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Report Author(s): Jill Hruby  
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# HYPERSONIC DELIVERY SYSTEMS

Three of the six new Russian capabilities are hypersonic weapon systems: Kinzhal, Avangard, and Tsirkon. Since hypersonic systems dominate Russia's new weapon-delivery systems development, a brief introduction to hypersonic weapon systems is included here before the description of the Russian development activities.

Hypersonic vehicles travel at speeds of Mach 5 or higher—that is, over 6100 kph (3800 mph) at sea level.<sup>39</sup> While the name implies that speed is the distinguishing factor of hypersonic vehicles, for weapon systems it is only one of the characteristics that provide advantage. Compared with today's cruise missiles, hypersonic vehicles do offer significant speed advantages. However, compared with long-range ballistic missile systems, hypersonic vehicles do not have such an advantage, because such ballistic missiles already travel at hypersonic speeds during a large portion of their flight.<sup>40</sup> Other characteristics of hypersonic systems, however, are potentially advantageous compared with ballistic missiles. Of particular interest are the ability to fly at low altitude, making detection by earth-based sensors difficult; the ability to maneuver during flight to avoid detection and interception; and the unpredictability of targets, since hypersonic vehicles don't follow a ballistic trajectory. For these reasons, hypersonic weapons—combining the speed of ballistic weapons with the low-altitude flight and maneuvering capabilities of cruise missiles—are considered militarily advantageous, especially to evade missile-defense systems.

Traditionally, hypersonic systems have been considered in two broad categories: glide vehicles and cruise missiles.<sup>41</sup>

A hypersonic glide vehicle is typically boosted to hypersonic speed in the upper atmosphere by a missile, then released from the boost vehicle to glide unpowered at high speeds at the edge of the atmosphere before descending through the atmosphere to a target. Because glide vehicles need to be delivered to altitude and speed by a lift vehicle, these hypersonic systems are often referred to as boost-glide vehicles. Research begun in the late 1930s has continued on both hypersonic glide missiles and spacecraft.<sup>42</sup>

*Hypersonic weapons—combining the speed of ballistic weapons with the low-altitude flight and maneuvering capabilities of cruise missiles—are considered militarily advantageous, especially to evade missile-defense systems.*

Characteristics of hypersonic glide vehicles include:

- ▶ high lift-to-drag ratio
- ▶ maneuverability during flight and on descent
- ▶ a shape that determines performance characteristics such as glide distance, speed, and maneuverability, which is usually a conical body with fins or a delta-shaped body, somewhat like a space shuttle but with sharper edges

Recently, the attributes of hypersonic glide vehicles, including speed, maneuverability, and low-altitude flight, have made them particularly attractive as weapons to evade missile defenses. Although hypersonic glide vehicles are not usually powered, a propulsion system to increase speed or maneuvering capability (especially in the supersonic portions of the flights) can be integrated.

Like other types of cruise missiles, hypersonic cruise missiles are powered throughout flight and offer maneuverability combined with high speed. Their range is determined by the type of engine and fuel used. Hypersonic missiles typically operate using air-breathing supersonic combustion ramjet (scramjet) engines to accelerate and maintain missile speed. A scramjet usually begins operating at Mach 4 or Mach 5. Therefore, a hypersonic cruise missile must first be accelerated to Mach 4 or Mach 5 by other means, such as rocket engines. The study of scramjet engines has been underway since the 1950s,<sup>43</sup> with the first successful flight tests in the 1990s<sup>44</sup> and some breakthroughs since then.<sup>45</sup> While elegant in theory, since they have no moving parts and use air as the oxidant, scramjet engines that operate more than a few hundred seconds have not yet been designed and tested; their range is significantly limited.<sup>46</sup> Because of the challenge of developing long-life scramjet engines or an alternative, development of hypersonic cruise missiles technically lags behind that of hypersonic glide vehicles.

In addition to the technical challenges already mentioned, there are some overarching issues for any type of hypersonic weapon system. The most challenging is considered to be heat management, because hypersonic travel in the atmosphere results in surface temperatures of about 2000°C.<sup>47</sup> These temperatures require the development of new materials and/or heat-removal methods to ensure survivability of the delivery vehicle (especially the nose cone, sharp edges, and fins) and interior guidance systems. The other significant technical challenge involves communication to and from the vehicle through the surrounding plasma sheath<sup>48</sup> that forms when vehicles travel at speeds above about Mach 8 or Mach 10 in the atmosphere.<sup>49</sup>

Hypersonic weapons are under development not only in Russia but also in the United States and China, and to a lesser extent in the United Kingdom, India, France, Australia, Japan, Germany, and likely elsewhere.<sup>50</sup> The U.S. and Chinese hypersonic weapon programs will be briefly described later in this section, after the Russian system descriptions. Importantly, Russia and China are the only nations to declare intent to develop dual-capable hypersonic missiles, which could carry either conventional or nuclear warheads. The Russian motivation for hypersonic weapons is repeatedly stated to be missile-defense evasion.<sup>51</sup>

As described in the following sections, the Russians are developing both a hypersonic glide vehicle and a hypersonic cruise missile. In addition, Russia has developed an air-launched hypersonic ballistic missile that it claims is in trial deployment. The hypersonic ballistic missile is a modified existing solid-propelled missile delivered by a high-speed interceptor aircraft. If successful in its efforts on these three programs, Russia could deploy dual-capable air- and ground-launched hypersonic weapons, and a conventional sea-launched hypersonic weapon that could be modified to be nuclear-capable.

