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THE MISSILE THREAT: A TAXONOMY FOR MOVING BEYOND BALLISTIC

STEVEN T. DUNHAM AND ROBERT S. WILSON
THE AEROSPACE CORPORATION

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STEVEN T. DUNHAM

Steven T. Dunham is a senior project engineer for The Aerospace Corporation's Strategic and Global Awareness Directorate, also known as Project West Wing, where he is responsible for transforming missile threat expertise, research, and insight into practical solutions to the challenges facing U.S. National Security Space. Dunham has 30 years of applied missile and launch system technical analysis experience in support of a variety of programs across many phases from early acquisition through operations. He has a bachelor's degree in mechanical engineering from Rensselaer Polytechnic Institute and a master's degree in systems architecture and engineering from the University of Southern California.

ROBERT S. WILSON

Robert Samuel Wilson is a policy analyst at The Aerospace Corporation's Center for Space Policy and Strategy, where he is responsible for leading work on international space; nuclear command, control, and communications; and missile issues. Prior to joining Aerospace, he served as a senior analyst in the Defense Capabilities and Management division at the U.S. Government Accountability Office. There, he led reports on nuclear command, control, and communications; strategic force structure; arms control; and U.S. nuclear forces in Europe. Wilson received his bachelor's degree from the University of Virginia in political theory and his master's degree from the University of Virginia's Batten School in public policy.

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Summary

U.S. approaches to missile warning and missile defense remain predicated on the idea that most adversarial missiles will follow parabolic ballistic trajectories to predictable targets. That no longer adequately describes the threat. Based on a survey of missile systems from Russia, China, Iran, and North Korea, most potential adversarial missiles have maneuvering capabilities that distinguish them from ballistic missiles. Yet, because more appropriate constructs for classifying missiles do not exist, U.S. guidance mischaracterizes many of these systems as ballistic. If we mislabel missiles because we are using outdated heuristics, we may find ourselves surprised and ill-equipped to confront current and anticipated threats. Our current constructs tend to treat maneuverability as a binary—e.g., hypersonic glide vehicles are maneuverable and ballistic missiles are not. But, in fact, there is a spectrum of maneuverability, which creates the need for more nuanced distinctions. A more comprehensive taxonomy for capturing the threat, as presented in this paper, could affect decisions for missile warning, missile defense, and broader strategic policy.

Introduction

Sixty years after Bernard Brodie's venerable "Strategy in the Missile Age," missiles continue to be at the forefront of national security strategies.[1] More than 30 countries now possess missile systems and potential adversaries are expanding their capabilities, adding new types to their arsenals and integrating them more thoroughly into their military strategy and war planning.[2] This spotlight on missiles is not just limited to experts in the defense community. In 2019, the word "missile" appeared on the front page of U.S. newspapers more than in any year dating back to 1990.[3] Whether it is ballistic missile exchanges in the Middle East, tests in North Korea, debates over missile-based arms control, or hypersonic missile developments in Russia and China, these weapons grab our attention and those of our competitors.

However, the language we use to characterize missiles is rooted in decades-old arms control definitions. These definitions helped reach agreements that limited the spread and development of missiles, but missile technology was making the definitions obsolete even as the treaties were being written. Today, we should no longer think of ballistic missile trajectories as following a predictable parabolic arc. Nor can we think of cruise missiles as maneuverable but slow. Nor should we think of hypersonic glide vehicles as some completely new category unrelated to these more traditional threats. Most missiles now have characteristics of maneuverability, which creates the need for more nuanced distinctions.[4]

If we mischaracterize missiles because we are using outdated heuristics, we may find ourselves surprised and ill-equipped to confront current and anticipated threats. For instance, our missile warning systems have focused on detecting the heat signature generated by the booster (rocket) to determine where an incoming missile attack is headed and when it will impact. But this approach does not account for maneuvering done by the payload rather than the booster. And if we do not know the missile's trajectory or target with confidence, defending against it becomes more complicated. The United States' Ground-based Midcourse Defense program is designed for traditional ballistic missiles; as the predictable parabolic trajectories of ballistic missiles become a thing of the past, the value of such defenses diminishes.[5] The modern missile environment also presents complications for arms control. Absent an extension, the last of the nuclear arms control agreements between the United States and Russia, the New Strategic Arms Reduction Treaty (New START) will expire on February 5, 2021. Future arms control treaties, whether bilateral or multilateral, will have to grapple with the spectrum of modern missile capabilities that are not captured simply by range and delivery vehicle.

This paper sets out a new heuristic for characterizing missiles. It identifies the fundamental physical elements of modern missiles that enable a spectrum of nonballistic trajectories and suggests a new taxonomy for clearer, more comprehensive discussions of priorities and concerns in support of decisions on offensive systems, missile warning, missile defense, and broader policy and strategy. To prepare for the threat modern missiles pose, we must develop a more sophisticated understanding of what makes a missile a missile.[6]

Today's Ballistic Missile Taxonomy

The ballistic missile taxonomy widely applied today remains rooted in missile classifications derived in large part from strategic arms control treaties.[7] This taxonomy, shown in Table 1, focuses on range and launch platform and misses important developments in missile technology that are common today. The lag between the missile taxonomy and the actual missile environment is not new; in fact, it dates to the beginning of U.S.-Soviet arms control negotiations in the early years of the Cold War. Summaries and taxonomy-related definitions from these agreements are listed in Table 2.[8]

Table 1. Ballistic Missile Taxonomy Widely Applied Today

Missile Class	Range (km)
Close-range ballistic missile (CRBM)	<300
Short-range ballistic missile (SRBM)	≥300 to <1000
Medium-range ballistic missile (MRBM)	≥1000 to <3000
Intermediate-range ballistic missile (IRBM)	≥3000 to <5500
Intercontinental ballistic missile (ICBM)	≥5500
Submarine-launched ballistic missile (SLBM)	Any range
Air-launched ballistic missile (ALBM)	Any range

Source: *Ballistic and Cruise Missile Threat*, Defense Intelligence Ballistic Missile Analysis Committee, Defense Intelligence Agency, NASIC-1031-0985-17, June 2017, p. 8.

In 1972, by the time the two countries signed the SALT I agreement, freezing the numbers of ballistic missile delivery systems, the United States had already deployed a means to deliver multiple warheads with a single booster; specifically, multiple independently targeted reentry vehicle (MIRV) payloads.[9] The discussion of limits on MIRVs in the SALT II agreement, signed in 1979, provided the first formal acknowledgment that ballistic missiles do not always follow predictable,

Table 2: Summary of Strategic Arms Control Agreements	
Agreement	**Summary and Term Definitions**
SALT I (1972 to 1979)	Froze number of fixed, ground-launched intercontinental ballistic missile (ICBM) and submarine-launched ballistic missile (SLBM) launchers at then current levels for five years.
	Defined ICBM launchers as launchers for strategic ballistic missiles capable of ranges in excess of the shortest distance between the northeastern border of the continental United States and the northwestern border of the continental USSR.
ABM Treaty (1972 to 2002)	Limited each party to one anti-ballistic missile (ABM) system deployment area centered on its national capital and one ABM system deployment area containing ICBM silo launchers.
	Defined an ABM system as a system to counter strategic ballistic missiles or their elements in flight.
SALT II (1979 to 1986)	♦ Limited the total number of strategic nuclear delivery vehicles – ICBM and SLBM launchers, heavy bombers, and air-to-surface ballistic missiles (ASBMs, a.k.a. ALBMs). ♦ Limited the numbers of ballistic missile delivery systems with multiple independently targeted reentry vehicle (MIRV) payloads and heavy bombers with long-range (>600 km) cruise missiles.
	♦ Defined intercontinental range as >5,500 km. ♦ Defined ASBM (a.k.a. ALBM) as any aircraft-launched ballistic missile with a range >600 km. ♦ Defined MIRV as any missile system that, after separation from the booster, can deliver more than one warhead to more than one target on trajectories that are unrelated to each other. ♦ Defined heavy bombers as bombers equipped to launch ASBMs (ALBMs) or long-range cruise missiles. ♦ Defined cruise missiles as unmanned, self-propelled, guided, weapon-delivery vehicles that sustain flight through the use of aerodynamic lift over most of their flight path.
INF Treaty (1987 to 2019)	Eliminated all ground-launched intermediate-range and shorter-range ballistic and cruise missiles.
	♦ Defined a ballistic missile as a missile that has a ballistic trajectory over most of its flight path. ♦ Defined intermediate range as >1,000 km and ≤5,500 km. ♦ Defined "shorter-range" ≥500 km and ≤1,000 km.
START (1991 to 2009)	♦ Reduced and limited the total number of ICBM and SLBM delivery systems and heavy bombers as well as the total number of warheads that could be deployed. ♦ Prohibited production, testing, or deployment of ASBMs (ALBMs).
	Redefined ASBM (ALBM) as any aircraft-launched ballistic missile with a range >600 km that *does not* sustain its flight using aerodynamic lift over any portion of its flight.
New START (2010 to 5 Feb 2021)	Reduces and limits the total number of ICBM and SLBM delivery systems as well as the total number of warheads that can be deployed.
	Defines an SLBM as a ballistic missile with a range >600 km launched from a submarine.

