can latch on to satellites in GEO, drag them out of their orbits, then maneuver back into GEO for another attack. Other Chinese orbital ASATs could use sprays to cover up sensors and other sensitive parts on U.S. satellites or even robotic arms to rip apart

Figure 15: Chinese Ground-launched Kinetic Anti-Satellite Weapon Credit: Chinese State Media

components critical to their operations. All these capabilities have the potential to disrupt, degrade, or destroy U.S. space-based missile warning operations in a crisis.[16] An effective response includes a disaggregated, integrated, space-based missile warning and tracking system that possesses defensive capabilities such as rapid maneuverability, anti-jam, and decoys.

Russia's counterspace forces

Like China, Russia views space as a warfighting domain, and they base their warfighting doctrine around the idea that achieving space supremacy is a precondition for winning a conflict with the United States. Consistent with these beliefs, Russia has committed to developing a robust set of space capabilities to deter the United States and its allies as well as attack their space assets in the event of war.

Russia has fielded a suite of non-kinetic options to create reversible effects on satellite systems in space, including ground-based systems to counter GPS navigation signals, tactical communications, satellite communications, and radars. For example, Russia has pursued ground-based directed energy weapons such as lasers to disrupt, degrade, or destroy satellites and their various sensors. Reportedly, Russia is also developing an airborne laser platform to use against space-based missile warning sensors. Similar to China's non-kinetic counterspace systems, many of these weapons systems are highly mobile, which complicates our ability to locate and attack them with precision. President Putin has called these systems "a new type of strategic weapons" capable of "fighting satellites in orbit."[17]

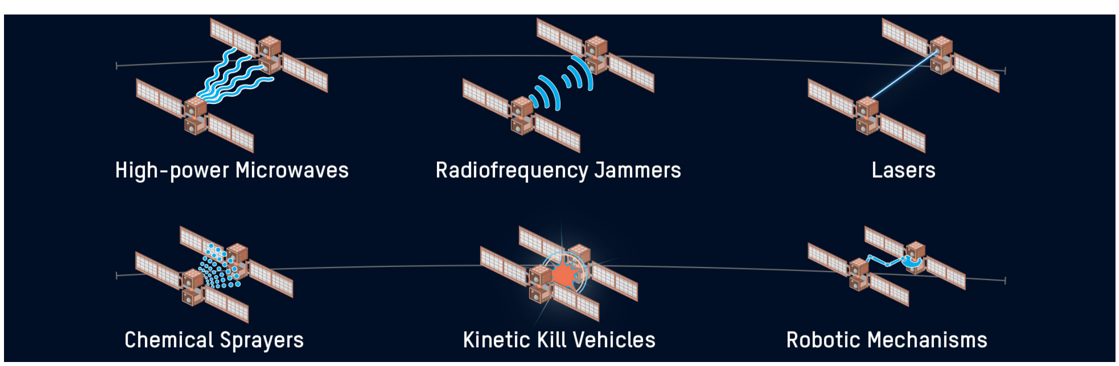


Figure 16: On-orbit Counterspace Attack Capabilities

Credit: Defense Intelligence Agency illustration.

