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U.S. Hypersonic Weapons and Alternatives

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This presentation summarizes information presented in Congressional Budget Office, *U.S. Hypersonic Weapons and Alternatives* (January 2023), www.cbo.gov/publication/58255.

At A Glance

Technological Challenges Must Still Be Overcome to Field Hypersonic Missiles

The fundamental remaining challenge involves managing the extreme heat that hypersonic missiles are exposed to by traveling faster than five times the speed of sound (Mach 5) in the atmosphere for most of their flight. (Heating is less of a problem for cruise missiles, which fly in the atmosphere at lower speeds, and for ballistic missiles, which fly mainly above the atmosphere.)

Extensive flight testing is necessary to shield hypersonic missiles' sensitive electronics, understand how various materials perform, and predict aerodynamics at sustained temperatures as high as 3,000° Fahrenheit.

Tests are ongoing, but failures in recent years have delayed progress.

Both Hypersonic and Ballistic Missiles Are Well-Suited to Operate in Potential Adversaries’ A2/AD Zones

The Department of Defense has developed a strategy to use accurate, high-speed missiles early in a conflict to neutralize the antiaccess and area-denial (A2/AD) zones being developed by potential adversaries, such as China and Russia.

Both hypersonic missiles and ballistic missiles equipped with maneuverable warheads could provide the combination of speed, accuracy, range, and survivability (the ability to reach a target without being intercepted) that would be useful in the military scenarios CBO considered.

Many missions do not require rapid strikes, however. For those missions, less costly alternatives to both hypersonic and ballistic missiles exist, including subsonic cruise missiles. Hypersonic weapons would mainly be useful to address threats that were both well-defended and extremely time-sensitive.

Hypersonic Missiles Would Probably Not Be More Survivable Than Ballistic Missiles With Maneuverable Warheads in a Conflict, Unless the Ballistic Missiles Encountered Highly Effective Long-Range Defenses

Hypersonic missiles can neutralize long-range (midcourse) defenses because they fly inside the atmosphere, below the altitude where midcourse ballistic missile defenses typically operate. Hypersonic weapons can also maneuver unpredictably at high speeds to counter short-range defenses near a target, making it harder to track and intercept them.

Ballistic missiles are also difficult to defend against, particularly if they are equipped with countermeasures to confuse midcourse missile defenses and maneuverable warheads to defeat short-range missile defenses.

Only very effective long-range defenses would be likely to threaten ballistic missiles in midcourse. To date, no potential U.S. adversaries have deployed such defenses.

Hypersonic Missiles Could Cost One-Third More to Procure and Field Than Ballistic Missiles of the Same Range With Maneuverable Warheads

CBO estimates that buying 300 ground- or sea-launched, intermediate-range ballistic missiles with maneuverable warheads and sustaining the missile system for 20 years would cost a total of $13.4 billion (in 2023 dollars).

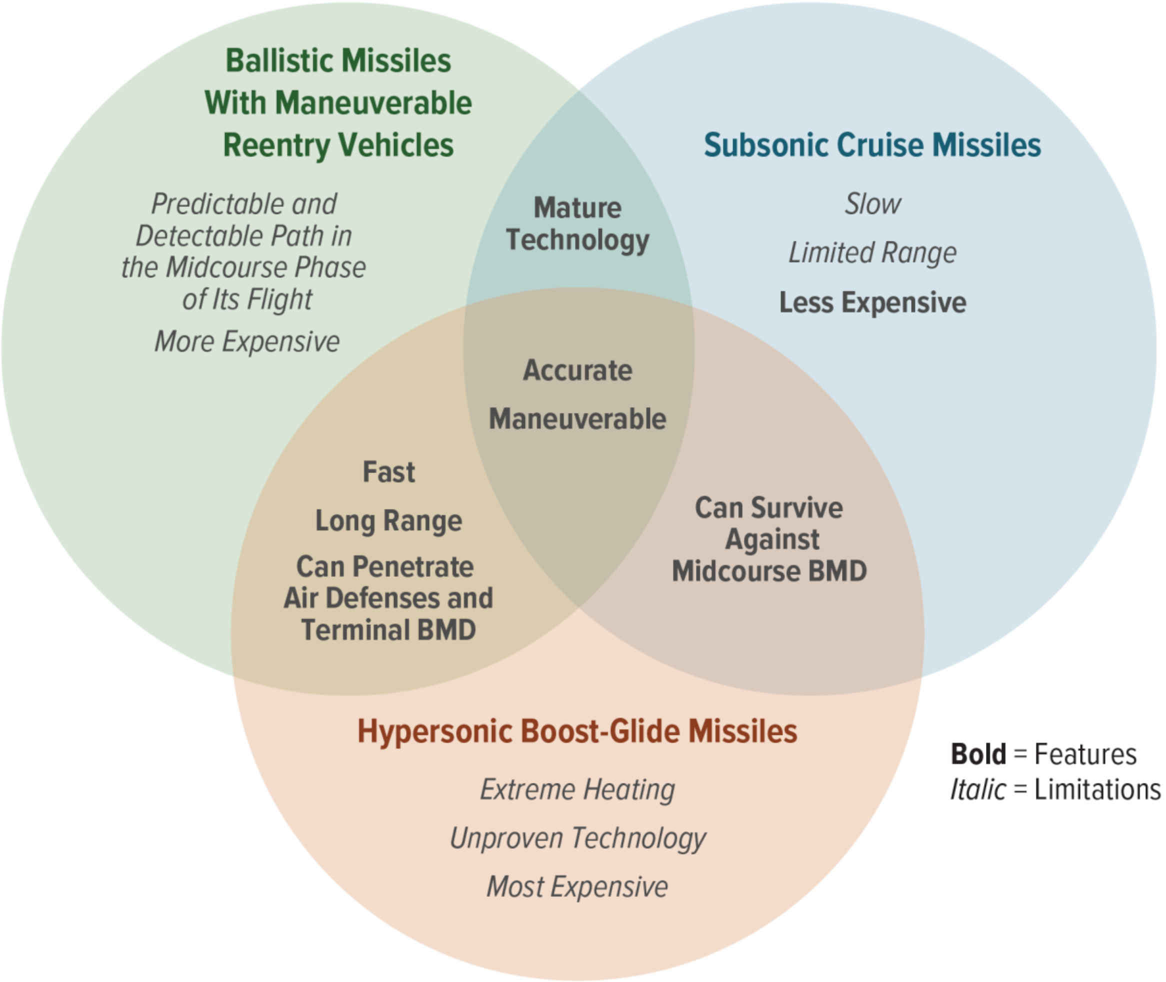
The same number of comparable hypersonic missiles would cost about one-third more, $17.9 billion, CBO estimates. (Neither estimate includes the cost overruns that are often associated with technically challenging programs.)

The higher costs for hypersonic missiles partly reflect the complexity of building systems that can withstand the heat of hypersonic flight.

CBO's estimates exclude research and development costs for the missiles.

Background

Comparison of the Features and Limitations of Hypersonic Missiles and Alternatives



The hypersonic missiles being developed by the U.S. military combine desirable traits of two types of U.S. missiles with well-developed technology: ballistic missiles' speed and long ranges, and subsonic cruise missiles' maneuverability and ability to survive against midcourse missile defenses. Hypersonic missiles introduce new technical challenges, however.

BMD = ballistic missile defense.