Note: The term *strategic* is fraught with ambiguity. Asymmetries between the strategic nuclear forces of the United States and Soviet Union had developed by the time the SALT negotiations began in earnest in 1969, ultimately making it necessary to use the term *strategic* without providing a single definition of "strategic missile" or "strategic range" in the series of agreements that followed.

ballistic trajectories after separating from the booster. The agreement defines a MIRV payload as a "self-contained dispensing mechanism" that, after separation from the booster, is capable of maneuvering and targeting two or more reentry vehicles "to separate aim points along trajectories which are unrelated to each other."[10] The treaty language limits these devices—typically referred to as *post-boost vehicles* (PBVs)—to providing an additional velocity of no more than 1,000 meters per second total to any one or all of the warheads dispensed.[11] The U.S. Peacekeeper intercontinental ballistic missile (ICBM) is shown in Figure 1 as an example. The Peacekeeper missile system was a single booster armed with a MIRV payload consisting of up to 10 warheads capable of producing 10 different trajectories.

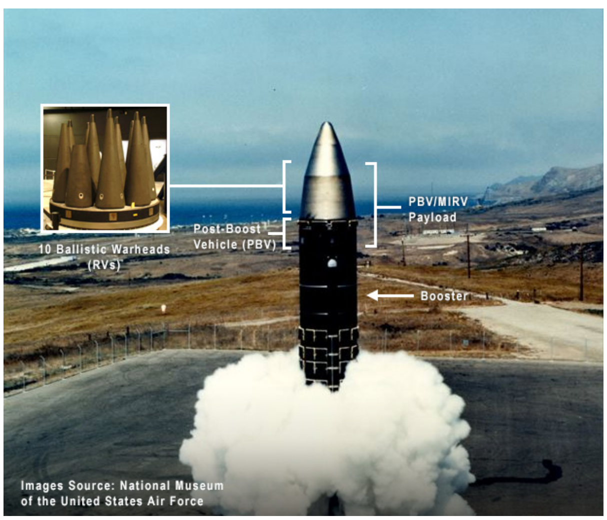


Figure 1: U.S. Peacekeeper ICBM. *(Operational from 1986 to 2005.)*

Though still labeled as ballistic (specifically ICBMs or submarine-launched ballistic missiles) in SALT II and subsequent treaties, the behavior of MIRV missile systems is not purely ballistic, meaning that it does operate essentially like a cannon by relying only on an initial rocket boost. Given that an ICBM will be travelling roughly 7,000 meters per second at the end of the booster burn, adding 1,000 meters per second later in the trajectory may not seem consequential. However, consider the example of an ICBM with a two-warhead MIRV payload on an initial 30-minute intercontinental ballistic trajectory from Moscow to New York City. Both warheads are released, say, about 5 minutes after launch, well after the booster has burned out and the payload has separated, leaving 25 minutes of flight time to the target. The PBV dispenses the first warhead but adds no additional velocity, which flies ballistically to New York. The PBV then delivers an additional 1,000 meters per second of velocity in the same direction to the second warhead. The greater impulse to the second warhead means it would land about 1,500 km farther, greater than the distance between New York and Atlanta. That has strategic consequences and emphasizes how even the trajectories of early so-called ballistic missiles were not so predictable.[12]

Submarine-launched ballistic missile (SLBM) developments also outpaced treaty negotiations from their onset. Since the early 1970s, years before the SALT II agreement was reached, all U.S. and Soviet (and subsequently Russian) SLBMs have been capable of ranges greater than 5,500 km and remain so today. Consequently, the agreed-upon limitations or reductions detailed in strategic arms treaties from 1972 through 2009 consistently refer to both ICBMs and SLBMs simultaneously without explicitly associating a range with SLBMs. During the Cold War, it could safely be assumed that launches originating from the ocean were likely to be Soviet intercontinental-range SLBMs. That is no longer the case. This misperception has grown increasingly misleading for two primary reasons. First, not all SLBMs are intercontinental-range or Russian, as shown in Figure 2.[13] Second, not all sea-launched ballistic missiles originate from submarines, nor are they all ballistic, as shown in Figure 3.

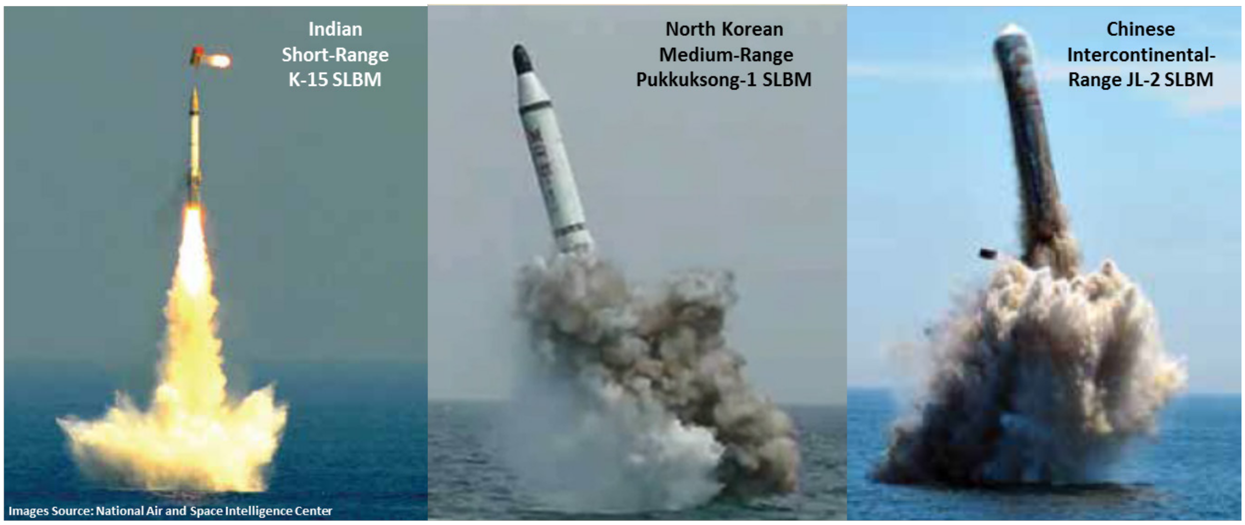


Figure 2: Examples of SLBMs active in many range classes and countries.

Figure 3: Indian Dhanush ship-launched short-range ballistic missile.

The air-launched ballistic missile (ALBM) class is similarly ambiguous. The START agreement, signed in 1991, redefined ALBM as any aircraft-launched ballistic missile with a range greater than 600 km that does not sustain its flight using aerodynamic lift over any portion of its flight.[14] Yet missiles active today with ranges greater than 600 km that are typically identified as ALBMs do maneuver aerodynamically. For example, the Russian Kinzhal shown in Figure 4, publicly debuted over Moscow in 2018, is a nuclear-capable maneuvering medium-range ALBM.[15] As with the SLBM label, the ALBM label captures the missile system launch platform at the expense of providing insight into threat-range class.[16]

Anchored by the definition of intercontinental range in strategic arms control agreements, other range-based classes of so-called ballistic missile systems emerged from successful negotiation of the Intermediate-Range Nuclear Forces (INF) Treaty, signed in December 1987, which eliminated U.S and Soviet land-launched "intermediate-range" and

Figure 4: Russian Kinzhal medium-range ALBM on Mig-31 Interceptor. *(Capable of maneuvering aerodynamically after boost.)*

"shorter-range" ballistic and cruise missiles. The INF Treaty defined "intermediate range" as greater than 1,000 km and less than 5,500 km, chosen specifically to dovetail with intercontinental range. "Shorter range" was defined as greater than or equal to 500 km and less than 1,000 km.[17]

More recently—and independent of the history of bilateral treaties—the close-range ballistic missile (CRBM) class arose as the result of two developments: (1) the 300-km limit on the range of for-export missiles stipulated in the multinational Missile Technology Control Regime, and (2) the rapid expansion and proliferation of very short-range guided missiles.[18] However, most missile systems classified as CRBMs, like the Russian Iskander-E and the Chinese M-20, which are available for export, do not leave the atmosphere, are aerodynamically guided through all phases of flight, and may not be ballistic at all.

Most of these missile classifications echo Cold War perspectives on specific threats and projections of how U.S. and Soviet missile systems might be employed or evolve. The definition of an ICBM, for example, is based on the distance between the continental United States and the former Soviet Union. The INF Treaty eliminated Soviet intermediate and shorter-range missiles that threatened U.S. and allied forces fielded in Europe as well as forward-deployed U.S. missiles that threatened Soviet forces at home or maneuvering in an invasion. Additionally, changes to the definition of ALBM incorporated into the START agreement were made at the insistence of the United States in order to protect U.S. plans to develop air-launched aerodynamically maneuvering missiles, which China and Russia are now successfully flying.[19]

Collectively, the broadening nature of geopolitical competition, the potential for expanding arms control beyond a bilateral context, and the modern missile environment drive a need for a new approach. The ability to parse missiles by their range capability remains an essential element of any missile taxonomy, but range should be combined with other capabilities to more comprehensively characterize the threat. Such a taxonomy can help simplify the missile environment for purposes of designing responses and could be valuable for future arms control agreements.