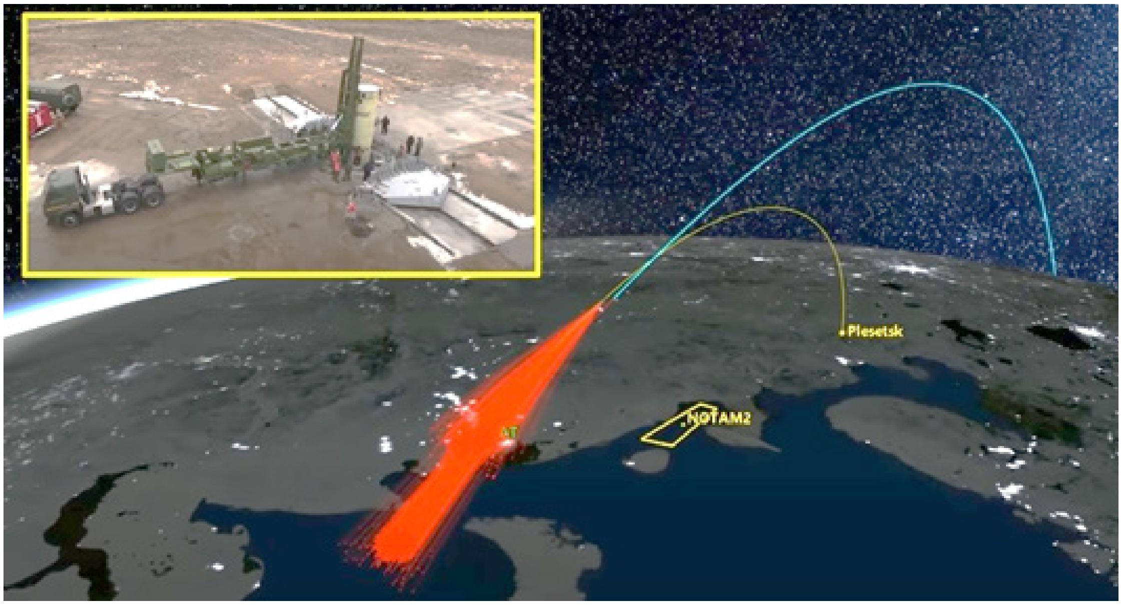


Figure 17: Russian ASAT Demonstration in 2021 Credit: Photo by Russian Ministry of Defense

These systems will complement future Russian on-orbit capabilities that could serve as dual-use satellites, conducting inspections and servicing other satellites on-orbit in peacetime, then approaching and attacking their enemy's satellites in war. In 2017, Russia launched what it described as an "inspector satellite," but its orbital maneuvers and behaviors during testing were "inconsistent with on-orbit inspection activities or space situational awareness activities," according to open-source intelligence reports.[18]

Perhaps most importantly, Russia has demonstrated several ASAT missiles that could become operational within the next few years that can destroy targets in LEO. In late 2021, Russia demonstrated this capability in a live-fire, hit-to-kill demonstration that Russian government officials claimed was prosecuted with the "precision worthy of a goldsmith." The Russian government also appeared unfazed by orbital debris created by this demonstration, emphasizing instead that it had gained another means of threatening an adversary's space systems in a crisis.[19]

China and Russia's rapid development and deployment of counterspace forces are unambiguous evidence that space is now a warfighting domain. Neither heeded previous U.S. decisions to forego fielding space weapons systems, despite the hope that the unilateral U.S. example would promote responsible behaviors in space by others. Instead, both have developed a continuum of kinetic and non-kinetic capabilities to attack current U.S. missile warning systems and other space-based networks. In combination with China and Russia's growing inventories of long-range maneuvering hypersonic weapons, an increasingly contested space environment means that DOD should develop a more effective, resilient missile warning architecture as quickly as possible.

Addressing the Challenge: Synergy of a More Diversified Space-Based Missile Tracking Force Design

It cannot be overstated that DOD must create a multi-layered missile warning architecture that is capable against Chinese and Russian next-generation long-range missiles that are maneuverable and can fly unpredictable flight paths at lower altitudes than ballistic missiles. However, the force design for this new space-based architecture must also be resilient and survivable, given the growth in anti-satellite weapons and other counterspace threats. This section provides greater detail and analysis of different proposed concepts for missile tracking systems based on their designed orbital regime. While each of these proposed basing concepts has its advantages and disadvantages, the "diversified" architecture envisioned by General Raymond should include a mix of systems in all three orbital regimes to achieve these objectives.