Comparison of the Missile Options That CBO Analyzed

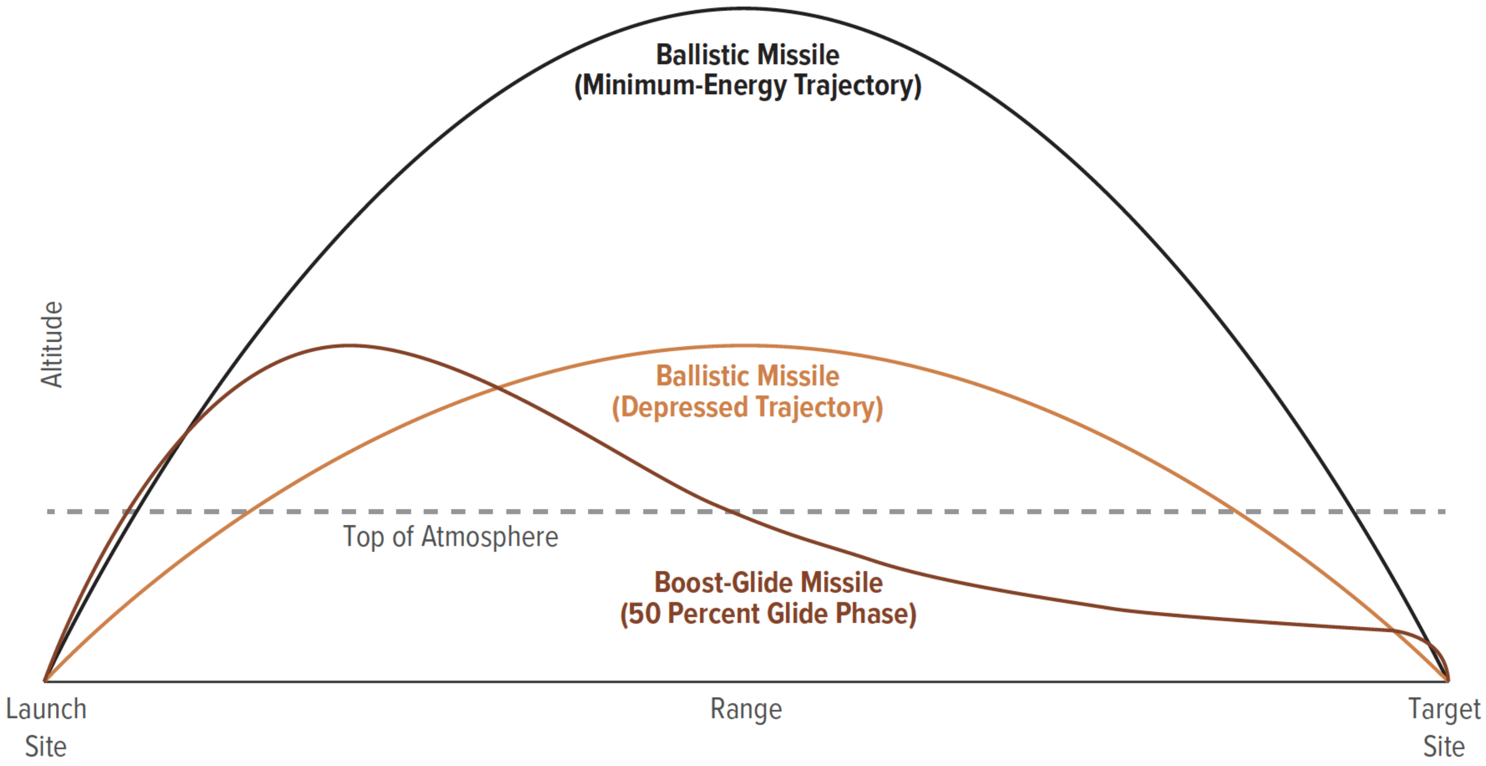
Option	Launch Mode	Estimated Range (Kilometers)	Average Speed Over Estimated Range (Mach number)	Number of Missiles Purchased	Estimated Procurement Cost per Missile (Millions of 2023 dollars)	Estimated Cost of Option (Billions of 2023 dollars)[a]
Intermediate-Range Hypersonic Boost-Glide Missiles (Similar to LRHW/IR-CPS)	Land or ship	3,000	10	300	41	17.9
Intermediate-Range Ballistic Missiles Equipped With MaRVs	Land or ship	3,000	9	300	26	13.4
Medium-Range Hypersonic Boost-Glide Missiles (Similar to ARRW)	Aircraft	1,000	7	300 100	15 18	5.3 2.2
Short-Range Hypersonic Cruise Missiles (Similar to HACM/HALO)[b]	Aircraft	Less than 500	7	n.e.	n.e.	n.e.
Short-Range Ballistic Missiles (Similar to SM-6 Block IB)	Land or ship	Less than 1,000	6	300	6	3.5

ARRW = Air-Launched Rapid Response Weapon (being developed by the Air Force); HACM = Hypersonic Attack Cruise Missile (being developed by the Air Force); HALO = Hypersonic Air-Launched Offensive Antifsurface Warfare missile (being developed by the Navy); IR-CPS = Intermediate-Range Conventional Prompt Strike missile (being developed by the Navy); LRHW = Long-Range Hypersonic Weapon (being developed by the Army); MaRVs = maneuverable reentry vehicles; n.e. = not estimated; SM = Standard Missile (the SM-6 Block IB is being developed by the Navy as a variant of the existing Block IA).

a. Consists of the costs to procure the missiles; the costs to integrate the missiles with existing platforms and to buy associated equipment, such as launchers; and the costs to sustain the missile system for 20 years. Costs to develop the missiles are not included.

b. The Department of Defense is early in the process of developing this missile. Little is known about its characteristics, so CBO did not have a basis for estimating the missile’s cost.

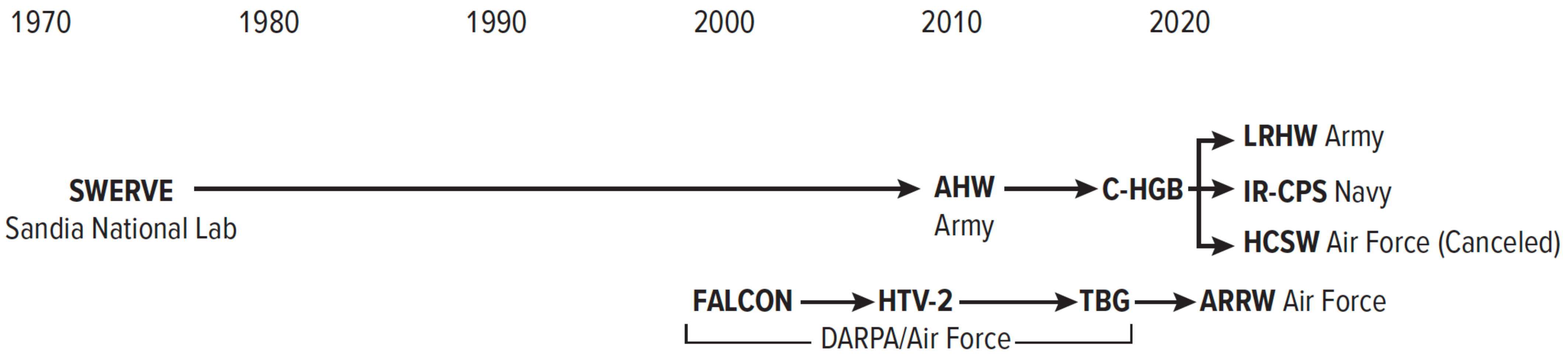
Notional Flight Paths for Different Ballistic and Boost-Glide Missile Trajectories With the Same Range



A missile's ballistic trajectory can be shaped in many ways. This figure shows a simple minimum-energy trajectory that is very close to a parabola, influenced mainly by gravity after the missile's rocket booster burns out, and a depressed trajectory, when the ballistic missile is launched at a shallower angle.