A New Approach

To describe modern missiles more accurately, we need to capture the capabilities of the booster and the basic capabilities of the payload. Besides just how far the payload can travel, we need to account for how much it can alter its trajectory along the way. This section provides that more complete taxonomy by breaking down missile systems into three fundamental elements: the booster with weaponized payload, whether the payload can maneuver aerodynamically, and whether the payload is powered. Combining these elements generates five distinct payload categories, illustrated in Figure 5, which can then be matched to range to get a more comprehensive description of modern missiles. Modern missiles are complex, and we need to acknowledge that.

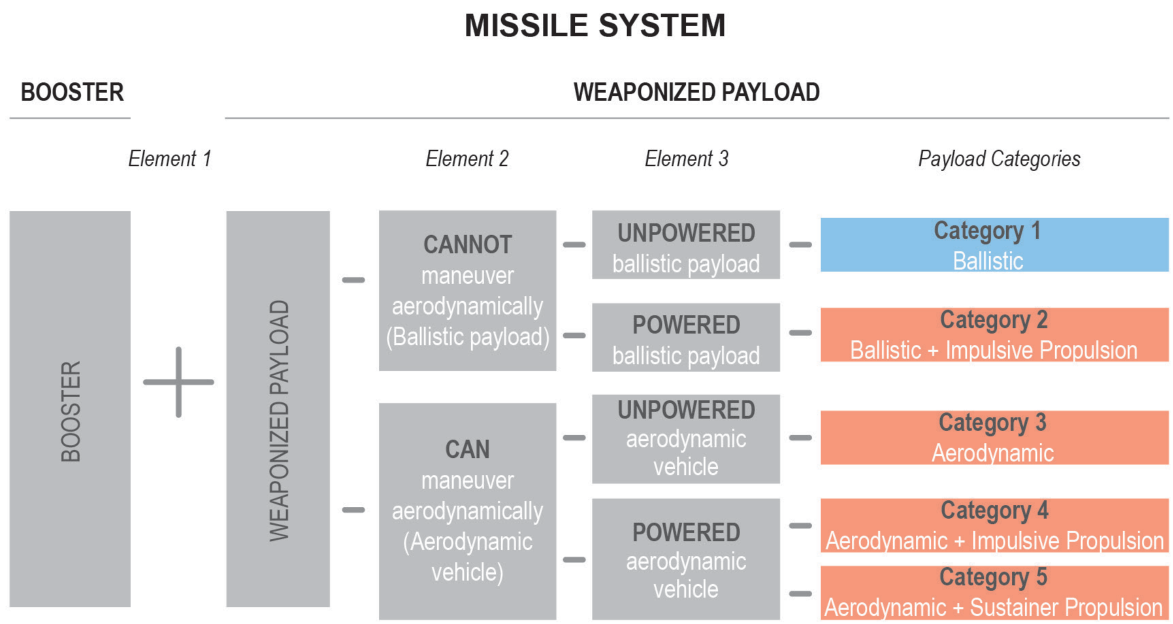


Figure 5: Combinations of fundamental missile system elements.

Three Fundamental Missile System Elements

1. A missile system is a rocket (booster) plus a weaponized (munitions-carrying) payload
2. Weaponized payloads can be divided into two distinct groups:
   a. Those that cannot maneuver aerodynamically after boost: *ballistic warheads*
   b. Those that can: *aerodynamic vehicles*
3. Weaponized payloads can also be independently powered after booster operation is complete:
   a. *Ballistic warheads:* by impulsive propulsion systems, such as PBVs or other small upper stages
   b. *Aerodynamic vehicles:* by impulsive or sustainer propulsion systems, such as air-breathing engines

This new perspective on missile payloads is illustrated in Figure 6. Missile systems that combine a given booster with a payload in Category 1 through Category 4 are typically identified using the established ballistic missile taxonomy in Table 1. However, only Category 1 payloads result in missile systems that are ballistic in the classical sense: once booster-powered flight is complete, the only forces acting on the payload are gravity and atmospheric drag during reentry. The same booster combined with payloads in Category 2, 3, or 4 involves a variety of post-boost aerodynamic and propulsive maneuvering capabilities and techniques better characterized as nonballistic—many of which have been routinely demonstrated by adversary missile systems that are in development or in operations. The same booster combined with Category 5 payloads (aerodynamic vehicles powered by sustainers, such as air-breathing ramjet or scramjet engines) are cruise missiles, which clearly do not fly ballistic trajectories.

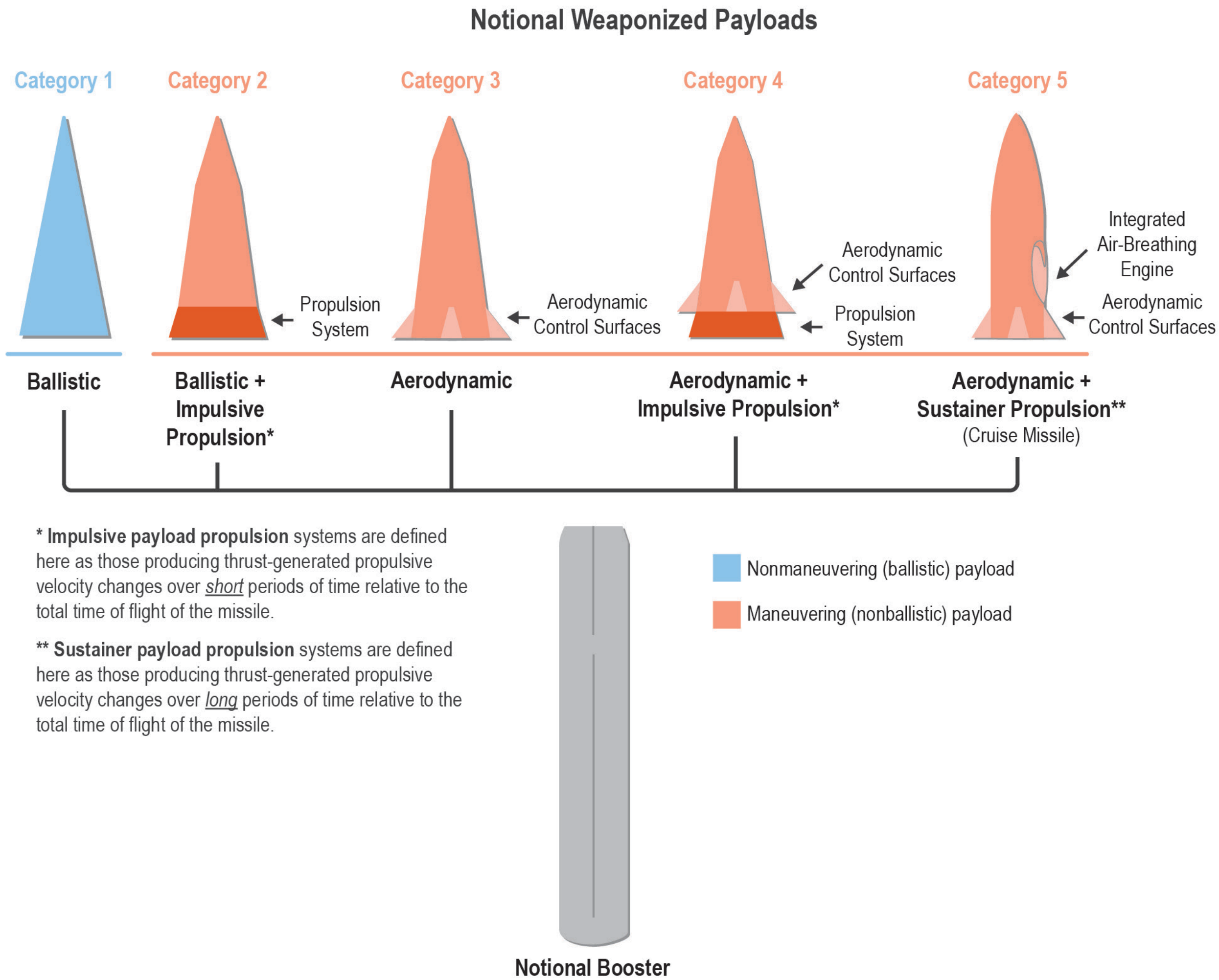
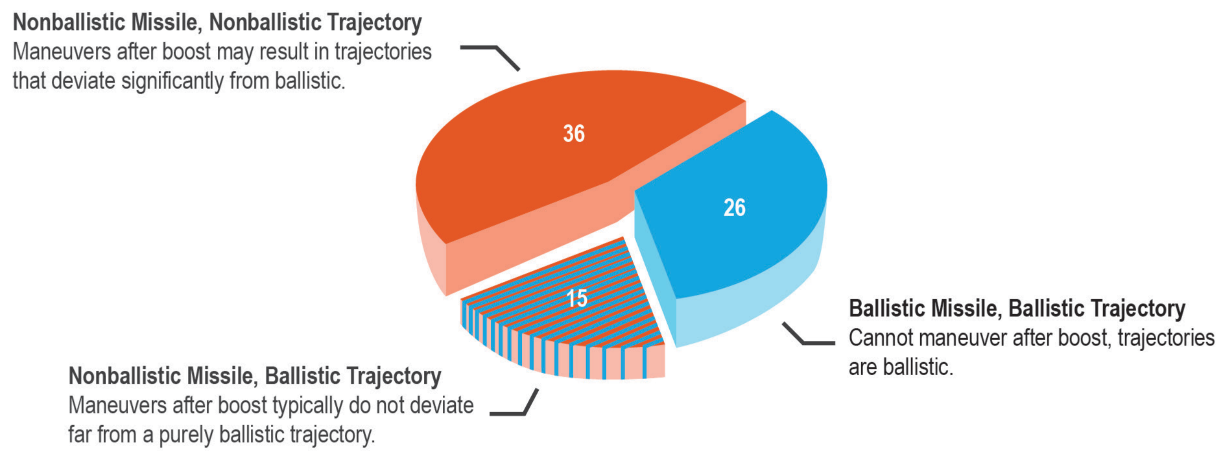