Proliferated-LEO Tracking Layer concept

The Space Development Agency's (SDA) National Defense Space Architecture Tracking Layer is one concept in development that is intended to increase the DOD's ability to receive timely warning of attacks by hypersonic weapons and other emerging missile threats. To achieve this, SDA's design evolves over time with advances in technologies through various tranches. Tranche 1 will initially consist of 28 tracking vehicles that each carry IR sensors to detect and track missiles; over 100 transport layer vehicles to "provide assured, resilient, low-latency military data and connectivity worldwide to the full range of warfighter platforms"; and other orbiting satellites to experiment and demonstrate new sensors and other technologies.[20] Over time, SDA will field a more mature tracking layer with hundreds of satellites that will "expand its global coverage and chain of custody of various missile threats."[21]

The objective for this force design is to provide "global indications, detection, and tracking of advanced missile threats, including hypersonic missile systems" using a combination of SDA's Wide Field of View (WFOV) sensors and the Missile Defense Agency's Medium Field of View (MFOV) sensors.[22] In Tranche 1, WFOV sensors will be deployed into what is called a proliferated-LEO (p-LEO) constellation designed to detect and track low-flying and hypersonic, maneuvering missile threats over very large areas. MFOV sensors will increase the accuracy of missile tracks and warnings provided by the Tranche 1 constellation and will also take advantage of tracking cues provided by legacy space-

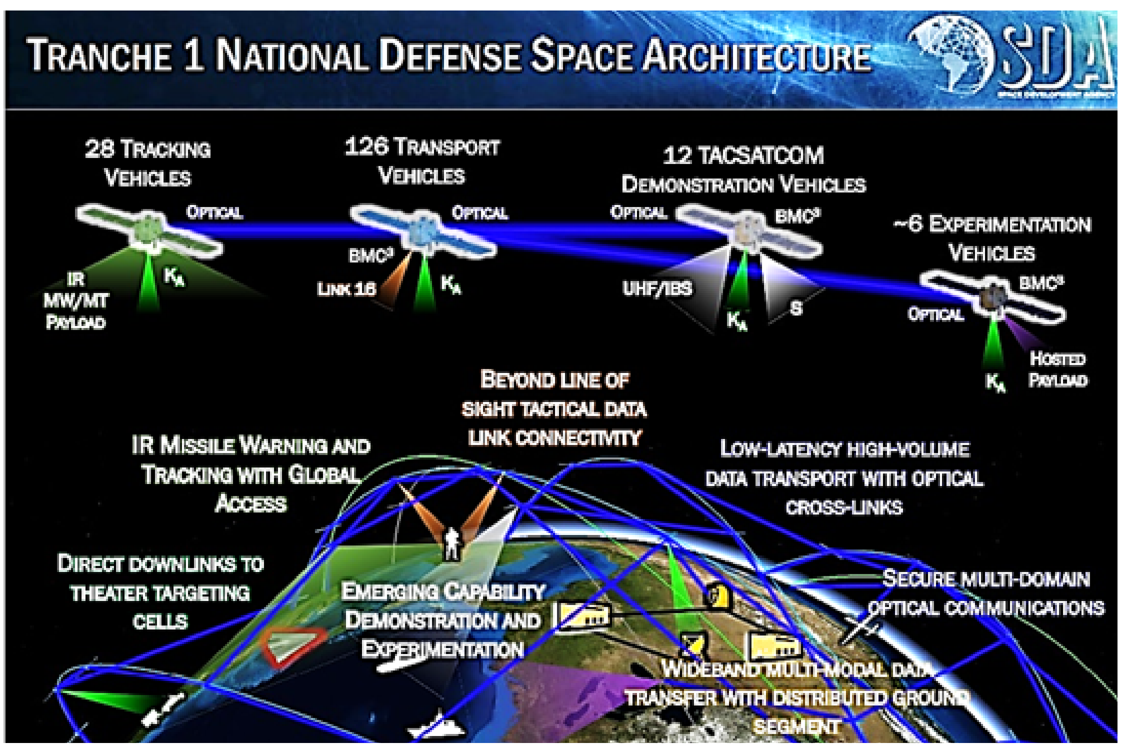


Figure 18: SDA's Proposed Tracking Layer

Credit: SDA illustration

based and ground-based radars. SDA will divide the constellation into four different orbital planes to maximize its ability to detect missile launches globally.[23] Satellites in each orbital plane will communicate directly with each other and with Transport Layer vehicles that will pass missile warning and tracking information over secure datalinks down to air-, land-, and sea-based tactical users.