## Kinzhal Air-Launched Hypersonic Ballistic Missile

Kinzhal, meaning “dagger,” is a hypersonic short-range ballistic missile launched from a high-speed aircraft. The Kinzhal weapon-delivery system mates a short-range solid-fuel aeroballistic missile to a modified MiG-31 interceptor jet, to provide hypersonic medium-range standoff strike. Putin claimed, “The missile flying at a hypersonic speed, 10 times faster than the speed of sound, can also maneuver at all phases of its flight trajectory, which also allows it to overcome all existing and, I think, prospective anti-aircraft and anti-missile defense systems, delivering nuclear and conventional warheads in a range of over 2,000 kilometers.”<sup>52</sup> Of all the systems announced by Putin in 2018, the Kinzhal is believed to be the one either in trial deployment or closest to operational deployment.<sup>53</sup>

The Kinzhal is reported to be a substantially modified Iskander-M short-range (400 km to 500 km, 250 mi to 310 mi),<sup>54</sup> ground-launched, nuclear-capable ballistic missile using a solid-propellant rocket with small fins for maneuverability.<sup>55</sup> The Russian designation for the Kinzhal is Kh-47M2. The MiG-31 interceptor jet is called the Foxhound by NATO, and the version modified to carry the Kinzhal is referred to as the MiG-31K.

### Technical characteristics

The Kinzhal hypersonic system involves the MiG-31K jet carrying the Kinzhal missile to altitudes of about 18 km (59,000 ft) at supersonic speeds. The missile is released and falls probably tens of meters (about 100 ft), ejects a rocket cap that is used to protect the rocket motor during the jet flight, then uses its solid rocket motors to accelerate to hypersonic velocity. A video released on March 11, 2018 shows a flight test of this system.<sup>56</sup> The MiG-31K interceptor jets can carry and launch one Kinzhal at a time.<sup>57</sup> The MiG-31K aircraft is maneuverable, and because the Iskander-M can

maneuver during the terminal phases of flight<sup>58</sup> it is likely the Kinzhal can as well. Additionally, because the Iskander-M has a thermonuclear option with a 10–50 kt warhead,<sup>59</sup> it is reasonable to assume that the Kinzhal would have a similar yield. Some Russian literature has indicated that the upgraded Tu-22M3 bomber also may carry and launch up to four Kinzhals, although there is some skepticism about whether the bomber is fast enough or flies high enough for this purpose.<sup>60</sup> The range of Kinzhal if carried on the MiG-31K is 2000 km (about 1240 mi), and 3000 km (about 1900 mi) if carried on a Tu-22M3. (The range cited includes the one-way aircraft flight distance



Kinzhal mounted on MiG-31K, 2018 Moscow Victory Day Parade

Source: [www.kremlin.ru](http://www.kremlin.ru)



Russian Aerospace Forces launch the Kinzhal missile

Source: Ministry of Defense, Russia

and the missile range combined.) This a medium- or intermediate-range system (never covered by the Intermediate-Range Nuclear Forces Treaty, because it is not land based) even though Putin calls this and the other new systems “strategic.”<sup>61</sup> There are some reports of air refueling the MiG-31K while carrying the Kinzhal, suggesting the desire to increase the overall range of the delivery system.<sup>62</sup> The Su-57 stealth fighter is a prospective carrier if that jet is ever developed and deployed.<sup>63</sup>

### *Deployment schedule*

Putin claims the Kinzhal began trial deployment in December 2017 in the Southern Military District, and Russian news media variously claim either more than 250 or 380 flights have occurred.<sup>64</sup> Reports in U.S. literature tend to corroborate significant testing and trial deployment, although not necessarily the number of flight tests. It is reported that 10<sup>65</sup> to 50<sup>66</sup> MiG-31Ks will be modified to carry the Kinzhal, with at least six operational in March 2018.<sup>67</sup> There is no specific reporting about the deployed Kinzhal missiles carrying a nuclear warhead. A nuclear-tipped Kinzhal would allow more military effectiveness with less accuracy than a conventionally tipped Kinzhal but would risk nuclear escalation. The Iskander-M has a 5–7 m (16–23 ft) circular error probable (CEP)<sup>68</sup> when coupled with optical homing, a 30–70 m (98–230 ft) CEP when operating autonomously.