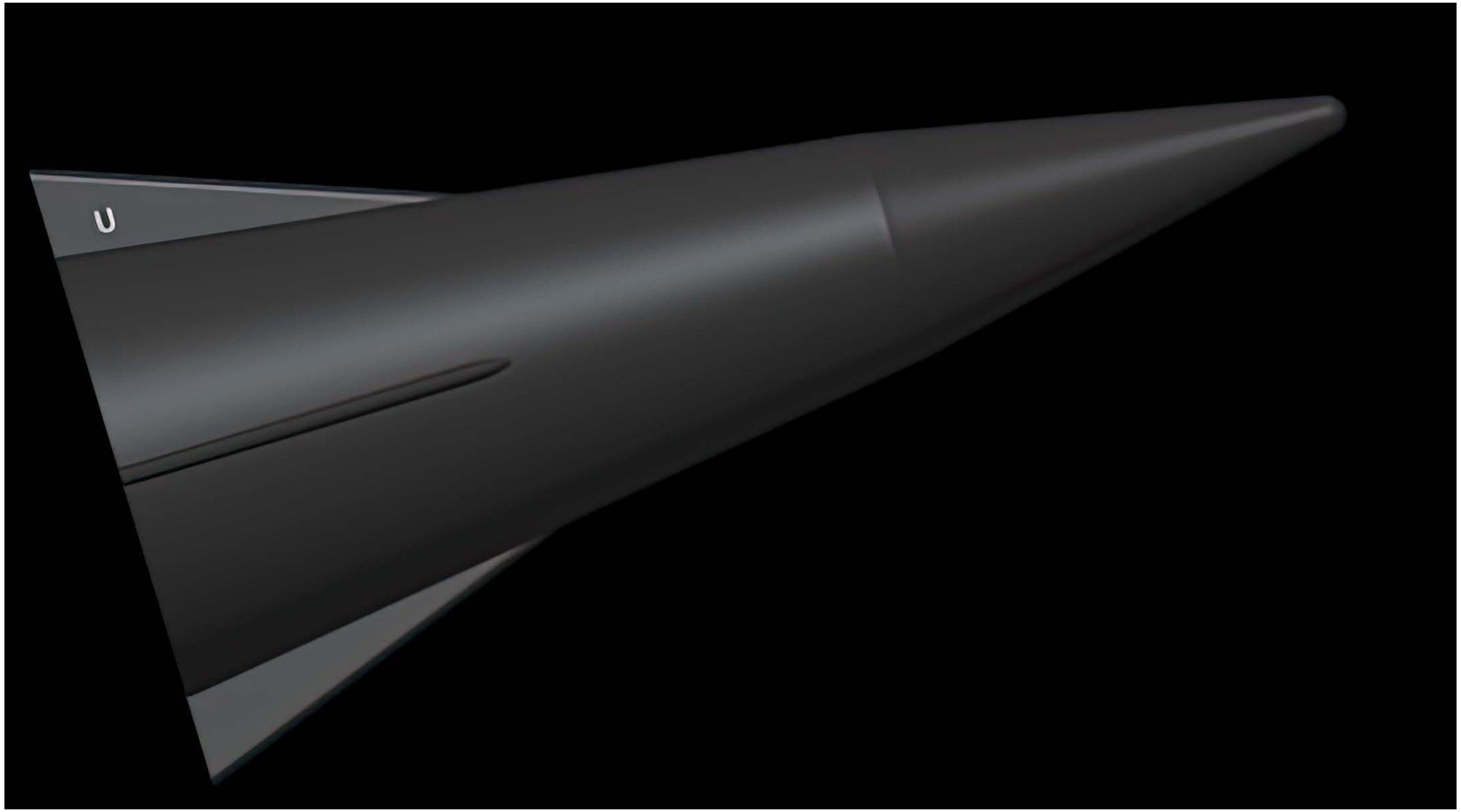
A boost-glide missile would start on a ballistic trajectory, but thrusters would be used in the first half of its flight to bring it back toward Earth sooner than in the ballistic flight. Control surfaces on the missile's glide body would be used in the second half of the flight to initiate gliding.

Progression of DoD's Research Programs for Hypersonic Boost-Glide Missiles



AHW = Advanced Hypersonic Weapon; ARRW = Air-Launched Rapid Response Weapon; C-HGB = Common Hypersonic Glide Body; DARPA = Defense Advanced Research Projects Agency; DoD = Department of Defense; FALCON = Force Application and Launch From Continental United States; HCSW = Hypersonic Conventional Strike Weapon; HTV = Hypersonic Technology Vehicle; IR-CPS = Intermediate-Range Conventional Prompt Strike; LRHW = Long-Range Hypersonic Weapon; SWERVE = Sandia Winged Energetic Reentry Vehicle Experiment; TBG = Tactical Boost Glide.

Depiction of the Common Hypersonic Glide Body



The Army and Navy are collaborating on the Common Hypersonic Glide Body (C-HGB), the part of a hypersonic boost-glide missile that detaches from the spent rocket booster and glides to its target. Both services plan to use the C-HGB in the hypersonic boost-glide missiles they are developing: the Army's Long-Range Hypersonic Weapon and the Navy's Intermediate-Range Conventional Prompt Strike missile.

Depiction of the Air-Launched Rapid Response Weapon

The Tactical Boost Glide (TBG) vehicle developed by the Defense Advanced Research Projects Agency forms the basis for the hypersonic boost-glide missile that the Air Force is developing, the Air-Launched Rapid Response Weapon. The TBG is shown here as a slender, pointed object on the front end of the missile. The cone in the upper left of the drawing is the protective shroud from the front of the missile, which has just been ejected in preparation for releasing the TBG.

U.S. Hypersonic Weapons Programs and Their RDT&E Funding

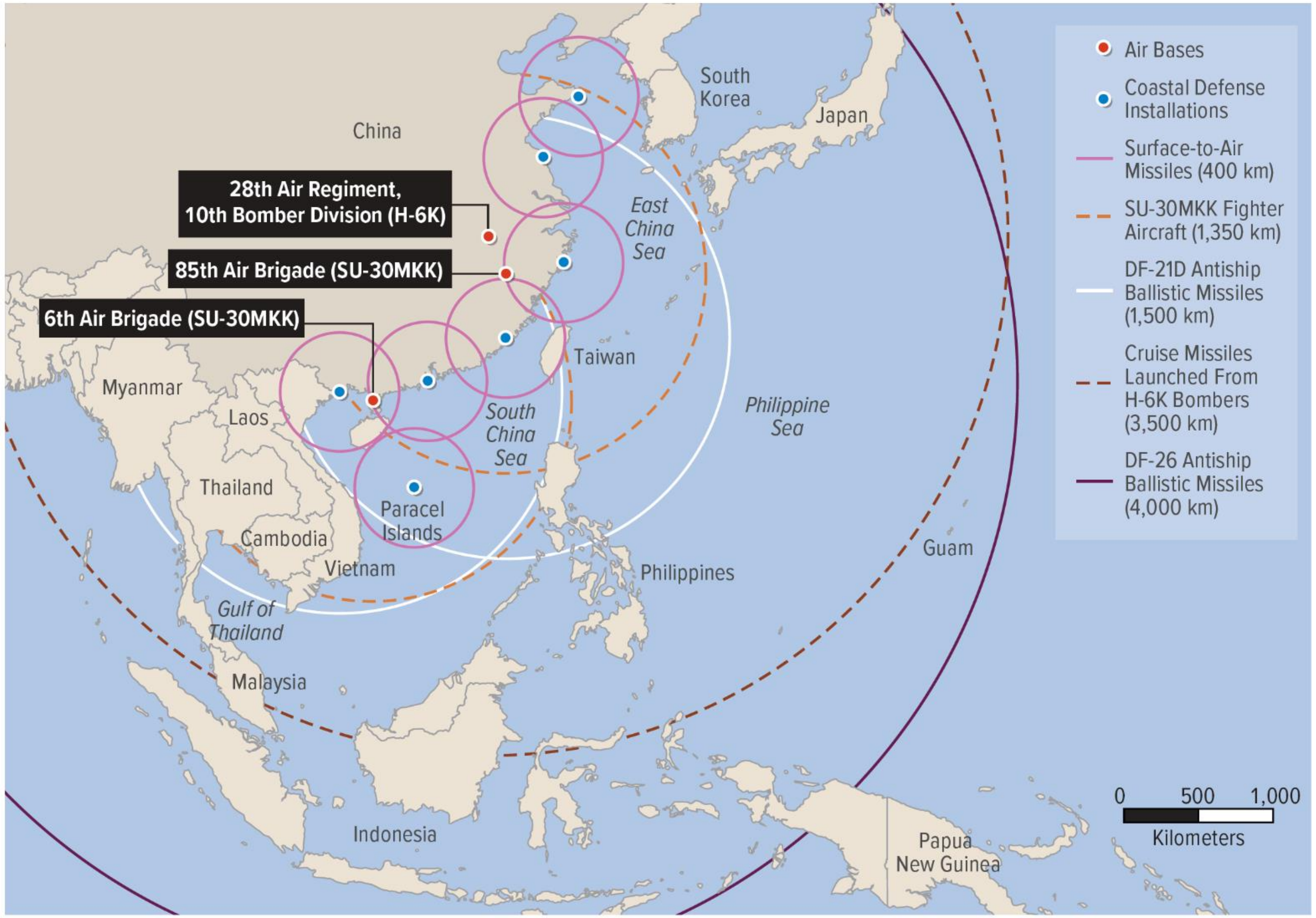
Service or Agency	Program	Description	Estimated Range (Kilometers)	RDT&E Funding (Millions of nominal dollars): Request for 2023	RDT&E Funding (Millions of nominal dollars): Total Past and Planned Funding[a]	Planned Initial Fielding Date
Army	Long-Range Hypersonic Weapon (LRHW)	Ground-launched boost-glide missile	3,000	807	5,269	2023
	Operational Fires	Ground-based launcher for hypersonic boost-glide missiles; uses the TBG and a tunable rocket motor for variable range	500	11	66	2023
Navy	Intermediate-Range Conventional Prompt Strike (IR-CPS)	Sea-launched boost-glide missile	3,000	1,205	At least 8,902 (continuing)	2025
	Hypersonic Air-Launched Offensive Antisurface Warfare (HALO)	Air-launched cruise missile	N.A.	92	At least 444 (continuing)	2028
Air Force	Air-Launched Rapid Response Weapon (ARRW)	Air-launched boost-glide missile	1,000	115	1,315	2023
	Hypersonic Attack Cruise Missile (HACM)	Air-launched cruise missile	500	462	1,812	N.A.
Defense Advanced Research Projects Agency	Hypersonic Air-Breathing Weapon Concept (HAWC)	Cruise missile technology	N.A.	60	At least 195 (continuing)	n.a. (Transitioned to the Air Force)
	Tactical Boost Glide (TBG)	Glide body prototype for ARRW	n.a.	30	At least 555 (continuing)	n.a. (Transitioned to the Air Force)
	Operational Fires	Ground-based launcher for hypersonic boost-glide missiles; uses the TBG and a tunable rocket motor for variable range	n.a.	N.A.	169	n.a. (Transitioned to the Army)

