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Cruise missile proliferation: Trends, strategic implications, and counterproliferation

GLOBAL SECURITY REPORT

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The European Leadership Network (ELN) is an independent, non-partisan, pan-European network of nearly 200 past, present and future European leaders working to provide practical real-world solutions to political and security challenges.

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Executive Summary

This report seeks to inform public debate about the proliferation of cruise missiles and their strategic implications. It provides a detailed discussion of the technology behind cruise missiles, analyses how the proliferation of cruise missiles has proceeded and considers the strategic implications of cruise-missile proliferation on the European continent. The paper also outlines several policy recommendations intended to curtail the proliferation of cruise missiles and mitigate its adverse strategic consequences.

Overall, the report arrives at the following conclusions:

1. Over the decades, dozens of cruise-missile systems have come into existence, using a large variety and blend of subsystems. This makes it difficult to provide a general definition of the term 'cruise missile,' a fact that may be particularly problematic in the context of potential arms control agreements.

2. Several trends with regard to cruise-missile technology are discernible: for the near future, liquid-fuel turbojet and turbofan engines will likely remain the dominant propulsion systems used in cruise missiles. The increased adoption of solid-fuel ramjets is a possibility. Improved guidance, especially the large-scale adoption of two-way datalinks will allow cruise missiles to fly more complex missions, including swarm attacks. In addition, the increased adoption of multi-effect warheads will render cruise missiles more destructive.

3. The proliferation of cruise missiles has progressed significantly. Today, dozens of states are in possession of advanced cruise-missile capabilities, including both anti-ship and land-attack cruise missiles. In addition, nuclear-capable cruise missiles have proliferated significantly, a trend that can be expected to continue in the future.

4. The proliferation of cruise missiles has far-reaching strategic implications. While providing certain benefits, the proliferation of cruise missiles also comes with significant strategic drawbacks. Especially in a strained regional context, the proliferation of cruise missiles has the potential to undermine conventional and nuclear crisis stability.

5. A proactive attitude is required in order to counter the negative strategic implications of cruise-missile proliferation and to reverse the dangerous proliferation trends outlined in this report. In this regard, the international community should pursue a short-term agenda of establishing confidence and transparency-building measures surrounding the deployment and use of cruise missiles, while focusing on comprehensive and verifiable arms control agreements in the long-term.

Introduction

> "Today, cruise missiles are deployed by a variety of actors, both state and non-state, which seek to capitalise on the manifold advantages they possess."

In recent years, cruise missiles have received growing attention. This can be attributed to at least three developments. First, cruise missiles have been used widely in the Middle East and especially within the context of the Syrian civil war. Russia has used cruise missiles extensively against terrorists operating in Syria as well as Syrian opposition forces.[1] The US and its allies employed cruise missiles repeatedly against the Syrian army in response to chemical weapons attacks conducted by government-loyal forces.[2] More recently, cruise missiles have been used by Houthi rebels against oil facilities in Saudi Arabia, causing significant damage and interrupting the world's oil supply.[3] Second, the threat perception with regard to cruise missiles has increased in the context of the 'hypersonic turn' in missile technology. So-called scramjet engines promise to accelerate cruise missiles to speeds beyond Mach 5 (>1.7 km/s), thus improving their penetrability and destructiveness. Third, Russia has widely mediatized its development of next-generation cruise-missile capabilities, especially of its Zircon cruise missile, which reportedly reaches speeds of up to Mach 8.[4] As a result, Russia's efforts were widely shared, and the international profile of cruise missiles has correspondingly increased.

While the strong international attention paid to cruise missiles is relatively novel, their deployment and use are not. Cruise missiles were already employed during World War Two by Nazi Germany, and cruise missiles proliferated widely throughout the Cold War. However, it wasn't until the Gulf War (1990-1991) that their utility was first demonstrated in conflict.[5] The military value of cruise missiles was later reconfirmed during the military interventions in Bosnia, Serbia, Afghanistan, and especially during the Second Iraq War, where cruise missiles played a significant role in destroying the enemy's means of resistance, at least in terms of regular forces.[6]

Today, cruise missiles are deployed by a variety of actors, both state and non-state, which seek to capitalise on the manifold advantages they possess. For one thing, cruise missiles are stealthy, manoeuvrable, and able to fly at extremely low altitudes, making them difficult to intercept, especially for missile-defence systems construed for use against ballistic missiles.[7] Furthermore, cruise-missile systems enable their operators to cause significant harm without exposing their own forces to enemy fire. The deployment of cruise missiles promises, therefore, to reduce same-side casualties, rendering them perfect weapon systems for use in contested battle zones. In addition, due to their ability to be deployed in versatile land and sea-based environments as well as their high accuracy even when engaging moving targets, cruise missiles are ideal for creating and reinforcing so-called anti-access/area denial (A2/AD) networks.[8] Lastly, compared to ballistic missiles, cruise missiles are not only significantly cheaper (up to 10 times) but are also more reliable military systems.[9]

Because of their strategic value and military utility, cruise missiles will likely continue to proliferate. As a result, understanding the technology behind them and the strategic implications of their deployment and use becomes increasingly important. This report attempts to shed light on these issues.

This report is divided into four parts. The first section provides a comprehensive introduction to the technology behind cruise missiles. More specifically, it outlines the functioning of propulsion, guidance, and warhead technology employed in cruise missiles. This information is subsequently used to provide a new definition of cruise missiles that improves on earlier definitions in several points. Section two introduces three different types of cruise-missile systems that states deploy today (anti-ship, land-attack, and nuclear-armed cruise missiles) and explains how their proliferation has proceeded. The third section dives into the strategic implications of the proliferation of cruise missiles; specifically, it looks at the strategic implications of cruise-missile proliferation on the European continent, outlining several strategic benefits and drawbacks. It is argued that while cruise missiles may hold significant deterrence value, they have the potential to significantly undermine conventional and strategic stability, especially in strained regional contexts. In light of these drawbacks, section four concludes the paper by recommending a number of measures that can be taken by the international community to mitigate the adverse strategic consequences of cruise-missile proliferation and to promote cooperative security on the European continent. In this regard, it is suggested that states should aim their short-term attention at establishing confidence and transparency building measures while focusing on comprehensive and verifiable agreements in the long-term.

Cruise missiles 101

“Dozens of cruise-missile definitions exist, emphasizing different aspects of the missile system.”

At this point, a definition of the term ‘cruise missile’ seems appropriate. Unfortunately, this easier said than done. Today, dozens of cruise-missile definitions exist, emphasizing different aspects of the missile system. To a large extent, this is a result of the fact that dozens of cruise-missile systems have come into existence over the decades, using a large variety and blend of various subsystems. In addition, the technical aspects and capabilities of these subsystems have changed significantly over time. As a result, it becomes increasingly difficult to discern any universal characteristics of cruise missiles across time and space.

Generally speaking, cruise missiles consist of three critical subsystems: guidance, warhead, and propulsion. In the following, the technology behind each of these subsystems is analyzed in more detail. Subsequently, this information is used to provide an appropriate definition of the term ‘cruise missile.’

Propulsion

The propulsion system is arguably the most important subsystem with regard to the cruise missile’s performance. This is because it affects, to a significant extent, the maximum range the cruise missile is able to fly as well as its maximum speed.

In terms of the propulsion system, a basic differentiation is to be made between airbreathing and non-airbreathing engines. For combustion to take place inside the engine, two ingredients are required: a propellent and an oxidizer. Cruise missiles powered by non-airbreathing engines, usually referred to as rocket engines, must carry an oxidizer next to the propellant.[10] This increases the cruise missile’s size and weight and renders it less fuel-efficient. Cruise missiles that are powered by airbreathing engines, also called jet engines, do not have to carry this extra weight. Jet engines use the missile’s surrounding air as the engine’s oxidizer. Because of this, jet-propelled cruise missiles can carry considerably more fuel and, because of their reduced weight, are relatively more fuel-efficient.

Several types of jet engines have been developed and used in cruise missiles. The most basic form is the turbojet, a German-British coinvention dating back to the late 1930s.[11] In a turbojet engine, air is drawn into the missile through an inlet, usually located at the front, bottom, or sides of the engine. Subsequently, the drawn-in air is compressed and heated by a compressor. The compressed air is then passed through the 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. The main advantage of the turbojet is that the technology is relatively simple and well-understood. The major drawback is that turbojets, while more efficient than rocket engines, are still relatively inefficient, especially when travelling at speeds of less than Mach 2, too fast for most cruise missiles.