### *Military objective*

The Kinzhal provides standoff air-launched hypersonic strike capability with limited maneuverability. The Russian press states that the military purpose of Kinzhal is to strike U.S. or NATO ship-based anti-missile systems or land-based anti-missile systems in Romania (and Poland in the future). The declared Russian purpose to destroy missile defenses is consistent with the technical characteristics and the number of modified jets, although this system could be used for other high-value targets such as carrier groups.

The Kinzhal provides evidence that the Russian military, like the U.S. military, views air-launched standoff, speed, and maneuverability as critical assets for future warfare and deterrence. The United States has plans for a nuclear-tipped long-range standoff (LRSO) air-launched weapon, but the U.S. version is to be a strategic weapon deployed on heavy bombers and is not intended to be hypersonic.

## **Avangard Boost-Glide Hypersonic Missile**

The Avangard is a “traditional” boost-glide vehicle.<sup>69</sup> The hypersonic glide vehicle is lifted into space using a multi-phase ballistic missile and then released in low-earth orbit, descending to the edge of the atmosphere and gliding at hypersonic speeds.<sup>70</sup>

Other than acknowledging Avangard’s development by the industrial sector and stating that Russia is “one step ahead ... in most essential areas” of hypersonic technology, Putin did not elaborate on the Avangard in his 2018 speech. In 2019, Putin said, “We have launched serial production of the Avangard system ... As planned, this year, the first regiment of the Strategic Missile Troops will be equipped with Avangard.”

### *Technical characteristics*

The Avangard boost-glide hypersonic missile is believed to have been under development since the 1980s, first in the Soviet Union and then in Russia. There have been a few different development campaigns, with the most recent beginning in 2014. In total, there were about 14 reported flight tests between 1990 and 2018, many of which were failures or only partially successful.<sup>71</sup> In the latest campaign, there have been four confirmed tests, one reportedly unsuccessful and three reportedly successful. The latest successful test was conducted in late December 2018 with the launch of an Avangard on an SS-19 ICBM from the Dombrovsky ICBM base in the southern Ural Mountains to Komchatka 6000 km (about 3700



mi) away. The test was declared by Putin an “excellent New Year’s gift to the nation.”<sup>72</sup>

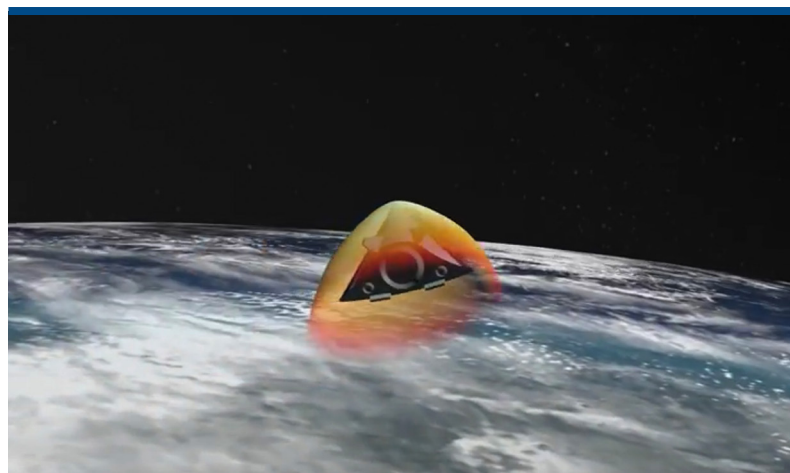
The December 2018 Avangard test reportedly reached speeds of Mach 20 or as high as Mach 27.<sup>73</sup> The boost-glide vehicle was shown by Putin as a computer graphic,<sup>74</sup> but the actual geometry is undisclosed. The Avangard is typically depicted as a delta-shaped vehicle, surrounded by a plasma sheath. The Avangard is a large vehicle, reported to be 5.4 m (almost 18 ft) long.

To date, SS-19 ballistic missiles (produced in Ukraine during Soviet times) have provided the ICBM boost for the Avangard tests.<sup>75</sup> An SS-18 missile silo was converted for use because the SS-19 with the Avangard is too long for the SS-19 silo. It is expected that initial deployment of Avangard will be with SS-19 ballistic missiles, and longer-term deployment will be on the new Sarmat missile<sup>76</sup> described earlier in this report.

The Avangard was announced as dual-capable, with a warhead that could be either conventional or nuclear. There are inconsistencies in the expected nuclear yield, ranging from 150 kt to 2 Mt.<sup>77</sup> A 150-kt warhead<sup>78</sup> on the Avangard seems more likely for the intended targets, assuming successful development of a navigation system.