n.a. = not applicable; N.A. = not available; RDT&E = research, development, test, and evaluation.

a. Total RDT&E funding from the beginning of the program through the 2023–2027 Future Years Defense Program. Programs labeled “continuing” are expected to receive additional RDT&E funding after 2027.

Scenarios That Define Potential Requirements for Hypersonic Missiles

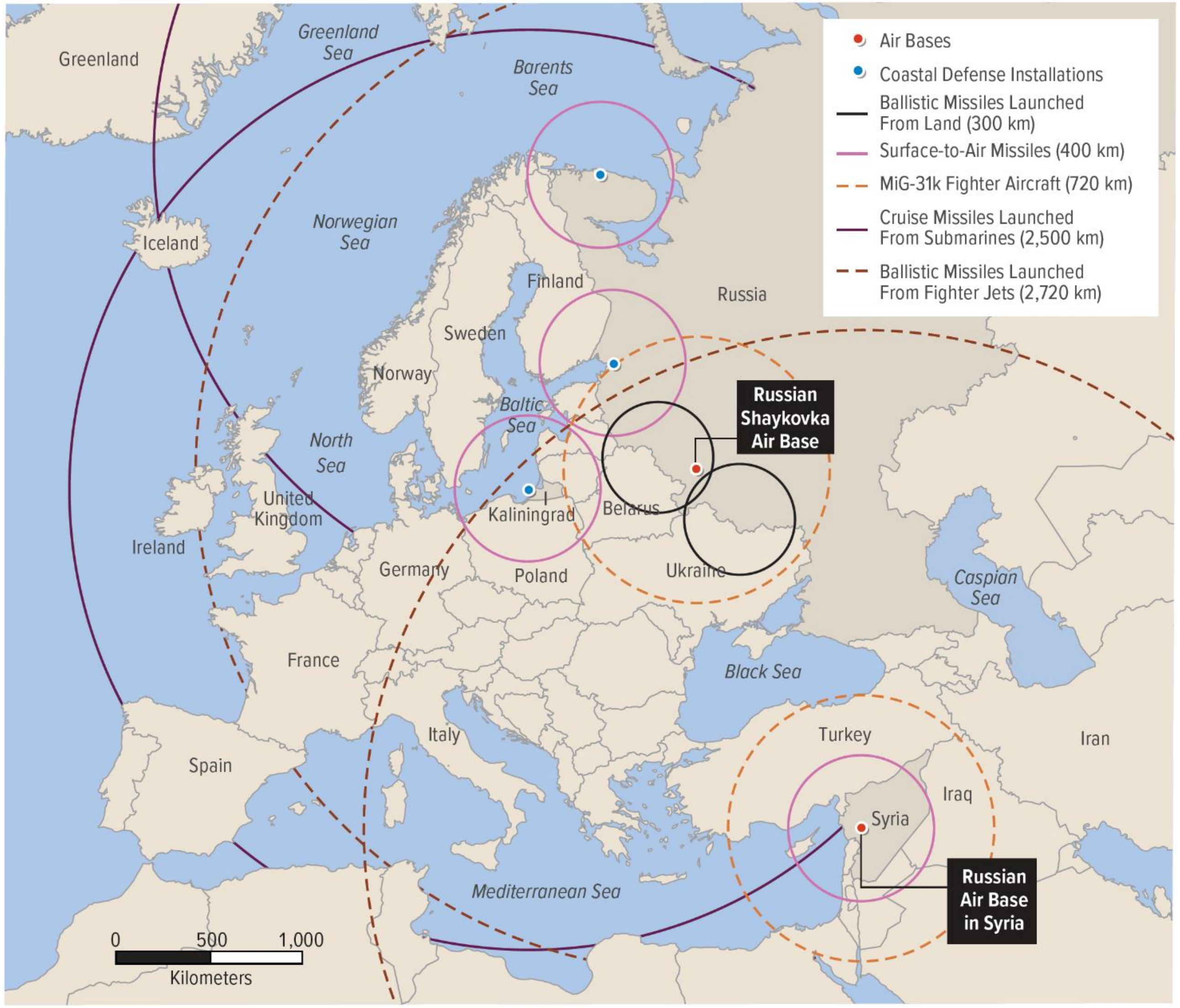
Approximate Coverage Areas of China's Potential A2/AD Defenses



China has been developing a variety of weapon systems designed to keep U.S. and U.S. allies' forces far away from its coasts. In a potential conflict with China, those antiaccess and area-denial systems could be targets for U.S. hypersonic missiles or alternatives.

The weapon systems that make up China's A2/AD zone include air- and missile-defense systems that are assumed to cover China's coastline. Some air-defense sites might also be launch sites for antiship ballistic missiles; those launchers are potentially mobile. China's military airfields, where fighter aircraft and bombers that could launch cruise missiles are based, are generally located farther inland. Basing those A2/AD systems on Chinese-occupied islands in the South China Sea would extend their coverage areas.

Approximate Coverage Areas of Russia’s Potential A2/AD Defenses



Russia has been developing weapon systems that could keep U.S. and NATO allies’ forces far away from its borders. In a potential conflict with Russia, those antiaccess and area-denial systems could be targets for U.S. hypersonic missiles or alternatives.

