Missiles

This unit provides a comprehensive analysis of missile systems, encompassing technical specifications, strategic implications, and political ramifications. It examines proliferation dynamics, including dual-use technologies and the evolving landscape of missile development.

Fabian Hoffmann
Oslo Nuclear Forum/Oslo University

Cite as: Fabian Hoffmann, "Missiles" in EUNPDC eLearning, ed. Niklas Schoernig, Peace Research Institute Frankfurt. Available at https://eunpdc-elearning.netlify.app/lu-07/, last modified 4 December 2025

The EU Non-Proliferation and Disarmament eLearning Course aims to cover all aspects of the EU non-proliferation and disarmament agenda. It's produced by PRIF with financial assistance of the European Union. The contents of individual learning units are the sole responsibility of the respective authors and don't necessariy reflect the position of the European Union.

Funded by
the European Union

1. Introduction

This unit provides a comprehensive analysis of missile systems, encompassing technical specifications, strategic implications, and political ramifications. It examines proliferation dynamics, including dual-use technologies and the evolving landscape of missile development.

Missiles have become an integral part of modern war.

The Dutch frigate De Zeven Provinciën (F802) fires an AGM-84 Harpoon
Dutch Ministry of Defence CC0 1.0/Wikimedia

They constitute the most widespread and arguably most important type of delivery vehicle for nuclear warheads. At the same time, missiles armed with conventional warheads have proven essential for conventional warfighting purposes in recent wars and conflicts.[1]

Prior to the war in Ukraine, missiles were often discussed in the context of emerging and disruptive technologies. Analysts and the media frequently debated the implications of relatively novel missile types, such as hypersonic boost-glide vehicles or hypersonic cruise missiles. However, the war in Ukraine and other recent conflicts have demonstrated that relatively basic types of missiles that have been around for decades, such as subsonic cruise missiles or short-range ballistic missiles, are also still highly relevant.[2]

Remnants of a Russian Iskander-M ballistic missile with cluster warhead shot down over Kramatorsk, Ukraine
National Police of Ukraine (npu.gov.ua) (CC BY 4.0)

While arguably more attention is being paid to missiles right now than ever before, the existence of missiles in the arsenals of nuclear and non-nuclear weapon states is not new. What is new, however, is the dramatic horizontalisation of missile manufacturing capabilities seen in recent years, as well as the large-scale proliferation of these weapon systems around the world, including to non-state actors. A better understanding of missiles and their implications for international security is therefore needed.

This learning unit explores definitional and technical aspects related to different types of missiles, the role of missiles in nuclear and conventional warfare, as well as efforts to counter their proliferation and to keep in check their most destabilising implications.

1. Fabian Hoffmann, “The Strategic-Level Effects of Long-Range Strike Weapons: A Framework for Analysis,” Journal of Strategic Studies (2024), 1-33, [https://doi.org/10.1080/01402390.2024.2351500].
2. Fabian Hoffmann, Strategic Stability and the Ukraine War: Implications of Conventional Missile Technologies (Washington, DC:

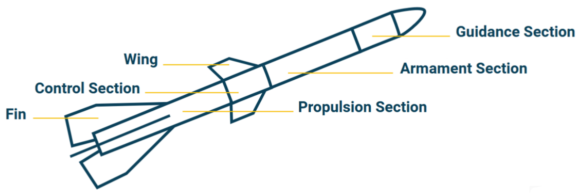
Center for Naval Analyses, 2024).

2. The technical side of missiles

Missiles 101

What are missiles and what are they good for?

On a basic level, the term missile describes a single-use, airborne, self-propelled and unmanned weapon system designed to travel a certain distance and neutralise a target, typically through kinetic effects. Despite their differences, all missiles share several common components found in nearly every type of missile.

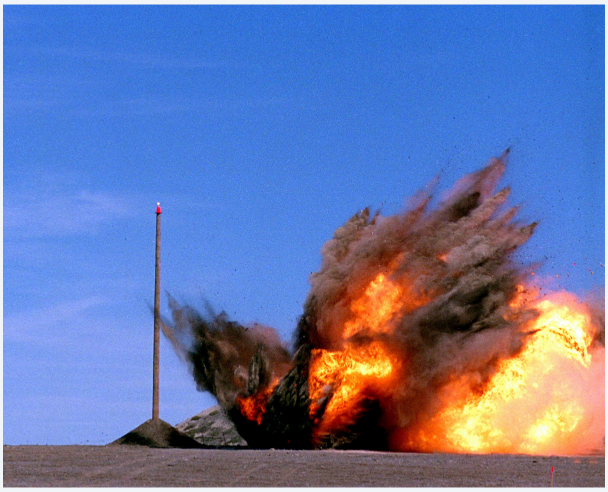


Components of a missile
Grübelfabrik Frankfurt, CC BY-NC

These components include the missile warhead (nuclear or conventional; low-yield or high-yield), the propulsion system (air-breathing or non-air-breathing), a guidance section (including midcourse guidance and terminal guidance, if available), a battery that powers the missile system during its flight, as well as a computation unit that stores information and translates targeting inputs into steering outputs.

Different types of missiles exist for different purposes. The missiles discussed in this unit relate exclusively to anti-surface warfare, meaning they are supposed to engage surface-based targets.

A tactical Tomahawk, the next generation of Tomahawk cruise missiles, approaching the target area of the Naval Air Station (NAS), San Clemente Island, California (CA) during a contractor test and evaluation
U.S. National Archives, unrestricted use



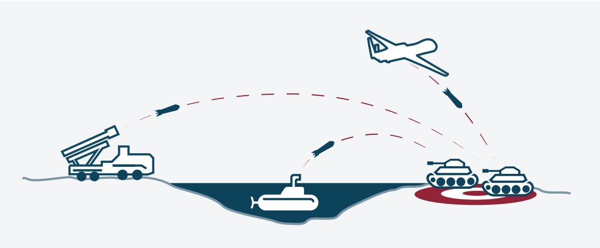
A Tactical Tomahawk, the next generation of Tomahawk cruise missile, explodes on target at the Naval Air Station (NAS), San Clemente Island, California (CA) during a contractor test and evaluation
U.S. National Archives, unrestricted use

Other types of missiles, such as anti-aircraft missiles or missile defence interceptors are optimised for other kinds of threats and are not discussed in this learning unit. This being said, the basic principles behind how missiles function apply to virtually all types of missiles.

In addition, it is important to point out that some missiles can be used for different types of purposes. For example, some surface-to-air missiles can be employed in a secondary surface-to-surface role. Russia has used a large number of air and missile defence interceptors in surface attack mode by launching them against Ukrainian cities rather than

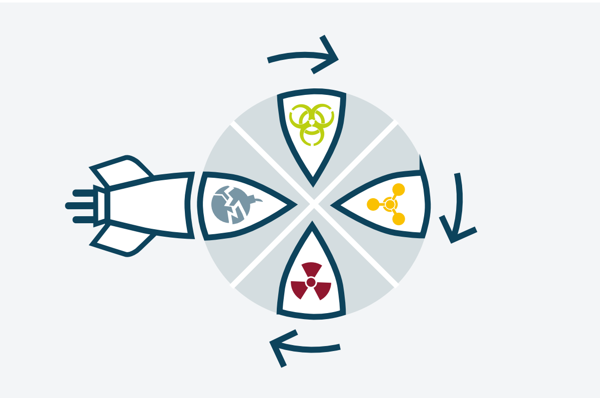
Ukrainian aircraft or missiles. This hints at what will be a recurring theme throughout this section, namely that delineations between different types of missiles are not always clear cut.

Missiles can be launched from air-based, surface-based or subsurface-based launchers. Air-based launchers include fixed-wing aircraft (fighter jets and bombers), as well as rotary-wing aircraft (helicopters). Surface-based platforms include surface vessels (e.g. guided missile destroyers), ground-mobile launchers or stationary ground-based launchers. Subsurface-based platforms refer to submarines and in the not too distant future are also likely to include unmanned underwater vehicles (UUVs).



Types of Missile Launchers
Grübelfabrik Frankfurt, CC BY-NC

In principle, missiles can be flexibly equipped with conventional, nuclear or other types of warheads (e.g. chemical or biological), provided of course the state deploying the missile has access to the relevant warhead technology. Missiles that can carry both conventional and nuclear warheads are typically referred to as "dual-capable".



Dual-capable missile
Grübelfabrik Frankfurt, CC BY-NC

Turning a conventional missile into a weapon of mass destruction (WMD) is not as simple as replacing the warhead, however. Depending on the warhead configuration, it may be necessary to rebalance the missile to account for changes in internal weight. Additionally, the missile fusing system must be adapted to match the new warhead's characteristics. But with proper preparation and the appropriate design choices, warheads can be replaced at relatively short notice. Dual-capable missiles whose warheads can be rapidly replaced in the field or at forward-deployed bases are sometimes referred to as "hot-swappable".

History of Missile Development

June 1944 · V1
The first V1 "Flying Bomb", which can be described as the world's first cruise missile, is launched by Nazi Germany against London.

September 1944 · V2
The first V2 ballistic missile is launched by Nazi Germany against a recently liberated Paris.

October 1957 · Sputnik 1
Sputnik 1, the world's first satellite, is launched into low orbit by the Soviet Union employing a derivative of the R-7 Semyorka (SS-6 Sapwood), the world's first operational ICBM.

February 1959 · R-7 Semyorka
The Russian R-7 Semyorka (SS-6 Sapwood), the world's first operational ICBM, enters into service.

1960 · P-15 Termit
The Soviet P-15 Termit (SS-N-2 Styx), one of the first and most widely produced, exported and used anti-ship cruise missiles, enters into service.

1983 · Tomahawk cruise missile
The American Tomahawk cruise missile, one of the first and most widely used and produced dedicated land-attack cruise missiles, enters into service

1983 · Pershing II
The Pershing II IRBM, the famous missile that was deployed to West Germany as part of the 1979 NATO dual-track decision, enters into service.

2003 · AGM-158A JASSM
The AGM-158A JASSM, the first variant of the American JASSM family of land-attack cruise missiles, which is increasingly becoming the standard LACM in Western arsenals, enters into service.

2017 · 9M729
The Russian 9M729 (SS-C 8 Screwdriver), the land-attack cruise missile that saw the end of the Intermediate-Range Nuclear Forces Treaty (INF Treaty) by breaching the treaty's range limitations, enters into service.

2017 · DF-17
The DF-17, a Chinese hypersonic boost-glide vehicle missile system, enters into service.

2021 · Shahed 131/136
The first images of the Shahed 131/136, the long-range OWA drone that has been extensively used by Russia in its war against Ukraine, are published.

Types of missiles

Broadly speaking, two types of missiles can be identified: **air-breathing** and **non-air-breathing** missiles. These terms refer to the missile's propulsion system and whether it carries an oxidiser on board (either mixed with the fuel or separately) or whether oxygen is sucked in through an air inlet. Air-breathing engines, such as turboprop, turbojet, turbofan, ramjet and scramjet engines are generally more fuel efficient, allow for a more controlled flight profile and produce substantially fewer infrared signatures, which can be helpful to retain a stealthy flight profile. In contrast, non-air-breathing engines, such as rocket engines, are less energy efficient but can generally convert potential energy into kinetic energy much faster, resulting in much higher levels of acceleration. In addition, they offer greater flexibility, especially when they are powered by solid fuel, and are often less maintenance heavy.

Three types of non-air-breathing missiles are discussed in this unit:

1. **Ballistic missiles**
2. **Boost-glide vehicles**
3. **Rocket artillery**

The principle behind all these missiles is relatively similar. They are rapidly propelled high up into or outside of the atmosphere and then, after reaching a zenith, come back down to the ground, either in the form of a separated payload section or as the entire missile system. The extent to which the trajectory approaches or deviates from a ballistic arch depends on the manoeuvrability of the missile system.

Air-breathing missiles include cruise missiles and some types of long-range one-way attack drones. These missiles stay within the atmosphere, often approach their targets from relatively low altitudes (though they do not have to), and have significant manoeuvrability, both vertically and horizontally, during flight.

Before exploring different kinds of missiles in more detail, a note on range specifications and categories is necessary. Missiles can vary widely in range, from a few kilometres to several thousand kilometres. Security analysts are typically more interested in longer-range missiles which can produce effects in the adversary's operational and strategic depth, while sidelining shorter-range missiles that largely fulfil tactical functions, such as close air support, for example. This learning unit will similarly focus on longer-range missiles.

Importantly, the meaning of "long-range" is context dependent. For example, in the denser geographical context of Europe, where population centres and military targets are located in closer proximity, "long-range" has a different meaning than in the Indo-Pacific context, where distances between potential missile targets are vaster[1]. In addition, it is important to keep in mind that range categories often reflect political negotiations and decisions. For instance, the INF Treaty defined ground-launched missiles with a range of 500 to 5,500 km as "intermediate-range". This classification is not technically inherent to the kilometre range; it reflects a purely political agreement between two states (for more information on the INF Treaty, see LU11 `[/lu-11/]`).