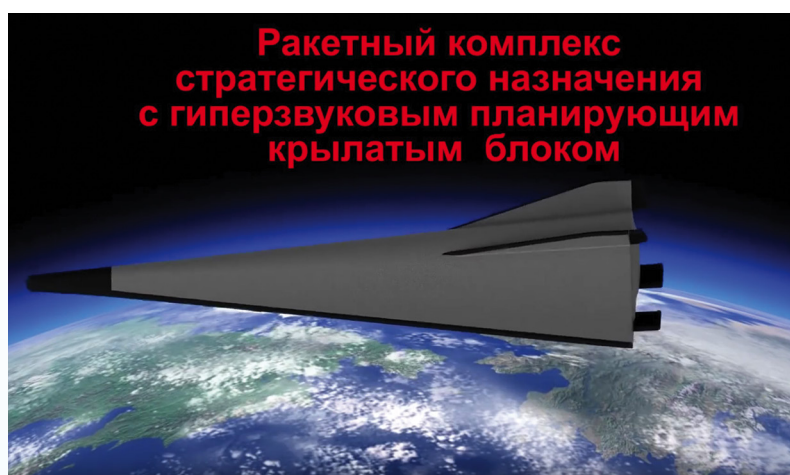
The successful testing of the Avangard represents a significant materials-science and heat-management achievement. In order to achieve success, Russia is said to have developed a special composite material that withstood the 2000°C temperatures for the tens of minutes of intercontinental hypersonic flight. The vehicle may also be equipped with a thermoregulation system,<sup>79</sup> but this is not widely reported.

It is unclear how the Avangard communicates and what accuracy the vehicle achieved during its testing.<sup>80</sup> Technologies have been maturing to enable communication through plasma, including use of high or low frequencies, vehicle design, antenna placement, particle injection, and magnetic



Avangard computer graphic

Source: Ministry of Defense, Russia



Avangard depiction

Source: Ministry of Defense, Russia

plasma shaping, among others.<sup>81</sup> Without communication through plasma or another sophisticated guidance method, the accuracy of the Avangard could be low, increasing the likelihood of a nuclear capability.

### Deployment schedule

It is probable that the Avangard development and the Sarmat development were aligned for initial deployment but the Sarmat fell behind schedule. The Kremlin seems to be using a stopgap measure by testing and planning initial deployment of the Avangard on SS-19s. Each SS-19 will carry one Avangard.<sup>82</sup> The

number of Avangard systems that can be deployed on the Sarmat is uncertain. Russian reporting claims the Sarmat can carry 16 Yu-71s (conventionally tipped Avangard systems) and up to 24 Yu-74s (nuclear-tipped Avangard systems).<sup>83</sup> However, some sources suggest that these numbers are overstated and that the Sarmat could in fact carry only up to three Avangard systems, and only if lower-yield and lighter glide vehicles are designed.<sup>84</sup> The Avangard length (5.4 m or 18 ft) suggests a heavy system, and the large numbers (16 to 24) on a single ICBM seem unrealistic unless a lighter version of the Avangard is being developed.

It was announced that serial production of the Avangard has begun and two SS-19 missiles deployed with Avangards are planned at Dombarovsky by the end of 2019.<sup>85</sup> By the end of 2027, that regiment and one other are to have six Avangard systems each, for a total of 12 systems. Given that only three successful flight tests of this design have occurred, the 2019 deployment seems ambitious and probably unrealistic. However, the overall number of 12 by 2027 seems credible given the existence of the SS-19 missiles and the maturity of the Avangard, although it is confusing relative to potential Sarmat deployment. In July 2019, there were U.S. media reports that Russia was struggling to manufacture the Avangard due to a lack of critical carbon-fiber components. In response to the U.S. reporting, Russian officials issued a statement that the production and delivery of the Avangard were proceeding on schedule and that it was still slated to achieve initial operating capability by 2020.<sup>86</sup>

By today's standards in either the United States or Russia, more testing would be prudent before deployment of a nuclear warhead on these advanced systems. Perhaps the three successful tests are considered adequate for the initial deployment of two conventionally armed missiles, but an increased rate of testing would be a strong signal of potential deployment of the full slate of 12 missiles or

the deployment of nuclear-tipped Avangard systems.

In the next decade, there does not seem to be a reasonable path for Russia to replace all, or even most, of its ICBM-based warheads with Avangard systems. The limited number of 60 Avangard systems sometimes reported seems more likely.<sup>87</sup>

### *Military objective*

The Russians have said the purpose of the Avangard hypersonic boost-glide weapon is to destroy missile-defense installations and high-value targets. In the case of the Avangard hypersonic boost-glide weapon on the SS-19 or Sarmat ICBM, high-value targets could include hardened targets such as missile silos or command centers in the United States. It is conceivable that a conventionally armed Avangard boost-glide system with modern guidance and high speeds could be engineered to damage or penetrate hardened structures, and a nuclear-armed Avangard would be expected to be effective against these targets.