Because of this, many modern cruise missiles use turbofan engines (also called bypass engine), especially when longer ranges are desired. In this engine design, not all of the drawn-in air passes through the engine core. A considerable part (determined by the bypass ratio) bypasses it and is only accelerated by a ducted fan in front of the engine. The bypassing air remains relatively cool and mixes with the hot stream exhaust that passes through the engine core in the back of the turbine. This decreases the overall temperature of the exhaust stream and decelerates the velocity of the exhaust flow. In return, this increases the vehicle's fuel efficiency at subsonic speed by matching the speed of the exhaust flow more closely to the vehicle's design speed. In addition, less energy is wasted in turbulences at the back of the engine. The use of bypass engines also reduces the exhaust flow's infrared signature, making the missile harder to detect and track for enemy sensors. Many subsonic long-range cruise missiles are therefore nowadays equipped with turbofan engines.[12]

In order to reach higher velocities in the supersonic spectrum, another type of jet engine is necessary, a so-called ramjet. A ramjet is an airbreathing engine that does not include a compressor. Instead, the engine uses the forward motion of the vehicle to compress the drawn-in air. This design not only makes the engine lighter compared to a traditional jet engine, but it also allows the drawn-in air to pass through the engine faster, thus accelerating the speed of the exhaust flow. Ramjets work most efficiently at speeds of around Mach 3 but can – for physical reasons – not exceed speeds of Mach 6. In a ramjet, the air is drawn into the engine at supersonic speed and subsequently slowed down to subsonic speed and compressed. This causes the pressure and temperature in the inlet to rise significantly. As pressures and temperatures in the inlet and exhaust approach each other, less energy can be extracted through combustion, decreasing the ramjet's efficiency at higher velocities and reaching a cut-off point at around Mach 6.

In order to reach velocities beyond Mach 6, a scramjet engine is required. In contrast to the ramjet, the air in the scramjet's inlet is not slowed down to subsonic speed, allowing combustion to take place at supersonic speed. This allows the missile to reach velocities

Engine type	Airbreathing	Most efficient	Maturity
Rocket engine	No	Always	Matured
Turbojet engine	Yes	~ Mach 2	Matured
Turbofan engine	Yes	> Mach 1	Matured
Ramjet engine	Yes	~ Mach 3-6	Advanced
Scramjet engine	Yes	~Mach 3-10+	Developmental stage

Figure 1: comparison of different engine types

in the hypersonic spectrum. Although the idea behind a scramjet is relatively simple, scramjets are still in the experimental phase of development, and very few scramjet demonstrators have been successfully built and flown. This is because the challenges associated with designing a reliable scramjet engine as well as maintaining a stable trajectory at hypersonic velocities are significant.[13] And while several countries are actively working on developing an airbreathing engine capable of supersonic combustion,[14] it is rather unlikely that a fully operational scramjet engine suitable for military purposes enters into service any time soon. All the more dubious, therefore, seem Russia's recent claims to have tested successfully a scramjet-powered hypersonic cruise missile.[15] It is more likely that the reported maximum speed of "more than Mach 8" was achieved by combining a large solid-fuel rocket-booster with a regular ramjet engine. [16]

To this date, most cruise missiles are powered either by turbojet engines or more efficient turbofans. In the early stages of cruise missile development, a considerable number of cruise missiles had also been powered by rocket engines, especially when velocities in the supersonic spectrum were sought. A decreasing number of currently deployed cruise missiles, predominantly of Soviet/Russian design, are still powered by rocket engines. While ramjet-powered missiles have been around for a relatively long time[17], faster cruise missiles are becoming more and more relevant nowadays, especially in light of increasingly effective missile defence.

Finally, a note on propellants used in cruise missiles. All airbreathing cruise missiles currently deployed are powered by liquid-fuel engines.[18] This constitutes an interesting contrast with ballistic missiles, which include many designs propelled by solid-fuel rocket motors. Over the years, the possibility of turbine engines (turbojet and turbofan) running on solid propellant has been studied extensively without any groundbreaking success. To a large extent, this relates to the difficulties of regulating thrust in solid-fuel engines. In addition, cooling such solid-fuel turbine engines is difficult, impacting negatively on their durability. The general reliance on liquid fuel in cruise missiles comes with certain drawbacks, such as shorter shelf life, decreased operational readiness, and more difficult handling.[19] While turbine engines will likely continue to run on liquid fuel for the time being, solid-fuel ramjet engines are already a reality. At the moment, only one missile system exists – MBDA's Meteor air-to-air missile – that incorporates such a solid-fuel ramjet.[20] However, several other projects attempting to produce similar propulsion systems, including in India and the US (in cooperation with Norwegian partners), are currently ongoing.[21] The increased reliance on solid-fuel ramjets in future cruise missiles and other missile systems is, therefore, a possibility.

Guidance

When looking at the guidance and navigation of cruise missiles, a basic differentiation is to be made between midcourse and terminal guidance. During mission planning a so-called 'nominal trajectory' of the cruise missile is determined which meets the mission requirements. During the flight, corrections are continually applied to the trajectory in order

"When looking at the guidance and navigation of cruise missiles, a basic differentiation is to be made between midcourse and terminal guidance."

to return to the nominal. It is this sustained application of control that constitutes the distinguishing feature of midcourse guidance.[22] Importantly, the nominal trajectory of a cruise missile does not have to follow a straight line. Especially modern (but also older) cruise missiles are able to fly along much more complex trajectories with significant variation along the x and y-aches, in order to remain undetected and circumvent enemy air defences. Terminal guidance, on the other hand, refers to the guidance system that is active during the terminal stage of the light and provides final corrections to steer the missile into its target.

Midcourse Guidance	Terminal Guidance
• Inertial guidance • TERCOM • Satellite navigation	• Radar homing (active/passive/semi-active/dual-mode) • Infrared homing • Electro-optical navigation • Laser guidance • DSMAC • Image recognition software

Figure 2: types of midcourse and terminal guidance used in today's cruise missiles

The oldest and most basic tool for midcourse guidance in cruise missiles is inertial navigation. Inertial guidance systems continuously monitor the position, velocity, and acceleration of the cruise missile through at least three gyroscopes and three accelerometers.[23] This allows the system to calculate its position without recourse to external data. Unfortunately, inertial guidance suffers from 'integration drift,' a phenomenon that refers to small measurement errors that are integrated into progressively larger errors over time. In order to achieve greater precision and to shrink the cruise missile's circular error probable (CEP), some other type of navigation system must therefore periodically provide information on the position of the vehicle. During the Cold War, this was achieved by combining inertial guidance with terrain contour matching (TERCOM) navigation, a system that compares the terrain underneath the cruise missile with mapping data stored inside the missile to detect deviations from its nominal trajectory.[24] Nowadays, midcourse guidance of most cruise missiles is enhanced by satellite navigation systems, such as GPS, GLONASS, or BeiDou, which provide regular updates on the exact position of the cruise missile relative to its target.

In cruise missiles, active and passive radar homing have been used most commonly for terminal guidance. Terminal guidance also provides significant potential for AI enhancement, especially with regard to autonomous target recognition and discrimination. Interestingly, image recognition is not necessarily a novel invention in the context of cruise missile guidance. Digital scenematching area correlation (DSMAC), whereby images taken during the flight by an onboard camera are compared with stored ones, has already been used during the Cold War.[25]

Finally, datalinks become increasingly important in the guidance and navigation of cruise missiles.[26] Datalinks enable the missile system to communicate with its operator and/or other weapon systems by receiving and sending signals. For example, two-way datalinks allow cruise missiles to provide their operators with realtime updates on the field of battle (e.g. in the form of electro-optical signals), which increases situational awareness and allows operators to redirect the cruise missile, if necessary. In addition, datalinks might be used to coordinate cruise missile swarm attacks or attacks in conjunction with other types of weapon systems. By exchanging data in realtime, cruise missiles can prioritize, discriminate, and allocate targets among themselves and/or with other types of weapons, maximizing the effectiveness of cruise-missile attacks.

Warhead

While propulsion and navigation are extremely important, the relevance of the warhead system should not be underestimated. Ultimately, it is the type and size of the warhead that determines the damage the cruise missile is able to cause, and hence its warfighting and deterrence value.