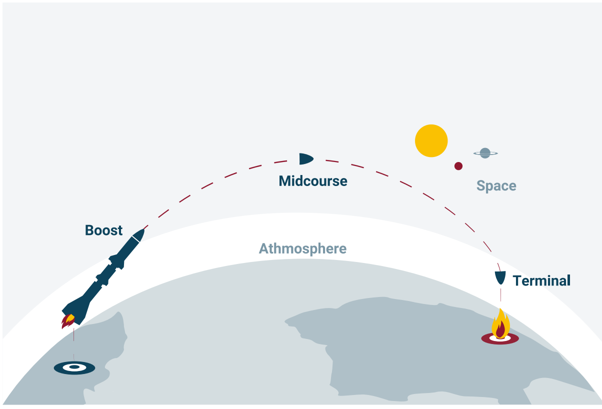
Instead of focusing on more or less arbitrary range thresholds, it may be better to use functional requirements to delineate longer-range from short-range missiles. The main purpose of longer-range missiles is to engage enemy targets at stand-off range and from outside the enemy's **weapon engagement zone (WEZ)**. This stands in contrast to stand-in and direct attack munitions, such as short-range tactical missiles that attack the enemy from within its WEZ. As such, longer-range missiles allow possessor states to achieve effects against enemy targets while keeping their platforms and operators at a safe distance from enemy counter-measures, at least in theory. This being said, nothing prevents operators from employing stand-off capabilities against targets in close proximity and for tactical effects. The following section explores different types of non-air-breathing and air-breathing missiles in more detail.

Non-air-breathing missiles

BALLISTIC MISSILES

A ballistic missile follows an arcing trajectory to deliver a warhead to a target. It is initially powered by a rocket engine comprising one or more booster stages but then follows a guided or unguided free-fall path under the influence of gravity and aerodynamic drag once the engine's fuel is exhausted.

The trajectory of a ballistic missile includes three phases: the boost phase, midcourse phase and terminal phase[2].



Trajectory of a ballistic missile

1. **Boost phase**: The boost phase is the initial phase of the ballistic missile's flight, during which it accelerates to high speeds, from launch until the rocket engines stop firing. The length of the boost phase is determined by the size of the fuel tanks and

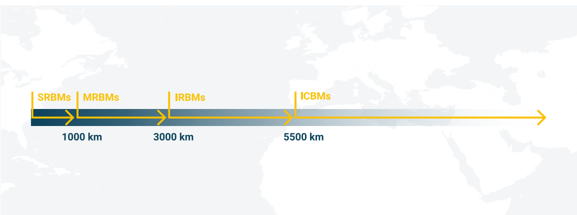
the number of boosters. This phase typically lasts from 1 to 5 minutes and depending on the missile's range, can reach altitudes of several hundred kilometres.

2. **Midcourse phase**: The midcourse phase begins when the engines are no longer firing and often constitutes the longest part of the ballistic missile's flight. The missile follows an unpowered free-fall parabolic path under the influence of Earth's gravity, with minimal aerodynamic forces acting on it due to the thinner atmosphere at higher altitudes. The maximum altitude the missile reaches, as well as the time spent in the midcourse phase, is again determined by the missile's range. For intercontinental ballistic missiles, this phase can last from 15 to 20 minutes and can occur at altitudes of 1,000 km or more. For short-range ballistic missiles, the midcourse phase is significantly shorter.
3. **Terminal phase**: The terminal phase is the final phase of the missile's flight when it descends towards its target, often re-entering the atmosphere if it has travelled outside it. This phase lasts from around 30 seconds to a few minutes and involves high-speed descent.

Ballistic missile projectiles slow down significantly during their descent due to increasing aerodynamic drag at lower altitudes. Nevertheless, the missiles reach their targets quickly, often within minutes of reaching their zenith, making them ideal for responding to time-sensitive targets.

Ballistic missiles are usually categorised by their range:

- **Short-range ballistic missiles (SRBMs)**: Up to 1,000 km
- **Medium-range ballistic missiles (MRBMs)**: 1,000–3,000 km
- **Intermediate-range ballistic missiles (IRBMs)**: 3,000–5,500 km
- **Intercontinental ballistic missiles (ICBMs)**: Greater than 5,500 km



Ballistic missile categories by range (thresholds may vary)
Grübelfabrik Frankfurt, CC BY-NC

Range thresholds are not strictly defined and may vary by analyst. Missiles with a range of 1,000 km or more typically leave the atmosphere for longer periods of time and re-enter later, while some SRBMs remain entirely within the atmosphere.

Most ballistic missiles are surface launched from missile silos or ground-mobile launchers, and sub-surface launched from ballistic missile submarines. Some states also deploy air-launched ballistic missiles and are exploring integration on surface vessels. The majority of ballistic missiles today serve land-attack purposes, with a focus on stationary point or area targets. A few states are developing or deploying anti-ship ballistic missiles capable of engaging moving maritime targets. This includes the Chinese DF-21D anti-ship ballistic missile and the American Precision Strike Missile Inc. 2 currently under development, also referred to as the Land-Based Anti-Ship Missile

DF-21D as seen after the military parade held in Beijing 2015
IceUnshattered/Wikimedia, CC BY-SA 4.0

Ballistic missiles are powered either by solid fuel or liquid fuel, each of which has different advantages and disadvantages that need to be weighed up against each other:

- **Solid fuel ballistic missiles**: Ballistic missiles powered by solid fuel are less maintenance heavy, enabling quick launch capability, and facilitate storage and handling, making them ideal for rapid response scenarios and mobile platforms. However, this comes at the expense of thrust control during flight and fuel efficiency.
- **Liquid-fuel ballistic missiles**: Ballistic missiles powered by liquid fuel have higher fuel efficiency, better thrust control during flight and greater payload capacity. At the same time, they are more complex, require more extensive maintenance and need fuelling before launch, delaying readiness and undermining quick launch capability.

The choice between solid and liquid fuel depends on the specific operational needs of the states employing them. Historically, states have often started with liquid-fuel missiles before advancing to solid-fuel missiles.

We can also differentiate between ballistic missiles that feature separable re-entry vehicles (RVs) and unitary ballistic missiles.[3]

- **Ballistic missiles featuring separable RVs**: This type of ballistic missile leaves the atmosphere during the boost and/or midcourse phase and delivers a payload via a separated RV that re-enters the atmosphere during descent. Examples of this type of ballistic missile include the Iranian Ghadr-1 MRBM and the Chinese DF-21 MRBM.

Ghadr-110 starting (2016)
Tasnim News Agency/Wikimedia (CC BY 4.0)

Dong-Feng 21 at the Beijing Military Museum
Max Smith/Wikimedia, public domain

- **Unitary ballistic missile**: This type of ballistic missile remains unitary throughout its flight, meaning the payload is not separated from the rest of the missile during its descent. This applies to a number of SRBMs, also sometimes referred to as quasi-ballistic missiles, that do not leave the atmosphere. Examples include the American MGM-140 ATACMS SRBM and the Russian 9M723 Iskander-M SRBM.

M57A1 Army Tactical Missile System
U.S. Army Acquisition Support Center, public domain

T250-1 Transport Loader for Iskander-M system, Victory Day Parade, Moscow, 2015
Boevaya mashina/Wikimedia, CC BY-SA 4.0

The free-fall trajectory of most basic ballistic missiles is unguided, meaning that once the RV separates from the booster section, no further course corrections occur. These missiles are guided only during the boost and potentially during the midcourse phase, rendering them rather inaccurate and ineffective against pinpoint or even area targets, especially when equipped with conventional warheads that do not carry submunitions. Examples include the Chinese DF-11 and the Russian R-17 (commonly known as "Scud-B").

MaRVs and MIRVs

More advanced ballistic missiles retain the ability to manoeuvre and course correct longer into their flight, potentially up until the last moments before impact, which can significantly increase their accuracy.[4] So-called manoeuvring re-entry vehicles (MaRVs) employ control surfaces on the RV to exploit aerodynamic drag after re-entry into the atmosphere to guide the RV more accurately towards its target. Additionally, enhanced manoeuvrability can help overcome enemy terminal missile defences. This is the case for the Iranian Fateh-110 SRBM and the North Korean KN-21 SRBM, for example. Quasi-ballistic missiles, like the above-mentioned MGM-140 ATACMS and 9M723 Iskander-M SRBMs, operate on the same principle. In this case, the entire missile body, not just the RV, acts as an aerodynamic object to perform manoeuvres.

Other types of ballistic missiles are equipped with some form of active propulsion system to increase the manoeuvrability of their RVs. This is especially relevant in the context of multiple independently targetable re-entry vehicles (MIRVs), which employ a powered "bus" that carries several RVs outside the atmosphere and launches them at separate stages to engage different targets. This technology has most prominently been employed on ICBMs equipped with nuclear payloads. While the utility of MIRV technology has been discussed in the context of conventional warfare, no "MIRVed" conventional ballistic missile capabilities exist today. [5] Examples of nuclear-armed ballistic missiles employing this type of technology include the French M51 ICBM, the British UGM-133 Trident II ICBM and the Russian RS-24 Yars ICBM.

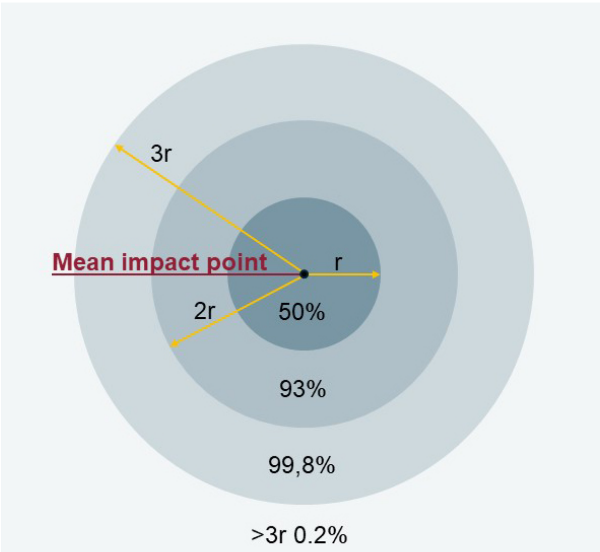
The final ballistic missile type is one that employs powered RVs. In this case, manoeuvrability during the ballistic missile's terminal stage is facilitated by some form of propulsion system mounted directly on the RV to enhance late-stage manoeuvrability. This can be particularly relevant when engaging mobile targets such as ships that can travel significant distances between the missile being launched and the payload reaching its target. At the same time, boosted RVs may also be useful in overcoming terminal missile defences deployed by the adversary. For example, China reports that its DF-26 IRBM has this type of powered RV capability.

Precision and guidance

The first operationally deployed ballistic missile was the Aggregat 4, better known as "Vergeltungswaffe 2", or "V-2", developed and used by Nazi Germany during World War II.

Replica of a V2 at the Peenemünde Museum

Similar to early Cold War ballistic missiles, the V-2 was highly inaccurate. Ballistic missile accuracy is typically indicated by **circular error probable (CEP)**, which denotes the smallest possible radius n within which 50 percent of projectiles will fall.

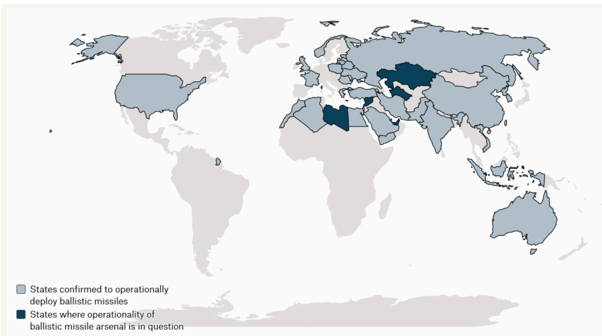


Circular error probable (CEP)

The CEP of early ballistic missiles was measured in kilometres rather than metres. This inaccuracy necessitated the use of massive nuclear warheads to compensate for the missile's expected deviation from its intended target area, and to maintain a minimum level of effectiveness.

Throughout the Cold War, advancements in guidance technology significantly reduced the CEP of ballistic missiles[6]. By the end of the Cold War, the United States' most advanced ICBM, the LGM-118 Peacekeeper, could deliver nuclear warheads over a distance of 10,000 km with a CEP of less than 100 metres. Since then, satellite-assisted navigation and the integration of terminal guidance seekers has further enhanced the precision of ballistic missiles, even allowing ballistic missiles armed with conventional warheads to credibly threaten pinpoint targets. However, manufacturing accurate and reliable ballistic missiles remains challenging, and only a few countries have developed the ability to do so, although their numbers have been steadily increasing.

Ballistic missile technology was initially advanced and dominated by the Cold War superpowers. Despite efforts to curb their proliferation, SRBMs and MRBMs have become fairly widespread due to their relative ease of development, their availability on the international arms market and the strategic value they offer in regional conflicts. In contrast, the proliferation of IRBMs and ICBMs has been largely limited to nuclear weapon states, with no non-nuclear weapon state deploying these types of ballistic missiles today.