Integration with other missile warning and tracking systems. An important SDA goal is to fully integrate information from its Tracking Layer with other space-based missile warning capabilities to provide highly accurate fire control solutions for both current and future missile defense operations. This will be the mission of battle management, command, control, and communications (BMC3) modules in each Tracking Layer satellite. These modules will be designed to support key mission functions such as processing data from sensors, fusing data from multiple satellites in the p-LEO constellation into three-dimensional missile tracks, and managing operational tasks. Over time, this design will continually conduct tests and demonstrations using sensors and other components on orbit to provide timely fire control solutions for use in current and future missile defenses.[24]

Increased resiliency and survivability. Tranche 1 vehicles will orbit at an altitude of approximately 1,000 km above the Earth—in Low Earth Orbit—with an inclination between 80 and 100 degrees. One advantage of a p-LEO constellation force design is the added operational resilience that its hundreds of satellites create. According to proponents of the concept, deploying large numbers of satellites in a p-LEO orbit presents an enemy with an overwhelming number of potential targets, and the prospect that attacking them could create enough orbital debris to degrade their own space operations might serve as an additional deterrent.[25]

P-LEO missile warning and tracking force designs are only part of the solution

While p-LEO constellations will increase the resiliency of DOD's future missile warning operations, p-LEO architectures alone will not be enough to offset growing counterspace threats. Without question, more potential targets will make it harder to fully destroy a P-LEO satellite constellation, but recent Chinese and Russian advances in developing non-kinetic counterspace capabilities make this threat more, not less, likely in a major conflict. These non-kinetic threats include radio frequency (RF) jamming and high power microwave (HPM) weapons that could affect multiple systems in LEO in very short periods of time.

RF jamming includes ground-based systems capable of using RF frequencies to block or damage communications links between satellites in LEO and their user ground stations. Downlink jamming can enhance the "noise" of a satellite signal to the extent that the signals are not useful or cannot be received by ground users. Uplink jamming can likewise block or otherwise interfere with signals going up to the satellite from major operational commands or ground sites that provide command and control over the vehicle. Targets of these jamming systems are typically high-value GEO satellites or SATCOM systems.

HPM weapons are another emerging threat to assets operating in LEO. Emitters that could be ground-based or mounted on ships, aircraft, or even other satellites could generate pulses of HPM energy that can "disrupt a satellite's electronics or cause permanent damage to electrical circuits and processors in a satellite."[26] The "kill" mechanism of counter-electronics HPM weapons is to create a buildup of energy in a vulnerable circuit or electronic component in a satellite past its tolerance levels, causing them to stop working or even burn out

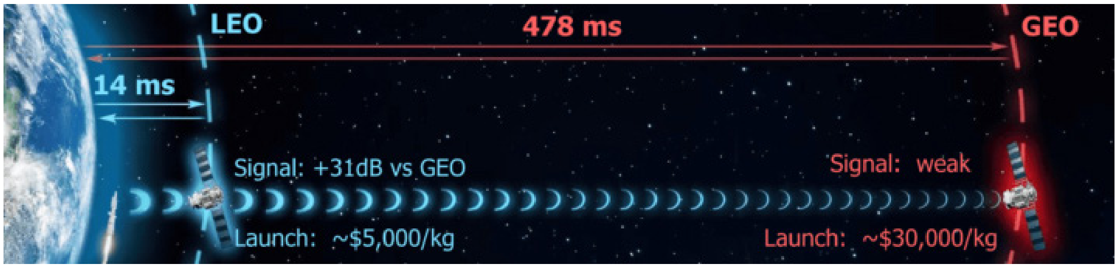


Figure 19: Comparing Times to Transmit Signals

Credit: DARPA illustration

depending on the power of the pulse. Like RF jamming, these effects on a satellite target can be achieved without creating an explosive effect that would create hundreds of pieces of debris in orbit. It is also difficult to pinpoint the source of an HPM attack, especially if it is moving, which complicates both defensive operations and attribution.

Given the growth in these counterspace threats, a more resilient, survivable space-based architecture capable of providing continuous, global missile warning coverage should include systems based in Medium Earth Orbit and Geosynchronous Earth Orbits.

