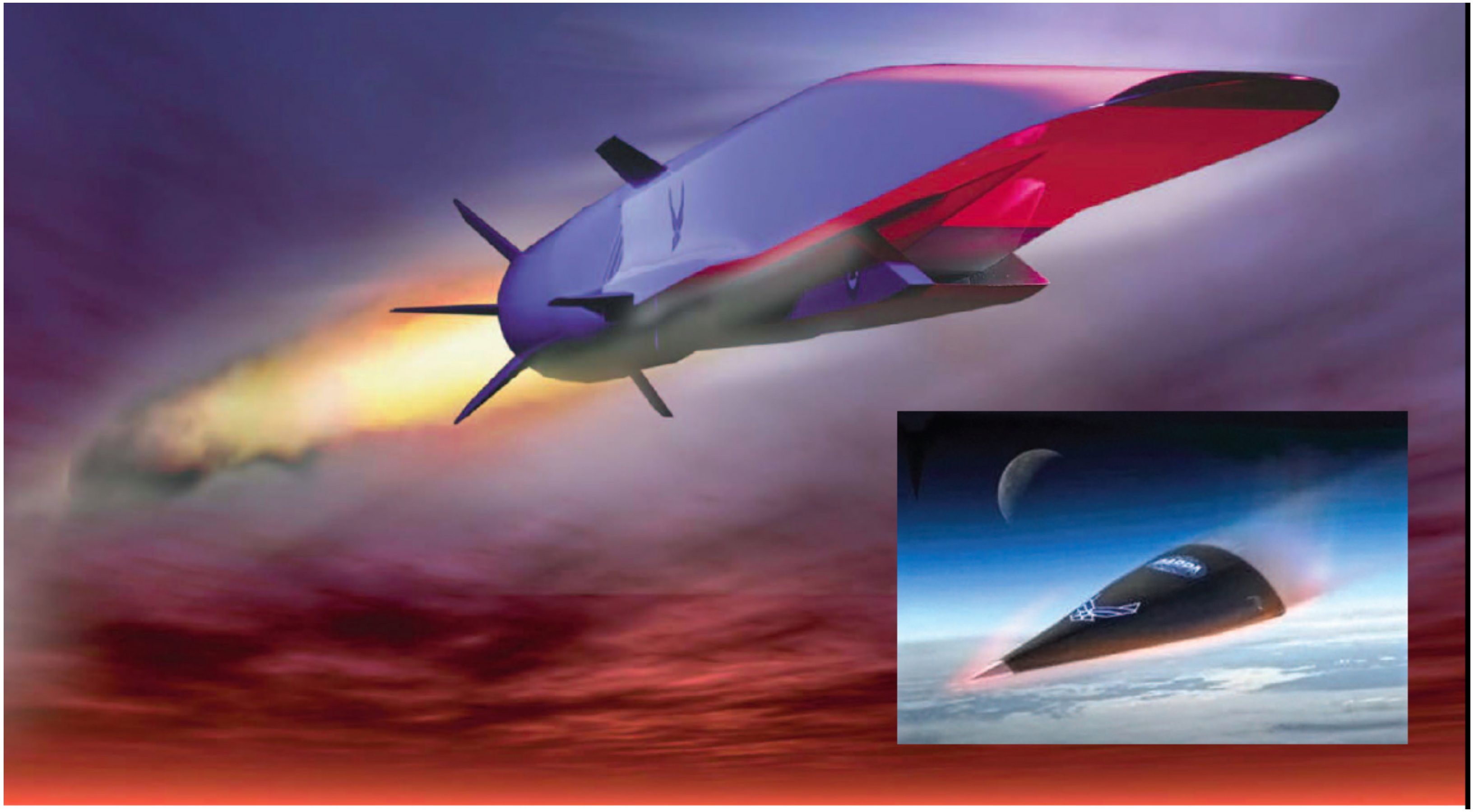


Hypersonic missiles: how does the technology impact stability

January 2020 Alessandro Pascolini

A new arms race?