A typical cruise missile will usually have a conventional warhead weighing several hundred kilograms (some cruise missiles are also able to carry nuclear warheads, see below). Due to the heavyweight of the warhead, there is an important trade-off to be made between warhead size and cruise-missile range. Several types of warheads have been mounted on top of cruise missiles, such as blast, fragmentation-blast, penetrator, and, more recently, multi-effect warheads. The type of warhead that is chosen determines which targets can be effectively engaged. Fragmentation-blast warheads, for example, will be ineffective against hardened targets, such as bunkers (a lesson the US had to learn during the first Iraq war[27]). Conversely, the point-effect damage of a penetrator warhead may be insufficient when larger structures are engaged.

In the recent past, multi-effect warheads seem to have become increasingly important. These warheads combine a primary with a secondary charge in order to cause maximum damage. Modern cruise missiles like the German/Swedish KEPD 350 and the Turkish SOM B2, for example, first explode a shaped charge to weaken or puncture the engaged structure before a follow-through bomb (a penetrator warhead) is fired and detonated deep inside the target.[28] This design makes it possible to engage even well-protected and hardened targets, such as silos and underground bunkers. The recently announced Block V version of the Tomahawk will also include a variant carrying a multi-effect warhead.[29]

Defining 'cruise missile' – easier said than done?

The analysis presented above suggests that a typical 'cruise missile' does not exist. Existing cruise missiles use a large variety and blend of different subsystems, espcially in terms of propulsion, guidance, and warhead. In addition, these subsystems have constantly evolved and significantly changed over time. Specifying that a

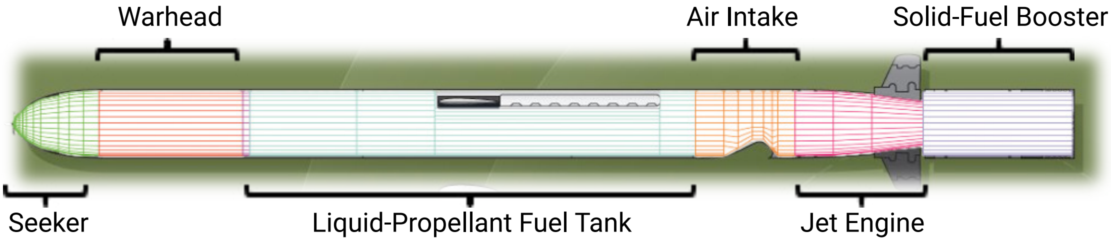

Figure 3: annotated cross-section of a cruise missile (3M14-Kalibr)

missile system must meet a certain standard in terms of subsystems in order to be termed a 'cruise missile' may therefore lead to the exclusion of relevant missile systems, a fact that may be particularly problematic in the context of potential arms control agreements.

For example, stating that only jet-propelled missiles should be considered cruise missiles, as is often the case[30], a priori excludes all those missile systems propelled by rocket engines. In addition, such a definition invites arguments that call for the exclusion of ramjet and scramjet-propelled missiles, based on the objection that these engines have strayed too far from the traditional jet-engine design due to their lack of a combustor. Particularly fastidious lawyers could also argue that turbofan engines with bypass ratios greater than 1:1 (meaning that more air bypasses the engine core than passes through it) should also be excluded, as the majority of the drawn-in air is accelerated by a ducted fan in front of the engine and not by the engine itself. If this were accepted, virtually all turbofan-propelled missiles would have to be excluded as turbofan engines used in cruise missiles usually have relatively high bypass ratios.

The negotiators of the INF-Treaty – which prior to its demise in 2019, was the most important international instrument limiting the deployment and use of cruise missiles – were conscient of this problem. The cruise-missile

"Specifying that a missile system must meet a certain standard in terms of subsystems in order to be termed a 'cruise missile' may lead to the exclusion of relevant missile systems, a fact that may be particularly problematic in the context of potential arms control agreements."

definition they chose was therefore extremely broad in order not to inadvertently exclude any relevant missile systems. According to the INF Treaty, a cruise missile constitutes "an unmanned, self-propelled vehicle that sustains flight through the use of aerodynamic lift over most of its flight path."[31] There is no reference made to any specific guidance, propulsion, or warhead system. At the same time, the INF treaty referred to another critical element in the design of cruise missiles, namely the ability to create aerodynamic lift in order to sustain the missile's flight path.

The INF definition is far from perfect either. The treaty's language is so broad and general that, in theory, it includes several types of non-ballistic missile systems. Most importantly, cruise missiles are not the only vehicles that make active use of aerodynamic lift to sustain their flight. Cruise UAVs, for example, a type of loitering munition intended to seek and destroy targets over a designated area, do the same. Because these systems have to be able to stay airborne for up to several hours before engaging their target, they critically depend on aerodynamic lift to sustain their flight, thus fulfilling the INF criterion. While there is some overlap between cruise missiles and cruise UAVs, they are nevertheless distinct types of missile systems. Most significantly, although a number of cruise missiles exist that have the ability to loiter, this is usually not their primary purpose. Moreover, while both types of systems are able to cover long ranges, cruise missiles fly at much faster speeds than cruise UAVs. Whereas the former usually reach speeds in the high subsonic spectrum (or far above), the latter cruise at low subsonic speeds, making them potentially much more vulnerable to enemy countermeasures.[32] In addition, whereas cruise missiles today are normally jet-propelled, cruise UAVs are usually propeller-driven. Thus, it is clear that there are significant differences between cruise missiles and cruise UAVs; yet, the INF definition theoretically describes both. Indeed, Russia accused the US of violating the INF Treaty due to its deployment of UAVs, such as the MQ-1 Reaper and MQ-9 Predator.[33]

Therefore, the use of aerodynamic lift cannot constitute the defining feature of cruise missiles. If there is one defining feature, it is the intended use of cruise missiles as stand-off weapons, meaning that cruise missiles usually engage their targets at long ranges. How long the missile system's range needs to be in order to be termed a stand-off weapon is once again a difficult question, not least because it depends on the geographic, temporal, and political context. For example, what is considered a stand-off weapon today is certainly different from what it was considered in the 1960s. In addition, in a regional context where militarily valuable targets are located in close proximity to each other (e.g. in Europe), 'stand-off' has a different meaning than in regions where such targets are spread further apart (e.g. the Middle East). Lastly, the meaning of 'stand-off' is always subject to political purpose. For the INF Treaty, for example, it was determined that a range threshold of 500 km would fulfil the treaty's political objectives.[34]

Because of this, the meaning of stand-off remains ambiguous, and the dividing line between cruise missiles and other types of missile systems become somewhat blurred, creating an analytical grey zone highly visible in the literature. For example, analysts regularly include short-range missiles, such as the C-701 (approximately 20 km range), in their analysis of Chinese cruise-missile capabilities.[35] At the same time, analysts never include – and rightly so – comparable short-range systems, such as the AGM-65 in their analysis of American cruise missiles.[36] However, especially in the contemporary context, calling short-ranged rocket-propelled tactical missiles, such as the C-701, 'cruise missile' appears to be a misnomer. Given its short flight duration (about 70 seconds at Mach 0.8 or 277 m/s), it is difficult to describe its flight profile as 'cruising' through the air, in the sense of staying airborne for a considerable amount of time. In addition, the missile can hardly be said to engage targets at stand-off range.[37]

Definitional clarity with regard to cruise missiles is therefore needed both for the sake of analytical clarity as well as to facilitate confidence and trust in future political agreements, should they come into existence. In this regard, cruise missiles should clearly be understood as stand-off range weapons. While it is impossible to provide a general range threshold, given the contextual dependency outlined above, it is safe to say that it should be relatively high (probably above 100-200 km). In addition, cruise missiles should be more clearly delimited from loitering ammunitions, such as cruise UAVs. This can be done, for example, by stating that cruise missiles follow a relatively direct flight path. Of course, one must be careful not to insinuate that cruise missiles engage their targets in a straight line, as this does not have to be the case. Lastly, it is appropriate to define cruise missiles as vehicles propelled by airbreathing engines. While it would theoretically be possible for states to produce stand-off range cruise missiles propelled by rocket engines, it is highly unlikely that any state will choose to do so in the future. Rocket engines are relatively outdated and turbojet technology is now widely available. This being the case, precision should be preferred over broadness. At the same time, analysts should drop the word 'jet-propelled' as this could invite unnecessary debate about what type of engine truly constitutes a jet-engine and which doesn't.

"While not constituting a silver bullet, these three elements – stand-off range, relatively direct flight path, and airbreathing engine – provide definitional clarity and help delimit cruise missiles more clearly from other types of missile systems."