Figure 6: Illustration of the modern missile threat.

A survey of Category 1 through 4 threat systems active today in China, Iran, North Korea, and Russia (nations identified as potential adversaries in the *2018 National Defense Strategy*) further illustrates the divergence between the established ballistic missile taxonomy and the increasingly nonballistic nature of the modern missile threat. The survey sample consists of 77 unique missile systems that are either operational or undergoing flight testing.[20] Analysis of this sample, shown in Figure 7, reveals two important features of the missile threat environment. First, most of these systems have some ability to maneuver after boost (either aerodynamically or by propulsive force, or both). Although all are commonly labeled ballistic missiles (i.e., short-range ballistic missiles [SRBMs], medium-range ballistic missiles [MRBMs], intermediate-range ballistic missiles [IRBMs], ICBMs, SLBMs, and ALBMs), only 26, roughly one-third, are nonmaneuvering ballistic missiles (that operate essentially like a cannon). Second, many of the maneuvering systems operate in ways that deviate significantly from ballistic trajectories. Of the nonballistic systems, 15 have post-boost aerodynamic and propulsive maneuvering capabilities that simply allow them to more precisely strike a target on a predictable parabolic ballistic trajectory while the remaining 36 use these



Sample total: 77 ballistic missile systems. Payload Categories 1 through 4 only. Does not include CRBMs or Category 5 (booster-delivered cruise missile) payloads. Sample is not exhaustive. Values are approximate.

Figure 7: Survey of Category 1 Through 4 missile systems in China, Iran, North Korea, and Russia.

capabilities to follow more complex, nonballistic trajectories.

To complete this new approach, all five payload categories are mapped against the overall missile system range. The result is the matrix shown in Figure 8, with the five range classes from the established taxonomy—with the term *ballistic* removed—defining the rows and the five payload categories defining the columns. Removing *ballistic* from the established range class labels allows space for the payload category to be added to create four-character labels that communicate both the range of the missile system and essential information about the potential capability of the payload. For example, instead of classifying a missile as a CRBM, our taxonomy would call it "CRM3" to signify that it is a close-range missile with a Category 3 (aerodynamic) payload. Each of the five payload categories defining the columns of the missile threat classification matrix are described further below, along with several of the key insights and limitations associated with application of this new approach.

Payload Category 1: Ballistic

Category 1 missile systems are ballistic missiles, as are their trajectories, illustrated in Figure 9. New Category 1 missiles continue to emerge, including the array of recent North Korean entrants shown in Figure 10 that, at least for now, appear to have only classical ballistic missile capabilities. Evolution to missile systems with the ability to maneuver beyond the end of booster powered flight (Categories 2 through 5) is a global trend, however, with new and existing ballistic missile systems increasingly acting as stepping-stones along the way.

Payload Category 2: Ballistic + Impulsive Propulsion

Missile payloads frequently include propulsion systems independent of the booster that change the path of the warhead or warheads by changing their velocity after separating from the expended booster. Category 2 missile payloads are a combination of ballistic warheads and one of a variety of propulsion systems capable of impulsive velocity changes after

MISSILE PAYLOAD CATEGORY / MISSILE SYSTEM RANGE CLASS	Category 1 *(Ballistic)*	Category 2 *(Ballistic + Impulsive Propulsion)*	Category 3 *(Aerodynamic)*	Category 4 *(Aerodynamic + Impulsive Propulsion)*	Category 5 *(Aerodynamic + Sustainer Propulsion)*
Close-Range Missile (CRM) *Max Rng < 300 km*	CRM1	CRM2	CRM3	CRM4	CRM5
Short-Range Missile (SRM) *300 km ≤ Max Rng < 1000 km*	SRM1	SRM2	SRM3	SRM4	SRM5
Medium-Range Missile (MRM) *1000 km ≤ Max Rng < 3000 km*	MRM1	MRM2	MRM3	MRM4	MRM5
Intermediate-Range Missile (IRM) *3000 km ≤ Max Rng < 5500 km*	IRM1	IRM2	IRM3	IRM4	IRM5
Intercontinental-Range Missile (ICM) *Max Rng ≥ 5500 km*	ICM1	ICM2	ICM3	ICM4	ICM5

Ballistic missile systems (blue)
Nonballistic missile systems (orange)

Note: Removing "ballistic" from the established range class labels provides the option of adding a new character representing the payload category, allowing each new label to communicate both the range of the missile system as well as essential information about the potential capability of the payload.

Figure 8: New approach: missile threat characterization matrix.

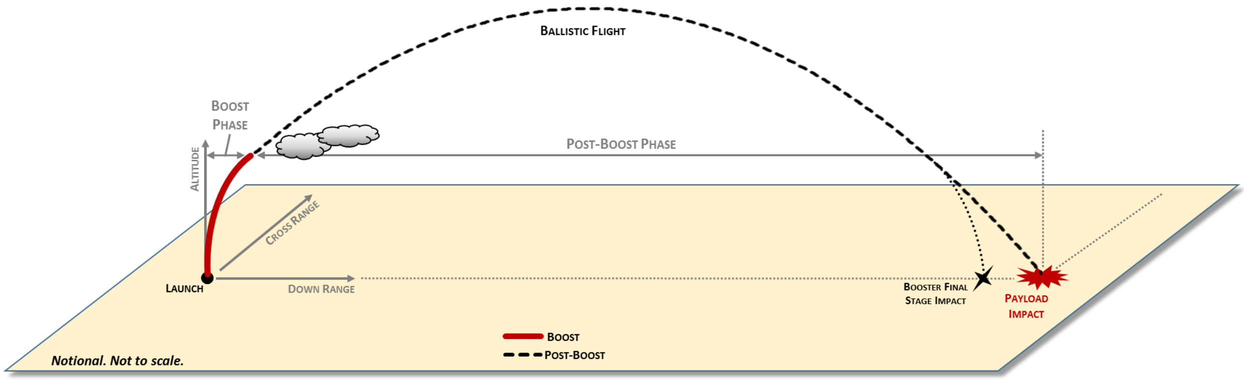


Figure 9: Notional Category 1 Trajectory.

Figure 10: Examples: new North Korean Category 1 missile systems.

the boost phase of flight is complete. These velocity changes, referred to as ΔVs, vary in magnitude from very small corrections that improve the accuracy provided by the booster alone to multiple larger ΔVs, deploying multiple warheads on independent trajectories to targets separated by hundreds to a few thousand kilometers. Category 2 propulsive system operation is typically limited to altitudes outside the atmosphere (exoatmospheric).

Although all Category 2 systems can maneuver after boost, some Category 2 systems follow trajectories that look essentially ballistic. Combining increasingly ubiquitous, compact, and inexpensive satellite-based navigation technology with the small ΔVs produced by a simple attitude control module (ACM) can, for example, differentiate unsophisticated weapons from modern weapons able to reliably strike a specific city block or airfield runway.[21] While the payloads are capable of changing their trajectories by propulsive force after boost, those changes may simply help ensure the payload follows the intended ballistic trajectory. The Pakistani Ghauri MRBM, shown in Figure 11, is an example of such a system.