In addition to defense installations or high-value targets in the United States, the Avangard could provide a limited first-strike or retaliatory nuclear capability that could not be challenged by missile defense.<sup>88</sup> Essentially, the Avangard can be viewed as an ICBM warhead replacement that can satisfy the same military objectives while evading missile detection or defense, and may be capable of destroying high-value or hardened targets.

### **Tsirkon Hypersonic Cruise Missile**

While addressing the Russian Federal Assembly on February 20, 2019, Putin described the Tsirkon as "a hypersonic missile that can reach speeds of approximately Mach 9 and strike a target more than 1,000 km (620 mi) away... It can be launched from water, from surface vessels and from submarines..."<sup>89</sup> In that same speech, Putin announced, "Russia will be forced to create and deploy weapons

that can be used ... in areas that contain decision-making centers for the missile systems threatening us.”

The Tsirkon is a hypersonic cruise missile with two stages. The first stage uses a solid-fuel rocket to lift and accelerate the missile, and the second phase uses a scramjet motor to move the missile at hypersonic speeds over a range likely limited by the lifetime of the scramjet engine. If the Tsirkon were tested (or deployed) on aircraft in a way similar to the deployment scheme for the Kinzhal, the solid-fuel first stage could be eliminated.

To date, the Tsirkon has not been officially described as a nuclear-capable missile; however, the reference in Putin’s address to Tsirkon deployment to attack decision-making centers suggests it might be deployed with a nuclear payload (like the U.S. Tomahawk sea-launched cruise missile when it was initially deployed), and news reporting occasionally mentions a nuclear-tipped option.<sup>90</sup> The 2018 U.S. Nuclear Posture Review indicates that the United States will study and potentially pursue in the coming years a nuclear-armed sea-launched cruise missile, perhaps increasing the possibility that the Tsirkon will be given a nuclear-tipped option in turn. For these reasons, the Tsirkon is covered in this report of new nuclear-weapon systems.

The Russian designation for the Tsirkon<sup>91</sup> is 3M-22 or 3K-22, and the NATO designation is SS-N-33.<sup>92</sup>

### *Technical characteristics*

Open-source reporting on the Tsirkon is quite scarce, although the Tsirkon is reported to have been in development since at least 2011,<sup>93</sup> with a period of active testing beginning in 2015. The body length is estimated at 8 to 11 m (24 to 33 ft),<sup>94</sup> warhead weight is 300 kg to 400 kg (660 lb to 880 lb), and peak altitude along the trajectory at 30 km to 40 km (100,000 ft to 130,000 ft).<sup>95</sup> The production agency is the Scientific Production Organization for Machinery-building, or NPO

Mashinostroyeniya.<sup>96</sup> The Tsirkon is said to be designed to use the 3S-14 Russia Universal Vertical Launching System, the same seaborne launcher as the Onyx and Kalibr missiles, in order to make it easy and affordable to deploy on ships and submarines.<sup>97</sup>

The Tsirkon is reported to have some sophisticated features potentially including:

- ▶ A new fuel for the scramjet, called Decilin-M, to extend the range of the missile. Decilin-M is reported to be a high-calorie synthetic aviation fuel rumored to be like the U.S. synthetic fuel JP-10.<sup>98</sup>
- ▶ A new metal alloy to withstand the temperatures obtained during hypersonic flight. The composition of this new material is reported to be highly classified and likely the result of a long development effort.<sup>99</sup>
- ▶ Pyrotechnic release of the scramjet engine from the missile before final approach to target for more stability. There is a Russian patent that describes this concept.<sup>100</sup>
- ▶ Maneuverable during the terminal target approach, allowing for extra protection from any defensive system.<sup>101</sup>

In reporting about the Tsirkon, the plasma sheath is largely described as a positive feature that allows the missile to go undetected by radar, since the plasma absorbs radar frequencies.<sup>102</sup> As with the Avangard, however, the communication through the plasma sheath for guidance is not mentioned.