While not constituting a silver bullet, these three elements – stand-off range, relatively direct flight path, and airbreathing engine – provide definitional clarity and help delimit cruise missiles more clearly from other types of missile systems. This research, therefore, proposes to define cruise missiles as *airborne vehicles continuously propelled by airbreathing engines, following a non-ballistic and relatively direct flight path, and engaging their targets at stand-off range.*

Types of cruise missiles and cruise missile proliferation

"Generally speaking, three categories of cruise missile systems exist: anti-ship cruise missiles (ASCMs), land-attack cruise-missiles (LACMs), and nuclear-armed cruise missiles capable of delivering a nuclear warhead."

Generally speaking, three categories of cruise missile systems exist: anti-ship cruise missiles (ASCMs) designed to target shorebased structures and surface vessels, land-attack cruise missiles (LACMs) intended to target landbased structures, and nuclear-armed cruise missiles capable of delivering a nuclear warhead.

Anti-ship cruise missiles

ASCMs are typically shorter and wider than other types of cruise missiles. This design allows them to deliver a relatively large payload into their target while maintaining agility, which is especially important in the terminal stage of their flight. This is because surface vessels usually do not stand still and are able to perform evasive manoeuvres. In addition, most modern battleships have some form of active countermeasures (e.g. gun turrets, defensive missiles) that attempt to interrupt the ASCM on its flight path. These countermeasures often require the ASCM to perform evasive manoeuvres itself, while not losing track of its target. Today, most ASCMs are armed with blast or fragmentation-blast warheads and fly at subsonic speeds, powered by turbojet engines.[38] The relatively modest range of most ASCMs (100-300 km) does not require more efficient turbofan engines, and many cruise-missile manufacturers have emphasized stealthiness and manoeuvrability over supersonic speed. This being said, a relatively large amount of ASCMs has been developed over the decades that fly at supersonic velocities and that are powered by rocket and ramjet engines, some of which are depicted in Figure 4. Some ASCMs, such as the Russian 3M54 Kalibr, also combine subsonic and supersonic flight, with the missile reaching supersonic velocities in its terminal approach.[39]

The majority of next-generation ASCM systems will likely continue to use turbojet engines and fly at subsonic speeds. Increased use of turbofans in ASCMs is also conceivable, should longer ranges be sought.[40] Precision of ASCMs is also expected to increase, as well as the ability to conduct more complex operations, including swarm attacks.

ASCMs started to proliferate in the 1970s and continue to do so until this day.[41] Because of their relatively low

Model	Origin	Range (km)	Engine Type	Speed (Mach)	Warhead	Exports	Initial Operationality
YJ-12/C-302	China	400	Ramjet	2-4	500 kg HE	Pakistan (export variant)	2015
RGM-84/UGM-84/AGM-84 Harpoon Block II	USA	120-250	Turbojet	0.9	220 kg HE fragmentation	30+ countries	2009
MM40 Exocet Block III	France	180	Turbojet	0.9	160 kg HE semi-armor piercing	Greece, Indonesia, Morocco, UAE, Vietnam	2010
3M54 Klub (SS-N-27 Sizzler)	Russia	220-300	Turbojet	0.9	450 kg HE	Algeria, China, India, Iran, Vietnam (export variant)	1987
PJ-10 Brahmos	Russia/ India	500	Ramjet	2-2.8	300 kg HE submunitions	Vietnam (export variant)	2006
Naval Strike Missile	Norway	185	Turbojet	0.9	125 kg HE fragmentation	Poland, USA, Germany, Romania, Malaysia	2012

Figure 4: selected operational anti-ship cruise-missile capabilities[42]

range and payload, most ASCMs do not fall under the export restrictions imposed by the Missile Technology Control Regime. Today, dozens of states possess either indigenously-produced or imported ASCMs rendering them one of the most widely proliferated advanced weapon systems in the world.

“Dozens of states possess either indigenously-produced or imported ASCMs rendering them one of the most widely proliferated advanced weapon systems in the world.”

Land-attack cruise missiles

LACMs are often longer than their anti-ship counterparts. This design allows them to carry more weight, thus increasing their maximum range by providing more space for fuel. In addition, the longer body also allows the system to carry multiple explosive charges, should this capability be desired. While the elongated design restricts the missile’s agility, this represents less of an issue in the case of LACMs, seeing that their intended use is usually to engage stationary targets, such as buildings, bunkers, and air-defence sides. The majority of LACMs developed to this date fly at subsonic velocities and are powered either by a turbojet or a turbofan engine. Generally speaking, the higher efficiency of a turbofan becomes desirable when the LACM is supposed to cover distances greater than 500 km. Modern LACMs are typically armed with blast, fragmentation-blast, or penetrator warheads. More recently, multi-effect warheads have become more important.

Throughout the Cold War, the proliferation of LACMs had been restricted mainly to the Soviet Union and the US. Both great powers continuously upgraded their own LACM arsenals, while the spread to other countries had been largely limited. Since the 1990s, several more countries have acquired LACMs, either through indigenous production or import. Today, at least 23 states field an operational LACM capability, 12 of which have produced their LACMs indigenously.[43] Drivers of LACM proliferation are manifold, including their attractiveness for security purposes (as demonstrated repeatedly in modern conflicts), the inadvertent and illegal transfer of sensitive missile technology (including dual-use goods),[44] business interests,[45] and the prestige that comes with possessing a sophisticated LACM capability.[46]

"At least 23 states field an operational LACM capability, 12 of which have produced their LACMs indigenously."

In the future, LACM proliferation is likely to continue to both state and non-state actors, although it is difficult to predict its pace.[47] Next to the more traditional LACM designs, several states are also currently working on a hypersonic LACM capability. However, given the difficulties in developing an operational scramjet engine capable of sustaining hypersonic flight over a long period of time, the deployment of hypersonic LACMs will likely not occur for some time to come. For the near future, most cruise missiles will continue to fly at subsonic and supersonic speeds, using turbojet,

Model	Origin	Range (km)	Engine Type	Speed (Mach)	Warhead	Exports	Initial Operationality
AGM-158 JASSM-ER	USA	1.000	Turbofan	0.8	450 kg penetrator	Australia, Finland Poland	2009
RGM-109/UGM-109 Tomahawk Block IV	USA	1.600	Turbofan	0.7	450 kg fragmentation	UK	2006
3M14 Kalibr	Russia	2.500	Turbofan	0.7	450 kg HE	-	2015
SOM B2	Turkey	250	Turbojet	0.9	230 kg multi-effect	South Korea, Spain	2021
Taurus KEPD 350	Germany/ Sweden	500	Turbojet	0.9	480 kg multi-effect	South Korea, Spain	2005
Storm Shadow/ SCALP EG	France/ UK	400	Turbojet	0.8	400 kg penetration	UK, Italy, Greece, Saudi Arabia, UAE (export variant)	2004

Figure 5: selected operational land-attack cruise-missile capabilities

turbofan and ramjet engines. Looking at LACM guidance, improved navigation tools and datalinks will allow LACMs to conduct more complex operations and increase their kill-probability. The destructiveness of cruise missiles will also be increased by the adoption of multi-effect warheads.

Nuclear-armed cruise missiles

Finally, it is worth considering another category of cruise missiles: nuclear-armed cruise missiles. The idea of mating cruise missiles with nuclear warheads is almost as old as the missile itself. In the 1950s and early 1960s, cruise missiles vied with ballistic missiles over constituting the primary delivery vehicle for strategic warheads. As a result, both the Soviet Union and the US attempted to develop several intercontinental cruise missiles, capable of delivering a large nuclear payload to each other's homelands.[48] However, these systems were plagued by low reliability and accuracy, as well as high susceptibility to enemy countermeasures, and so were eventually sidelined by more reliable and harder to intercept ICBMs.

"Today, five of the nine nuclear-weapon states are either confirmed or suspected of deploying operational nuclear-armed cruise missiles. These are France, Israel, Pakistan, Russia, and the US."

Today, five of the nine nuclear-weapon states are either confirmed or suspected of deploying operational nuclear-armed cruise missiles. These are France, Israel, Pakistan, Russia, and the US. India will likely join this club soon, once the development of its Nirbhay cruise missile is completed.[49] Both nuclear-armed LACMs and ASCMs remain in service today, though the deployment of ASCMs tipped with nuclear warheads is confined exclusively to Soviet legacy systems developed during the Cold War (see Appendix A).[50] Although Russia's nuclear-capable ASCMs remain in service, it is unclear what role these systems continue to play in Russia's nuclear planning.