Russian A2/AD systems are made up of air- and missile-defense systems strategically located in coastal and inland locations, covering much of Europe and nearby waterways. Basing those systems outside mainland Russia, such as in Syria and Kaliningrad, would extend their coverage areas.

Comparing the Capabilities of Hypersonic Missiles and Potential Alternatives

Ranges of Various U.S. Weapon Systems

Type of Weapon System	Example	Range (Kilometers)
Existing Weapons		
Ground-launched tactical ballistic missile	Army Tactical Missile System (ATACMS)	300
Subsonic cruise missile	Tomahawk	1,000 to 2,400
Submarine-launched ballistic missile	Trident	7,400
Ground-launched ballistic missile	Minuteman III	13,000
Supersonic stealth fighter aircraft	F-22 Raptor	1,500[a]
Subsonic stealth bomber	B-2 Bomber	4,800[a]
Weapons Under Development		
Intermediate-range hypersonic boost-glide missile (Ground- or sea-launched)	Long-Range Hypersonic Weapon (LRHW)/ Intermediate-Range Conventional Prompt Strike (IR-CPS) prototype	3,000[b]
Medium-range hypersonic boost-glide missile (Air-launched)	Air-Launched Rapid Response Weapon (ARRW) prototype	1,000[c]

a. This range is the unrefueled combat radius, which reflects an assumption that the aircraft has enough fuel to return to base. Range will be longer if the aircraft is refueled in flight.

b. The Department of Defense has released information suggesting that the LRHW and IR-CPS missiles will have a range of at least 2,775 km. CBO used 3,000 km for its estimate.

c. This range is an estimate based on the lower boundary of the range stated by DoD.

Average Speeds of Selected Weapons at Different Ranges

Mach Number

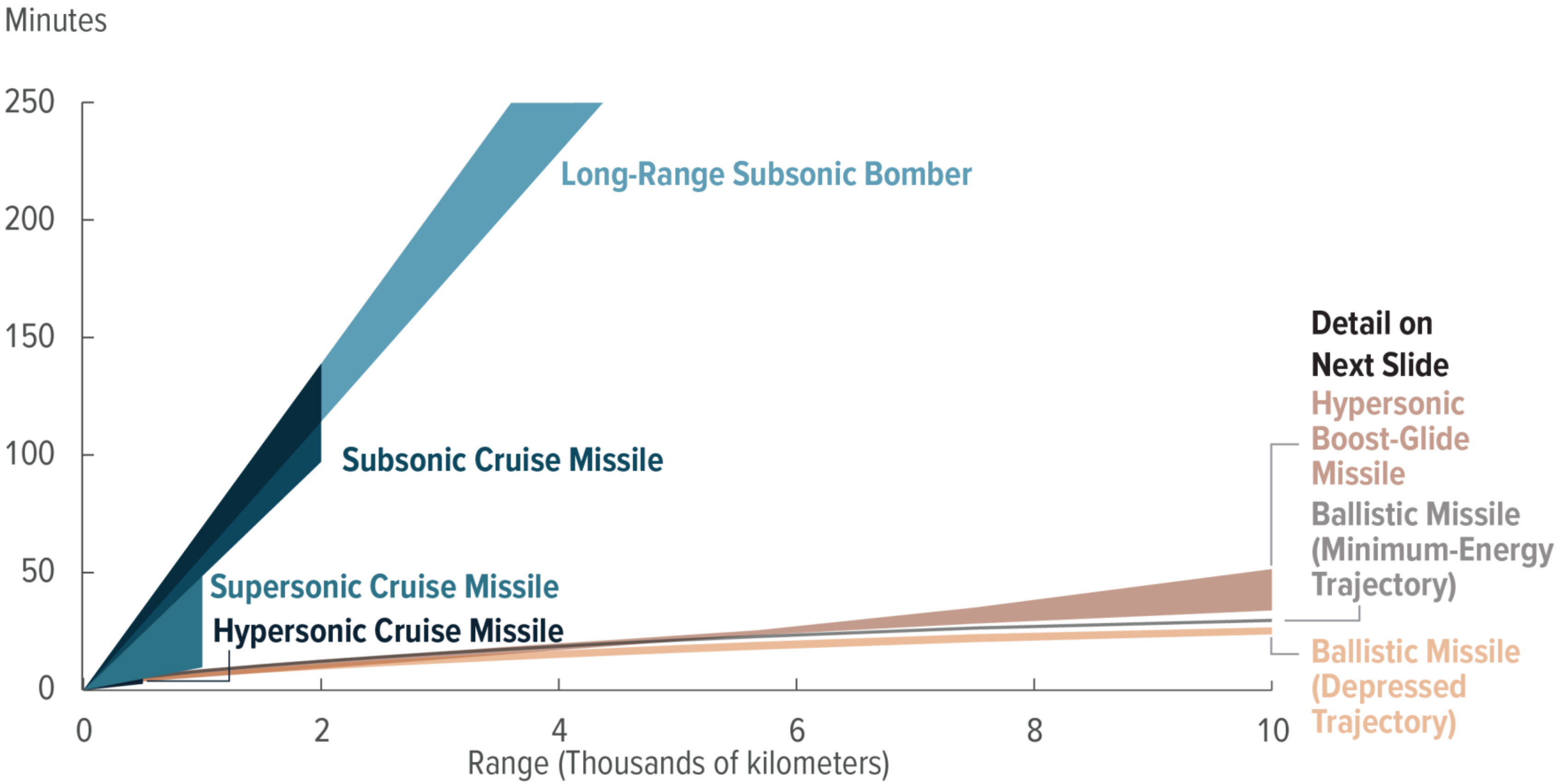
	Ballistic Missile					
Range (Kilometers)	Minimum-Energy Trajectory	Depressed Trajectory	Hypersonic Boost-Glide Missile	Hypersonic Cruise Missile	Long-Range Subsonic Bomber	Subsonic Cruise Missile
1,000	6	7–8	5–9	5–9	0.95	0.7
3,000	9	10–13	9–11	n.a.	0.85	0.7
10,000	16	18–20	9–14[a]	n.a.	0.7	n.a.

Average speed is calculated with respect to the ground—that is, velocity equals range divided by flight time. Where the table shows a range of average speeds, the lower number reflects conservative estimates of a weapon's trajectory and design considerations, and the higher number reflects optimistic estimates of trajectory and design considerations.

n.a. = not applicable.

a. CBO concluded that with current technology, hypersonic boost-glide weapons are unlikely to be able to reach a range of 10,000 kilometers because of heating. However, estimates for that range are included for purposes of comparison.

Spans of Flight Times for Hypersonic and Other Weapon Systems (Overview)

