Pugwash Briefing Paper

Hypersonic Weapon Series

#2

What technical challenges do Hypersonic Weapon raise?

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 technical challenges do hypersonic weapons raise?

The development of weapon systems with hypersonic speed, sustained atmospheric flight time, high-manoeuvrability, and high-accuracy, raises a set of technical challenges requiring specific supporting sub-systems, materials, designs and test facilities.

<u>Hypersonic Glide Vehicles (HGVs)</u>

HGVs undergo serious stress during their mid-course and terminal phases.

Heat and G-force

The very high temperatures generated by the interaction with the atmosphere and the high G-loading generated by any manoeuvring can damage the vehicle and interfere with its aerodynamics properties.

As shown in *Tab.1*, the only known materials that cumulate all those advantages are certain composites such as carbon fibre reinforced carbon (CFRC) which have been used for the nose cone of intercontinental ballistic missiles and space shuttles.

However, even carbon composites cannot fully maintain their integrity for a long time in hypersonic conditions. They will last longer than other materials, but will still degrade (ablation and oxidation).

The question then is whether one can somehow actively cool the missile or whether the deleterious effects of aeroshell damage, such as reduced accuracy, are acceptable.

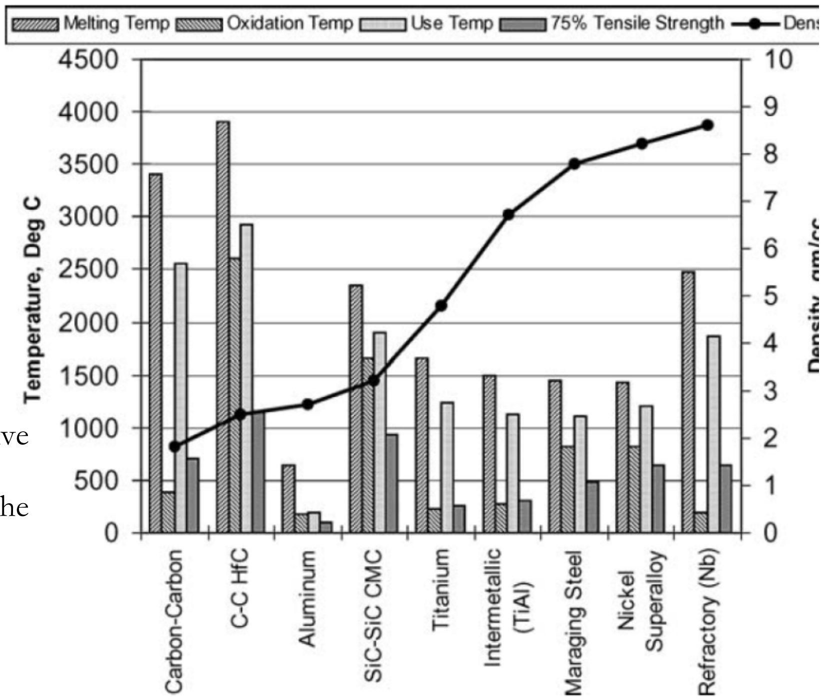
Box.1 Aeroshell proprieties:

- Reducing drag and enhancing lift
- Ensuring stability throughout the long gliding phase
- Ensuring structural integrity so that on-board instrumentation and payload remain functional

In order to attenuate the negative impact of high temperatures and high G-force, materials used for the fabrication of the aeroshell must:

- ➢ withstand temperatures of 2'200 Celsius
- ➢ have good tensile strength to prevent the frame from breaking under high G-force
- ➢ have low-density to make the frame as light as possible
- ➢ have good resistance to oxidation.

Tab.1 Overview of material limitations



D.M. Van Wie, D.G. Drewry, D.E. King, C.M. Hudson, “The Hypersonic Environment: Required Operating Conditions and Design Challenges”, *Journal of Materials Science* 39, 19 (2004)

Ionization

An object moving at increasing hypersonic speed will generate a staged chemical alteration of the airflow surrounding it, thereby triggering an ionization process. At the end of this ionization process, the object will be surrounded by a layer of plasma.

Guidance systems – GPS, electro-optical and RF seekers – can be affected by the plasma. It could undermine the accuracy and navigation control of the vehicle.

Hypersonic Cruise Missiles (HCMs)

Propulsion

Cruise missiles with standard turbojets cannot reach hypersonic speed. HCMs need to employ advanced scramjet and ramjet propulsion systems to reach hypersonic speed.

However, scramjets and ramjets are very delicate systems to operate. They become functional only within a certain speed range. They first need to reach a high initial speed through an airplane or a rocket booster. After which scramjets and ramjets can be turned on. But switching in-flight from turbojet to scramjet or ramjet is technically challenging.

Those propulsion systems also require special fuels. There are two types of fuel that can be used with scramjets and ramjets:

- hydrogen fuel
- hydrocarbon fuel.

Heat, G-force and Ionization

While traveling at lower hypersonic speeds than HGVs, HCMs are nevertheless exposed to:

- high temperatures
- high G-force
- chemical alterations of the airflow (as they typically fly in lower denser part of the atmosphere than HGVs)

Those physical phenomena raise similar issues of:

- airframe integrity
- signal and sensor distortion

This, in turn, has an impact on navigation, communication, guidance and flight stability.

Box.2 Testing

For both HGVs and HCMs, advanced testing facilities are required to ensure that the designs, materials, and many critical supporting sub-systems (and propulsion for HCMs) are well-integrated.

Standard wind tunnels cannot reproduce conditions to test hypersonic weapons. Only few facilities can reproduce those conditions for a very short time.

Most development is done through computer modelling which is not sufficient to validate a weapon. The only way to make sure the weapon is working correctly is through flight tests.

Conclusion

HCMs and HGVs are exposed to:

- High temperatures
- High G-force
- Chemical alterations of the airflow (ionization)

Those physical phenomena raise a number of technical issues. These include:

- An aerodynamic design that reduces drag and guarantees stability throughout the gliding phase for HGVs and the cruising phase for HCMs
- Materials that withstand high temperatures, have a high tensile strength, have low-density, and have good resistance to oxidation
- Propulsion systems with stable combustion at hypersonic speed for HCMs
- On-board navigation, communication and guidance instruments that withstand high temperatures, high G-force, and can get through plasma
- Testing facilities and simulation modelling that can reproduce hypersonic conditions

This, ultimately, has an impact on HCMs' and HGVs':

- Speed
- Range
- Flight stability
- Manoeuvrability
- Accuracy
- Penetration
- Detection

However, due to the lack of open data on HCMs and HGVs, it is unclear whether those technical issues have been resolved. Without a proper technical understanding, it is impossible to accurately evaluate the real capabilities of HCMs and HGVs and assess the risks they pose.

Acknowledgements

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