States with confirmed ballistic missile launch capabilities and states that possessed ballistic missiles but where the continued existence of these missiles in a state capable of being launched is no longer certain and therefore in question.
Grübelfabrik Frankfurt, CC BY-NC

BOOST-GLIDE VEHICLES

Similar to a ballistic missile system, a boost-glide vehicle consists of a large rocket motor that launches a glide vehicle to high altitudes, typically within the mesosphere or lower thermosphere (around 40 to 100 km, depending on design and mission profile). At the end of the boost phase, the missile system releases the glide vehicle, transitioning from powered to unpowered flight, similar to a ballistic missile system releasing an RV.

Boost-glide vehicles are frequently discussed in the context of hypersonic weaponry (the term **"hypersonics"** is frequently used).

Hypersonic missiles travel at five times the speed of sound or faster. This provides states under attack from hypersonic missiles with little warning time and allows those deploying these weapon systems to service time-sensitive targets very effectively[7].

In reality, however, boost-glide vehicles share many similarities with some of the types of ballistic missiles described above. The main difference between boost-glide vehicles and ballistic missiles is the trajectory of the projectile that is released. Glide vehicles travel at hypersonic speed for the majority of their flight through the atmosphere. Unlike traditional ballistic missiles, which follow fairly predictable, arced trajectories, boost-glide vehicles follow a highly manoeuvrable skipping trajectory through the atmosphere, allowing them to alter their flight path substantially.

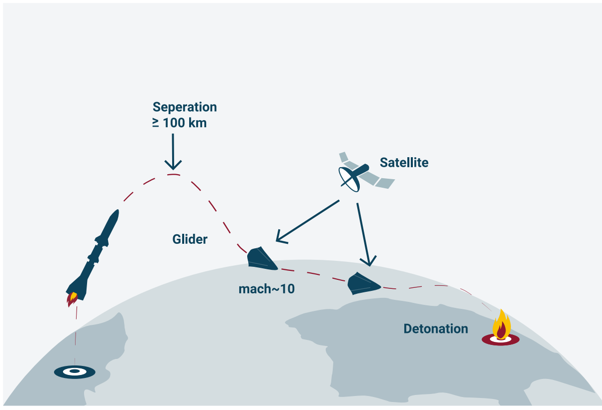


Illustration of the flight phases: take-off - separation - gliding flight - attack
Grübelfabrik Frankfurt, CC BY-NC

This combination of high speed and manoeuvrability makes boost-glide vehicles difficult to detect and intercept for missile defence systems optimised for less manoeuvrable ballistic missile threats.

Because of their high speeds at the upper bounds of the atmosphere, boost-glide vehicles are often hyped because of their hypersonic speed. This is not wrong, given that glide vehicles do indeed reach hypersonic velocity, especially at higher altitudes, before slowing down due to increased atmospheric drag as they descend. However, their velocity is comparable to that of many ballistic missiles, which also reach hypersonic speeds during part of their flight. Arguably, the main advantage of a glide vehicle over a ballistic missile is its superior manoeuvrability and potentially its ability to stay undetected for longer periods. That said, the time-to-target of boost-glide vehicles can be longer than that of ballistic missiles, and excessive manoeuvring early in the glide vehicle's trajectory can slow it down and limit its range.[8]

The physical design principles and advantages of deploying boost-glide vehicles have been known for decades. It is only in more recent years, however, that advancements in material science and guidance technology have enabled the development and deployment of this type of weapon system. This being said, the technical barriers to deploying boost-glide vehicles remain high. At present, only two states, Russia and China, claim to deploy boost-glide vehicles (the Chinese DF-17 and the Russian Avangard). Several other states, including the United States, France and North Korea, are actively working on boost-glide vehicle programmes.

ROCKET ARTILLERY

The final type of non-air-breathing missiles that deserves a mention is rocket artillery munitions. Rocket artillery is a type of artillery system that delivers rocket-boosted payloads to a target, launched from a tube or rail. This stands in contrast to traditional artillery which uses artillery shells launched from a gun or howitzer. Rocket artillery can deliver a relatively large volume of fire over a long distance and, depending on the weapon system, with high precision.

Multiple launch rocket system (MLRS) of the Republic of Korea Army

Compared to ballistic and other types of missiles, rocket artillery has received relatively little attention from analysts, at least until the war in Ukraine demonstrated the enormous utility of rocket artillery on the modern battlefield. Ukraine has employed the American M-142 HIMARS rocket artillery launcher together with guided multiple launch rocket system (GMLRS) munitions to great effect in its fight against Russia's illegal invasion.

M-142 HIMARS

Rocket artillery munition shares several features with ballistic missiles, especially with some types of SRBMs. Most notably, both types of systems feature a rocket-powered boost phase, an unpowered midcourse phase and an unpowered terminal phase. Modern rocket artillery munitions similarly make use of aerodynamic control surfaces to guide the payload more accurately to its target. Much like some types of SRBMs, rocket artillery munitions remain unitary throughout their flight and do not separate their payload in the form of an RV that re-enters the atmosphere.

There are differences, however. Most importantly, rocket artillery munitions are several times smaller than even small ballistic missiles in terms of length and diameter. As such, rocket artillery cannot store the same amount of fuel, meaning the boost phase is typically shorter, resulting in a lower trajectory and a more limited range. For example, GMLRS rocket artillery, and comparable rocket artillery munitions, only have a range of around 70 to 80 km. This being said, the United States is currently working on an extended-range version of GMLRS, the GMLRS-ER, which will have a range of 150 km. This is comparable to some SRBMs, such as the American MGM-140 Block I ATACMS SRBM or the Russian 9K79-1 Tochka-U SRBM, which have ranges of around 120 to 165 km, though most other operational ballistic missiles have ranges of at least 300 km. The relatively small size of rocket artillery munitions also means that they have a relatively limited payload capacity.

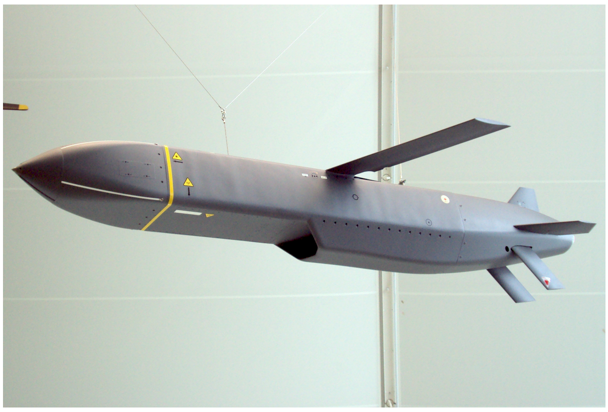
The small size of rocket artillery munitions is of course a feature, not a bug in their design. The shorter length and smaller diameter enable launcher platforms to carry several more rocket artillery rounds than ballistic missiles. For example, the HIMARS rocket artillery system can either carry up to six GMLRS rounds or one MGM-140 ATACMS SRBM at a time. This facilitates rocket artillery barrages and salvo attacks, which might be necessary given that rocket artillery is often used to engage more dispersed tactical targets, rather than single-point targets and high-value objects. Limited size and payload capacity also bring down costs, meaning that rocket artillery munitions are typically several times cheaper than ballistic missiles. Finally, it is important to note that the line between rocket artillery munitions and ballistic missiles is not clear cut. In general, as the length, diameter and payload capacity of a rocket artillery munition increase, it will behave more and more like a ballistic missile, and is likely to be employed in a similar fashion, too.

Rocket artillery has been around since the Second World War. However, it has only been in recent decades that rocket artillery munitions have become longer in range and highly accurate, giving them potent precision-strike capabilities. Due to their relatively limited range and payload capacity, rocket artillery munitions are freely available on the international arms market and few constraints to their proliferation exist, especially compared to ballistic and longer-range cruise missiles. Artillery munitions can be expected to proliferate widely in the years ahead.

Air-breathing missiles

CRUISE MISSILES

Cruise missiles are airborne vehicles propelled by air-breathing engines, following a non-ballistic and relatively direct flight path to their targets.[9]



Storm Shadow cruise missile, RAF Museum, London

There are two main differences between cruise missiles and the types of non-air-breathing missiles outlined above:

1. **Trajectory**: Cruise missiles do not follow a ballistic trajectory and always stay within the atmosphere, irrespective of range. They often fly a ground-skimming trajectory, especially during their terminal approach when they get close to the target.
2. **Propulsion**: Cruise missiles do not usually carry an oxidiser. Instead, they use an air-breathing engine that pulls in the surrounding air through an inlet to supply oxygen.

Two types of cruise missiles can be distinguished:

1. **Land-attack cruise missiles (LACMs)**: Designed to engage land-based and typically stationary or semi-stationary targets, including ammunition depots, logistics centres, command and control facilities and leadership bunkers, among others. These missiles are typically longer in range and carry a larger payload.
2. **Anti-ship cruise missiles (ASCMs)**: Designed to engage mobile and stationary targets in a maritime environment, typically surface vessels. These missiles are often shorter in range and carry a comparatively smaller payload. Depending on the types of guidance systems they feature, they can have land-attack capability.

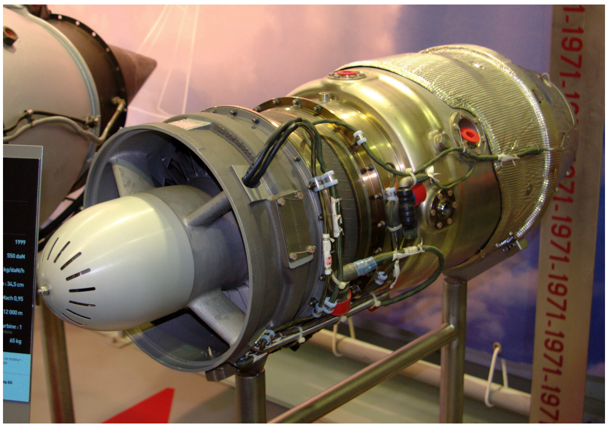
Unlike ballistic missiles which are often categorised by their maximum range, cruise missiles are often categorised by reference to their cruising speed. Three categories of cruise missiles are typically differentiated:

- **Subsonic cruise missiles**: Fly at speeds slower than the speed of sound (< Mach 1).
- **Supersonic cruise missiles**: Fly at speeds faster than the speed of sound but below hypersonic velocity (> Mach 1, < Mach 5).
- **Hypersonic cruise missiles**: Fly at hypersonic speed (>= Mach 5).

One of the most important components of a cruise missile is the air-breathing engine. The type of air-breathing engine used in the cruise missile determines to a substantial degree the maximum range and speed of the cruise missile. Four types of air-breathing engines relevant to cruise missile propulsion can be identified: turbojet engines, turbofan engines, ramjet engines., and scramjet engines.

Turbojet engine

The most basic type of air-breathing engine is a turbojet engine. In this type of engine, the air is drawn into the engine through an air inlet, compressed and heated by a compressor. The compressed air is then passed through a combustion chamber where fuel is added, and the air-fuel mixture is ignited. This ignition adds energy to the exhaust stream, moving the vehicle forward at high velocity. Examples of cruise missiles employing this type of engine include the British Storm Shadow/SCALP-EG LACM, the American AGM-158A JASSM LACM and the French Exocet ASCM, for example. Turbojet technology for use in cruise missiles is matured and well understood. The main problem with this kind of engine is its relative inefficiency at subsonic velocity, limiting the range of turbojet-propelled cruise missiles.



Microturbo TR60-30 of a Storm Shadow presented in exploded form at the Safran Museum, France

Turbofan engine

To increase their range, several modern cruise missiles employ turbofan engines. This type of engine functions similar to a turbojet, with the exception that some of the drawn-in air bypasses the engine core and is only accelerated by a ducted fan in front of the engine (hence the name turbofan). The bypassing air remains relatively cool and reduces the overall temperature of the exhaust stream, decelerating the velocity of the exhaust flow. This, in turn, increases the vehicle's fuel efficiency at subsonic speed, allowing the cruise missile system to fly longer ranges. Many land-attack cruise missiles intended for deep-strike purposes are therefore equipped with turbofan engines, including the German-Swedish Taurus KEPD-350 LACM, the American AGM-158B JASSM-ER LACM and the Russian Kh-101 LACM, among others.

Ramjet engine
To sustainably cruise at high supersonic speed a ramjet engine is necessary. A ramjet is an air-breathing engine that does not include a compressor. Instead, the engine uses the forward motion of the vehicle to ram the air into the engine, compressing it in the process (hence the name ramjet). This design allows the drawn-in air to pass through the engine faster, thus accelerating the speed of the exhaust flow. Cruise missiles employing ramjet engines include the Russo-Indian PJ-10 Brahmos ASCM, the Chinese YJ-12 ASCM and the French ASMP-A nuclear LACM.