Early tests of the Tsirkon are believed to have been completed with the Tu-22M3 bomber as the “first stage,” followed by at least five tests from a coastal platform using both the rocket and scramjet.<sup>103</sup> There are reports that tests conducted from the coastal platform in Nyonoksa in late 2015, in March 2016, and in February 2017 may not have been completely successful. Tests in April 2017 and December 2018 were reportedly successful, with the missile obtaining a maximum speed of Mach 8.<sup>104, 105</sup> The priority for the Tsirkon is sea-



based deployment, and tests from sea-based platforms are said to be scheduled for late 2019. Some believe the Tsirkon will have a light version that will be air-deployed, likely from a Tupolev Tu-160/M/M2 jet, although this seems to be quite speculative.<sup>106</sup>

The range and speed mentioned in Putin's 2019 speech (1000 km and Mach 9) are higher than previously reported. The difference between the prior reporting and Putin's speech could come from technical improvements (such as a new fuel or longer-lasting scramjet), misstatements about Tsirkon's performance, or different versions of the Tsirkon being developed simultaneously; or it could be a matter of various flight altitude and trajectory options for the Tsirkon. Since previously designed and tested scramjets have lasted about six minutes, the range provided by the scramjet at Mach 5 would be around 500 km (310 mi). Therefore, the highly reported Mach 5 to Mach 6 and 500 km (310 mi) range seems to be a realistic estimate. However, a semiballistic trajectory could potentially reach Mach 9 and 750 km (466 mi).<sup>107</sup> If the speculated air-launched version were to be developed, then a range of over 1000 km (620 mi) could be possible, because the aircraft would provide some of the range.<sup>108</sup> The lower-altitude version has the advantage of being more difficult to observe than the semiballistic version. It is unclear whether the Tsirkon has high-g evasive-maneuvering capability.

### *Deployment schedule*

There are many discrepancies in the reported deployment schedule. Tsirkon is expected to be deployed on Russia's two heavy nuclear-powered battle cruisers currently undergoing maintenance and modernization,<sup>109</sup> the first expected to be complete 2021 or 2022.<sup>110</sup> During modernization, the battle cruisers will be equipped with 10 universal vertical launchers to allow Tsirkons or other missiles to be used interchangeably.<sup>111</sup> The launchers are said to hold up to eight missiles each for a total of 40 to 80 missiles depending on the type.<sup>112</sup>

The Tsirkon deployment date has been variously reported as 2018, 2022, and 2025<sup>113</sup> and is likely planned to coincide with the refurbishment schedule of the battle cruisers. However, given the significant technical challenges of developing and producing a reliable scramjet and a specialized metal-alloy cruise missile body, deployment before the mid- to late 2020s seems highly unlikely without an increased pace of development and testing.

In addition to deployment on the battle cruisers, it is reported, the Tsirkon will be carried by the Yasen-class (also called Husky-class) submarine<sup>114</sup> and perhaps the Steregushchiy-class corvettes,<sup>115</sup> although neither carrier appears to be in near-term plans. As mentioned earlier, there is also speculation that a lighter version of the Tsirkon could be air-carried, and a version could be created for export to India or elsewhere.<sup>116</sup>

### *Military objective*

The claimed military objective of the Tsirkon is to destroy carrier groups before it can be intercepted. Given the hypersonic speeds and the relatively short travel distances if it were launched either from either shore or sea, the total time to detect and intercept would likely be less than five minutes. Today's U.S. and U.K. ship-based defenses are not designed to work at those speeds, and even if the missile were destroyed it would be close enough that fragments could cause significant damage.

Secondary missions of the Tsirkon are said to be land-based targets such as command and control centers or missile-defense installations. Tsirkons carried by submarines that move close to shore could target command and control centers within a few hundred kilometers (about 100 mi) from the coast. The missiles would travel quickly and might be able to penetrate underground bunkers due to the momentum imparted by their high speed.<sup>117</sup> Tsirkon missiles deployed in Kaliningrad could potentially reach the missile-defense installation in Poland.

Russian state TV channel Russia-1 has presented a list of five U.S. decision-making centers, some of which are not currently operating, that would be likely targets for Russia's Tsirkon hypersonic missiles deployed on submarines:<sup>118</sup>

- ▶ the Pentagon
- ▶ Camp David
- ▶ Fort Ritchie
- ▶ McClellan Air Force Base
- ▶ Jim Creek Naval Radio Station

This list of targets seems to indicate that the Tsirkon's target list of decision-making centers has not yet been fully developed.

## Russian Hypersonic Technology Investment

The long-term success of Russian hypersonic efforts may depend on both near-term investments in hypersonic vehicles and delivery systems and long-term investments in infrastructure and research. While this is not the focus of this paper, it has been reported that Russia has three test ranges that have been used for the hypersonic program, and two wind tunnels.<sup>119</sup> Little is available in open sources about advanced research programs underway in Russia beyond the three systems discussed. As measured by papers presented at the AIAA International Space Planes and Hypersonic Systems and Technologies Conference over nine years ending in 2017, Russia's research publications lag significantly behind those of China, the United States, and others.<sup>120</sup>

## Russian Hypersonic Delivery System Summary

Open-source reporting and observed testing of Russian hypersonic missile efforts provide evidence that Russia is developing three types of hypersonic vehicles. Jet aircraft, ICBMs,

and battle cruisers are being modified or developed in parallel with hypersonic vehicle development. Each hypersonic vehicle type has a unique delivery platform, and together they provide air-delivered, ground-delivered, and sea-delivered capabilities. It is credible that any of these systems could carry nuclear warheads, and the air- and ground-delivered systems have been announced as dual-capable.