The majority of the Category 2 systems, however, are ICBMs or SLBMs with MIRV payloads, common examples of Category 2 missile systems that do not follow single predictable ballistic trajectories. A notional MIRV missile system

Figure 11: Example Category 2 missile system with an ACM payload.

trajectory is illustrated in Figure 12. After booster-powered flight and payload separation, the PBV delivers multiple warheads to multiple targets by delivering an additional ΔV to each reentry vehicle (RV) at the desired time and in the desired direction. The targets for the individual RVs may be hundreds to thousands of kilometers away from one another.

Most Russian ICBMs and all Russian SLBMs are Category 2 missile systems with MIRV payloads, including the road mobile SS-27 Mod 2, armed with up to four nuclear warheads, shown in Figure 13.[22] The new Chinese DF-41 ICBM, also road-mobile, and intercontinental-range JL-3 SLBM are MIRV-capable missile systems as well.[23] And MIRV payloads are no longer limited to major military powers. In March 2018, Defense Intelligence Agency (DIA) Director Lt Gen. Robert Ashley testified before the Senate Armed Services Committee that Pakistan conducted the first flight test launch of its nuclear-capable Ababeel ballistic missile in January 2017, demonstrating South Asia's first MIRV payload.[24] While the individual warheads of a MIRV payload may be ballistic, the missile system is not.[25]

Common Propulsion Techniques for Category 2 Missile Payloads

Attitude Control Module (ACM): A small propulsion module used for payload attitude control that includes the ability to make small trajectory adjustments after boost to correct booster guidance errors and improve targeting accuracy. In general, ACMs deliver small velocity changes—up to a few tens of meters per second—to the warhead over one or more "trim ΔV" or "velocity correction burns" using propulsion systems like pressurized gas or hydrazine thrusters.

Kick Motor: A small motor used to deliver additional energy to a warhead in a single burn. Kick motor burns may change the trajectory significantly by adding many hundreds of meters per second of velocity gain in any direction and may occur any time after the booster powered flight. Payloads that include a kick motor may also include an ACM to perform finer velocity corrections after boost.

Post Boost Vehicle (PBV): Typically, a restartable engine used to correct booster guidance errors and deploy one or, more often, multiple warheads. Like kick motors, PBVs may deliver many hundreds of meters per second of velocity gain or more, although frequently in different directions over several propulsive burns (ΔVs), one for each warhead, separated in time.

Payload Category 3: Aerodynamic

Booster-delivered weaponized payloads in all three of the remaining categories are capable of a wide range of controlled post-boost aerodynamic maneuvers. The unpowered, purely aerodynamic capabilities of Category 3 payloads overlap and range from simple applications to hypersonic glide vehicles. In simple applications, missile accuracy is improved using aerodynamic control surfaces to guide a payload more precisely to help ensure the

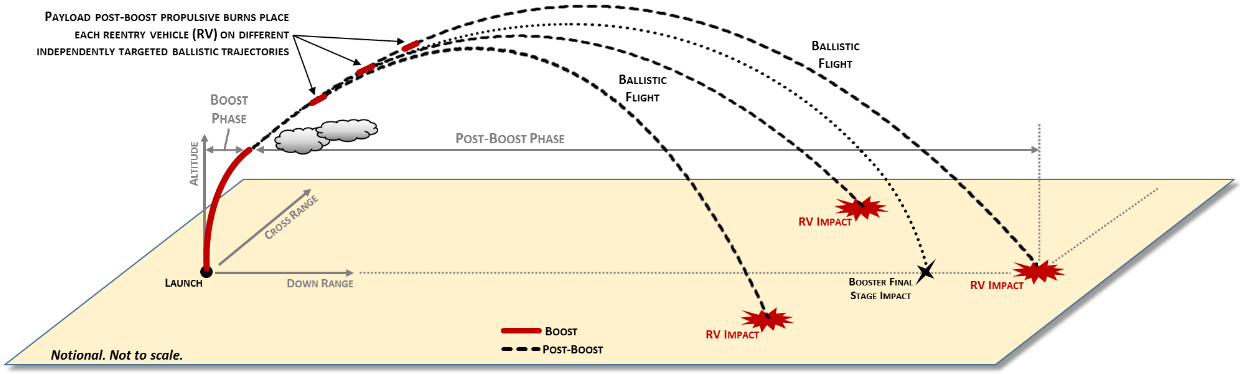


Figure 12: Notional Category 2 (PBV/MIRV) Trajectory.

Russian SS-27 Mod 2 ICBM (ICM2: MIRV) **Chinese DF-41 ICBM (ICM2: MIRV)**

Figure 13: Example: Russian SS-27 Mod 2 ICBM (ICM2: MIRV).

parabolic ballistic trajectory hits the target. At the other end of the spectrum, hypersonic glide vehicles are capable of gliding in the atmosphere at speeds significantly greater than Mach 5 for intercontinental distances. These unpowered aerodynamic capabilities are typically classified as one of the three types: aeroballistic, maneuvering reentry vehicle (MaRV), and hypersonic glide vehicle (HGV). An example of each type is shown in Figure 14.[26]

Although all Category 3 payloads maneuver, some Category 3 systems aerodynamically maneuver only in so much as they improve the likelihood of striking their intended ballistic-trajectory targets. Many others, however, can fly a wide assortment of nonballistic trajectories. Examples are illustrated in Figure 15.

Category 3 Missile System Aerodynamic Capabilities

Aeroballistic: Typically, a nonseparating combination of a booster and payload that is unpowered after boost and guided aerodynamically through all phases of flight. Aeroballistic missiles may be capable of significant glide phases and maneuvers and are generally limited to shorter (CRBM or SRBM) ranges.

Maneuvering Reentry Vehicle (MaRV): A vehicle that can alter its trajectory aerodynamically after boost, typically after reentry, and may be capable of significant glide phases and maneuvers, usually at hypersonic speeds.

Hypersonic Glide Vehicle (HGV): An aerodynamic vehicle that can sustain unpowered hypersonic glides for the majority of the total range achieved aerodynamically after boost.

Figure 14: Examples of Category 3 missile systems.

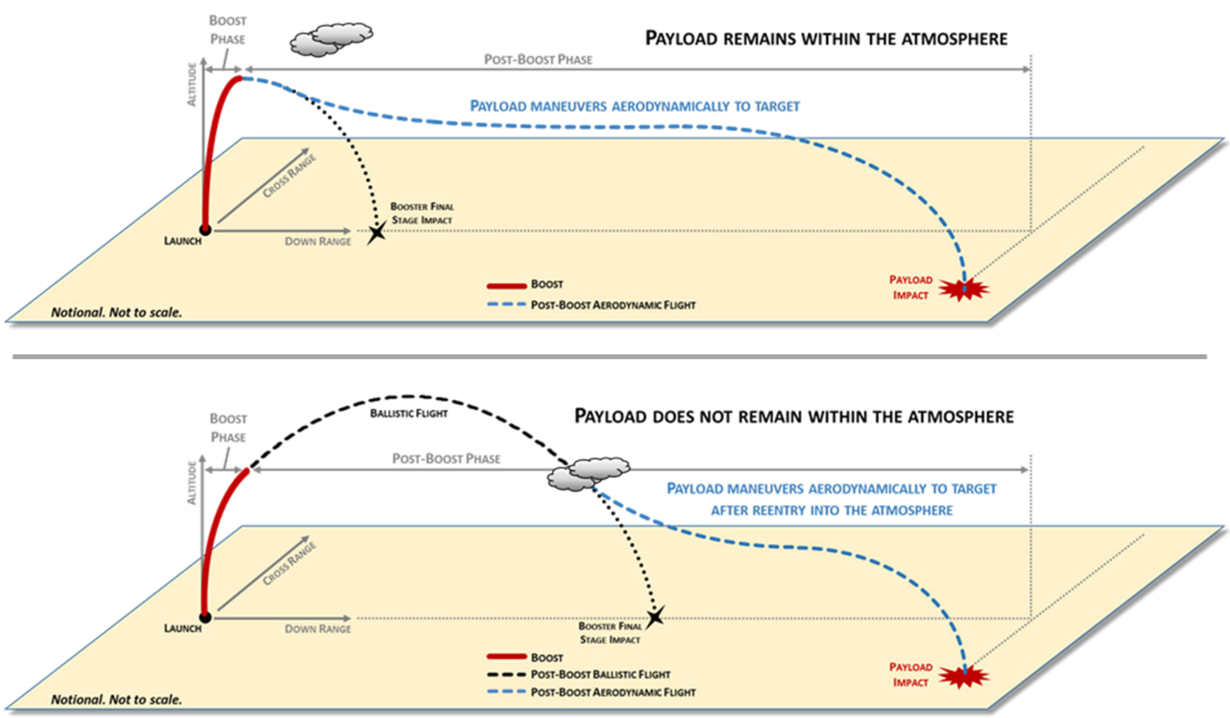


Figure 15: Notional Category 3 Trajectories.