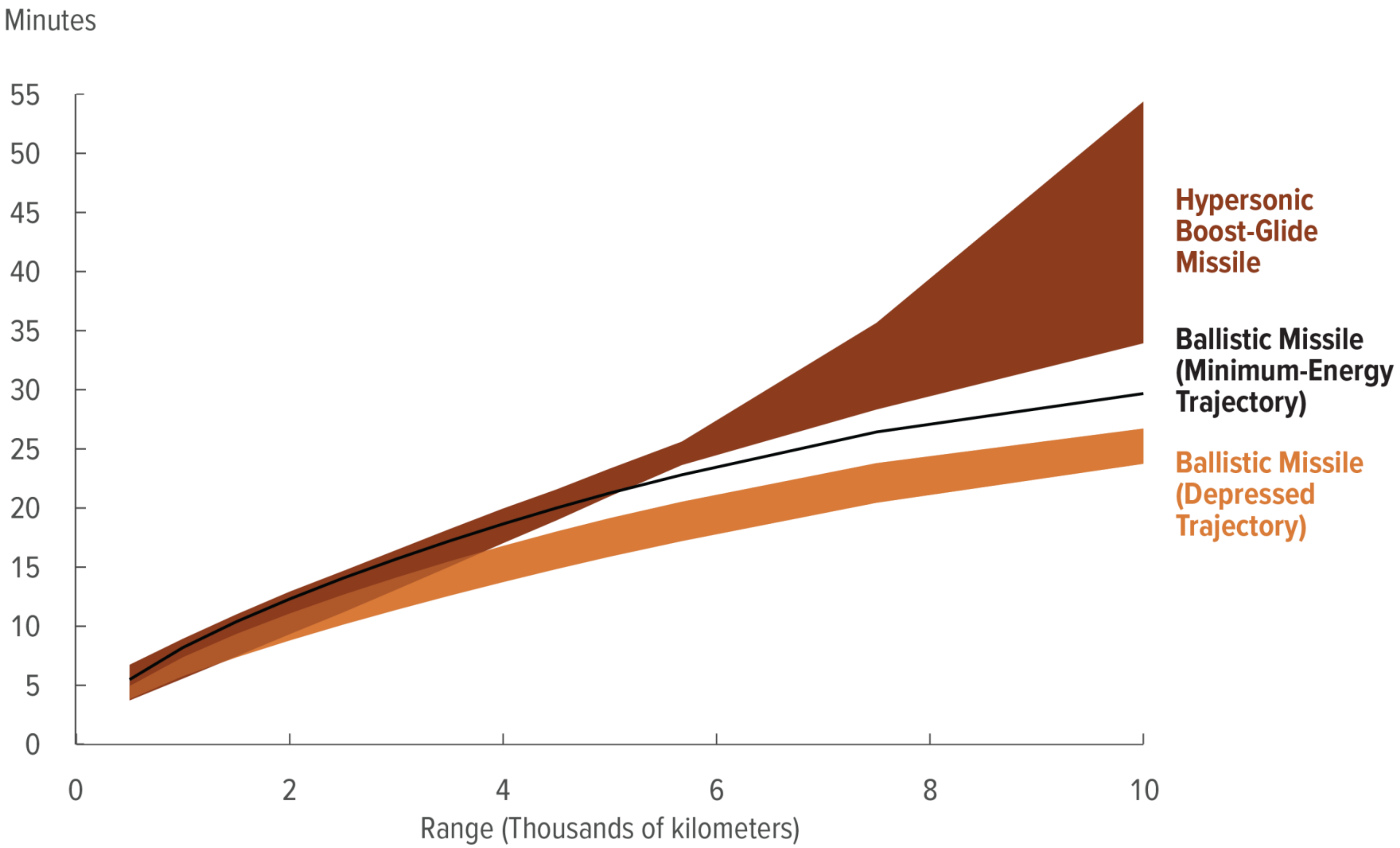


CBO modeled the flight times for various types of missiles and bombers. Ballistic and hypersonic missiles had the shortest flight times over all of the ranges in CBO's analysis.

CBO modeled flight times for cruise missiles and long-range subsonic bombers using average speed along a flat trajectory. The range of flight times for those weapon systems reflects their range of speeds. For example, a supersonic cruise missile may travel 1,000 kilometers in as little as 10 minutes when flying at the fastest supersonic speed (just below Mach 5) or in as much as 48 minutes when flying at the slower end of the supersonic range (just above Mach 1). For ballistic missiles, CBO modeled flight times for a missile on a minimum-energy trajectory (which allows the missile to fly the longest distance) and on a range of depressed trajectories (with lower overall altitudes and modified booster properties that increase initial speeds). For hypersonic boost-glide missiles, the range of estimated flight times reflects a range of potential initial energies and trajectories that span the performance parameters suggested by current U.S. development programs.

For cruise missiles, the end of the colored band represents the estimated maximum range. CBO does not know the maximum range for hypersonic boost-glide missiles, but it extended the analysis to 10,000 km to compare their potential flight times with those of ballistic missiles, which can achieve intercontinental ranges up to 12,000 km.

Spans of Flight Times for Hypersonic and Other Weapon Systems (Detail)

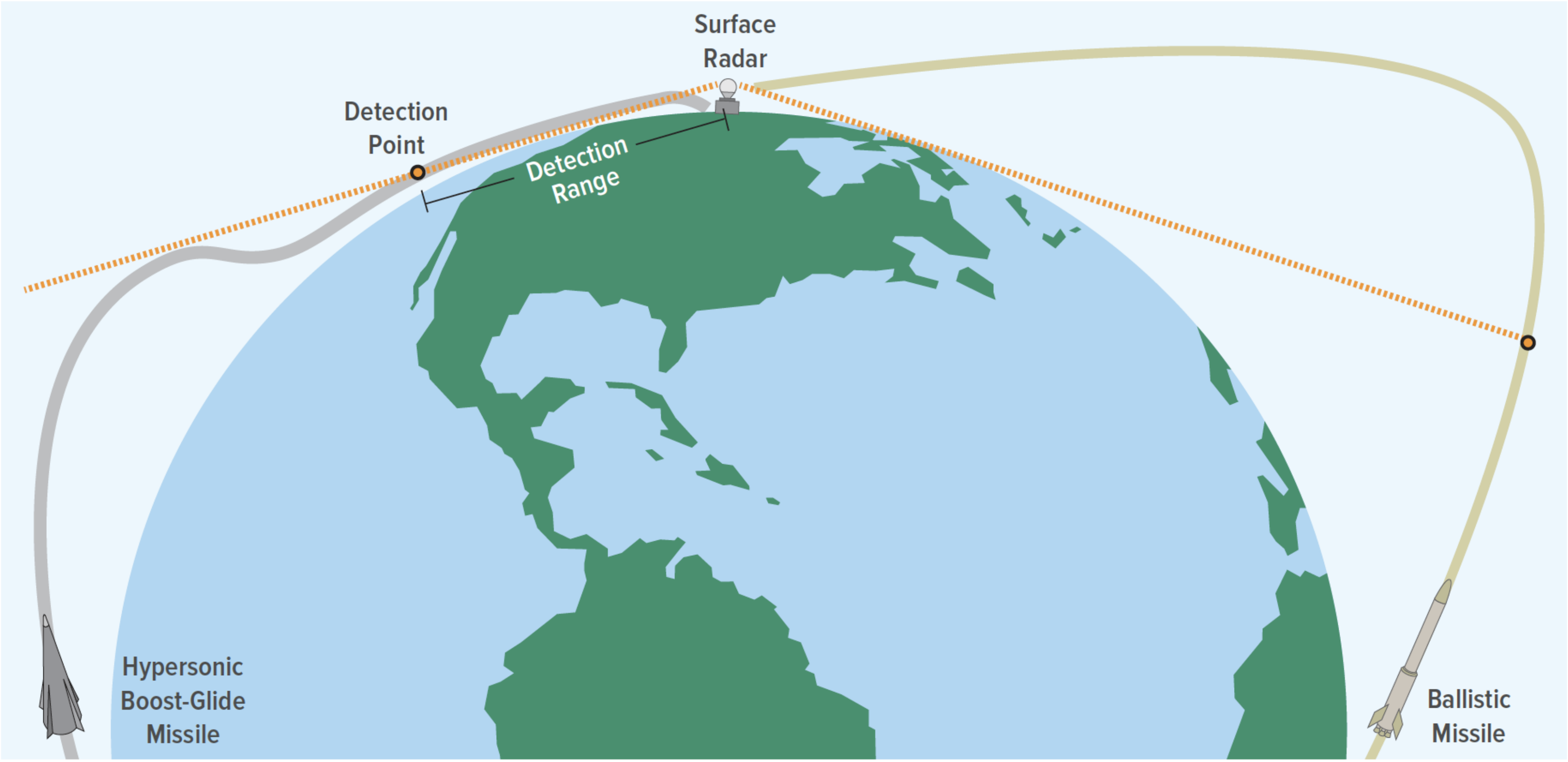


Currently planned hypersonic boost-glide missiles are likely to have longer flight times than ballistic missiles flying minimum-energy or depressed trajectories.