Bristol Thor ramjet engine of a Bloodhound Missile modified for display purposes at the (closed) Bristol Industrial Museum in 2004
Adrian Pingstone/Wikimedia, public domain

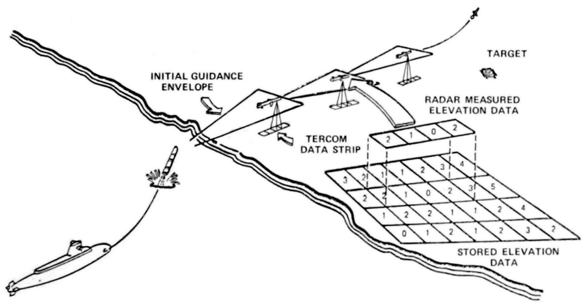
Scramjet engine
To reach and sustain hypersonic cruise velocities, a scramjet engine is necessary. Scramjet stands for supersonic combustion ramjet. A scramjet operates like a ramjet but keeps the air at supersonic speeds as it enters the engine. In a regular ramjet, the air is slowed down to subsonic velocity, allowing less energy to be extracted through combustion. By allowing for supersonic combustion, a scramjet solves this issue. The basic idea behind a scramjet is relatively simple. However, developing a functioning and reliable scramjet engine, and integrating it into a capable and well-rounded cruise missile system, has proven extremely challenging. Currently, only Russia claims to deploy an operational hypersonic cruise missile, the 3M22 Zircon. However, recovered wreckage from Ukraine provides no evidence of a functioning scramjet. Several states are currently working on fielding hypersonic cruise missiles powered by scramjet propulsion, including the United Kingdom, Australia, the United States and Japan, among others.

Compared to ballistic missiles, cruise missiles have historically achieved higher accuracy. This is due to the relative ease of integrating terminal guidance seekers into cruise missiles, as opposed to ballistic missiles. Typically, cruise missiles rely on one of three types of seekers for terminal guidance:

- **Electro-optical (E/O) seeker**: Uses a camera to capture images of the target area and compares them to prestored images to identify and home in on the correct target.
- **Imaging infrared (IIR) seeker**: Operates similarly to an E/O seeker but captures images in the infrared spectrum. It detects the heat signatures of targets, making it useful for identifying targets based on their thermal profile, which increases effectiveness in poor visibility conditions such as night, fog or heavy weather.
- **Active radar seeker**: Emits radar waves and detects the reflections (echoes) from the target. It can actively scan the target area and lock onto the specific radar return signature of the target.

Integrating these types of terminal guidance seekers into ballistic missiles is feasible in principle. However, due to high speed and atmospheric friction, ballistic missiles endure significantly more stress in their terminal phase than cruise missiles. This makes it more challenging to operate delicate camera or radar equipment. Moreover, the high terminal velocity and limited manoeuvrability of ballistic missiles make terminal course corrections difficult. In contrast, cruise missiles are generally slower and allow for a more controlled approach to their target, making it easier to integrate and operate terminal guidance seekers successfully.

In addition, cruise missiles can make use of a number of navigation systems for midcourse guidance that are inaccessible to ballistic missiles, most notably **terrain contour matching (TERCOM)**. This technique involves a process where an altimeter installed on the cruise missiles measures and compares the topography of a terrain underneath the cruise missile with mapping data stored inside the missile to detect deviations from its nominal trajectory. This means that even if the satellite navigation system inside the missile fails, either because of systemic error or enemy jamming/spoofing, the cruise missile still has an effective way to navigate towards its target



Sea-launched cruise missile terrain contour matching (TERCOM) guidance system as visualised in 1975 by the U.S. Navy
U.S. Department of the Navy, public domain

Owing to the sophisticated guidance systems that can be integrated into cruise missiles for midcourse and terminal navigation, cruise missiles have traditionally demonstrated higher levels of precision than ballistic missiles. However, modern ballistic missiles have become increasingly accurate thanks to satellite-assisted midcourse guidance, with several short- and medium-range ballistic missiles now rivalling the accuracy of cruise missiles. Technological advancements have also made it easier to integrate terminal guidance seekers into ballistic missiles, further improving their precision, including against mobile targets.

Anti-ship cruise missiles (ASCMs) began to proliferate widely in the 1970s and 1980s. Like rocket artillery munitions, their limited range and payload have made ASCMs widely available on international arms markets. Today, ASCMs are the most widely proliferated type of missile. In contrast, LACM proliferation has been slower, partly due to efforts by LACM-producing states to prevent their spread. However, in recent years, LACM proliferation has increased significantly, a trend that is likely to continue.

LONG-RANGE ONE-WAY ATTACK DRONES

The second type of air-breathing missile threat involves long-range one-way attack (OWA) drones. The emphasis on "long-range" is crucial. Drones have proliferated significantly in recent years and are used for various purposes, from direct frontline applications to weapon systems targeting homeland objects deep inside enemy territory.[10] In this section, we focus on drone systems with a more substantial range, enabling them to undertake tasks beyond frontline operations.

The term "one-way attack" distinguishes between drone munitions that can return to their operator after launch and those that cannot. Examples of the former include multi-use, multi-purpose drones such as the American MQ-9 Reaper, whereas examples of the latter include the Iranian Shahed 131/136 drone.

Iranian Shahed 136 exhibited in Qom, Iran, 2023
Tasnim News Agency/Wikimedia (CC BY 4.0)

In addition, some modern tactical drones can loiter over a target before potentially returning to their operator if no target is found, while longer-range drone systems typically do not have this option, though some may include limited loitering capabilities.

In terms of their flight profile, long-range OWA drones share several features with cruise missiles, most notably their ability to maintain a continuously propelled flight through an air-breathing engine at relatively low altitudes. However, there are also important differences:

- **Speed**: While cruise missiles fly at high subsonic speed or supersonic speed, sometimes even reaching hypersonic velocity, most long-range OWA drones are significantly slower, often flying at low to medium subsonic speed.
- **Shape**: Given their slow speed, long-range OWA drones require more aerodynamic surface area to maintain their flight, resulting in wider shapes.
- **Payload**: Long-range OWA drones do not have the same payload capacity as cruise missiles. Modern land-attack cruise missiles typically carry warheads weighing up to 450 kg or more. In contrast, long-range OWA drones carry substantially smaller warheads, usually below 100 kg.
- **Sophistication**: Generally speaking, long-range OWA drones are less sophisticated than cruise missiles. They often do not feature terminal guidance seekers, are less resistant to enemy electronic warfare counter-measures (jamming/spoofing), and frequently offer more limited stealth capabilities.
- **Costs**: Given their less sophisticated nature, long-range OWA drones are typically cheaper than cruise missiles. While modern cruise missiles have price tags of well over 1,000,000 US dollars, long-range OWA drones typically come in at around or under 100,000 US dollars apiece.

  Commentary on long-range OWA drones sometimes has a tendency to overemphasise the comparatively lower price tag of long-range OWA drones, hailing them as an alternative to expensive cruise missiles. This misses the point, however, as the lower cost comes with less capability. Long-range OWA drones will, under most circumstances, demonstrate more limited lethality and survivability. This does not mean that long-range OWA drones are inevitably worse than cruise missiles. There are types of operations that do not require the sophistication of a cruise missile. In these cases, it is more cost effective to launch a long-range OWA drone. However, there are some types of mission that cannot be fulfilled by long-range OWA drones and that require the advanced capabilities of a cruise missile.

While it is possible to increase the sophistication of long-range OWA drones, this will also increase their price. For example, replacing the turboprop engine that is used in many long-range OWA drones with a turbojet engine will increase the drone's speed. Similarly, it is possible to integrate terminal guidance seekers for improved accuracy, or better electronic warfare protection to enhance survivability. Doing so would make the long-range OWA drone more capable, but its costs will approach that of a cruise missile. This suggests that, similar to the blurry line between rocket artillery munitions and ballistic missiles, the distinction between long-range OWA drones and cruise missiles is not entirely clear cut.

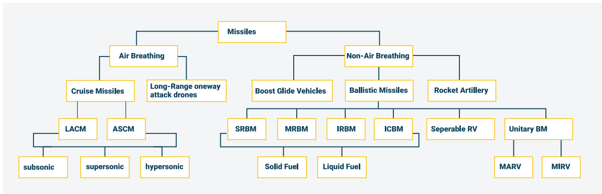
Long-range OWA drones have garnered increasing attention in recent years, particularly due to the war in Ukraine, where both sides have used these weapon systems to strike enemy homeland targets. Russia has deployed the infamous Shahed 131/136 drone (known in Russia under the designation Geran 1/2), imported from and now license-produced by Iran.

Still from the video address by the President of Ukraine Volodymyr Zelenskyy on the 246th day of Russia's full-scale war against Ukraine, 28 October 2022.
Courtesy of the Presidential Office of Ukraine (https://www.president.gov.ua)

In contrast, Ukraine has relied on domestically produced designs, some of which are highly improvised, such as the conversion of a two-seater commercial airplane into a long-range OWA drone [11]. Even before the war in Ukraine, non-state actors in the Middle East had increasingly been using long-range OWA attack drone technology to threaten high-value targets of state actors. Long-range OWA drone proliferation to both state and non-state actors is likely to continue in the coming years.

Summary

This was a lot of detailed information. To make it easier for you to process, the following chart summarises the different types of missiles discussed above



Overview: Different types of missiles

1. Fabian Hoffmann and William Alberque, Non-Nuclear Weapons with Strategic Effect: New Tools of Warfare? (London: International Institute for Strategic Studies, 2022), [https://www.iiss.org/en/research-paper/2022/03/non-nuclear-weapons-with-strategic-effect-new-tools-of-warfare/].
2. Markus Schiller, Missile Identification and Assessment (London: International Institute for Strategic Studies, 2022), [https://www.iiss.org/de-DE/research-paper/2022/04/missile-identification-and-assessment/].
3. Ankit Panda, Indo-Pacific Missile Arsenals: Avoiding Spirals and Mitigating Escalation Risks (Washington D.C.: Carnegie Endowment for International Peace, 2023), [https://carnegieendowment.org/2023/10/31/indo-pacific-missile-arsenals-avoiding-spirals-and-mitigating-escalation-risks-pub-90772].
4. Ibid.
5. Eric Edelman et al., Rings of Fire: A Conventional Missile Strategy for a Post-INF Treaty World (Washington D.C.: Center for Strategic and Budgetary Assessments, 2022), [https://csbaonline.org/research/publications/rings-of-fire-a-conventional-missile-strategy-for-a-post-inf-treaty-world].
6. Donald MacKenzie, Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance (Cambridge, MA: MIT Press, 1993).
7. Steve Fetter, Tim Thies and Victor Mizin, Hypersonic Boost-glide Vehicles: Evaluating Inadvertent Escalation Risks (Hamburg: Deept Cuts Commission, 2024), [https://deepcuts.org/media/pages/publications/issue-briefs/hypersonic-boost-glide-vehicles/f5f8115ddd-1719229200/hypersonics_issue_brief_with-policy-recommendations.pdf]
8. Cameron L. Tracy and David Wright, "Modelling the Performance of Hypersonic Boost-Glide Missiles," Science & Global Security 28, no. 3 (2020): 135–170, [https://scienceandglobalsecurity.org/archive/sgs28tracy.pdf].
9. Fabian Hoffmann, Cruise Missile ProliferationFabian Hoffmann, Cruise Missile Proliferation: Trends, Strategic Implications, and Counterproliferation (London: European Leadership Network, 2021), [https://www.europeanleadershipnetwork.org/wp-content/uploads/2021/03/Fabian_Final-2.pdf].
10. Marcel Plichta and Ash Rossiter, "A One-Way Attack Drone Revolution? Affordable Mass Precision in Modern Conflict," Journal of Strategic Studies (2024), 1-31, [https://www.tandfonline.com/doi/full/10.1080/01402390.2024.2385843].
11. David Axe, Ukraine Packed a Cessna-Style Plane With Explosives, Added Remote Controls and Kamikaze'd It Into A Russian Drone Factory 600 Miles Away, Forbes, 2024, [https://www.forbes.com/sites/davidaxe/2024/04/02/ukraine-packed-a-cessna-style-plane-with-explosives-added-remote-controls-and-kamikazed-it-into-a-russian-drone-factory-600-miles-away/]

3. The strategic side of missiles

Military interests, proliferation and missile defence

Strategic considerations for missile procurement

Given the different types of missiles, what types of missiles are states most likely to procure? There is no easy answer to this, and it depends on a range of factors, most notably the exact requirements of the operator, the ability to manufacture the weapon system domestically or its availability on the international arms market, the availability of platforms for launching missiles, and relative costs, among others.

Importantly, every type of missile has distinct advantages and disadvantages. For example, ballistic missiles and boost-glide vehicles are ideal weapon systems for time-sensitive targets due to their low time-to-target, but comparatively expensive and difficult to manufacture. Subsonic cruise missiles can often provide the highest levels of accuracy while maintaining a stealthy approach. At the same time, they are rather slow and if they are detected, they are relatively easy to intercept. Long-range drones and rocket artillery constitute comparatively cheap and potentially more easily available options but may lack the survivability and yield necessary to reliably destroy their targets.