Aeroballistic-, MaRV-, and HGV-equipped missile trajectories often include glides or maneuvers that produce an unreliable projection of warhead impact locations and time based solely on the trajectory of the initial boost phase of flight. In addition, MaRV aerodynamic capabilities can overlap significantly with those of HGVs, making them challenging to reliably and distinctly characterize.[27]

The number and variety of ballistic missile systems with aerodynamically maneuvering payloads are growing rapidly. Many ballistic missile boosters have, or are in the process of adding, Category 3 payloads with the potential to eventually replace their less accurate, purely ballistic, counterparts. North Korea has added a rudimentary MaRV payload to SCUD boosters, for example, as shown in Figure 16. Several different Iranian boosters first

Figure 16: Example: Transition of ballistic missile boosters to Category 3 (MaRV) payloads (North Korean SCUD booster).

developed to deliver ballistic warheads have now been equipped with MaRV payloads.[28] And China has been developing and flying ballistic missiles with aerodynamically maneuvering payloads since at least 2006.[29]

Ballistic missiles with HGV payloads are now fielded operationally as well, with new HGVs expected to reach operational status soon. For example, in December 2019, Russian president Vladimir Putin declared publicly that the first Avangard weapon systems, Russia's intercontinental-range, nuclear-tipped HGVs, had been loaded into silos and were now operational. And during the military parade in Beijing on October 1, 2019, celebrating the 70th anniversary of the founding of the People's Republic of China, Chinese president Xi Jinping unveiled an unprecedented number of new missile systems. These included 16 DF-17 MRBM HGV launchers with missiles, suggesting that this new hypersonic threat may soon reach an operational capability.

Payload Category 4: Aerodynamic + Impulsive Propulsion

Missile systems with payloads in this category combine the impulsive propulsion techniques used by Category 2 missile systems with an aerodynamically maneuverable Category 3 payload. Given the variety and inherent overlap of the maneuvering capabilities within payload Categories 2 and 3, conclusively identifying and characterizing missile systems with Category 4 payloads may be challenging. However, the purported capabilities of several missile threats indicate that booster-delivered Category 4 missile systems are both active and operational. Examples, shown on parade in Figure 17, include the Chinese medium-range DF-21D "carrier killer" anti-ship ballistic missile, operationally deployed with Chinese missile forces by 2012, and the intermediate-range DF-26, which has both precision land attack and anti-ship payloads.[30]

The growing number of ballistic missile systems that reportedly have precision strike missions implies an ability to maneuver both with propulsive force and aerodynamically after boost to, at a minimum, ensure correction of any errors introduced during the boost phase of flight. As the ranges of precision strike ballistic missiles increase, so do the demands on payload maneuverability, particularly for systems intended to strike moving targets, such as naval vessels.

The ability of MaRV-equipped MRBM and IRBM systems — like those now fielded by China, for example — to strike ships at sea likely requires propulsive trajectory adjustments while outside the atmosphere to account for the motion of the ship. Then MaRV aerodynamic maneuvers are required on reentry to guide the warhead the rest of the way to the target.[31]

The use of a post-boost impulsive propulsion capability in the form of a small kick motor on the

DF-21D Anti-Ship MRBM
(MRM4: MaRV + probable post-boost impulsive propulsion)

DF-26 Precision Land Attack and Anti-Ship IRBM
(IRM4: MaRV + probable post-boost impulsive propulsion)

Figure 17: Examples of probable Category 4 missile systems.

payload, for example, would enable potentially significant trajectory changes. Examples of Category 4 trajectories are illustrated in Figure 18. The kick motor burn could occur in any direction at any time after the boost phase of flight, enabling a missile to fly a wide range of nonballistic trajectories to static or moving targets.

The advancements in post-boost maneuverability necessary to ensure accuracy or the ability to strike moving targets can also be employed to significantly increase weapon system utility and survivability. For example, a Category 4 missile system with a payload consisting of a MaRV and an impulsive propulsion system like a kick motor means expanded targeting options, such as in-flight retargeting or target feints, as well as abilities to maneuver to avoid or evade missile defenses.[32]

Payload Category 5: Aerodynamic + Sustainer Propulsion

Like Category 4, Category 5 payloads are a combination of a propulsion system and an aerodynamic vehicle with one critical difference: Category 5 propulsion systems operate for long periods of time, even continuously, after booster-powered flight. These aerodynamic payloads are powered by sustainers, typically air-breathing engines classified by their operating velocities: subsonic (turbojet or turbofan), supersonic (ramjet), or hypersonic (scramjet).

Category 5 threats are cruise missiles, which fly highly maneuverable trajectories, as illustrated in Figure 19. Until recently, however, the technical challenges of *sustained propulsive* flight at supersonic and hypersonic speeds with a meaningful munitions package proved difficult to

Category 5 Payload Sustainer Velocity Regimes

Subsonic: Sustained speeds of less than Mach 1 powered by turbofan or turbojet engines. Subsonic cruise missiles may or may not require a booster to achieve sustained powered flight.

Supersonic: Sustained speeds of between Mach 1 and Mach 5 powered by ramjet engines. Speeds of Mach 2 to Mach 3 are necessary for ramjet engines to begin operating, typically requiring delivery by a booster.

Hypersonic: Sustained speeds greater than Mach 5 power by supersonic combustion ramjet (scramjet) engines. Speeds of about Mach 5 are necessary for scramjet engines to begin operation, meaning hypersonic cruise missiles are likely to employ large boosters.

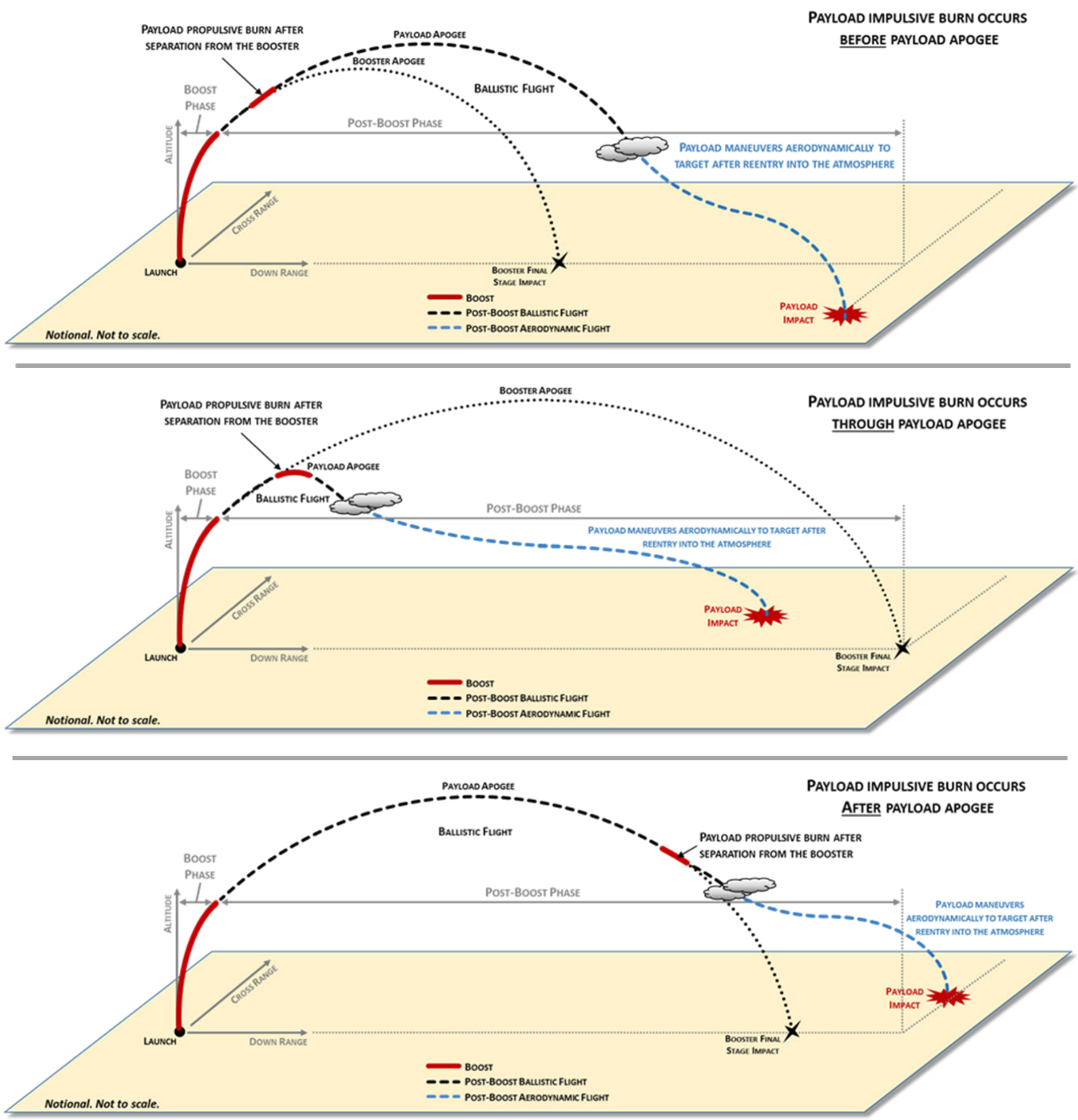


Figure 18: Notional Category 4 Trajectories.