With future improvements and high-speed boosters, boost-glide missiles could be as fast as depressed-trajectory ballistic missiles at ranges up to 1,000 km. At longer ranges (assuming proportionately long glide phases), boost-glide missiles would probably have much longer flight times than ballistic missiles.

For ballistic missiles, CBO modeled flight times for a missile on a minimum-energy trajectory (which allows the missile to fly the longest distance) and on a range of depressed trajectories (with lower overall altitudes and modified booster properties that increase initial speeds). For hypersonic boost-glide missiles, the range of estimated flight times reflects a range of potential initial energies and trajectories that span the performance parameters suggested by current U.S. development programs. CBO does not know the maximum range for hypersonic boost-glide missiles, but it extended the analysis to 10,000 km to compare their potential flight times with those of ballistic missiles, which can achieve intercontinental ranges up to 12,000 km.

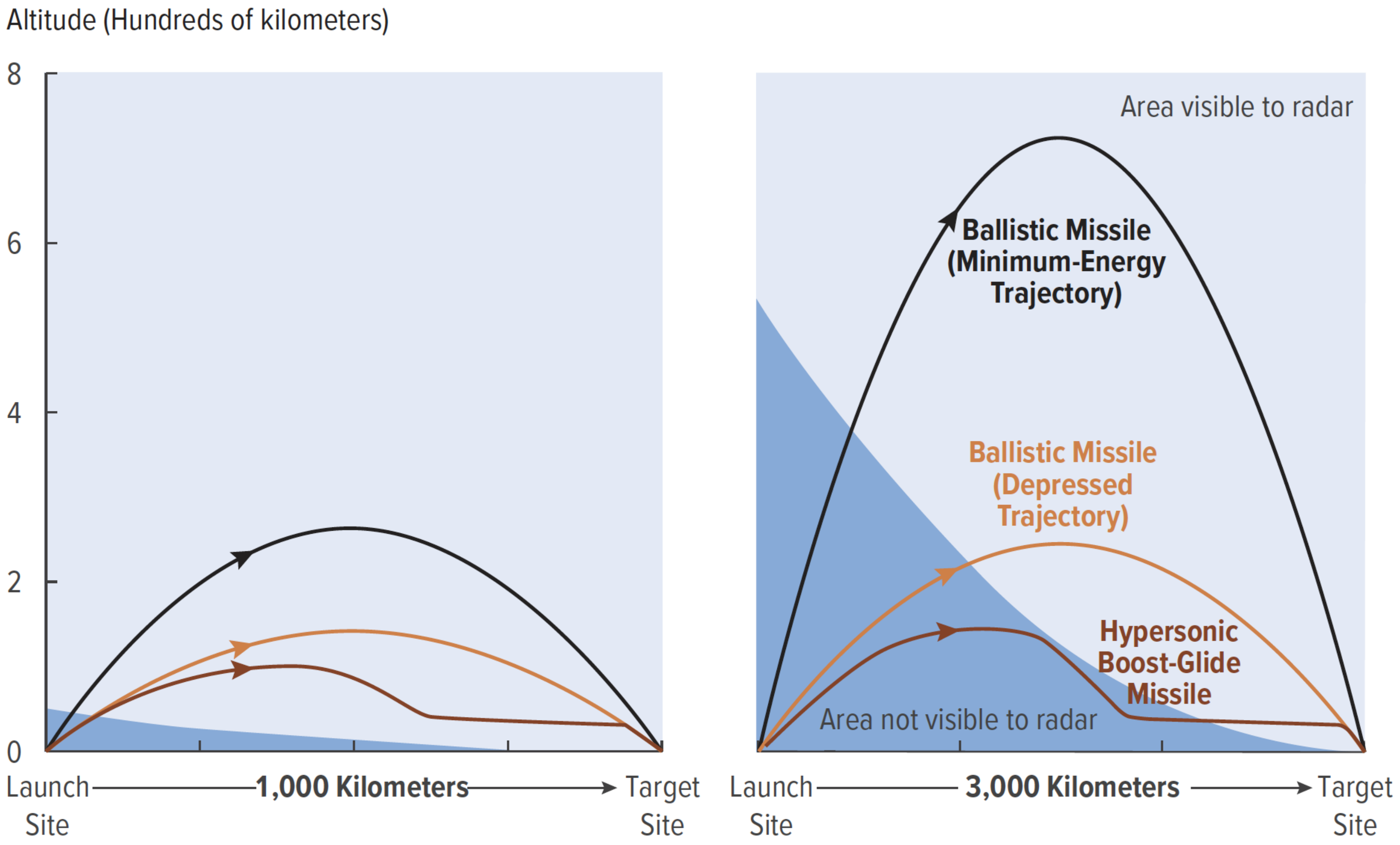
Effects of Altitude on a Radar's Ability to Detect a Missile



Because of the curvature of the Earth, a radar cannot detect a missile that is below the horizon. The distance to a radar's horizon increases with the height of the radar's antenna and the altitude of its target.

Radars' actual horizon limits are much shorter than they appear in this figure because the figure is not to scale.

Points at Which Hypersonic and Ballistic Missiles Are Visible to Ground-Based Radar at Ranges of 1,000 Kilometers and 3,000 Kilometers



Because of its altitude, a ballistic missile would theoretically be visible to a radar located at the target site much earlier in its flight than a hypersonic boost-glide missile would be. To detect and track a missile, however, the radar would have to be powerful enough to generate a signal that would reach the missile.

In this example, the radar is located next to the target and has an antenna 30 meters high. In CBO’s modeling, visibility to radar is a simple geometric calculation based on the curvature of the Earth, the altitude of the missile, the distance to the target, and the refraction of the radar caused by the atmosphere. That calculation indicates only that the missile could be visible above the horizon; the radar would need to have enough power and resolution to actually detect the missile.

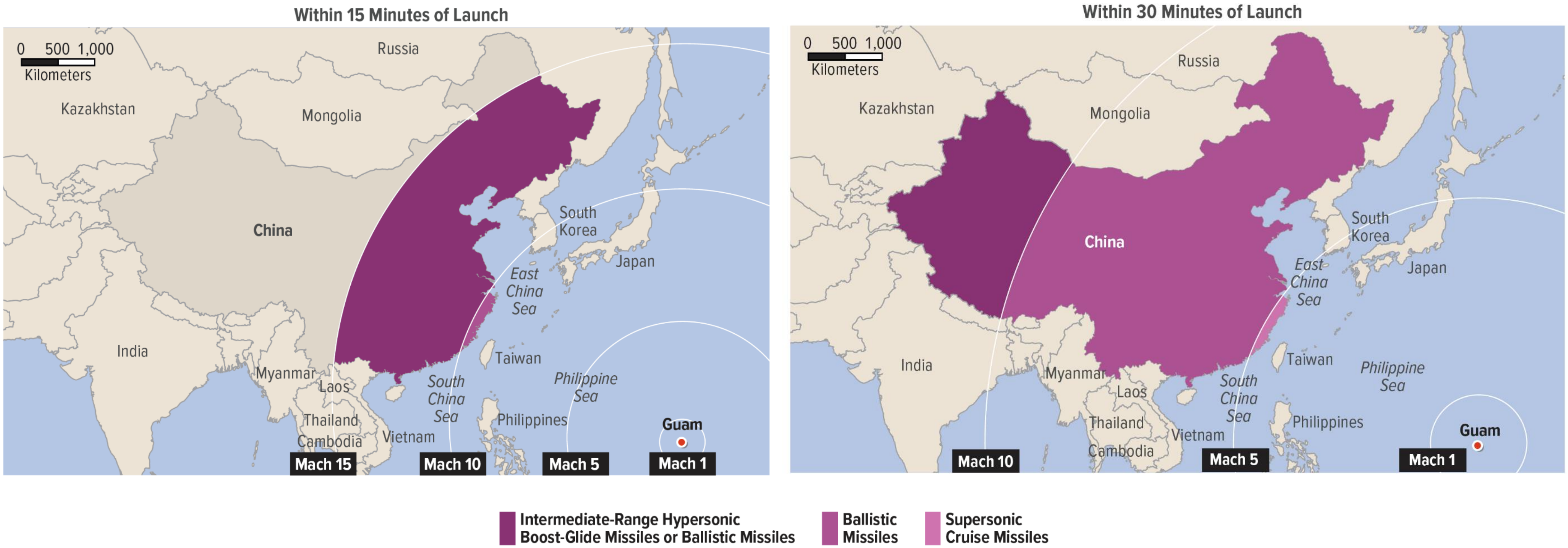
Range That a Missile Can Travel in 15 Minutes at Various Average Speeds