Medium Earth Orbit basing concept

The U.S. Government and the defense industry are also assessing concepts for basing satellites in Medium Earth Orbit to enhance future global missile warning and tracking operations. MEO orbits—the area of space between 2,000 km and 35,766 km (the edge of GEO) above the Earth—have been called the "sweet spot" for satellite systems.

Satellites in MEO are closer to the Earth than GEO-based legacy DSP and SBIRS satellites, which reduces the time needed for them to transmit missile warning information signals to air and missile defenses. Closer proximity to the Earth also means MEO sensors provide faster and higher fidelity missile warning information transmission compared to sensors operating in more distant Geosynchronous Earth Orbits.

Conversely, compared to LEO, sensors orbiting in MEO have longer pass times over target areas and wider fields of view due to their higher altitudes. This also means MEO sensors can also maintain custody of missile tracks for longer periods of time. With these advantages, it would require between 9 and 36 missile warning satellites in MEO, depending on the desired orbital altitude, to achieve continuous global coverage. This number is relatively low compared to the hundreds of satellites needed to achieve the same coverage for a LEO constellation, but depending on the requirements, it can be higher.

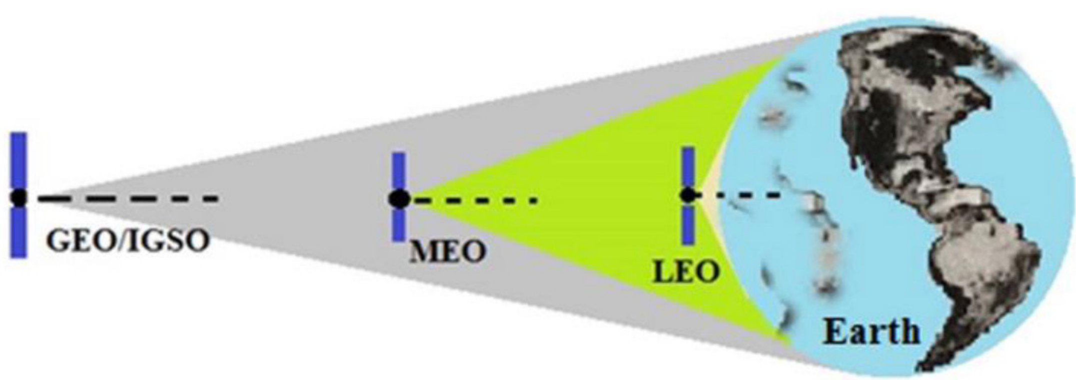


Figure 20: Comparing Field of Views of Satellite in LEO, MEO, and GEO

Credit: Delft University of Technology

While this “sweet spot” seems to be a winning combination, MEO-based systems are also vulnerable to numerous counterspace threats. Adversaries have demonstrated MEO-capable ASAT systems since 2014 that could become operational in several years. RF jammers and HPM weapons will also threaten uplinks and downlinks for MEO spacecraft and, in the future, could be capable of directly damaging or disabling their mission systems. Chinese and Russian co-orbital ASATs and counterspace systems that are capable of operating across multiple orbits to attack targets are also clear threats to satellites in MEO. It is clear that a resilient, survivable space-based missile warning and tracking force design with onboard defensive capabilities such as maneuver, decoys, or active defense weapons should be based across all orbital regimes and hardened against the threats that will exist in the “rapid and destructive” dynamic space warfighting environment China and Russia seek to create.[27]

Geosynchronous Earth Orbit basing concept—Next Generation Overhead Persistent IR (OPIR)

The final concept—GEO basing infrared sensors—is the one that most defense entities are already familiar with since it has been used by DSP and the current SBIRS. GEO-based satellites have the advantage of providing “persistent stare” coverage for boost-phase ballistic missile warnings while monitoring specific theaters for shorter-range theater ballistic missile events simultaneously.

Just as SBIRS and DSP replaced earlier GEO systems, DOD is developing a Next Generation OPIR space-based capability to replace SBIRS.