Therefore, states wanting to build up a formidable missile arsenal will ideally be able to procure a mix of missile capabilities, allowing them to flexibly choose in different scenarios. However, this will not be realistic for most states, given the budgetary constraints they face and/or their inability to procure the weapon system, even if they wanted to. This is either because they are unable to manufacture certain types of missiles at home or because they cannot buy them on the international arms market. In addition, states may lack access to certain platforms, such as surface vessels or aircraft, preventing them from deploying certain types of missiles, such as air-launched cruise missiles or submarine-launched ballistic missiles, for example.

As such, with the exception of a few powerful states that have significant financial, industrial and military resources to deploy large and diverse missile arsenals (arguably only the United States, China and potentially Russia, at present), most states will not be able to build the missile arsenals of their dreams. Instead, they will have to adapt their needs to the material realities within which they conduct their arms procurements.

Missile proliferation

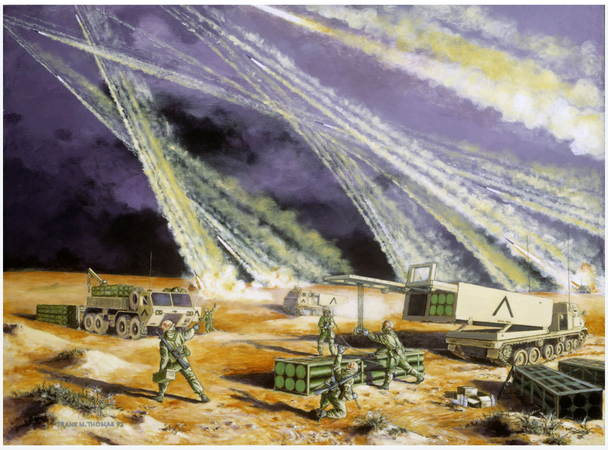
Missiles have proliferated significantly since the end of the World War Two. [1] This has especially been the case since the end of the Cold War, and even more so in recent years. Reasons for this relate both to the demand side and the supply side of missile proliferation. On one hand, missiles provide enormous military utility for their possessor states both in conventional and nuclear warfare. On the other hand, missiles have become increasingly available due to a horizontalisation of missile manufacturing capabilities across the globe.

Demand side drivers

Missile arsenals can provide key advantages in both short and protracted warfighting scenarios, as demonstrated in recent wars and conflicts. Missiles can play an instrumental role in creating the conditions for victory at the outset of a conflict by inflicting "shock and awe" and rapidly undermining the adversary's warfighting potential and its morale, even before larger military operations are underway.

For example, the United States employed large-scale missile strikes at the outset of Operation Desert Storm in 1991 and Operation Iraqi Freedom in 2003 to launch their campaigns against Saddam Hussein's Iraq, targeting key military installations, leadership headquarters, critical infrastructure and air defence sites.

U.S. M-270 multiple launch rocket system, Saudi Arabia, December 1991
U.S: Army/PFC John F. Freund



Painting "Steel Rain" (Desert Storm 1991), by Frank M. Thomas
U.S. Army/Frank M. Thomas – National Guard Heritage Series

Although the ultimate effectiveness of these missile attacks is still debated, they left a lasting impression on observers. The prospect of large-scale missile strikes rapidly undermining the warfighting capacity of a state before a coordinated military response could be formulated and implemented became real and daunting. Accordingly, states started to invest heavily in missile defences, but also acquired substantial missile arsenals of their own and developed comprehensive missile doctrines for employment in conventional and nuclear war.

Russia similarly started its invasion of Ukraine with a large-scale missile attack. Although the immediate effects of this attack were underwhelming, the war in Ukraine has demonstrated the advantages missile capabilities can provide in protracted warfighting scenarios. Missile strikes have placed Ukraine and its international partners under tremendous pressure in the medium- to long-term both by threatening critical civilian infrastructure and terrorising the Ukrainian population through direct strikes on population centres.

Ukraine for its part has employed domestic and foreign missile capabilities to destroy Russian logistics depots, military targets and command and control facilities in occupied Ukrainian territory, as well as critical infrastructure and industry targets deep inside Russia. Ukraine would undoubtedly be in a worse position today without access to Western and domestic missile capabilities.

In terms of nuclear strategy, missiles, for now, remain the most effective and survivable delivery vehicles for both strategic and non-strategic nuclear warheads.

U.S. nuclear missiles: Peacekeeper, the Minuteman III and the Minuteman I. (f.l.t.r.)
U.S. Air Force/R.J. Oriez

Recent conflicts have shown that both air-breathing and non-air-breathing missiles are more vulnerable to missile defences than previously thought. However, they are generally still more survivable than aircraft deploying nuclear gravity bombs, unless perhaps those aircraft are equipped with advanced stealth capabilities. Additionally, unlike aircraft-deployed gravity bombs that require operators to penetrate the adversary's weapons engagement zone, stand-off missiles can generate effects without risking the safety of the operators and their platforms.

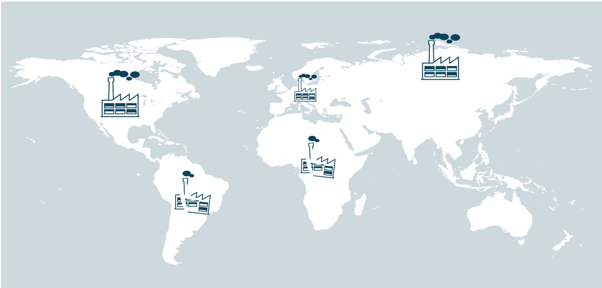
What is more, the utility of missiles in creating timely effects remains unmatched. Intercontinental ballistic missiles (ICBMs) can reach the other side of the planet within 20 to 30 minutes. At shorter ranges, SRBMs can engage targets 500 to 1,000 km away in just 3 to 7 minutes. Aircraft deploying gravity bombs cannot match these timeframes, especially if they are initially grounded. Consequently, states with nuclear arsenals will remain highly invested in advancing their missile programmes to ensure the effectiveness of their nuclear deterrents. Overall, this indicates a significant demand for missile capabilities for both conventional and nuclear warfare.

Supply side drivers

For a long time, the number of countries capable of manufacturing missiles has been relatively small. During the Cold War, this capacity was primarily limited to the Soviet Union, the United States and a few other advanced economies, mostly in Europe, with significant industrial manufacturing capabilities.

Although some countries in Latin America and Africa attempted to develop and produce indigenous missile designs, they were largely unsuccessful. This was partly due to counter-proliferation measures designed to limit the global spread of missile technology, which will be discussed in the next section.

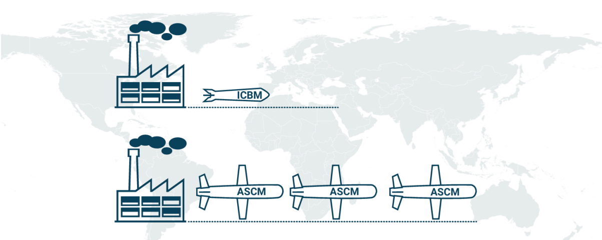
Missile Production Capabilities before the 1980s



Missile Production Capabilities before the 1980s

In around the 1980s, the number of missile-producing states started to increase, albeit at a rather slow pace. This has changed in the last two decades, which have witnessed a dramatic horizontalisation of missile manufacturing technology. This applies to both air-breathing and non-air-breathing missile designs. Nowadays, even states that have not traditionally been known for their advanced manufacturing capabilities and defence industries are involved in the design and production of different kinds of missiles.

This does not mean that it has become easy to manufacture missiles or that manufacturing capabilities for all types of missiles have spread equally. For example, while many more states now manufacture ASCMs, the number of states building their own ballistic missiles remains relatively small



Missile Production Capabilities before the 1980s

Additionally, the most advanced missiles are still produced by states with traditionally strong positions in the global missile market and with advanced industrial manufacturing capabilities. However, the emergence of states such as South Korea, which had no market share during the Cold War but is now a leading missile producer and exporter, along with the increase in the raw number of missile-producing states, indicates that the global missile market has been disrupted by new suppliers of missile technology.

Overall, increasing availability on the supply side, coupled with growing global demand for missile technology, has resulted in an international environment that is prone to proliferation. Further, as the sections below demonstrate, the availability and effectiveness of dedicated missile counter-proliferation tools is limited.

Missile defence

Although not the main focus of this learning unit, it is useful to briefly consider the requirements for effective missile defence, given that they directly relate to the characteristics of the types of missile capabilities outlined above. Further, it's important to recognise that missile defence is not just a technical issue but also a deeply political one, especially considering its implications in the nuclear domain.

Modern missile defence systems consist of several elements. Typically, this includes a radar system that detects and potentially classifies incoming threats, the interceptor that engages incoming missile projectiles, one or several launcher units that launch said interceptors and a command and control unit that coordinates the missile defence engagement, for example by prioritising and allocating targets. Depending on the missile defence system, two or more of these elements may be integrated into one vehicle or combat station.

German Patriot system at an exhibition, 2013

Test-firing of Patriot missiles, 2019
U.S. Army/Jason Cutshaw

Depending on the type of missile threat the missile defence system is defending against, the set-up and capabilities of the missile defence system differ, especially in terms of the radar and the interceptor. Missile defence systems optimised to engage non-air-breathing threats, such as ballistic missiles, must be equipped with radars that can look high up into and potentially outside the atmosphere to detect and track incoming objects, and to guide an interceptor to the missile target. Given the trajectory of ballistic missiles, ballistic missile defence radars must be able to detect targets at high altitudes and at fairly long ranges.

In contrast, missile defence systems optimised for engaging air-breathing threats, such as cruise missiles, typically employ radars that scan for targets much closer to the ground, due to the relatively low altitude from which these threats approach. This means that the radar often has to deal with much more radar clutter, such as birds, treetops, buildings and terrain features that are not present at higher levels of the atmosphere. To overcome this, low-altitude radars employ clutter maps, mechanical and software-based filtering techniques, and narrow beam widths, among others. However, there are trade-offs between the radar's ability to discriminate clutter and its range, limiting the distance at which low-altitude objects can be detected.

Given the longer range of engagement, interceptor missiles optimised for defending against high-altitude non-air-breathing threats are typically equipped with larger boosters and sometimes consist of several stages, similar to some types of ballistic missiles. These types of interceptors can also be equipped with a kill vehicle that separates from the booster to intercept the incoming missile threat, either by directly colliding with the projectile or by detonating a warhead. Depending on the range of the ballistic missile being engaged, interception may take place outside the atmosphere. In this case, late stage manoeuvring can be difficult for the interceptor due to the low atmospheric density. To retain the manoeuvrability necessary to successfully engage incoming missiles and RVs, thrust motors on the interceptor may be necessary. In contrast, interceptors optimised to engage air-breathing threats are usually single stage, employ fragmentation warheads and rely on aerodynamic control surfaces for manoeuvring, which is feasible due to the higher atmospheric density at lower altitudes.

The important thing to remember is that the flight profile and characteristics of the missile system matter for missile defence. Moreover, given the different requirements for distinct types of missiles, not every type of missile defence system will be able to deal with every type of missile threat. This is why analysts typically talk about the need to deploy layered missile defence systems whereby different types of missile defence capabilities defend a target area together.[2]

For example, if a state only deploys missile defence systems optimised to defend against non-air-breathing threats such as ballistic missiles, the defended area may still be vulnerable to air-breathing threats, such as cruise missiles. In addition, the attacker might be able to attack and destroy the ballistic missile defence system with a cruise missile, and can subsequently attack the target area again with ballistic missiles and other types of non-air-breathing threats. Different types of missile defence systems must therefore not only coordinate to defend a certain target area, but also to defend one another against distinct types of missile threats.

As outlined above, missile defence has always had a strong political dimension, especially within the context of nuclear strategy. During the Cold War, ballistic missile defence was often seen as an offensive capability. This perception stemmed from the potential for such systems to enable a nuclear first strike by intercepting and neutralising an adversary's remaining nuclear weapons after an initial attack, thereby undermining the assured second-strike capability of a nuclear-armed state.

In response, the United States and the Soviet Union signed the **Anti-Ballistic Missile (ABM)** Treaty in 1972 (see also LU20 `[/lu-20/]`). This treaty limited each superpower to two missile defence complexes each, with no more than 100 interceptors deployed – an amount deemed insufficient to threaten the adversary's assured retaliatory capability. While the Soviet Union decided to place their system near Moscow, the US placed theirs near an ICBM base not far from Grand Forks, North Dakota.

Placement of the missile defence systems agreed in the ABM Treaty during the Cold War
Data: Natual Earth. Graphic: PRIF

Despite this agreement, strategic missile defence remained controversial.[3] Thirty years after the treaty was signed, the George W. Bush administration withdrew from the ABM Treaty, citing a growing ballistic missile threat from "rogue actors" such as Iran and North Korea.