Model	Origin	Range (km)	Engine Type	Speed (Mach)	Warhead Yield	Platform	Initial Operationality
AGM-86/ALCM	USA	2.500	Turbofan	0.7	200 kT	Aircraft	1982
Kh-102 Raduga	Russia	2.500	Turbofan	0.8	250 kT	Aircraft	2012
R-500 Iskander-K/9M728	Russia	500-1..500	Turbofan	0.7	10-50 kT	Ground Mobile	2017
ASMP-A	France	600	Ramjet	2-3	300 kT	Aircraft	2009
Hatf-7 Babur	Pakistan	350-700	Turbojet	0.8	10-35 kT	Aircraft	2010
Popeye Turbo SLCM (?)	Israel	1.500	Turbofan	?	?	Submarine	After 2000

Figure 6: selected operational nuclear-capable cruise

Five nuclear weapon states are currently working on a new nuclear-armed cruise-missile capability. Next to India these are France, Pakistan, Russia, and the US. Pakistan and India are developing classic subsonic nuclear-capable LACMs powered by turbojet and turbofan engines, respectively. France, Russia, and the US, in contrast, work on next-generation designs. France's ASN4G and Russia's 3M22 Zircon are supposed to be powered by scramjet engines.[51] Russia is also working on an exotic cruise missile named 9M730 Burevestnik, which is apparently propelled by a nuclear-powered ramjet engine.[52] Not much is publicly known yet about the US's LRSO other than that it is going to replace the ageing AGM-86 by 2030.[53]

Interestingly, it seems that China has not yet pursued nuclear cruise-missile capability. This is not due to a lack of knowhow as China today possesses one of the most varied and sophisticated missile arsenals in the world and could easily field a nuclear-armed cruise-missile capability, should it desire to do so. The DH-10, a Chinese long-range LACM, could likely already serve as a nuclear delivery vehicle (and indeed, many prominent authorities, including the US government, designate the DH-10 as nuclear-capable[54]). The fact that China has not yet officially deployed nuclear-armed cruise missiles is likely due to three reasons. First, China's nuclear doctrine emphasizes strategic deterrence. Chinese decision-makers consider nuclear-armed cruise missiles unsuitable for this task due to their limited range.[55] Second, deploying air-launched nuclear-tipped cruise missiles would require the PLA's Rocket Force to relinquish its monopoly on control over the Chinese non-sea based nuclear arsenal. In addition, the PLA's Air Force would have to assume nuclear responsibility despite its traditional non-nuclear role. Both seem unlikely.[56] Third, even if China was to consider the tactical use of nuclear-tipped cruise missiles, for example, in the South-East Asian theatre, this would require the forward deployment of nuclear weapons and potentially the predelegation of launch orders. This, of course, seems incompatible with China's centralized command-and-control culture.

Model	Origin	Range (km)	Engine Type	Speed (Mach)	Warhead Yield	Platform	Initial Operationality
LRSO	USA	2.500+	?	?	?	Aircraft	2030
SLCM-N	USA	2.500+	?	?	5-7 kT	Submarine	~2030
3M22 Zircon	Russia	1.000	Scramjet?	8	?	Ship, Submarine, Ground Mobile?	2022
9M730 Burevestnik	Russia	100.000+	Nuclear Ramjet	?	?	Ground Mobile, Ship?	?
ASN4G	France	?	Scramjet	7-8	?	Aircraft	2035
Nirbhay	India	800-1.000	Turbofan	?	12 kT	?	Expected Soon
Hatf-8 Ra'ad	Pakistan	600	Turbojet	0.8	?	Aircraft	Expected Soon

Figure 7: confirmed nuclear-capable cruise missiles in development

Yet, analysts have noted for some time now that China is moving away from its no first-use posture and towards a nuclear-warfighting capability.[57] The deployment of the DF-26, a dual-capable medium-range ballistic missile that is capable of threatening US naval assets and military bases in the South China Sea region, is indicative in this regard.[58] A nuclear-capable intermediate-range cruise missile would multiply threat scenarios the US is faced with in the South China Sea and help significantly in keeping risks unpredictable for US decision-makers. Indeed, if China is serious about establishing an effective A2/AD network, it may hardly get around acquiring a nuclear-warfighting capability. This is because the US Navy is unlikely to be deterred by Chinese conventional-only missile capabilities in the long-term. If this line of thinking is correct, the development and deployment of nuclear-armed cruise missiles by China is likely only a question of time.

Whether or not China pursues its own nuclear cruise-missile capability, nuclear-armed cruise missiles are here to stay. While cruise missiles will probably never replace the ground-based ICBM, their profile within the nuclear triad can be expected to increase. In light of the proliferation of increasingly effective air defence, such as the American Patriot 3, the Russian S-400, and other advanced systems,[59] nuclear weapon states will consider it increasingly important to be able to deliver their air-launched nuclear weapons at stand-off range. Glide and gravity bombs do not offer this possibility; air-launched cruise missiles do.

Nuclear-armed cruise missiles also promise important tactical value. Low-yield nuclear warheads, combined with the precision of cruise missiles, enable the execution of 'surgical' nuclear strikes better than any other type of weapon system currently deployed. Some states, therefore, consider such a tactical nuclear cruise-missile capability an important tool for escalation management and deterrence. The US is currently developing a new submarine-launched cruise missile that, combined with a new 5-7 kT warhead, could serve in this capacity.[60] Russia's relatively newly deployed Iskander cruise missiles, which are reportedly armed with a lower-yield warhead of 10-50 kT themselves, seem to serve a similar function.[61] As long as the use of tactical nuclear weapons is considered a viable path of action, nuclear-armed cruise missiles will continue to be an attractive option for their delivery.

Strategic implications for Europe

As the previous section suggests, the proliferation of cruise missiles has progressed significantly. Today, dozens of states are in possession of highly effective and deadly cruise-missile capability which has significant strategic implications on a global level. Especially in strained regional contexts, cruise-missile proliferation may introduce increased instability and heightened risks. The following represents a brief (and necessarily incomplete) analysis with regard to crisis stability for the European continent. Some of the implications, however, can be transferred readily to other regional contexts, especially to South and East Asia.

Reshaping the European deterrence relationship

The proliferation of cruise missiles in Europe has the potential to fundamentally reshape the deterrence relationship between NATO states in Central and Western Europe and Russia.

Seven NATO states in Europe (France, Germany, Greece, Italy, Poland, Spain, and the UK) have acquired sophisticated LACM capabilities to date. These include Storm Shadow/SCALP EG, Taurus KEPD 350, JASSM, and JASSM-ER cruise missiles with ranges between 400-1.000 km. In

"The proliferation of cruise missiles in Europe has the potential to fundamentally reshape the deterrence relationship between NATO states in Central and Western Europe and Russia."

addition, Finland, NATO's partner in the region, is currently in the process of acquiring its own JASSM and JASSM-ER cruise missiles.[62] This provides the NATO Alliance with a significant stand-off capability in Europe that can threaten high-value targets deep inside Russia, including command-and-control structures, military bases, and sites of cultural and historical importance. These targets could be threatened by NATO in response to provocative Russian actions in order to deter the transgression of redlines and/or to deescalate a growing conflict.[63] Furthermore, because several NATO states possess stand-off range cruise missiles, the number of potential retaliatory decision-making centres increase as well, enhancing NATO's extended-deterrence credibility.[64] In this regard, Poland's LACMs are particularly significant due to its undeniable stake in Eastern Europe. Lastly, should deterrence break down and a militarized conflict ensue, cruise missiles will provide NATO with an important warfighting capability capable of targeting the enemy's rear, including its supply lines and logistics (assuming, of course, that NATO's long-range capabilities are not destroyed in an enemy first strike). Cruise missiles, therefore, improve NATO's deterrence posture vis-à-vis Russia both in terms of deterrence by punishment as well as deterrence by denial.

The flipside of this coin is that Russia may feel increasingly threatened by the proliferation of cruise missiles near its border, fueling a heightened security dilemma on the European continent. This may entice Russia to acquire its own improved stand-off capabilities, including improved cruise missiles. In the worst case, this interaction may end in a costly arms race, especially because cruise missiles strongly skew the offence-defence balance in favour of the offence.[65] Cruise missiles are difficult to counter and defend against, even for sophisticated air-defence systems. As a result, Russia can be expected to counter the acquisition of cruise missiles by NATO states through the acquisition of its own offensive capabilities and vice versa.

In addition, the above-mentioned conventional countervalue strikes may prove highly escalatory. This is especially the case since Russia, as a nuclear weapon state with a highly sophisticated conventional arsenal, generally holds escalation dominance in Europe, in particular vis-à-vis states like Finland and Poland.