Although Putin refers to these weapon systems as strategic, only one, the Avangard, has strategic-range strike capability. As initially deployed, the Kinzhal air-delivered weapon is expected to have medium-range capability, and the Tsirkon sea-delivered weapon is expected to have short-range capability.

The Russian efforts and successes to date suggest that the Kinzhal hypersonic ballistic missile is likely already in trial deployment. With continued and significant investment and technical accomplishments, Russia could have the Avangard hypersonic boost-glide vehicle deployed in the early to mid-2020s, and the Tsirkon sea-launched cruise missile in the mid- to late 2020s.

However, due to the failures and delays already experienced, coupled with the significant investment required to continue testing, producing, and deploying these weapons, the deployments are not expected to be as fast as Russian officials or open-source reporting suggests. Which systems are fully developed, the number produced, and when and how they are deployed will depend on the magnitude and pace of Russian investment and accomplishments, and perhaps U.S. or China advancements, or arms control agreements. Official government statements and open-source reporting provide insight into the most aggressive Russian deployment plan.

Some have argued that the dual-capable aspect of these weapons is quite troubling and destabilizing.<sup>121</sup> The Russians seem intentionally ambiguous about which and how many of the new hypersonic systems will carry

nuclear weapons, and secretive about what types of warheads will be deployed on these new systems.

## U.S. and Chinese Hypersonic Delivery System Summary

As mentioned earlier, the development of new hypersonic systems is proceeding not only in Russia but also in the United States and China, and to a lesser extent elsewhere. A brief summary of U.S. and Chinese developments is included here to provide a context for evaluation of the Russian program.

### *United States*

Although the United States had early and intermittent forays into hypersonic weapon and aircraft development, the latest weapon-development efforts began in the early 2000s as part of the conventional prompt global strike (CPGS) program.<sup>122</sup> The primary motivations for CPGS were to better execute the war on terror by quickly reaching time-urgent targets across the globe and to penetrate anti-aerial/anti-access denial systems. CPGS efforts resulted in two successful flight tests, in 2011 and 2017, of a hypersonic boost-glide vehicle, and a failed flight test in 2014. The 2011 test was launched from Hawaii and landed in the Marshall Islands, approximately 3700 km (2300 mi) away. The 2017 test was also launched from Hawaii.

With the intense development activities in Russia and China, hypersonic-weapons development was identified in 2019 by the U.S. Department of Defense as a priority research-and-development area, and development was accelerated by the John S. McCain National Defense Authorization Act for Fiscal Year 2019. The nature of the hypersonic-weapon development program changed from CPGS to conventional prompt strike, with emphasis on short-, medium-, and intermediate-range missiles.

Today's U.S. hypersonic-weapons program focuses exclusively on research and development for conventional-warhead delivery. Limiting the development of U.S. systems to conventional warheads requires that a high degree of accuracy be achieved for militarily effectiveness, and some have claimed this puts greater technical demands on U.S. development activities than those on Russia's.<sup>123</sup> The United States has no planned strategy for hypersonic systems acquisition and is unlikely to field a hypersonic-weapon system before 2022. It is expected that the Department of Defense will request an acquisition program if development programs succeed in the next few years.

The U.S. program comprises a common glide vehicle called the Advanced Hypersonic Weapon (AHW) along with Navy, Army, and Air Force delivery vehicles. In the original boost-glide mode, AHW was designed to provide a range of 6000 km (3700 mi), a 35-minute time of flight, and accuracy of 10 m (33 ft).<sup>124</sup> In addition, the Defense Advanced Research Projects Agency (DARPA) continues research activities on more advanced glide vehicle and cruise missile concepts, along with new delivery systems.<sup>125</sup>

The common hypersonic glide vehicle development is led by the Navy and is an adaptation of the prototype designed by Sandia National Laboratories and successfully tested in 2011 and 2017. The booster systems are being developed by the services separately. The Navy is developing an intermediate-range conventional prompt-strike weapon as a submarine-launched system, with flight tests and prototyping expected through 2024, and the Army is developing a medium-range (2250-km, 1400-mi) ground-based hypersonic two-phase booster system.<sup>126</sup> The Air Force is developing a short-range hypersonic conventional-strike weapon that is a solid-rocket-powered hypersonic system, to launch from the B-52, and a air-launched rapid response weapon with an range of 575 mi (925 km).<sup>127</sup> Notably, the United States is

not developing an ICBM-boosted conventional hypersonic missile weapon at this time. The Pentagon abandoned the ICBM-boosted approach out of concern that such systems could be confused with nuclear-armed missiles and could unintentionally cause a nuclear exchange.<sup>128</sup>

The United States is also investing in research infrastructure such as wind tunnels and test ranges for hypersonic technology at universities and government facilities. Today, the United States has 48 declared critical facilities for hypersonic development, more than 10 test ranges, and two hypersonic wind tunnels, with another in development. In testimony in March 2019, Michael Griffin, the Department of Defense's Under Secretary for Research and Engineering, said, "We have significantly increased flight testing, as we intend to conduct approximately 40 flight tests over the next few years, to accelerate the delivery of capability to our warfighters years earlier than previously planned."