DOD’s objective is to create multiple fields of view over designated regions or specific target areas without the need to deploy massive constellations into GEO. Next Generation OPIR sensors will be three times as sensitive and two times more accurate than SBIRS sensors to better

Figure 21: Next Generation OPIR Illustration

Credit: courtesy of Raytheon Technologies detect and track the weaker IR signatures of non-ballistic missiles such as hypersonic weapons.[28] Next Generation OPIR will also have a downlink data rate that is four times greater than SBIRS, which will help reduce lag time for missile defense operations.[29] The "open architecture" design of Next Generation OPIR means the system will have the capability to receive upgrades so it can link with missile warning/tracking satellite constellations in other orbital regimes in the future. This could include using ground data fusion to link it with different systems and even cross-links through SDA's Transport Layer. DOD's notional plan is to deploy a constellation of five satellites in GEO and two satellites in Polar orbit to provide global missile warning coverage without gaps. The first Next Generation OPIR satellite is scheduled to launch no later than 2025.[30]

Multi-layered warning and tracking is essential for the future

Proponents of each of these orbital basing options tend to believe their preferred approach is "the answer" for the future. In reality, strength and continuous advantage lie with a diversified and complementary set of capabilities. This means developing a multi-layered/multi-orbit missile warning and tracking system that is, in combination, more resilient, survivable, and provides continuous chain-of-custody tracking of ballistic and maneuvering missiles—including hypersonic weapons. Multiple, complementary layers of sensors in LEO, MEO, GEO, and Polar orbits should be a threshold requirement for any future missile warning and tracking architecture that is designed to operate and survive in future contested space environments. Each orbital basing layer provides capabilities that, when coupled with other layers, will give U.S. warfighters the ability to track maneuvering missile threats from space despite their highly diverse flight profiles.

How it could work. Next Generation OPIR in GEO and Polar orbits should serve as the most persistent layer of this future architecture—its global coverage and multi-look sensors can provide warfighters with initial indications and warning of missile threats while they are in their boost phase of flight immediately after launch. Data collected by Next Generation OPIR during the initial phase of a missile attack could then cue sensors in other layers of the architecture. Satellites deployed at MEO could use these cues to begin tracking threats such as maneuvering hypersonic missiles as they transition to their post-boost and mid-course phases of flight. The lower altitudes of IR sensors in MEO will help increase the fidelity of missile tracks in preparation for handing off threats to LEO layer sensors. Finally, a mature future p-LEO constellation with its hundreds of satellites will provide even higher fidelity tracks that give air and missile defenses on the ground, in the air, and at sea the information they need to achieve precise fire control solutions.

Countering the counterspace threat is another part of the solution

Three orbital layers will provide additional resiliency and survivability necessary to contend with anti-satellite weapons and other counterspace threats across the continuum. While Russia and China have threatened to destroy entire constellations of satellites in single orbits in a conflict, it would be much more difficult for them to target **all three** orbital layers at the same time. This increased resiliency will enable satellite operators to quickly fill gaps in coverage using other surviving systems in the event attacks disable some number of LEO or MEO satellites.

Countermeasures are also needed. The increase in resiliency from fielding a multi-orbit missile warning and tracking system alone may not be sufficient to counter the multi-layered attacks Chinese and Russian space forces are preparing for in the future. As such, DOD and the U.S. Space Force should consider the following active and passive capabilities that would help deter attacks on the force design and counter them should deterrence fail.

First, DOD should take advantage of mature technologies that will increase the maneuverability of satellites in MEO and GEO. Given the limited numbers of satellites deployed to MEO and GEO, increasing their survivability by giving them the ability to rapidly maneuver to avoid threats and fill gaps in a post-attack environment at LEO will be vital.

Second, it should be prepared to deploy multiple satellite decoys in the event of a crisis. Like late Cold War ICBMs that carried decoy reentry vehicles to complicate an enemy's missile defense operations, mixing decoys with active missile warning and tracking satellites across all orbital regimes, but especially MEO and GEO, will pose a targeting dilemma for China and Russia. It could possibly even cause them to waste high-value ASAT assets on non-operational, low-cost decoys. While the United States has not sought this type of warfighting environment in space, the Chinese and Russians have nevertheless created such a situation, and U.S. forces must be capable of matching or surpassing enemy threats for self-defense and deterrence of war.