Missile defence has since been a contentious issue in NATO-Russia and US-China relations. China and Russia accuse the United States and its European and Asian allies of undermining strategic stability by increasing their missile defence capabilities, especially in combination with other types of advanced non-nuclear technologies. [4] Conversely, the United States and its partners argue that these deployments are essential due to the rising conventional missile threat from various actors, most notably China and Russia.

1. Fabian Hoffmann, Cruise Missile Proliferation: Trends, Strategic Implications, and Counterproliferation (London: European Leadership Network, 2021), [https://www.europeanleadershipnetwork.org/wp-content/uploads/2021/03/Fabian_Final-2.pdf]
2. The Strategic Implications of Layered Missile Defence, Strategic Comments (London: International Institute for Strategic Studies, 2021), [https://www.iiss.org/en/publications/strategic-comments/2021/layered-missile-defence/]
3. Andrew Futter and Benjamin Zala, "Advanced Conventional Weapons and Nuclear Disarmament: Why the Obama Plan Didn't Work," The Nonproliferation Review 20, no. 1 (2013): 107-122, [https://doi.org/10.1080/10736700.2012.761790].
4. Tong Zhao,"Conventional Long-Range Strike Weapons of US Allies and China's Concerns of Strategic Instability," The Nonproliferation Review 27, no. 1–3 (2020), 109–22, [https://www.tandfonline.com/doi/full/10.1080/10736700.2020.1795368]

4. The political side of missiles

Restrictions and limitations

States have generally demonstrated an interest in limiting the proliferation of missiles and regulating their most destabilising implications. This pertains especially to longer-range missiles that could be suitable delivery vehicles for chemical, biological or nuclear warheads.

As a result, state actors have included missile technologies in several binding arms control agreements, especially those related to nuclear weapons. They established treaties with stringent regulations on missile technology, such as the Interim Agreement on Strategic Offensive Arms resulting from the SALT I negotiations, the Intermediate-Range Nuclear Forces Treaty, and the New START Treaty.

In addition, state actors devised a range of missile counter-proliferation tools designed to stop or at least slow down the global spread of missiles by creating several voluntary export control regimes and confidence-building measures surrounding the acquisition, deployment and use of missile technologies, including dual-use components. These include the Missile Technology Control Regime, the Hague Code of Conduct, the Wassenaar Arrangement and the Australia Group.

The following section looks at these arms control treaties and counter-proliferation tools in more detail. The section starts by discussing landmark treaties that comprehensively regulated the deployment and use of missile technology before reviewing voluntary agreements related to missile technology counter-proliferation.

Legally binding agreements

Binding political agreements impose legally enforceable obligations on member states, with established mechanisms for accountability and consequences for violations. In the context of missile proliferation, three politically binding agreements are of particular importance: The Strategic Arms Limitation Treaty (SALT I) and the Interim Agreement on Strategic Offensive Arms, the Intermediate-Range Nuclear Forces (INF) Treaty and the New START Treaty (as well as its predecessor).

The primary goal of these treaties was not to curb missile proliferation but to ensure strategic stability between participating states in the nuclear domain. Further, since 2019, the INF Treaty has no longer been in force, and the New START Treaty is in a precarious state after Russia announced in February 2023 that it was suspending its participation. Nevertheless, the treaties mentioned in this section have played an important role in shaping the global missile landscape of the 21st century.

SALT I and the Interim Agreement on Strategic Offensive Arms

The **Interim Agreement on Strategic Offensive Arms**, signed in 1972 as part of the broader Strategic Arms Limitation Talks (SALT I), was the first major instrument of control between the United States and the Soviet Union during the Cold War (see also LU20 `[/lu-20/]`). This agreement aimed to cap the escalating arms race, particularly the proliferation of strategic ballistic missile technology.

The agreement specifically regulated the deployment of ICBMs and submarine-launched ballistic missiles (SLBMs), which were the primary means of delivering strategic nuclear warheads across vast distances. Under the terms of the Interim Agreement, both Cold War superpowers agreed to freeze the number of ICBM and SLBM launchers at the levels that were either operational or under construction as of 1 July 1972. The United States was allowed to retain 1,054 ICBMs and 656 SLBMs, while the Soviet Union was permitted 1,618 ICBM launchers and 740 SLBM. [1] These limits reflected the existing strategic balance, with the Soviet Union having a larger number of ICBMs and the United States maintaining a superior number of SLBMs.

As such, the Interim Agreement played an important role in curbing the vertical proliferation of strategic nuclear delivery vehicles, particularly ICBMs and SLBMs, in the arsenals of the participating states. However, it did not address MIRV technology, which was beginning to enter into service on a larger scale at the time. Consequently, while the agreement limited the growth of strategic missile launcher capabilities in American and Soviet arsenals, it did not prevent the overall increase in the number of strategic nuclear warheads.

The Interim Agreement was intended to have a duration of five years and was thus due to expire in October 1977. However, both sides continued to abide by its provisions beyond this date until the SALT II agreement was signed in 1979, though SALT II was never ratified by the United States Senate due to the Soviet invasion of Afghanistan. Despite the lack of ratification, both countries largely observed the terms of SALT II until it was superseded by **the Strategic Arms Reduction Treaty (START I)** in 1991 (see also LU20 `[/lu-20/]`).

TREATY

Treaty on the Non-Proliferation of Nuclear Weapons

Effective 05 April 1970 Legally binding 191 Member States

The Treaty on the Non-Proliferation of Nuclear Weapons (NPT) is a central part of the global effort to prevent the spread of nuclear weapons, promote cooperation in peacful uses of nuclear energy, and to further the goal of nuclear and general disarmament.

Current Adoption

AFG	AUS	AUT	BRB	BEL	BEN	BOL	BWA	BGR	BFA	CMR	CAN
TCD	COL	COG	CRI	CIV	CYP	COD	DNK	DOM	ECU	EGY	SLV
SWZ	ETH	FIN	GMB	DEU	GHA	GRC	GTM	HTI	HND	HUN	ISL
IDN	IRN	IRQ	IRL	ITA	JAM	JPN	JOR	KEN	KWT	LAO	LBN
LSO	LBR	LBY	LUX	MDG	MYS	MDV	MLI	MLT	MUS	MEX	MNG
MAR	NPL	NLD	NZL	NIC	NGA	NOR	PAN	PRY	PER	PHL	POL
KOR	ROU	RUS	SMR	SEN	SGP	SOM	LKA	SDN	SWE	CHE	SYR
TGO	TTO	TUN	TUR	GBR	USA	URY	VEN	YEM	ALB	DZA	AND
AGO	ARG	ARM	AZE	BHR	BGD	BLR	BTN	BRA	BRN	BDI	CPV
KHM	CAF	CHL	CHN	COM	CUB	PRK	DJI	GNQ	ERI	EST	FRA
GAB	GEO	GIN	GNB	GUY	VAT	KAZ	KGZ	LVA	LIE	LTU	MWI
MHL	MRT	FSM	MCO	MOZ	MMR	NAM	NRU	NER	OMN	PLW	PNG
PRT	QAT	MDA	RWA	KNA	WSM	STP	SAU	SYC	SLE	ZAF	ESP
PSE	TJK	THA	TLS	TKM	UGA	UKR	ARE	TZA	UZB	VUT	VNM
ZMB	ZWE	ATG	BHS	BLZ	BIH	HRV	CZE	DMA	FJI	GRD	KIR
MNE	MKD	LCA	VCT	SRB	SVK	SVN	SLB	SUR	TON	TUV	COK
IND	ISR	NIU	PAK	SSD							

- Adopted by ratification
- Adopted by accession, acceptance, or succession
- Not adopted

Data: United Nations Treaty Collection

The Intermediate-Range Nuclear Forces Treaty (INF)

The **INF Treaty**, signed in 1987 by the United States and the Soviet Union, aimed to eliminate all ground-launched ballistic and cruise missiles with ranges between 500 and 5,500 kilometres, along with their launchers. [2] Its purpose was to reduce the threat of intermediate-range nuclear missiles in Europe, which were seen as posing a significant risk to strategic stability because of their short flight time and the minimal warning time they provide. By 1991, nearly 2,700 missiles had been destroyed, including the well-known American Pershing II and Soviet RSD-10 Pioneer (SS-20 Saber) IRBMs.

The INF Treaty significantly reshaped the missile landscape by eliminating large parts of ground-launched missile arsenals in NATO and Warsaw Pact countries. However, its influence persisted long after the Cold War because the treaty not only temporarily reduced missile stockpiles but completely banned a specific class of missiles. As a result, countries ceased developing and producing ground-launched intermediate-range missile capabilities, at least until Russia violated the treaty by developing the 9M729 ground-launched cruise missile (SS-C-8 Screwdriver), which fell within the range limitations of the INF Treaty.

As such, the INF Treaty significantly reduced the demand for ground-launched missile systems within NATO and beyond, dramatically curbing both their vertical and horizontal proliferation. Since the treaty's demise, NATO member states, particularly the United States, have scrambled to rebuild missile systems that had previously been banned. Efforts include the American precision strike missile, or short PrSM, an SRBM with a range of 499 to 1,000 km (depending on the variant), a containerised ground-launched Tomahawk variant, and a joint European project for a ground-launched cruise missile with a range of over 1,000 km, for example.

This indicates that the effects of the INF Treaty on missile proliferation, while significant, were only of a temporary nature. This is especially the case since the war in Ukraine has highlighted the military utility of ground-launched missile systems with ranges of 500 kilometres or more.[3]

TREATY

Intermediate-Range Nuclear Forces Treaty (INF)

Effective 08 December 1987 Ended 2 Member States

The Intermediate-Range Nuclear Forces (INF) Treaty was a landmark arms control agreement signed by the United States and the Soviet Union on December 8, 1987. It aimed to eliminate both nations' land-based missiles with ranges between 500 and 5,500 kilometers. The treaty resulted in the destruction of 2,692 missiles and included extensive verification measures, fostering trust during the Cold War. However, the treaty faced challenges due to alleged violations, leading to the U.S.'s withdrawal in 2019. Despite its termination, the INF Treaty set a precedent for arms control negotiations and efforts to limit the proliferation of nuclear-capable missile systems.

Current Adoption

		AFG	AGO	ALB	AND	ARE	ARG	ARM	ATG	AUS	AUT
AZE	BDI	BEL	BEN	BFA	BGD	BGR	BHR	BHS	BIH	BLR	BLZ
BOL	BRA	BRB	BRN	BTN	BWA	CAF	CAN	CHE	CHL	CHN	CIV
CMR	COD	COG	COK	COL	COM	CPV	CRI	CUB	CYP	CZE	DEU
DJI	DMA	DNK	DOM	DZA	ECU	EGY	ERI	ESP	EST	ETH	FIN
FJI	FRA	FSM	GAB	GBR	GEO	GHA	GIN	GMB	GNB	GNQ	GRC
GRD	GTM	GUY	HND	HRV	HTI	HUN	IDN	IND	IRL	IRN	IRQ
ISL	ISR	ITA	JAM	JOR	JPN	KAZ	KEN	KGZ	KHM	KIR	KNA
KOR	KWT	LAO	LBN	LBR	LBY	LCA	LIE	LKA	LSO	LTU	LUX
LVA	MAR	MCO	MDA	MDG	MDV	MEX	MHL	MKD	MLI	MLT	MMR
MNE	MNG	MOZ	MRT	MUS	MWI	MYS	NAM	NER	NGA	NIC	NIU
NLD	NOR	NPL	NRU	NZL	OMN	PAK	PAN	PER	PHL	PLW	PNG
POL	PRK	PRT	PRY	PSE	QAT	ROU	RWA	SAU	SDN	SEN	SGP
SLB	SLE	SLV	SMR	SOM	SRB	SSD	STP	SUR	SVK	SVN	SWE
SWZ	SYC	SYR	TCD	TGO	THA	TJK	TKM	TLS	TON	TTO	TUN
TUR	TUV	TZA	UGA	UKR	URY	UZB	VAT	VCT	VEN	VNM	VUT
WSM	YEM	ZAF	ZMB	ZWE							

■
■ Not adopted

Data: United Nations Treaty Collection

New START Treaty

The New Strategic Arms Reduction Treaty (New START), effective since 2011 between the United States and Russia, limits each country to 1,550 deployed strategic nuclear warheads and 700 deployed strategic nuclear launchers (ICBMs, SLBMs and bombers). It also caps the total number of deployed and non-deployed strategic nuclear launchers at 800. [4] The treaty includes extensive verification measures such as on-site inspections, data exchanges and notifications to ensure compliance. New START is the successor to the 1991 START Treaty. As mentioned above, the 1991 treaty succeeded the 1972 Interim Agreement on Strategic Offensive Arms and reduced the deployment levels of strategic delivery vehicles to 1,600, with a maximum of 6,000 deployed strategic nuclear warheads.

