Pugwash Briefing Paper

Hypersonic Weapon Series

#1

What is a Hypersonic Weapon?

Background

The Pugwash Foundation supported an international Pugwash workshop on hypersonic weapons, which took place in Geneva on 9 and 10 December 2019. The meeting brought together 30 international participants from various continents, including current and former government officials, scientists, engineers, academics and experts from think tanks and other non-governmental organisations.

The workshop aimed at fostering a constructive exchange of views on hypersonic weapons. Participants discussed factors driving the development, roles and purposes of hypersonic weapons, as well as the risks associated with their deployment and use.

Based on the workshop's discussions, the Pugwash Foundation produced a series of briefing papers on hypersonic weapons. The series covers the following themes:

- What is a hypersonic weapon?
- What technical challenges do hypersonic weapon raise?
- What are the current hypersonic weapon development programmes?
- Why do States develop hypersonic weapons?
- What are the roles and missions of hypersonic weapons?
- What are the risks associated with hypersonic weapons?
- How to mitigate the risks associated with hypersonic weapons?
- How to counter hypersonic weapons?

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What is a hypersonic weapon?

While in recent years hypersonic weapons have featured prominently in various media, academic publications and official statements, publicly available technical information about such weapons remains scarce. Their characteristics, the consequences of their introduction into the arsenals of major military powers and their eventual proliferation need to be better understood.

Today, it is still unclear what precisely the term 'hypersonic weapons' refers to.

In order to get closer to a working definition, the workshop identified the following criteria:

- Speed
- Trajectory
- Manoeuvrability
- Target accuracy

Speed

Speed regimes can be used to categorize and distinguish between different types of vehicle.

> As shown in *Tab.1*, speed regimes can be used to differentiate between traditional cruise missiles and Hypersonic Cruise Missiles (HCMs).
>
> However, speed regimes cannot be used to differentiate between traditional ballistic missiles and Hypersonic Glide Vehicles (HGVs).

Tab.1 Overview of speed regimes

Speed regimes	Speed	Examples
Subsonic (M<1)	Lower than the speed of sound (Mach 1 = ~1200km/h or 0,33 km/s)	ALCMs, JASSM, Commercial jet airplanes
Supersonic (M>1)	Greater than Mach 1	Cruise missiles such as BrahMos
Hypersonic (M>5)	Greater than Mach 5 (1,7 km/s or ~6100km/h)	Kinzhal, X-15, X-51A, Hypersonic Cruise Missiles such as Zircon
	Greater than Mach 20 (6,86 km/s or ~24696 km/h)	ICBM/SLBM such as Minuteman III and Trident II in the descent phase, Hypersonic Glide Vehicles such as Avangard (M=20)
	Mach 28 (9,6 km/s or ~34574 km/h)	Re-entry of orbiting stations and spacecraft
	Mach 36	Returns from lunar missions

Trajectory

Hypersonic Glide Vehicles (HGVs)

Boost-phase

Hypersonic Glide Vehicles (HGVs) are launched from a ballistic missile booster stage into a sub-orbital trajectory. They are released either in Near Space (20km and 100km in altitude) or Outer Space (above 100km), depending on the target location.

Mid-course

The gliding vehicle re-enters the atmosphere with its flat lower surface exposed to atmospheric forces. The large drag force and minimal lift generated will slow the gliding vehicle down. It will then undertake a pull-up manoeuvre by rotating into a high lift, low drag orientation. After the pull-up phase, the gliding vehicle will reach a gliding equilibrium and can glide at more than Mach 20.

However, HGVs cannot sustain a Mach 20+ speed for the entire duration of their mid-course flight. The longer the atmospheric flight time, the greater the HGV will decelerate before hitting its target.

Gliding is made possible thanks to the aerodynamic features of the vehicle which create extremely high compression waves of great amplitude.

Terminal phase

When the gliding vehicle is close to the target, it uses atmospheric forces to exit the glide and hit the target.

> The trajectory can be used to differentiate between traditional ballistic missiles and HGVs.
>
> Traditional ballistic missiles follow a ballistic or quasi-ballistic trajectory. Whereas HGVs (and HCMs) follow a non-ballistic atmospheric trajectory.

Hypersonic Cruise Missiles (HCMs)

Traditional cruise missiles and a Hypersonic Cruise Missiles (HCMs) have the same flightpath. HCMs also cruise at an altitude of 10-40 km except that they reach hypersonic speed of up to Mach 10. In order to reach hypersonic velocity, they use different types of engines i.e. scramjet and ramjet engines.

> The trajectory cannot be used to differentiate between traditional cruise missiles and HCMs. Both have the same flightpath.

Manoeuvrability

Manoeuvrability refers to the capacity of a delivery vehicle to change its course.

Hypersonic Glide Vehicles (HGVs)

HGVs have greater manoeuvrability over their mid-course and terminal phases than traditional ballistic missiles, including ballistic missiles fitted with manoeuvrable re-entry vehicles (MaRVs).

However, HGVs' manoeuvrability comes at the cost of speed and range. When HGVs deviate from their trajectory, kinetic energy is lost. Drag forces generated by the change of course will slow them down and therefore reduce their range too.

Hypersonic Cruise Missiles (HCMs)

HCMs' hypersonic speed makes them slightly less manoeuvrable than the current generation of traditional cruise missiles.

HCMs' manoeuvrability comes at the cost of speed, range and weight. In order to withstand high G-force and frictions generated by the change of course, the airframe needs to be reinforced. The more reinforced the airframe becomes, the less speed, range and room for payload and fuel the HCM will have.

Their manoeuvrability is the result of a trade-off between airframe, payload, fuel, speed and range.

> Manoeuvrability can be used to differentiate between traditional ballistic missiles and HGVs.
>
> HGVs have greater manoeuvrability than traditional ballistic missiles.

> It seems that the difference in manoeuvrability is too small to differentiate between traditional cruise missiles and HCMs.

Target accuracy

Due to the lack of open source information, the difference in target accuracy between HCMs and HGVs, and traditional cruise and ballistic missiles is hard to assess.

A number of factors could positively or negatively influence HGVs' and HCMs' accuracy.

Hypersonic Glide Vehicles (HGVs)

HGVs will hit their target at lower speed than traditional ballistic missiles because atmospheric forces slow them down. This may enhance their accuracy.

But the deleterious effects of aeroshell damage caused by a relatively long atmospheric flight time may undermine their accuracy. In addition, plasma may interfere with their on-board systems which would further reduce their accuracy.

Hypersonic Cruise Missiles (HCMs)

HCMs will hit their target at higher speed than traditional cruise missiles. This may make it more difficult to guarantee high accuracy. In addition, the impact of physical phenomena on their on-board systems and aeroshell may further undermine their accuracy.

Tab.2 Overview of criteria for hypersonic weapons

Criterion	**Description**
Speed	Greater than Mach 5
Trajectory	Non-ballistic and atmospheric for part or all of the flight
Manoeuvrability	High
Target accuracy	High

Conclusion

What distinguishes Hypersonic Cruise Missiles (HCMs) and Hypersonic Glide Vehicles (HGVs) from traditional cruise and ballistic missiles is the combination of all those criteria: HCMs and HGVs a) fly at hypersonic speed, b) have a high manoeuvrability, c) offer high target accuracy, and d) follow a non-ballistic atmospheric trajectory for part or all of their flight. Because of the underlying physics, reconciling all these characteristics proves difficult and may involve trade-offs.

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