Finally, DOD should deploy an architecture of its own ASATs and other counterspace capabilities. These capabilities would not only deter peer adversary attacks on U.S. space-based missile warning and tracking assets; they would also increase options to respond to attacks in space. Both Chinese and Russian strategic space writings indicate their militaries believe an effective deterrent in space must include capabilities that can attack an adversary's space infrastructure in a "rapid and destructive" manner.[31] A step toward the United States creating such a deterrent of its own would be to invest in existing programs of record that could produce interceptors modified to hold at risk enemy targets. DOD should complement these kinetic systems with offensive and defensive electronic warfare capabilities. Defensive electronic warfare capabilities are needed to protect LEO, MEO, and GEO uplinks and downlinks critical to the mission effectiveness and command and control of its satellites, while offensive capabilities are important to hold similar adversary systems at risk. Without these systems and operating concepts for their use, attacks on U.S. space-based assets that are critical to missile defense and other missions will be deterred by policy proclamations alone—which is a recipe for failure in a major conflict with China or Russia.

Conclusion and Recommendations for a Multi-Layered Missile Tracking and Deterrence Approach

America's military is now facing the threat of attacks by a new generation of missiles that it cannot effectively detect and track. Adversary missiles with highly predictable flight paths have given way to weapons that are highly maneuverable, can fly at supersonic or hypersonic speeds, operate at lower altitudes, and have lower IR signatures that current space- and ground-based systems cannot track. Moreover, many of these new weapons are designed to fly trajectories that exploit the curvature of the Earth, which limits the ability of ground-based radar systems to track them.

Our adversaries know our blind spots, and they built systems to take advantage of these detection shortfalls. Responsible consideration of the scale of this threat and the consequences such an attack would inflict upon our forces at home and abroad demands we pursue a new approach.

DOD has the technology to develop a new space-based missile warning and tracking architecture that is capable against these emerging threats. The following recommendations are intended to inform the development and fielding of a space-based force design that will meet these objectives and enhance our ability to deter, defend, and, if necessary, prevail in a conflict in space:

- DOD should adopt a multi-layered satellite architecture that combines legacy ballistic missile warning capabilities with enhanced sensors in LEO, MEO, GEO, and Polar orbits to detect and track hypersonic weapons and other novel missile threats over their entire flight profiles.
- DOD should develop the capability to deploy decoy satellites in LEO and MEO orbital regimes to complicate Chinese and Russian counterspace targeting operations. This defensive measure would enhance deterrence as well as increase the resiliency of DOD's space-based missile warning architecture in a conflict.
- Missile warning and tracking satellites in MEO and GEO basing layers should transition from using limited lifespan, chemically-based propellants to other more advanced propulsion capabilities to enhance their ability to maneuver to avoid attacks and change orbits post attack.
- DOD should rapidly and overtly field kinetic and non-kinetic ASAT systems in sufficient numbers to hold adversary space systems at risk to enhance deterrence and, in the event deterrence fails, achieve victory.

The U.S. Space Force is responsible for providing warfighting capabilities that are essential for the conduct of decisive military operations in space and on Earth. One of its most critical missions is to give warfighters the information they need to defeat large-scale missile attacks. Today, its space-based missile warning and tracking system is unmatched in what it was designed to do—detect missiles in the boost phase for early warning. It was never intended to track weapons that can maneuver while flying non-ballistic flight profiles at hypersonic speeds. It was not built for what is becoming a highly contested space domain. Increased orbital distances alone will not protect satellites from China and Russia's counterspace threats. The answer to these challenges is to develop and field a multi-layered space-based missile warning and tracking system that is coupled with a credible means to deter and respond if necessary to attacks. Without this new force design, the threat of missile attacks will continue to grow, and America's ability to defend itself and its allies and partners will continue to erode. As Secretary of the Air Force Frank Kendall recently said, missile warning and tracking is a "no-fail space mission" that must be addressed now, not in the distant future.[32] ✪

Endnotes

1 Boost-glide hypersonic weapons use a rocket to boost a maneuverable glide vehicle carrying a warhead to high altitudes and airspeeds that allow it to glide to a distant target. Air-launched hypersonic cruise missiles can also be powered by scramjet or ramjet engines.

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