Similar to the INF Treaty, the primary objective of the New START Treaty is to maintain and enhance strategic stability between participating states. This goal is pursued by alleviating arms race pressures through mutually agreed limits on strategic nuclear warheads and their delivery vehicles. New START reduced the need to build additional strategic nuclear delivery vehicles, including ICBMs and SLBMs. It also reduces the need to develop specific missile technologies like MIRVs, as the ratio of nuclear warheads to missiles and bombers renders MIRV technology less important. For example, the Mk-12A re-entry vehicle deployed on the American LGM-30G Minuteman III ICBM could theoretically carry up to three warheads. However, at present, each re-entry vehicle carries only one to comply with New START limits.

Since Russia announced its intention to suspend its participation in the treaty in February 2023, New START faces an uncertain future. This has made vertical proliferation of strategic nuclear delivery vehicles and warheads more likely, although neither the United States nor Russia have publicly acknowledged a desire to go beyond the treaty’s deployment limits. Given China’s nuclear expansion and the growing Russian threat, the United States is likely to face mounting pressure to engage in vertical proliferation efforts. Depending on the future expansion of ICBM and SLBM arsenals in both Russia and the United States, the missile-related counter-proliferation benefits of the New START Treaty and its predecessor may be temporary.

TREATY

New Strategic Arms Reduction Treaty (New START)

Effective 08 April 2010 Legally binding 2 Member States

The New START Treaty (Strategic Arms Reduction Treaty) is a bilateral arms control agreement between the United States and Russia, signed on April 8, 2010, in Prague. It limits each country to 1,550 deployed nuclear warheads, 700 deployed intercontinental ballistic missiles (ICBMs), submarine-launched ballistic missiles (SLBMs), and heavy bombers, as well as 800 total launchers. The treaty includes robust verification measures, such as data exchanges, on-site inspections, and notifications to ensure compliance. It builds on previous arms control agreements to promote strategic stability. Originally set to expire in 2021, it was extended for five years until February 2026, remaining a critical framework for reducing nuclear arsenals.

Current Adoption

RUS	USA	AFG	AGO	ALB	AND	ARE	ARG	ARM	ATG	AUS	AUT
AZE	BDI	BEL	BEN	BFA	BGD	BGR	BHR	BHS	BIH	BLR	BLZ
BOL	BRA	BRB	BRN	BTN	BWA	CAF	CAN	CHE	CHL	CHN	CIV
CMR	COD	COG	COK	COL	COM	CPV	CRI	CUB	CYP	CZE	DEU
DJI	DMA	DNK	DOM	DZA	ECU	EGY	ERI	ESP	EST	ETH	FIN
FJI	FRA	FSM	GAB	GBR	GEO	GHA	GIN	GMB	GNB	GNQ	GRC
GRD	GTM	GUY	HND	HRV	HTI	HUN	IDN	IND	IRL	IRN	IRQ
ISL	ISR	ITA	JAM	JOR	JPN	KAZ	KEN	KGZ	KHM	KIR	KNA
KOR	KWT	LAO	LBN	LBR	LBY	LCA	LIE	LKA	LSO	LTU	LUX
LVA	MAR	MCO	MDA	MDG	MDV	MEX	MHL	MKD	MLI	MLT	MMR
MNE	MNG	MOZ	MRT	MUS	MWI	MYS	NAM	NER	NGA	NIC	NIU
NLD	NOR	NPL	NRU	NZL	OMN	PAK	PAN	PER	PHL	PLW	PNG
POL	PRK	PRT	PRY	PSE	QAT	ROU	RWA	SAU	SDN	SEN	SGP
SLB	SLE	SLV	SMR	SOM	SRB	SSD	STP	SUR	SVK	SVN	SWE
SWZ	SYC	SYR	TCD	TGO	THA	TJK	TKM	TLS	TON	TTO	TUN
TUR	TUV	TZA	UGA	UKR	URY	UZB	VAT	VCT	VEN	VNM	VUT
WSM	YEM	ZAF	ZMB	ZWE							

□ Adopted by ratification
■ Not adopted

Data: United Nations Treaty Collection

Voluntary agreements

Voluntary political agreements depend on the goodwill and commitment of participating states to follow the agreed-upon guidelines. Although compliance can be enforced externally, such as through sanctions or political pressure, these agreements lack internal enforcement mechanisms. Additionally, they confer rights and duties only to member states and do not automatically apply to non-member states.

In the context of missile technology and missile non-proliferation, four voluntary agreements are particularly important: **The Missile Technology Control Regime (MTCR)**, **The Hague Code of Conduct against Ballistic Missile Proliferation (HCoC)**, the **Wassenaar Agreement** and the **Australia Group**.

The MTCR is arguably the most important for preventing missile proliferation, covering a broad range of missile-related technology transfers. The HCoC is a trust- and confidence-building measure focused particularly on ballistic missiles. While not an export control regime, the HCoC has contributed to missile non-proliferation by advancing a norm against ballistic missile proliferation. The Wassenaar Agreement and the Australia Group complement the MTCR and HCoC by enhancing the effectiveness and comprehensiveness of missile technology export controls and providing platforms for international exchange

Missile Technology Control Regime

Established in 1987, the Missile Technology Control Regime (MTCR) is a voluntary partnership among countries seeking to prevent the proliferation of missile and unmanned aerial vehicle technology capable of delivering weapons of mass destruction. Membership originally comprised seven countries with advanced industrial and missile manufacturing capabilities but has since grown to 35 member states.

The MTCR provides guidelines for controlling the export of missile-related technology. The MTCR Annex comprises a detailed list of items subject to export controls, divided into two categories based on their sensitivity and potential impact on missile proliferation. [5]

1. **Category I items**: Complete missile systems (including cruise missiles, ballistic missiles, long-range OWA drones) with the capability to deliver a payload of at least 500 kg to a range of at least 300 km, as well as major subsystems (e.g. rocket boosters, RVs or guidance kits).
2. **Category II items**: Less sensitive and dual-use missile-related components and technology, including propulsion systems, propellants, structural materials, navigation systems and related technologies that could be used in missile development but also have civilian applications.

Exports of Category I items are subject to a strong presumption of denial. This means that the default position is to deny export licenses for these items and approval is only considered under rare and exceptional circumstances. In the rare instances where an export license is granted for a Category I item, it typically involves stringent conditions, such as assurances regarding end-use and safeguards against diversion to unauthorised uses or third parties. In contrast, while Category II items are controlled, there is more flexibility regarding their export, allowing for case-by-case evaluations based on risk assessments.

The MTCR has been relatively effective in establishing a common framework for controlling missile technology exports. However, several challenges remain:[6]

- **No enforcement mechanism:** The MTCR is a voluntary regime without binding enforcement mechanisms. Compliance relies on the goodwill and commitment of member states.
- **Non-member states:** Some significant missile technology holders and proliferators, including China (though it claims to adhere to MTCR guidelines), North Korea, Iran, Pakistan and Israel, are not members of the MTCR, limiting its global reach.
- **Dual-use technologies:** The proliferation of missile-related dual-use technologies, which have both civilian and military applications, complicates export control efforts.
- **Variable national controls:** Differences in the national implementation and enforcement of the MTCR guidelines can create gaps and inconsistencies. For example, in the early 2000s, France exported land-attack cruise missiles to the United Arab Emirates, a move that was met with strong objections from the United States on the basis of the MTCR.[7]

Overall, the MTCR has been moderately effective in curbing missile proliferation by establishing guidelines and fostering international cooperation to control the export of missile-related technologies. It has successfully restricted access to key missile technologies on the global market. However, challenges persist, and its future relevance is uncertain, most notably due to the horizontalisation of missile-related manufacturing capabilities and the growing significance of missile-related dual-use items that are difficult to control.[8]

INSTITUTION

Missile Technology Control Regime

Established 16 April 1987 35 Members

The Missile Technology Control Regime (MTCR) is a multilateral, voluntary partnership to prevent the proliferation of missile and unmanned aerial vehicle (UAV) technology capable of delivering weapons of mass destruction (WMD). It focuses on controlling exports of missiles, equipment, software, and technology for missiles.

The Missile Technology Control Regime focuses on controlling exports of missiles, equipment, software, and technology for missiles falling into two categories

- **Category I**: Includes complete missile systems (including ballistic missiles, space launch vehicles and sounding rockets) with capabilities exceeding a 300km/500kg range/payload threshold; This category also includes major subsystems, and production facilities, with the strictest controls to discourage export entirely except under rare circumstances.
- **Category II**: Covers less sensitive items like complete missile systems not falling under category I with a maximum range equal to or greater than, 300km, as well as components and dual-use technologies, allowing more flexibility under carefully evaluated conditions.

A comprehensive “Equipment, Software and Technology Annex” covers the two categories in more detail. Though not legally binding, the MTCR has significantly influenced international efforts to curb the spread of missile technologies, promoting global security and non-proliferation.

There are currently 35 countries that are members (Partners) of the MTCR, with the date in brackets represents the initial year of membership: Argentina (1993); Australia (1990); Austria (1991); Belgium (1990); Brazil (1995); Bulgaria (2004); Canada (1987); Czech Republic (1998); Denmark (1990); Finland (1991); France (1987); Germany (1987); Greece 1992); Hungary (1993); Iceland (1993); India (2016); Ireland (1992); Italy (1987); Japan (1987); Luxemburg (1990); Netherlands (1990); New Zealand (1991); Norway (1990); Poland (1998); Portugal (1992); Republic of Korea (2001); Russian Federation (1995); South Africa (1995); Spain (1990); Sweden (1991); Switzerland (1992); Turkey (1997); Ukraine (1998); United Kingdom (1987); United States of America (1987).

Hague Code of Conduct against Ballistic Missile Proliferation

The Hague Code of Conduct against Ballistic Missile Proliferation (HCoC) aims to address the global security challenges posed by the proliferation of ballistic missile technology. The HCoC seeks to promote transparency, confidence-building, and restraint in the development and deployment of ballistic missiles capable of delivering weapons of mass destruction. [9] The code is not legally binding but represents a political commitment by its subscribing states to adhere to its principles and guidelines. The HCoC was adopted in 2002 by 96 states. Since then, membership has grown to 140 states.

Member states commit to exercising restraint in the development, testing and deployment of ballistic missile technologies capable of delivering weapons of mass destruction. This includes refraining from transferring technology that could contribute to the development or enhancement of such missiles.

In addition, the HCoC serves as an important transparency and confidence-building measure by facilitating pre-launch notifications for ballistic missile and space-launch vehicles (SLV), as well as the exchange of information related to ballistic missile programmes:

- **Pre-launch notifications:** Member states are encouraged to provide advance notification of planned ballistic missile launches, including SLVs, to enhance transparency and reduce misperceptions.
- **Exchange of information:** States are encouraged to exchange information on their ballistic missile policies, programmes and activities through confidence-building measures (CBMs), such as annual declarations and notifications of significant changes.

Similar to the MTCR, challenges to the HCoC's effectiveness largely relate to its non-binding nature, implementation and limited membership:

- **Non-binding nature:** Much like the MTCR, the HCoC is only a politically binding commitment and compliance with its provisions is voluntary. There are no legally binding enforcement mechanisms.
- **Implementation challenges:** The effectiveness of the HCoC relies heavily on the willingness of member states to voluntarily implement its guidelines and transparency and confidence-building measures. For example, Russia has been criticised in the past for not providing timely or detailed notification of missile tests.
- **Limited membership:** Important non-member states and entities outside the regime's scope continue to engage in missile proliferation activities, undermining the code's objectives. Several states with significant ballistic missile programmes and arsenals, such as China, North Korea, Pakistan and Iran, remain outside the HCoC's membership.

The HCoC's future appears uncertain. Although there have been efforts to develop the code into a legally binding instrument, these efforts have not proven successful. In addition, the war in Ukraine has reinforced the military utility of ballistic missiles, likely increasing demand for the technology in the future. Nevertheless, the HCoC has played a role in creating a norm against ballistic missile proliferation and enhancing transparency between participating member states.

INSTITUTION

The Hague Code of Conduct against Ballistic Missile Proliferation

Established 26 November 2002 143 Members

The Hague Code of Conduct against Ballistic Missile Proliferation (HCoC) is a multilateral, voluntary initiative aimed at preventing the spread of ballistic missiles capable of delivering weapons of mass destruction (WMD). Established in 2002, it complements existing non-proliferation measures like the Missile Technology Control Regime (MTCR). The HCoC promotes transparency and confidence-building through annual declarations on ballistic missile and space-launch programs, as well as pre-launch notifications. While not legally binding, it encourages responsible behavior among its 145 subscribing states, serving as a critical tool for global security by fostering dialogue and cooperation to limit the proliferation of missile technologies.

Wassenaar Arrangement and Australia Group

The Wassenaar Arrangement and the Australia Group are international export control regimes that, while not exclusively focused on missile proliferation, play complementary roles in curbing the spread of missile-related technologies. Both regimes work alongside the MTCR and the HCoC to enhance global missile non-proliferation efforts.

The Wassenaar Arrangement on Export Controls for Conventional Arms and Dual-Use Goods and Technologies is a multilateral export control regime with 42 participating states. It was established in 1996 to promote transparency and responsibility in transfers of conventional arms and dual-use goods and technologies.