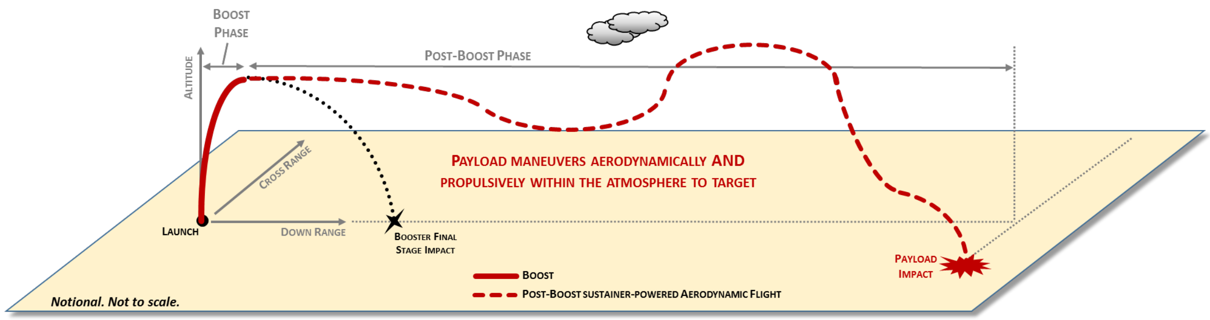


Figure 19: Notional Category 5 Trajectory.

overcome. As a result, the most common fielded cruise missile systems have been subsonic (traveling at a speed of less than Mach 1). Typically, propelling ground-launched subsonic cruise missiles to altitudes and speeds needed for turbofan or turbojet engine operation require only small, short-burning booster motors, commonly referred to as *rocket-assist take-off boosters*, while air-launched subsonic cruise missiles often require no booster at all.

This history, combined with the fact that cruise missiles operate in altitudes well within the atmosphere and the perception that ballistic missiles do not, has helped perpetuate characterizing *ballistic* missiles separately from *cruise* missiles.[33]

Today, however, the technical hurdles associated with sustained supersonic (ramjet) and hypersonic (scramjet) operations are rapidly being overcome. But unlike the turbofan or turbojet engines of subsonic cruise missiles, ramjet and scramjet engines must be traveling at several times the speed of sound before they can begin to operate, thus requiring some means of propelling the vehicle to the necessary altitude and velocity for the engine to ignite. The result is a growing number of missile systems that are combinations of boosters and aerodynamic + sustainer-powered (cruise missile) payloads. And as the operating velocities and range capabilities of these Category 5 missile systems increase, so do the size of the boosters they employ, exposing the established separation of so-called ballistic missiles from cruise missiles as increasingly artificial.[34]

Numerous Category 5 missile systems consisting of booster-delivered weaponized aerodynamic payloads with sustainer propulsion are fielded or in development worldwide. The medium-range supersonic DF-100 missile system — the combination of a booster and a ramjet sustainer payload — is shown in Figure 20 as an example.[35]

Figure 20: Example: Chinese medium-range DF-100 cruise missile dual-canister launchers *(MRM5: Supersonic).*

Capability Spectrum Within Payload Categories

Although this new approach can help us be more descriptive, it does not capture all the nuances in the ever-changing spectrum of missile system capabilities. Within each payload category (except for Category 1) exists a wide range of maneuverability, described in Table 3.[36] This new approach can, however, help manage and mitigate the ambiguities within payload categories by providing a better taxonomy for capturing what we know and, equally important, do not know about the threat environment as it evolves.

Table 3: Overview of Modern Missile Threat Maneuverability

Payload Category		Range of Post-Boost Payload Maneuverability
1	Ballistic	None
2	Ballistic + Impulsive Propulsion	Maneuverability ranges from very small trajectory corrections to multiple large propulsive burns deploying multiple warheads on independent trajectories with impact points separated by hundreds to a few thousand kilometers. Category 2 propulsive system operation is typically limited to altitudes outside the atmosphere (exoatmospheric).
3	Aerodynamic	Maneuverability ranges from very small corrections during portions of the trajectory that are within the atmosphere to extended glides and maneuvers in the atmosphere at hypersonic speeds for many thousands of kilometers.
4	Aerodynamic + Impulsive Propulsion	Maneuverability can include combinations of the propulsive and aerodynamic capabilities of Category 2 and Category 3 payloads, such as small propulsive and aerodynamic corrections to ensure the prescribed ballistic trajectory is maintained to large propulsive trajectory changes during exoatmospheric flight followed by extended glides and maneuvers in the atmosphere after reentry.
5	Aerodynamic + Sustainer Propulsion	Maneuverability includes sustainer-powered aerodynamic flight for all or part of the trajectory after boost. Range and maneuverability are limited largely by the velocity regime in which the missile flies and the amount of fuel carried on the payload.

Conclusion

Missiles are not just ballistic anymore, even many of the ones that are called ballistic. We need to evolve accordingly. Using old classifications, we risk mischaracterizing the threats missiles pose and pursuing incorrect and ineffective ways to mitigate them. The new approach offers a more holistic, integrated, and adaptive way of understanding this rapidly and continuously evolving ecosystem. This approach to characterizing the missile environment can help us grasp the limitations of our capabilities. It can spur new technological solutions to address the threat and help identify those challenges that cannot be solved by technology. As such, the taxonomy has bearing on decisions for early warning, missile defense, and arms control, as well as broader strategic policy. To respond to the missile environment, we must first understand it.

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[1] Brodie, Bernard, Strategy in the Missile Age, The Range Corporation, 1959.

[2] Missile Defense Review 2019, Office of the Secretary of Defense, January 2019, p X.

Worldwide Ballistic Missile Inventories, Arms Control Association, https://www.armscontrol.org/factsheets/missiles, accessed on 18 May 2020.

[3] On August 15, 2019, we conducted a news category search in the Lexis Advance database of U.S. newspaper headlines and leads appearing on the front page (A1) from 1989 through 2019 for the term "missile."

[4] Sample of common *ballistic missile* definitions, none of which accurately describe most modern ballistic missiles:

Arms Control Association: *Ballistic missiles are powered by rockets initially but then they follow an unpowered, free-falling trajectory toward their targets. They are classified by the maximum distance that they can travel, which is a function of how powerful the missile's engines (rockets) are and the weight of the missile's payload.*

Dictionary.com: *Any missile that, after being launched and possibly guided during takeoff, travels unpowered in a ballistic trajectory.*

Missile Defense Advocacy Alliance: *Ballistic missiles are means to rapidly and accurately deliver a lethal payload to a target. Once its fuel has been consumed, the ballistic missile follows an elliptical orbit around the center of the Earth, defined strictly by the combination of velocity/flight angle at burnout and the Earth's gravity. By careful control and maneuvering of the missile during its powered flight, the payload can be very accurately delivered to the desired target point.*

NATO: *A missile which does not rely upon aerodynamic surfaces to produce lift and consequently follows a ballistic trajectory when thrust is terminated.*

The Center for Arms Control and Proliferation: *Ballistic missiles are powered initially by a rocket or series of rockets in stages, but then follow an unpowered trajectory that arches upwards before descending to reach its intended target.*

[5] This paper looks only at surface-impacting missiles, which excludes other important missile systems, such as anti-satellite missiles, anti-ballistic missiles and surface-to-air missiles. These other systems deserve their own focused discussion.

[6] This paper describes a new approach to characterizing modern missile threats; however, it does not contain much detail on specific missiles systems for two reasons: (1) information in the public domain is often incorrect, and (2) many details are classified. While the amount of information that can be presented here is limited, this new missile characterization framework is being applied in classified realms where the full value of intelligence assessments can be realized.

[7] Examples of the application of the ballistic missile taxonomy defined in Table 1 include:

Ballistic and Cruise Missile Threat, Defense Intelligence Ballistic Missile Analysis Committee, Defense Intelligence Agency, NASIC-1031-0985-17, June 2017, p8.

Iran Military Power: Ensuring Regime Survival and Securing Regional Dominance, Defense Intelligence Agency, DIA_Q_00055_A, August 2019, pp. 43-47.

Russia Military Power: Building a Military to Support Great Power Aspirations, Defense Intelligence Agency, DIA-11-1704-161, 2017, pp. 47-49.

Annual Report to Congress – Military and Security Developments Involving the People's Republic of China 2019, Office of the Secretary of Defense, E-1F4B924, 2 May 2019, pp. 44-48.