Average Speed (Mach number)	Range in 15 Minutes (Kilometers)	Missiles That Can Travel at That Average Speed	Defensive A2/AD Systems in That Range
0.7	200	Subsonic cruise missiles	Surface-to-air missiles
1	300	Supersonic cruise missiles	Surface-to-air missiles
5	1,500	Hypersonic cruise missiles, medium-range ballistic missiles	Fighter aircraft
10	3,000	Hypersonic boost-glide missiles, intermediate-range ballistic missiles	Air-launched cruise missiles
15	4,500	Intermediate-range ballistic missiles	Antiship ballistic missiles

The distance that the missiles could travel in 30 minutes would be roughly twice the ranges shown here.

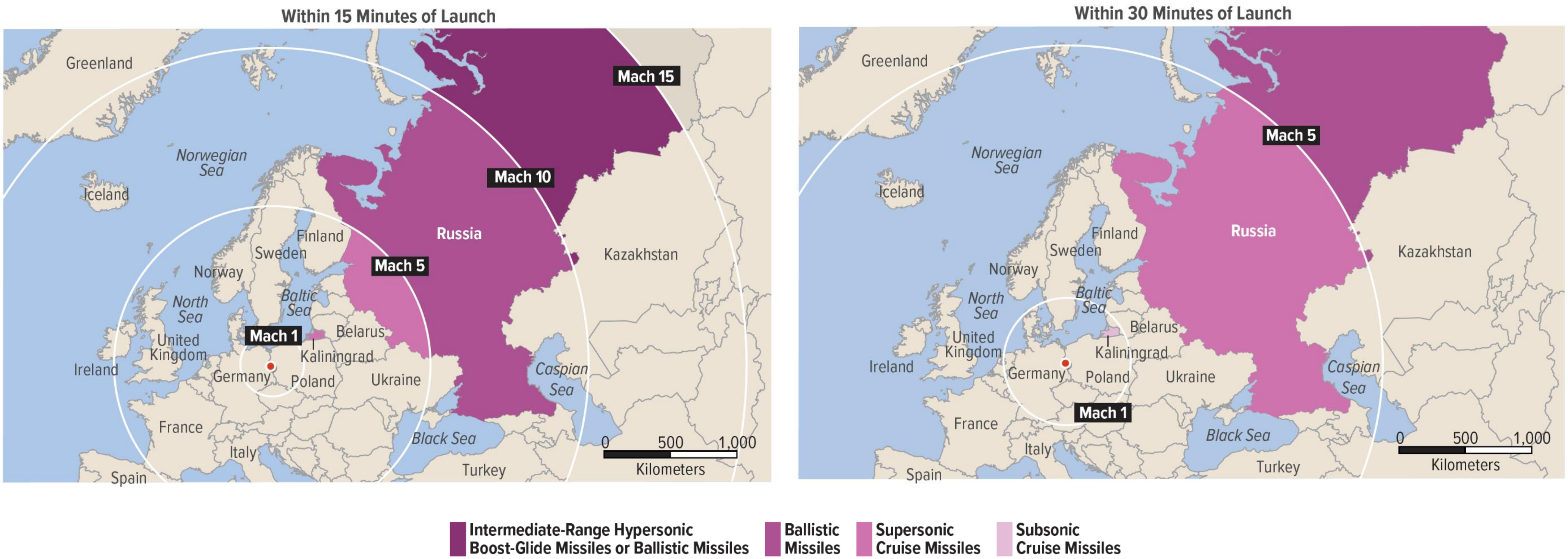
A2/AD = antiaccess and area-denial.

Areas of China That a Missile Launched From Guam Could Reach Within 15 Minutes and 30 Minutes, by Average Speed



A hypersonic boost-glide missile or intermediate-range ballistic missile launched from Guam that traveled at an average speed of Mach 10 could reach the eastern coast of China in 15 minutes.

Areas of Russia That a Missile Launched From Germany Could Reach Within 15 Minutes and 30 Minutes, by Average Speed



A hypersonic boost-glide missile or intermediate-range ballistic missile launched from the border of Germany and Poland that traveled at an average speed of Mach 10 could reach about 1,800 kilometers into Russia in 15 minutes.

Characteristics of Different Missiles Included in CBO’s Analysis, by Development and Funding Status

Key:
■ = Mature Technology
☑ = In Development as Part of DoD’s Current Budget Plan
☐ = Would Require Investment Not in DoD’s Current Budget Plan

					Able to Survive Defenses		
Weapon Type	**Exist Today in U.S. Inventory**	**Average Speed Greater Than Mach 5**	**Range Greater Than 3,000 km**	**Accurate Enough to Use a Conventional Warhead**	**Air Defenses**	**Midcourse Ballistic Missile Defenses**	**Terminal Ballistic Missile Defenses**
Intercontinental Ballistic Missiles	■	■	■	☐	■	☐	☐
Medium- to Intermediate-Range Ballistic Missiles		☐	☐	☐	☐	☐	☐
Hypersonic Boost-Glide Missiles		☑	☑	☑	☐	☑	☑
Subsonic Cruise Missiles	■			■	☐	■	■
Supersonic Cruise Missiles				☐	☐	☐	☐
Hypersonic Cruise Missiles		☑	Unknown	☑	☐	☑	☑

Comparing Options for Planned Hypersonic Missiles and Alternatives

Costs of the Missile Options That CBO Analyzed

	Number of Missiles Purchased	Average Procurement Cost per Missile (Millions of 2023 dollars)	Costs of Option (Billions of 2023 dollars)			
			Missile Procurement	Platform Integration	20 Years of Sustainment	Total[a]
			Intermediate-Range Missiles (Range 3,000–5,500 km)			
Option 1: Ground- or Sea-Launched Hypersonic Boost-Glide Missiles (Similar to LRHW/IR-CPS)	300	41	12.2	2.7	3.0	17.9
Option 2: Ground- or Sea-Launched Ballistic Missiles Equipped With MaRVs	300	26	7.7	2.7	3.0	13.4
			Medium-Range Missiles (Range 1,000–3,000 km)			
Option 3. Air-Launched Hypersonic Boost-Glide Missiles (Similar to ARRW)	300	15	4.5	0.2	0.6	5.3
	100	18	1.8	0.2	0.2	2.2
			Short-Range Missiles (Range less than 1,000 km)			
Option 4: Air-Launched Hypersonic Cruise Missiles (Similar to HACM/HALO)[b]	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.
Option 5: Ground- or Sea-Launched Ballistic Missiles (Similar to SM-6 Block IB)	300	6	1.9	1.0	0.6	3.5

ARRW = Air-Launched Rapid Response Weapon (being developed by the Air Force); HACM = Hypersonic Attack Cruise Missile (being developed by the Air Force); HALO = Hypersonic Air-Launched Offensive Antifsurface Warfare missile (being developed by the Navy); IR-CPS = Intermediate-Range Conventional Prompt Strike missile (being developed by the Navy); km = kilometers; LRHW = Long-Range Hypersonic Weapon (being developed by the Army); MaRVs = maneuverable reentry vehicles; n.e. = not estimated; SM = Standard Missile (the SM-6 Block IB is being developed by the Navy as a variant of the existing Block IA).

a. Excludes costs to develop the missiles.

b. The Department of Defense is early in the process of developing this missile. Little is known about its characteristics, so CBO did not have a basis for estimating the missile’s cost.