The proliferation of cruise missiles may also increase the perceived benefits of striking first, thus decreasing crisis stability. This is because cruise missiles are particularly useful when used in first-strike scenarios where the defender is insufficiently prepared.[66] In addition, while cruise missiles are able to wreak major havoc in enemy territory, they are vulnerable when attacked first. In particular, their launcher platforms and supporting infrastructure, such as air-bases, ground-launchers, and surface-vessels, are relatively susceptible to enemy attack. Dispersing and concealing cruise-missile units can increase their survivability, yet short of drastic (and uneconomical) measures, the aggressor can probably always overcome them. This may introduce a "use 'em or lose 'em mentality" into inter-state relations, which is, of course, highly destabilizing.

Furthermore, the proliferation of cruise missiles may also make escalate-to-deescalate strategies more attractive. Especially, when combined with other modern long-range precision-strike capabilities, such as hypersonic glide vehicles, theatre-range ballistic missiles, and long-range artillery, a comprehensive conventional firststrike using long-range precision-guided weapons may present the enemy with a fait accompli, rendering it defenceless before it can mobilize an effective response. Russia, for example, may hope that by firing a massive barrage of cruise missiles and other precision-guided ammunition at high-value targets deep inside NATO territory, it can rapidly reach a culminating point of victory and terminate the conflict on favourable terms before an effective defence can be mobilized.[67] Western analysts, and especially those in the US, have long warned that Russia has adopted an escalate-to-deescalate posture.[68] The proliferation of cruise missiles could thus further increase the perceived benefits of this strategy in the minds of Russian decision-makers, making it more likely for this dangerous posture to persist. This is extremely worrying as there is no guarantee that this strategy is successful, and there is a high likelihood that such an all-out attack, short of rendering the enemy defenceless, induces escalation and paves the way to a large-scale and potentially nuclearized conflict.

Heightening nuclear risks

The proliferation of cruise missiles in Europe also increases the risk of nuclear escalation between Russia and NATO. Most significant in this regard is the potential role of cruise missiles as kinetic non-nuclear strategic weapons. Russia may fear that the proliferation of cruise missiles within NATO increases its vulnerability to a disarming or decapitating nuclear first strike. During the Cold War, decision-makers calculated that in order to destroy one hardened ground-based missile silo, at least two to three nuclear warheads would have to be detonated within the target's vicinity in order to destroy it with adequate certainty.[69] This calculation was based on the relative imprecision of ICBMs with a CEP of several hundreds of meters. Today, Russia may fear that a single highly accurate nuclear-tipped cruise missile may achieve the same effect. In addition, while a nuclear-armed cruise missile fired with pinpoint accuracy at its target may certainly do the trick, a nuclear warhead may not even be required. Conventional cruise missiles armed with penetrator and bunker-busting ammunitions, such as the JASSM, the KEPD 350, and the SOM B2, may cause enough concentrated point-effect damage to destroy or to render unserviceable nuclear facilities, such as missile silos, mobile launchers, and underground command-and-control facilities. While a conventional cruise-missile attack alone would likely not be enough to disarm Russia, the fear is that cruise missiles, used in conjunction with US nuclear weapons and other precision-guided weapons, might be.[70] These considerations clearly undermine

> "While a conventional cruise-missile attack alone would likely not be enough to disarm Russia, the fear is that cruise missiles, used in conjunction with US nuclear weapons and other precision-guided weapons, might be."

strategic stability in Europe and are cause for increasing concern.

Another destabilizing byproduct of cruise-missile proliferation in Europe is the increasing entanglement of nuclear and non-nuclear assets. Conventional precision-guided weapons, including cruise missiles, generally use the same command-and-control (C2) systems as nuclear weapons. In addition, the guidance of conventional systems depends on the same intelligence, surveillance, and reconnaissance (ISR) assets as the guidance of nuclear delivery vehicles.[71] Degrading Russia's C2 and/or ISR systems for the sake of stopping or weakening a conventional assault, may therefore induce fear in Russia's decision-makers that their nuclear assets are being targeted, resulting in inadvertent escalation. A related but distinct issue refers to the fact that most types of nuclear-armed cruise missiles include a conventional variant that can be armed with a conventional warhead instead of the nuclear payload. In Russia, for example, these include the Kh-55/Kh-555, the Kh-101/Kh-102, Russia's vast arsenal of nuclear-capable ASCMs, and likely also the 3M14 Kalibr. Changing the warhead on a cruise missile may not necessarily alter the missile's appearance. In addition, nuclear and conventional variants generally use the same launcher platforms. It is therefore feasible that NATO, in a conventional crisis scenario, may inadvertently target nuclear-tipped cruise missiles and, in doing so, trigger nuclear escalation.[72]

> "The proliferation of cruise missiles on the European continent, especially long-range and nuclear-capable cruise missiles, may have significant destabilizing long-term consequences."

Lastly, as already stated above, the proliferation of cruise missiles may increase the likelihood of tactical nuclear weapons use. Because of their unmatched precision and high reliability, cruise missiles constitute the ideal delivery vehicle for tactical nuclear weapons. Many analysts and decision-makers believe that such a tactical nuclear capability is necessary to fill deterrence gaps and to provide coercive leverage.[73] However, no one can foretell the consequences of a tactical nuclear weapons attack. Even a low-yield explosion below the 10 kT threshold may spark confusion and outrage in the enemy, and start a devastating spiral of escalation which leads down a one-way street to general nuclear war. Indeed, there is much evidence that points in the direction that tactical weapons can hardly – if at all – be employed in a controllable manner.[74] Everything that makes the use of tactical nuclear weapons more feasible, including increasingly capable tactical delivery vehicles in the form of cruise missiles, should therefore be considered destabilizing.

All of the above suggests that the proliferation of cruise missiles on the European continent, especially long-range and nuclear-capable cruise missiles, may have significant destabilizing long-term consequences. While these weapons may provide important deterrence value, they have the potential to drastically undermine conventional and nuclear crisis stability in Europe. Renewed efforts should therefore be made control the proliferation of cruise missiles and to regulate their deployment and use.

Looking forward: How to respond to cruise-missile proliferation?

As the previous sections have shown, the proliferation of cruise missiles has progressed significantly. In addition, this trend can only be expected to continue. Even more worrying is the fact that a number of emerging technologies, including multi-effect warheads, scramjet engines, and AI-enhanced navigation, among others, render cruise missiles increasingly destructive tools of warfare, undermining conventional and strategic stability, especially in strained regional contexts. By itself, the proliferation of cruise missiles will not come to a halt or slow down any time soon, especially in the current geopolitical environment where tensions run high and cruise missiles are seen as an important means to promote national security objectives.

Because of this, active measures by the international community are required in order to counter the adverse strategic implications of cruise-missile proliferation and to slow down, and potentially reverse, the dangerous proliferation trends outlined above. Short-term attention should focus on establishing confidence and transparency between states concerning the deployment and use of cruise missiles. In the long-term, states should focus on agreeing and concluding comprehensive and verifiable agreements limiting the numbers of cruise missiles.

"Active measures by the international community are required in order to counter the adverse strategic implications of cruise-missile proliferation and to slow down, and potentially reverse, the dangerous proliferation trends outlined above."

Short-term fixes: Establishing communication, promoting trust

Most importantly, states possessing significant numbers of cruise missiles and locked in geopolitical and regional rivalries should work out codes of conduct concerning the use and deployment of cruise missiles without, at first, necessarily limiting their numbers. Such codes of conduct may relate to geographical criteria (e.g. to agree not to deploy these systems within 100 km of an international border) or communication (e.g. rules and procedures of crisis communication).[75] Second, possessor states of long-range cruise-missile systems should clarify their doctrinal use and purpose of employment of these systems.[76] NATO states in

Europe could, for example, publicly and unequivocally state that the deployment of cruise missiles serves conventional deterrence only, and does not play any role in NATO's nuclear planning. This could ease Moscow's fear that NATO's significant cruise-missile capabilities may take part in a US-led nuclear first strike. At the same time, nuclear weapon states like Russia should be more transparent about where their nuclear-tipped precision-strike capabilities are stored. This would lower the risk of inadvertent nuclear escalation as a result of accidentally targeting Russian nuclear sides during a conventional crisis scenario.

Agreeing to such transparency and confidence-building measures will not be easy. It should not be forgotten that the ambiguity surrounding the deployment of cruise missiles often constitutes not a bug but a feature of military strategy and deterrence.[77] However, while 'strategic ambiguity' may indeed serve the national security interests of a state in the short-term, it undermines crisis stability in the long-term. Serious efforts should therefore be made to get a dialogue going. In the European context, the OSCE may perhaps provide the right venue for this.