In addition to developing conventional hypersonic weapons, the United States is also investing in new missile-defense technologies that can defeat adversarial hypersonic weapons.<sup>129</sup>

## China

China appears to have been working on modern hypersonic weapon systems since the early 2000s in academic, industrial, and military research institutes.<sup>130</sup> The most significant weapon development in China has been the hypersonic glide vehicle originally referred to as the WU-14 and more recently called the DF-ZF HGV. The DF-ZF HGV has been tested at least nine times since 2014—the first seven tests aimed at the development of the DF-ZF HGV and the last two tests aimed at mating the DF-ZF HGV to a DF-17 medium-range ballistic missile. Only one of the tests was a failure.<sup>131</sup> Images of the DF-ZF HGV have not been released, and both conical-shaped renderings and delta-winged renderings have been posted.



Chinese Hypersonic Glide Vehicle

Source: AP Photo/Ng Han Guan

The DF-17 medium-range ballistic missile was reportedly specifically designed to deliver the DF-ZF HGV. Two tests of the mated hypersonic system conducted in November 2017 were successful; the missile was reported to have flown at Mach 5 to Mach 10 over 1400 km (870 mi) at an altitude of about 60 km (37 mi) and to have struck "within meters" of the intended target.<sup>132</sup> This system is reported to have extreme maneuverability.<sup>133</sup>

In addition to the DF-17 medium-range ballistic missile specifically designed for the DF-ZF HGV and used for testing to date, analysts speculate that other Chinese ballistic missiles could be used to boost the hypersonic glide vehicle. Some believe the DF-21 medium-range missile or DF-26 intermediate-range missile could support an anti-access/aerial denial strategy. Many believe the DF-41 ICBM under development, expected to carry multiple warheads and be capable of a 12,000-km (7456-mi) range, could carry the DF-ZF HGV. The DF-41 is capable of reaching the U.S. mainland.<sup>134</sup>

Some report the DF-17 hypersonic system will be ready for operation as early as 2020,<sup>135</sup> and given the number of tests, it is reasonable to assume that deployment in the early 2020s is possible. China recently announced its



hypersonic vehicle system would be capable of carrying a nuclear warhead.

In addition to the DF-ZF HGV, China tested a delta-shaped hypersonic plane called the Starry Sky-2 in August 2018,<sup>136</sup> dropped three different scaled-down hypersonic aerodynamic shapes from a balloon in September 2018,<sup>137</sup> released images of potential hypersonic cruise missile the Jai Geng No 1 in April 2019,<sup>138</sup> and is doing research on scramjet engines.<sup>139</sup> In the Starry Sky-2 test, a hypersonic glide plane was ground-launched, reached a top speed of Mach 6, conducted extreme maneuvers, maintained velocities above Mach 5.5 for 400 seconds, and landed fully intact.<sup>140</sup>

China has invested heavily in research capabilities for hypersonic technology and operates two test ranges and three wind tunnels, with a fourth in development.

### **Comparison of Russian, Chinese, and U.S. Capabilities**

Russia, China, and the United States are using different approaches to the pursuit of hypersonic weapons, in part because different military objectives and gaps are being filled. Therefore, it is not straightforward to declare who is ahead or behind in development. In addition, significant investments are being made in hypersonic weapon development in all countries, and advances are rapid.

For weapon efforts, China and the United States are each focusing on the maturation of one hypersonic glide body that will be carried by one or more boosters. In the case of China, the focus is on a ground-based rocket booster

with significant success. The United States adopted this focused approach later than China and is now developing multiple booster systems for air, ground, and sea launches. Russia has developed three types of hypersonic vehicles and has been developing air-, ground-, and sea-launched systems that use different boosters.

Each country can claim successes: China has completed the largest number of successful tests to date of a rocket-boosted glide vehicle. Russia was the first to trial deploy a hypersonic system, the Kinzhal air-launched ballistic missile. The United States was the first to have a successful test of a hypersonic glide vehicle with significant range and accuracy.

This technology race is playing out in real time, and all three countries are significant players. If the development and investments continue, it is likely that each country will deploy one or more hypersonic weapon systems. Whether or not any or all countries will deploy nuclear-tipped hypersonic weapons remains to be seen. Over the longer term, it is very likely that without any new arms-control agreements, additional countries will also eventually deploy hypersonic weapon systems.