[8] U.S.-former Soviet Union arms control treaty sources used in Table 2 include:

Strategic Arms Limitation Talks (SALT I) Narrative, U.S. Department of State

Treaty Between the United States of America and the Union of Soviet Socialist Republics on the Limitation of Strategic Offensive Arms (SALT II), U.S. Department of State, Treaty Narrative and Text

Treaty Between the United States of America and the Union of Soviet Socialist Republics on the Elimination of Their Intermediate-Range and Shorter-Range Missiles (INF Treaty), U.S. Department of State, Narrative and Text

Article by Article Analysis of the START Treaty and its Associated Documents (Part 1), U.S. Department of State,

Protocol to the Treaty Between the United States of America and the Russian Federation on Measures for

the Further Reduction and Limitation of Strategic Offensive Arms, U.S. Department of State, 8 April 2010.

[9] The United States successfully tested the Minuteman III ICBM with a three-warhead MIRV payload in 1968 and deployed the new missile in 1970. The first Soviet missile system with a MIRV payload, the SS-17 ICBM, did not reach operational deployment until December 1974. See for example:

Daniel Buchonnet, *MIRV: A Brief History of Minuteman and Multiple Reentry Vehicles*, Lawrence Livermore Laboratory, February 1976.

Robert S. Norris & Hans M. Kristensen, *Nuclear U.S. and Soviet/Russian Intercontinental Ballistic Missiles: 1959-2008*, Bulletin of the Atomic Scientists, 65:1, 62-69, DOI: 10.2968/065001008, 2009.

[10] *Treaty Between the United States of America and the Union of Soviet Socialist Republics on the Limitation of Strategic Offensive Arms (SALT II)*, Article II, U.S. Department of State.

[11] *Treaty Between the United States of America and the Union of Soviet Socialist Republics on the Limitation of Strategic Offensive Arms (SALT II)*, Article IX, U.S. Department of State.

[12] Note that the two warheads would impact at times that may differ by several minutes as well.

[13] SLBMs with ranges in all but the CRBM class are operationally deployed or in the flight test phase of development. Seven countries currently operate or are developing SLBMs: China, France, India, North Korea, Russia, United Kingdom, and the United States.

[14] *Article by Article Analysis of the START Treaty and its Associated Documents (Part 1)*, U.S. Department of State, pp. 50 and 65.

[15] Gady, Franz-Stephan, *Russia Showcases 'Kinzhal' Nuclear-Capable Air-Launched Ballistic Missile at Air Show*, The Diplomat, 13 August 2019

Lee, Connie, *Special Report: China, Russia Hypersonic Programs - Real Progress or Bluster?*, National Defense, 12 July 2019

[16] Additionally, in March 2018, DIA Director Lt Gen. Robert Ashley stated before the Senate Armed Services Committee that the Chinese were developing two new ALBMs, one of which may include a nuclear payload (*Statement for the Record: Worldwide Threat Assessment, DIA Director Lt. Gen Robert Ashley testifies before the Senate Armed Services Committee, Defense Intelligence Agency, 6 March 2018*).

Subsequently, images showing a Chinese H-6N long range bomber carrying what may be an intermediate-range ALBM with aerodynamic control surfaces attached to its payload section were published in a Chinese government technical journal (*Modern Ships, China Shipbuilding Information Center, State Administration for Science, Technology and Industry for National Defense, CN-11-1884/U, 2-279, 2019-23*).

The Russian Kinzhal and new Chinese ALBMs may both be nuclear capable, and neither are ballistic.

[17] *Treaty Between the United States of America and the Union of Soviet Socialist Republics on the Elimination of Their Intermediate-Range and Shorter-Range Missiles (INF Treaty)*, U.S. Department of State, Articles I and II. Other factors govern the division of "intermediate range" as defined in the INF treaty into the MRBM and IRBM classes commonly applied today, including the historical division of effort and management of resources within the U.S. defense intelligence community. See, for example, *Missile Defense – Further Collaboration with the Intelligence Community Would Help MDA Keep Pace with Emerging Threats*, Government Accountability Office, GAO-20-177, December 2019.

[18] Missile Technology Control Regime Annex Handbook – 2017.

Missile Technology Control Regime Equipment Software and Technology Annex, 11 October 2019.

[19] *Article by Article Analysis of the START Treaty and its Associated Documents (Part 1)*, U.S. Department of State, p27.

[20] The survey sample consists of threats commonly referred to as ballistic missiles with a maximum range capability of ≥300 km that are either operationally deployed or in the flight test phase of development as of May 2020.

[21] Note that some ballistic missile payloads may include an attitude control system (ACS), an attitude control module (ACM) *without* a nonrotational (axial/lateral) propulsive velocity correction capability.

[22] Hans M. Kristensen and Matt Korda, *Russian Nuclear Forces, 2019*, Bulletin of Atomic Scientists, Vol. 75, No. 2, pp 73–84, https://doi.org/10.1080/00963402.2019.1580891.

[23] *Annual Report to Congress – Military and Security Developments Involving the People's Republic of China 2019,* Office of the Secretary of Defense, E-1F4B924, 2 May 2019, p. 45.

China Touts New Submarine-Launched Nukes in Question for More Survivable Deterrence, Forbes, https://www.forbes.com/sites/sebastienroblin/2020/05/13/china-touts-new-submarine-launched-nukes-in-quest-for-more-survivable-deterrence/#768b69a21755, 13 May 2020.

China's JL-3 SLBMs Utilize Carbon Fiber Booster Castings for Longer Range, SINA News Agency, https://mil.news.sina.com.cn/jssd/2020-05-12/doc-iircuyvi2662473.shtml, 12 May 2020.

[24] *Statement for the Record: Worldwide Threat Assessment, DIA Director Lt. Gen Robert Ashley testifies before the Senate Armed Services Committee*, Defense Intelligence Agency, 6 March 2018.

[25] Several single-RV ICBMs payloads also employ what may be referred to as a PBV. Although generally capable of larger ΔVs than an ACM, the function of the PBV on a single-RV ICBM is essentially the same as that of an ACM.

[26] The DF-15B may employ a small ACM as well as a MaRV.

[27] Although HGVs are typically better able to withstand the aerodynamic heating and stresses of prolonged hypersonic glides, both HGVs and MaRVs are capable of significant glide phases and maneuvers at hypersonic speeds.

[28] A survey of numerous open source images of Iranian ballistic missile static displays, live-launches, and military parades reveals at least four different MaRV payload configurations on at least four different boosters with short- to medium-ranges.

[29] *Missile Defense Project, DF-15 (Dong Feng-15 / M-9 / CSS-6)*, Missile Threat, Center for Strategic and International Studies, January 11, 2017, last modified January 6, 2020, https://missilethreat.csis.org/missile/df-15-css-6/.

[30] *Annual Report to Congress – Military and Security Developments Involving the People's Republic of China 2013*, Office of the Secretary of Defense, 2013, p. 5. The DF-26 IRBM was first fielded in 2016 (*Annual Report to Congress – Military and Security Developments Involving the People's Republic of China 2019*, Office of the Secretary of Defense, E-1F4B924, 2 May 2019, p. 44.)

[31] In addition, such mid-course trajectory adjustments require onboard sensors or the C4ISR capabilities to track and communicate the updated location of the target to the missile in flight. See, for example, Fan Hangmu, *Satellite-Missile Attack: Exploring a model for Anti-Ship Ballistic Missile Combat Operations*, Beijing Xiandai Jianchuan (Modern Ships), November 2010, pp. 30-33, for a Chinese perspective on the challenges and benefits of targeting moving naval vessels at sea with ballistic missiles.

[32] Specifically, a kick-motor burn might be used as a missile warning countermeasure by changing the target indicated by the boost phase trajectory. The MaRV may then perform extended glides after reentry that further obscure the intended target, followed by evasive terminal maneuvers as a missile defense countermeasure.

[33] Two distinctly different taxonomies are used to characterize ballistic and cruise missiles. The former (Table 1) is focused on the boost phase of flight from the perspective of the space domain, and the latter is focused on the sustainer "payload" phase of flight from the perspective of the air domain. While the ballistic missile taxonomy identifies range class or launch platform, the established cruise missiles taxonomy identifies intended target or launch platform, such as anti-ship cruise missile (ASCM) and land-attack cruise missile (LACM) or air-launched cruise missile (ALCM) and ground-launched cruise missile (GLCM). The ballistic missile taxonomy may provide information regarding the overall range capability of the system but does not provide reliable insight into the maneuvering capabilities of the payload it carries. Conversely, the cruise missile taxonomy identifies the payload as a cruise missile (Category 5) and may identify the intended target but provides no information regarding the overall range capability of the missile.

[34] Category 5 missile systems with hypersonic (scramjet-powered) payloads are in development in China, France, India, Israel, Pakistan, Russia, and the United States.

[35] In additional to the DF-17 launchers, China also paraded 16 dual-missile DF-100 launchers as part of the 70th anniversary celebration of the founding of the People's Republic of China in Beijing on October 1, 2019, suggesting that this new medium-range Category 5 (supersonic) threat may soon reach an operational capability as well.

[36] Further integration of the principal maneuverability-enabling options described for each payload category with the fundamental missile system elements produces a missile threat capability "roadmap" of sorts. Such a roadmap has been developed and proposed as a practical guide for capturing and keeping pace with missile threat.