Long-term solutions: Towards comprehensive agreements

In the short-term, far-reaching and verifiable arms control agreements with regard to cruise missiles and missile technology more generally seem unlikely. In the long-term, however, serious efforts should be made to reach such solutions.

Today, kinetic non-strategic weapons like conventionally armed cruise missiles have a profound impact on the nuclear domain and nuclear decision-making. It, therefore, seems inevitable that future strategic arms-control agreements should integrate conventional and nuclear arms-control efforts. This is a difficult process, which faces many hurdles. While this course of action would include both nuclear and non-nuclear weapon states at some point (and indeed may require doing so in order to be effective), the process should be kicked off between the P-5 as, at present, these states have the greatest stake in regulating the deployment of conventional weapons with strategic impact.

In addition, a major driver of cruise-missile proliferation has been ballistic-missile defence (BMD). In the face of increasingly effective American BMD (actual or perceived), states like China and Russia, and also Iran, have been driven towards ballistic-missile alternatives, including cruise missiles. Tackling the proliferation of cruise missiles, especially with regard to nuclear-armed cruise missiles, will therefore not get around engaging the topic of missile defence constructively. This implies the need for a comprehensive trilateral dialogue between the US, Russia, and China.

European states should also engage more actively in the BMD discourse and become more cognizant of the implications of BMD capabilities being deployed on their territories. South Korea, which arguably finds itself in an even more precarious position than many Central and Eastern European States, and its proactive attitude toward American BMD on its territory, could serve as a model in this regard.[78]

Lastly, we must also work towards quantitatively limiting destabilizing missile technologies, including cruise missiles. This could be done, for example, by introducing missile ratios into the missile arsenals of certain nuclear and non-nuclear weapon states. Such an agreement would prescribe, for example, that only 25% of the state's nuclear missile arsenal may represent missiles that follow non-ballistic trajectories. Such a comprehensive agreement would set quantitative limits on the maximum number of non-ballistic missile systems, such as cruise missiles and hypersonic glide vehicles, and ease the fear that these systems are used in a comprehensive first strike.

Agreeing to such measures will be far from easy. Many obstacles lie between now and achieving comprehensive solutions. Yet, especially because the process is going to be a long one, it is important to start now. While immediate success should not be expected, we should allow for careful optimism about the arms control opportunities that lie ahead.

"It seems inevitable that future strategic arms control agreements should integrate conventional and nuclear arms control efforts."

Appendix A: Confirmed operational nuclear-capable cruise missiles

Modell	Origin	Range (km)	Platform	Engine Type	Speed	Warhead	Initial Operationality
ASMP-A	France	600	Aircraft	Ramjet	2-3	300 kT	2009
Popeye Turbo SLCM (?)	Israel	1.500	Submarine	Turbofan	?	?	After 2000
Hatf-7 Babur	Pakistan	350-700	Ground Mobile	Turbojet	0.8	10-35 kT	2010
Kh-22N Raduga / AS-4 Kitchen	Russia	500	Aircraft	Rocket	3-4	350 kT	1963
P-120 Malakhit	Russia	110	Surface Vessel, Submarine	Rocket	0.8	200 kT	1969
P-500 Bazalt	Russia	550	Surface Vessel, Submarine	Turbojet	2.5	350 kT	1973
P-700 Granit	Russia	625	Surface Vessel, Submarine	Turbojet	2.5	500 kT	Late 1970s
P-1000 Vulkan	Russia	700	Surface Vessel, Submarine	Turbojet	2.8	350 kT	1987
Rk-55 Relief	Russia	2.400	Submarine	Turbofan	0.7	200 kT	1984
P-270 Moskit	Russia	120	Surface Vessel	Ramjet	2.5	120 kT	1982
Kh-41 Moskit	Russia	120+	Aircraft	Ramjet	2.5	120 kT	1990
Kh-55 Granat / AS-15 Kent	Russia	2.500-3.000	Aircraft	Turbofan	0.7	250 kT	1984
Kh-102 Raduga	Russia	2.500	Aircraft	Turbofan	0.8	250 kT	2012
R-500 Iskander-K / 9M728	Russia	500-1.500	Ground Mobile	Turbofan	0.7	10-50 kT	2017
3M-14 Kalibr	Russia	2.500	Surface Vessel, Submarine	Turbofan	0.7	?	2015
Kh-32	Russia	600-1.000	Aircraft	Ramjet	4-5	150-500 kT	2016
9M729	Russia	1.500-2.500	Ground Mobile	Turbofan	0.7	10-50 kT	2017
AGM-86	USA	2.500	Aircraft	Turbofan	0.7	200 kT	1982

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13. Ivett Leyva, "The Relentless Pursuit of Hypersonic Flight," Physics Today, 2017, https://physicstoday.scitation.org/doi/10.1063/PT.3.3762.

14. Richard H. Speier et al., "Hypersonic Missile Nonproliferation: Hindering the Spread of a New Class of Weapons" (Santa Monica, 2017), https://www.rand.org/pubs/research_reports/RR2137.html, 53-93.

15. Newdick, "Russia Says This Is Our First Glimpse of Its Zircon Hypersonic Cruise Missile."

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17. The first aircraft powered solely by a ramjet engine was first flown in 1949. See "Leduc 0.10, 0.16," Aviastar, http://www.aviastar.org/air/france/leduc_010.php.

18. Note that most airbreathing cruise missiles launched from surface or sub-surface platforms include a solid-fuel rocket booster which brings the cruise missile up to speed in order for the jet engine to function properly. Howev-er, such a booster constitutes an auxiliary system that is jettisoned after a couple of seconds, right before the primary liquid-fuel propulsion system takes over.

19. U.S. Congress - Office of Technology Assessment, "Technologies Underlying Weapons of Mass Destruction" (Washington D.C., 1993), 216, 232.

20. "Meteor," MBDA, https://www.mbda-systems.com/product/meteor/.

21. India's Defense Research and Development Organization tested successfully a solid-fuel ramjet in February 2019. "India Conducts Ramjet Propulsion Test," CSIS Missile Defense Project, 2019, https://missilethreat.csis.org/india-conducts-ramjet-propulsion-test/. In addition, a US-Norwegian bilateral effort is currently ongoing to produce a solid-fuel ramjet engine. Involved partners are the US Navy's Naval Air Warfare Center, the Norwegian Defense Research Establishment, and the Norwegian weapons manufacturer and industry partner Nammo. "DOD Announces New Allied Prototyping Initiative Effort with Norway to Continue Partnership in Advancing Solid Fuel Ramjet Technologies," U.S. Department of Defense, 2020, https://www.defense.gov/Newsroom/Releases/Release/Article/2156251/dod-announces-new-allied-prototyping-initiative-effort-with-norway-to-continue/; "Norwegian-US Solid Fuel Ramjet Technology Initiative Pushes Ahead," Defense Brief, 2020, https://defbrief.com/2020/04/20/norwegian-us-solid-fuel-ramjet-technology-initiative-pushes-ahead/.

22. Pierre T. Kabamba and R. Girard Anouck, Fundamentals of Aerospace Navigation and Guidance (Cambridge: Cambridge University Press, 2014), 187-198.

23. For an excellent technical an historical account of inertial guidance technology in missile systems, see Donald Mackenzie, Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance (Cambridge: MIT Press, 1993), chapter 2.

24. Gormley, Missile Contagion: Cruise Missile Proliferation and the Threat to International Security, 50.

25. Ibid.

26. Virtually all current-generation cruise missiles in both anti-ship and land-attack roles are able to exchange data and communicate midair. Examples include Kongsberg's Joint Strike Missile and Naval Strike Missile and Saab's RBS15 Mk 4 cruise missile. "Flexibility On The Fly: Joint Strike Missile Has Abilities That Give Pilots the Upper Hand," Breaking Defense, 2020, https://breakingdefense.com/2020/03/flexibility-on-the-fly-joint-strike-missile-has-abilities-that-give-pilots-the-upper-hand/; Joseph Trevithick, "It's Official, the Navy's Next Anti-Ship Cruise Missile Will Be the Naval Strike Missile," The Drive, 2018, https://www.thedrive.com/the-war-zone/21233/its-official-the-navys-next-anti-ship-cruise-missile-will-be-the-naval-strike-missile; Beth Stevenson, "Saab Readies New Anti-Ship Missile for Swedish Air Force's Gripen Fighters," Defense News, 2018, https://www.defensenews.com/digital-show-dailies/farnborough/2018/07/19/saab-readies-new-anti-ship-missile-for-swedish-air-forces-gripen-fighters/. The implementation of two-way datalinks also figures prominent-ly in the coming Block V upgrade of Raytheon's Tomahawk cruise missile. "Tomahawk Cruise Missile," Raytheon Missiles & Defense, 2020, https://www.raytheonmissilesanddefense.com/capabilities/products/tomahawk-cruise-missile.