The Wassenaar Arrangement maintains detailed control lists of dual-use goods and technologies, including items relevant to missile development, such as precision machine tools, electronics and materials. By controlling the export of these dual-use items, the Wassenaar Arrangement helps prevent their diversion for use in missile programmes.

INSTITUTION

Wassenaar Arrangement

Established 12 July 1996 42 Members

The Wassenaar Arrangement is a multilateral export control regime established on July 12, 1996, in Wassenaar, Netherlands. It aims to promote transparency and responsibility in transfers of conventional arms and dual-use goods and technologies, thereby preventing destabilizing accumulations. Participating states implement national policies to ensure that such transfers do not contribute to the development or enhancement of military capabilities that undermine regional and international security. The Arrangement facilitates information exchange on transfers and denials of specified controlled items to non-participating states, enhancing cooperation among members. It is not legally binding and decisions are made by consensus. The Wassenaar Arrangement's Secretariat is located in Vienna, Austria.

The Australia Group is an informal forum of countries established in 1985 to prevent the spread of chemical and biological weapons. It currently has 43 member countries that coordinate export controls on chemical and biological materials, equipment and technologies.

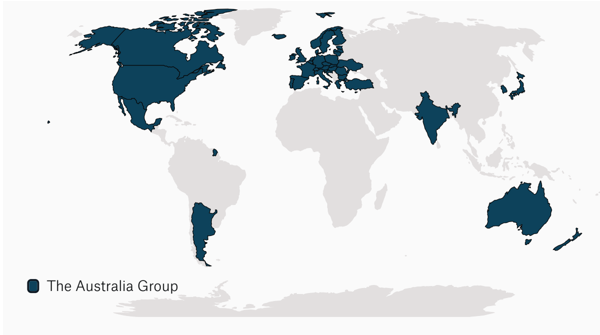
The Australia Group's control lists include precursor chemicals and biological agents that could be used in the manufacture of chemical or biological warheads for missiles. Controlling the export of these items reduces the risk of them being used in missile-delivered chemical or biological weapons. Member states harmonise their national export controls based on agreed guidelines to make sure that items critical to missile-related weapons of mass destruction programmes are tightly regulated.

INSTITUTION

Australia Group

Established 01 June 1996 43 Members

The Australia Group (AG) is a multilateral export control regime formed in June 1985 to prevent the proliferation of chemical and biological weapons. It harmonizes export controls among member countries to ensure that exports do not contribute to the development of such weapons. The AG maintains control lists of chemicals, biological agents, and related equipment that could be misused for weapons production. Members commit to implementing these controls and sharing information to enhance global security. The group convenes annually to review and update its control measures in response to emerging threats.



Member States of the Australia Group
Data: Natual Earth. Graphic: PRIF

Overall, the Wassenaar Arrangement and the Australia Group play an important role in curbing missile proliferation by controlling dual-use technologies, materials and equipment that could contribute to missile programmes. Their efforts complement the MTCR's focus on missile technology export control and the HCoC's transparency and confidence-building measures. These regimes increase the robustness of the global missile non-proliferation framework by addressing gaps and controlling otherwise unmonitored materials and technologies. Further, they offer additional platforms for information exchange and coordination.

1. Bureau of International Security and Non-Proliferation, Interim Agreement Between The United States of America and The Union of Soviet Socialist Republics on Certain Measures With Respect to the Limitation of Strategic Offensive Arms, U.S. Department of State, [https://2009-2017.state.gov/t/isn/4795.htm].
2. Bureau of Arms Control, Verification, and Compliance, 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, [https://2009-2017.state.gov/t/avc/trty/102360.htm].
3. Jonas Schneider and Torben Arnold, Significant and Sound: US Medium-Range Missiles in Germany, SWP Comment, 2024, https://www.swp-berlin.org/10.18449/2024C30/#:~:text=At%20the%20NATO%20summit%20in,reach%20targets%20in%20Russia’s%20heartland [https://www.swp-berlin.org/10.18449/2024C30/#:~:text=At%20the%20NATO%20summit%20in,reach%20targets%20in%20Russia's%20heartland]
4. Bureau of Arms Contro, Deterrence, and Stability, New START Trearty, U.S. Department of State, [https://www.state.gov/new-start/].
5. Missile Technology Control Regime, Guidelines for Sensitive Missile-Relevant Transfers, [https://www.mtcr.info/en/mtcr-guidelines/guidelines-for-transfer].
6. William Alberque, Revitalising Arms Control: The MTCR and the HCoC (London: International Institute for Strategic Studies, 2022), https://www.iiss.org/globalassets/media-library---content—migration/files/research-papers/iiss_revitalising-arms-control-the-mtcr-and-the-hcoc_mdi-02112021.pdf [https://www.iiss.org/globalassets/media-library---content--migration/files/research-papers/iiss_revitalising-arms-control-the-mtcr-and-the-hcoc_mdi-02112021.pdf].
7. Jeffrey Lewis, Storm Shadow, Saudi, and the MTCR, Arms Control Wonk, 2011, [https://www.armscontrolwonk.com/archive/204051/saudi-arabia-storm-shadow-the-mtcr/].
8. Kolja Brockmann, Dr Mark Bromley and Lauriane Héau, The Missile Technology Control Regime at a Crossroads: Adapting the Regime for Current and Future Challenges (Stockholm: SIPRI, 2022), [https://doi.org/10.55163/YCVA4831]
9. Hague Code of Conduct, Background Documents, [https://www.hcoc.at/background-documents/text-of-the-hcoc.html]

5. Outlook

The future of missile proliferation

Trends in missile proliferation

Moving into the future, missile proliferation is likely to continue at the current pace, if not accelerate. As outlined above, the reasons for this relate to both the demand and supply side of missile procurement. States recognise the military advantages that comprehensive and advanced missile arsenals provide them in conventional and nuclear war. At the same time, the number of missile-producing states has increased in recent decades, and missile manufacturing capability is likely to spread further. Moreover, **traditional missile counter-proliferation tools** lack proper means of enforcement and appear increasingly unequipped to deal with the dual-use nature of modern missile technology.[1]

Importantly, this also relates to the inherent and growing dual-use nature of missile technology. As civilian high-technology companies proliferate across the world, the availability of missile-related technology on the civilian market will also increase. Moreover, as these civilian products become more sophisticated, their potential for use in military programmes will grow.

For example, due to Western sanctions and the inability to import high-tech products from the West, Russia has reportedly been repurposing gyroscopes from heavy agricultural equipment such as tractors for use in inertial navigation units guiding their 9M723 SRBMs. This would have been unthinkable a few decades ago, and although the quality of these improvised systems is unlikely to match that of military-grade products, it demonstrates the sophistication of many civilian dual-use goods today that are relatively freely available on the open market.

The landscape of missile manufacturing is also changing dramatically . Private space companies such as **SpaceX** build rockets that instead of placing satellites into orbit could, in theory, be repurposed to transport nuclear warheads into space, from where they could re-enter the atmosphere to hit a target. While there is no indication that SpaceX or similar companies are interested in this, or that governments would seek such services from private companies, it indicates that more and more individuals are being trained in a civilian technology sector with direct military applications – in this case, long-range ballistic missiles.[2]

Falcon Heavy Side Boosters landing on LZ1 and LZ2 – 2018
Courtesy of SpaceX, CC0 1.0 Universal

At the same time, the seemingly insatiable demand for missiles has led to another group of disruptive actors entering the field: startups. Particularly in the United States, a growing amount of venture capital is flowing into the missile manufacturing sector. [3] These startups claim they can produce military missile systems that are as capable as, or even superior to, those made by traditional large manufacturers, all at a competitive price and on a faster timescale. For their development and production, these new companies often emphasise the use of novel industrial technologies and processes, such as additive manufacturing. Given that the missile industry is an extremely capital-intensive sector and missile manufacturing often relies on tacit knowledge, the success of these ventures remains uncertain. Nevertheless, if successful, the emergence of small, highly innovative companies could fundamentally transform the missile industry, potentially making the technology accessible to a broader range of actors.

Finally, when it comes to countering these **proliferation trends that all point in one direction – more proliferation** – it is important to also recognise the lack of motivation to reinvigorate the debate around missile counter-proliferation. Although efforts are occasionally made to raise the profile of the **MTCR** and **HCoC**, relatively little political capital is invested in pursuing these objectives. In general, missile counter-proliferation is no longer as much of a priority as it was.

Part of this relates to the fact that missile proliferation has been somewhat decoupled from nuclear, chemical and biological weapons proliferation. Initially, efforts to counter missile proliferation focused on hindering enemy WMD programmes by preventing the acquisition of effective delivery vehicles. Today, missile proliferation mainly involves acquiring weapon systems that offer advantages in conventional warfare.

Stopping missile proliferation against the backdrop of what are legitimate efforts to bolster conventional self-defence capabilities, or can relatively easily be construed as such, provides for a much weaker normative basis to step in and limit states' acquisition programmes.

The role of the EU

This has important implications for the EU and its member states. Missile proliferation will be difficult to stop. In fact, several EU member states are currently in the process of acquiring or developing new missile capabilities, and accord relatively high priority to these procurements. Given the need to prepare for a potential future confrontation with an increasingly aggressive and hostile Russia, this makes absolute sense.

The EU, through the **European Defence Fund**, allocates money for missile defence projects. In addition, several EU member states coordinate their procurement efforts to acquire missile defence (**European Sky Shield Initiative – ESSI**), as well as offensive counter-strike capabilities (**European Long-Range Strike Approach – ELSA**)[4]. Where possible and where it makes sense to do so, these efforts should be continued and expanded.

In addition, EU member states and EU institutions have played an important role in upholding norms and policies against the uncontrolled spread of missile technology, including in the fora and regimes outlined above. By providing a forum for coordination and harmonising export control laws, the EU has played and continues to play a key role in this.

In the future, the EU and its member states would be well advised to expand their missile-related efforts both in terms of missile procurement activities and counter-proliferation policies.

First, the EU is home to a relatively large missile-producing industry that remains internationally competitive, although market share has been lost to US, South Korean and Israeli manufacturers in recent decades. From a strategic autonomy perspective, retaining and expanding this industry is of great importance. Where possible, the EU should promote the competitiveness of this industry and missile-related sectors.[5] This would also be important in terms of Europe's nascent space industry which continues to lag behind the United States, China and other international actors.

Second, missile-related counter-proliferation will remain paramount to the EU and member states, and will perhaps increasingly focus on non-state actors. Recent events in the Red Sea, where Houthi rebels equipped with modern missile capabilities have disrupted international shipping, highlight the significant threat posed by missile proliferation to these types of actors. Stopping such instances of proliferation should be a major priority for EU member states in the future. This entails limiting the spread of missile technology that could facilitate proliferation to non-state actors, but also punishing states and organisations that engage in such behaviour, including through EU sanctions. The latter will likely become increasingly important given that, as outlined above, missile manufacturing capability has already spread far and wide and are anticipated to continue to do so in the future. Addressing the root cause of the problem may therefore no longer be a feasible option and tackling the symptoms may become the more viable path going forward.

Third, European member states have supported, and to some extent continue to support, the missile programmes of systemic rivals and potential adversaries, such as Russia, China and North Korea, for example. [6] While member states have not directly provided these countries with missile capabilities, missile production tools and technologies from the EU, some of which arrived at their destinations via third-country detours, have greatly contributed to their missile programmes. For example, Western precision manufacturing tools that have been exported to Russia, including from EU countries, continue to facilitate Russia's missile war against Ukraine's population centres and critical civilian infrastructure. Member states must become more cautious about providing such technologies to third parties and consider their potential end-uses more thoroughly. The EU can potentially play an important role in setting standards harmonising export control rules, as well as pressuring third countries to follow suit.

1. Lauriane Héau and Kolja Brockmann, Intangible Transfers of Technology and Software: Challenges for the Missile Technology Control Regime (Stockholm: SIPRI, 2024), [https://doi.org/10.55163/HLWP1722].
2. Kolja Brockmann and Lauriane Héau, Developing Good Practices in Export Control Outreach to the NewSpace Industry (Stockholm: SIPRI, 2023), [https://doi.org/10.55163/BQAO1685].
3. Y Combinator, Ares Industries: Building Low-Cost Cruise Missiles, [https://www.ycombinator.com/companies/ares-industries]
4. German Ministry of Defence, European Sky Shield - Overview of the Initiative, [https://www.bmvg.de/de/aktuelles/european-sky-shield-die-initiative-im-ueberblick-5511066]; European Nations Collaborate on Long-Range Precision Strike Capabilities, Defence Industry Europe, 2024, [https://defence-industry.eu/european-nations-collaborate-on-long-range-precision-strike-capabilities/]
5. Fabian Hoffmann, Europe's Missile Conundrum, War on the Rocks, 2023, [https://warontherocks.com/2023/07/europes-missile-conundrum/]
6. Amy Mackinnon, Russia's War Machine Runs on Western Parts, Foreign Policy, 2024, [https://foreignpolicy.com/2024/02/22/russia-sanctions-weapons-ukraine-war-military-semiconductors/].