27. Gormley, Missile Contagion: Cruise Missile Proliferation and the Threat to International Security, 50.

28. "Taurus KEPD 350," SAAB, https://www.saab.com/products/taurus-kepd-350; "SOM-B2," Deagel, https://www.deagel.com/Offensive Weapons/SOM/a003320. Also the Block V update of the US Tomahawk will include a variant with a multi-effect warhead, likely with a similar design

29. "Tomahawk Cruise Missile."

30. See, for example, the following definitions and descriptions: "Fact Sheet: Ballistic vs. Cruise Missiles," The Center for Arms Control and Non-Proliferation, https://armscontrolcenter.org/wp-content/uploads/2017/04/Ballistic-vs.-Cruise-Missiles-Fact-Sheet.pdf; "Land Attack Cruise Missiles," Federation of American Scientists, https://fas.org/irp/threat/missile/naic/part07.htm; "Cruise Missile Basics," Missile Defense Advocacy Alliance, https://missiledefenseadvocacy.org/missile-threat-and-proliferation/missile-basics/cruise-missile-basics/; U.S. Congress - Office of Technology Assessment, "Technologies Underlying Weapons of Mass Destruction," 244.

31. "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#:~:text=On March 4%2C 1987%2C the,submitted a comprehensive verification regime.&text=On July 22%2C 1987%2C General,range and shorter-range missiles. See in particular Art. 2(2).

32. The Israeli Harpy, for example, which is arguably one of the best known cruise UAVs to this date, reaches a maximum speed of only about 400 km/h, or about 260 mph. See "Harpy," IAI, https://www.iai.co.il/p/harpy.

33. Ulrich Kühn and Anna Péczeli, "Russia, NATO, and the INF Treaty," Strategic Studies Quarterly 11, no. 1 (2017): 81, https://www.jstor.org/stable/10.2307/26271591.

34. Intermediate-range forces with a range of 500-5.500 km were deemed politically and militarily destabilizing because of their ability to hit strategically significant targets in Europe in less than 10 minutes, thus decreasing first-strike stability between NATO and the Warsaw Pact.

35. S. Medeiros Evan, "A New Direction for China's Defense Industry" (Santa Monica, 2005), https://www.rand.org/pubs/monographs/MG334.html#purchase; Dennis M. Gormley, Andrew S. Erickson, and Jingdong Yuan, A Low-Visibility Force Multiplier: Assessing China's Cruise Missile Ambitions (Washington D.C.: National Defense University Press, 2014).

36. On the AGM-65, see "AGM-65," Federation of American Scientists, 1999, https://fas.org/man/dod-101/sys/smart/agm-65.htm.

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38. The standard ASCMs of the largest navies in the world, such as the American Harpoon, the French Exocet, the Russian 3M54 Klub, and the Chinese YJ-8, are all turbojet-powered missiles, flying at subsonic speeds (at least during the majority of their flight). “AGM/RGM/UGM-84 Harpoon Missile,” Boeing, https://www.boeing.com/history/products/agm-84d-harpoon-missile.page; “Harpoon,” CSIS Missile Defense Project, 2017, https://missilethreat.csis.org/missile/harpoon/; “Exocet MM40 Block 3,” MBDA, https://www.mbda-systems.com/product/exocet-mm40-block3/; “3M-54 Klub (SS-N-27 Sizzler),” Missile Defense Advocacy Alliance, 2017, https://missiledefenseadvocacy.org/missile-threat-and-proliferation/todays-missile-threat/russia/ss-n-27-sizzler/; “YJ-8,” Deagel, https://www.deagel.com/Offensive Weapons/YJ-8/a001830; Christopher P. Carlson, “China’s Eagle Strike-Eight Anti-Ship Cruise Missiles: Designation Confusion and the Family Members from YJ-8 to YJ-8A,” Defense Media Network, 2013, https://www.defensemedianetwork.com/stories/chinas-eagle-strike-eight-anti-ship-cruise-missiles-designation-confusion-and-the-family-members-from-yj-8-to-yj-8a/.

39. “3M-54 Klub (SS-N-27 Sizzler).”

40. Examples of future ASCMs that fit into this profile include the American LRASM, the Norwegian Naval Strike Missile, the Swedish RBS-15 Gungir, and the British Spear 3. See Sebastien Roblin, “LRASM: The Navy’s Game Changer Missile Russia and China Should Fear?,” The National Interest, 2018, https://nationalinterest.org/blog/the-buzz/lrasm-the-navys-game-changer-missile-russia-china-should-25490; “Long Range Anti-Ship Missile (LRASM),” Naval Technology, https://www.naval-technology.com/projects/long-range-anti-ship-missile/; “Naval Strike Missile (NSM),” Kongsberg, https://www.kongsberg.com/kda/products/defence-and-security/missile-systems/nsm-naval-strike-missile-nsm/; “Naval Strike Missile (NSM),” Naval Technology., https://www.naval-technology.com/projects/naval-strike-missile-nsm/; “The RBS15 Family,” SAAB, https://www.saab.com/products/the-rbs15-family; Tyler Rogoway, “Spear Mini-Cruise Missile Getting an Electronic Warfare Variant to Swarm with Is a Huge Deal,” The Drive, 2019, https://www.thedrive.com/the-war-zone/29789/spear-mini-cruise-missile-getting-an-electronic-warfare-variant-to-swarm-with-is-a-huge-deal.

41. Carus Seth, Cruise Missile Proliferation in the 1990s (Santa Barbara: ABC-Clio, 1993), 9-11.

42. The information provided in this and the following tables is based on a number of online databases, among oth-ers by the Federation of American Scientists, CSIS, Deagel, and the Missile Defense Advocacy Alliance. The data was cross-referenced and it was tried to confirm each datapoint by at least two independent sources. Where it was possible, other secondary-source literature was consulted in the form of journal articles and books. In case of conflicting information, data provided in academic and peer-reviewed publications was given precedence. In some cases also image analysis aided in the collection of the data. While the utmost of care was taken to provide the reader with truthful information, inaccuracies and mistakes may remain, given the clandestine nature of mis-sile programs.

43. International Institute for Strategic Studies, The Military Balance 2020 (Abingdon: Routledge, 2020).

44. For example, Iran’s cruise missile program has greatly benefited from illegal transfers of Russian Kh-55s from Ukraine. Paul Kerr, “Ukraine Admits Missile Transfers,” Arms Control Association., https://www.armscontrol.org/act/2005-05/ukraine-admits-missile-transfers. Pakistan’s and China’s LACM pro-duction, on the other hand, benefitted from recovering intact Tomahawks inside Pakistani territory. “Hatf 7 ‘Babur,’” CSIS Missile Defense Project, 2016, https://missilethreat.csis.org/missile/hatf-7/.

45. For example, France exported an export version of its Storm Shadow LACM to the UAE, despite a strong as-sumption of denial under the MTCR issued by the USA. Jeffrey Lewis, “Storm Shadow, Saudi & the MTCR,” Arms Control Wonk, 2011, https://www.armscontrolwonk.com/archive/204051/saudi-arabia-storm-shadow-the-mtcr/. Many see this case as a textbook example of business interests trumping international norms.

46. LACMs, by combining advanced propulsion, guidance, and warhead technology, are highly sophisticated weap-on systems that can easily be construed as symbols of the modern nation-state. Especially third-world countries, trying to reconfirm their independence and technological progress, have therefore went to great lengths to ac-quire LACMs. On the symbolic significance of certain weapon systems see Dana P. Eyre and Mark C. Suchman, "Status, Norms, and the Proliferation of Conventional Weapons: An Institutional Theory Approach," in The Culture of National Security: Norms and Identity in World Politics, ed. Peter Katzenstein (Ney York: Columbia University Press, 1996), 79–113.

47. Timothy Wright, "The Challenge on Non-State Actors and Stand-Off Weapons," International Institute for Strategic Studies, 2019, https://www.iiss.org/blogs/military-balance/2019/12/non-state-actors-stand-off-weapons.

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50. Dennis M. Gormley, Andrew S. Erickson, and Jingdong Yuan, A Low-Visibility Force Multiplier: Assessing China's Cruise Missile Ambitions, 74.

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