A competition is intensifying between China, Russia and the United States on the militarization of hypersonic vehicle technology:

- “natural” development of supersonic aeronautics
- necessary for the atmospheric re-entry of both powered and unpowered vehicles
- not necessarily involving nuclear weapons, but a new class of kinetic “conventional” weapons

The Guardian

Russia deploys first hypersonic missiles

Avangard capable of carrying 2-megaton nuclear weapon at 27 times the speed of sound

Vladimir Putin told an annual military meeting this week that Russia is the only country with hypersonic weapons. Photograph: Mikhail Klimentyev/AP

the offer

hypersonic flow technology

hypersonic weapons

hypersonic weapon programs

risks of proliferation

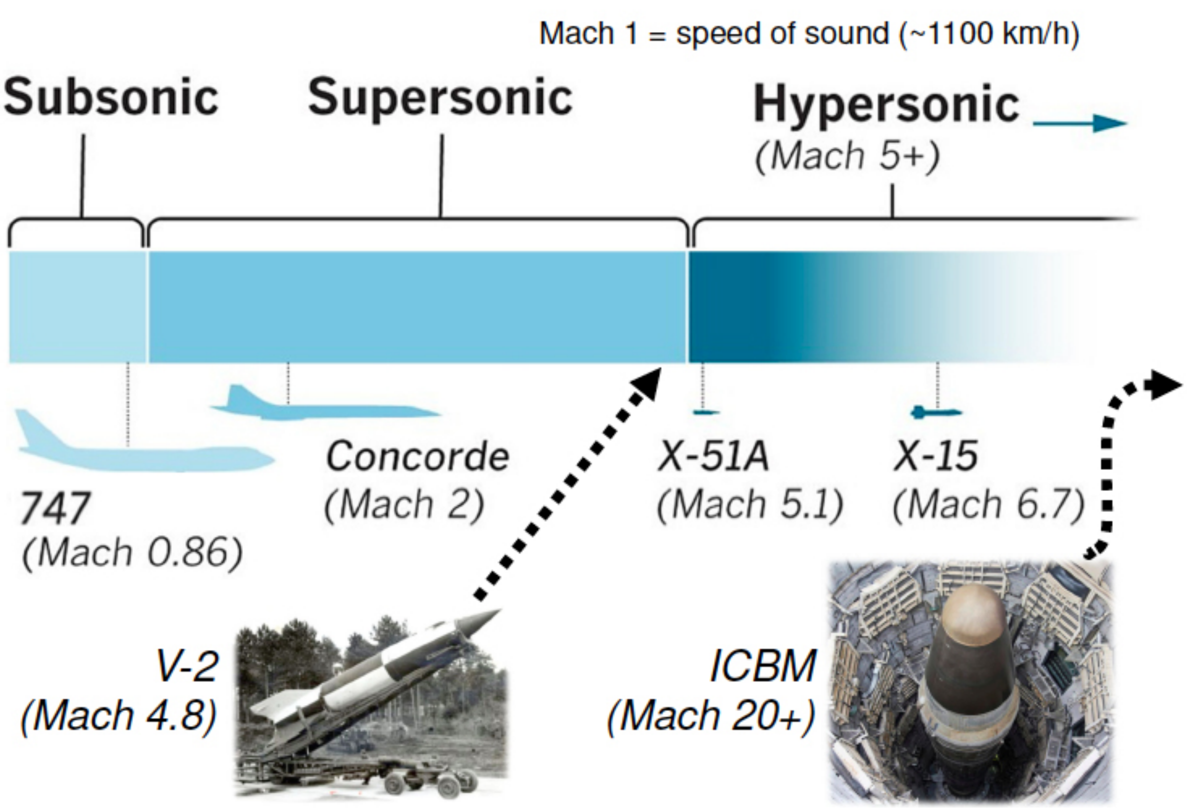
strategic implications

arms control

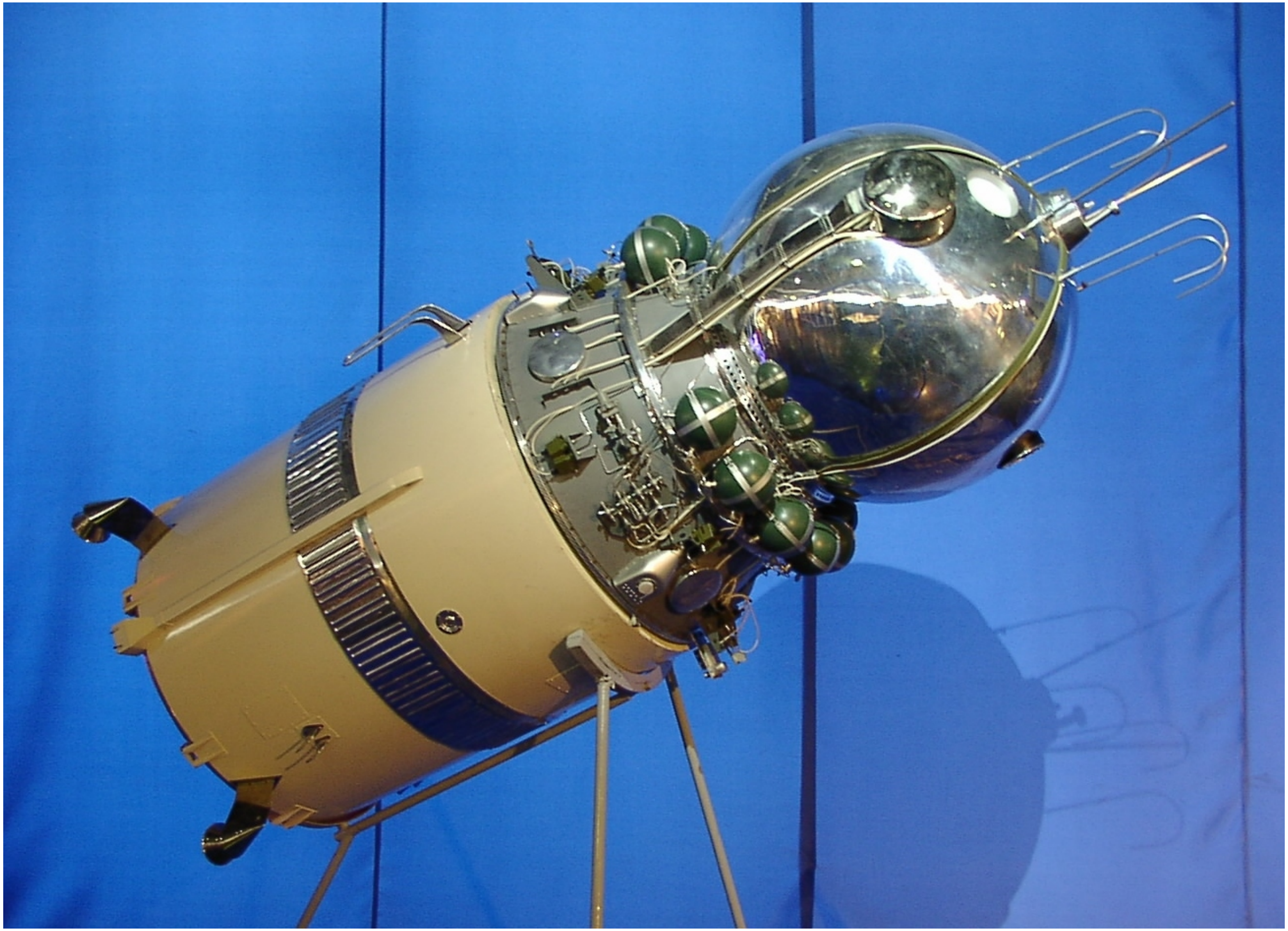
hypersonic flow technology

Speed regimes

- subsonic: velocities lower than the speed of sound in the atmosphere (Mach 1 ≈ 1100 km/h ≈ 0.33 km/s)
- supersonic: velocity between Mach 1 and Mach 3
- hypersonic: velocities above Mach 5



12 April 1961: Yuri Gagarin is the first man to esperience hypersonic flight



Vostok1

The hypersonic regime proposes increasing problems with increasing speed due to:

- highly non-linear gas-dynamics
- thermodynamics far from equilibrium with critical entropy gradients
- chemical alterations of the air flow
- triggering of ionization processes

All these phenomena are sharpened with the square of the Mach number

The environments faced by vehicles flying at hypersonic velocities are very different and harsher than vehicles flying at subsonic and supersonic speeds. Gases behave very differently at hypersonic speeds compared to subsonic and supersonic velocities drawbacks.

Physics challenges such as natural and forced boundary layer transition, separation caused by shock-boundary layer interaction, shock-shock interaction heating, isolator shock trains, boundary layer re-laminarization, non-equilibrium gas dynamics, molecular dissociations, and ionization are all characteristics of the environment produced by hypersonic flows.

physical effects

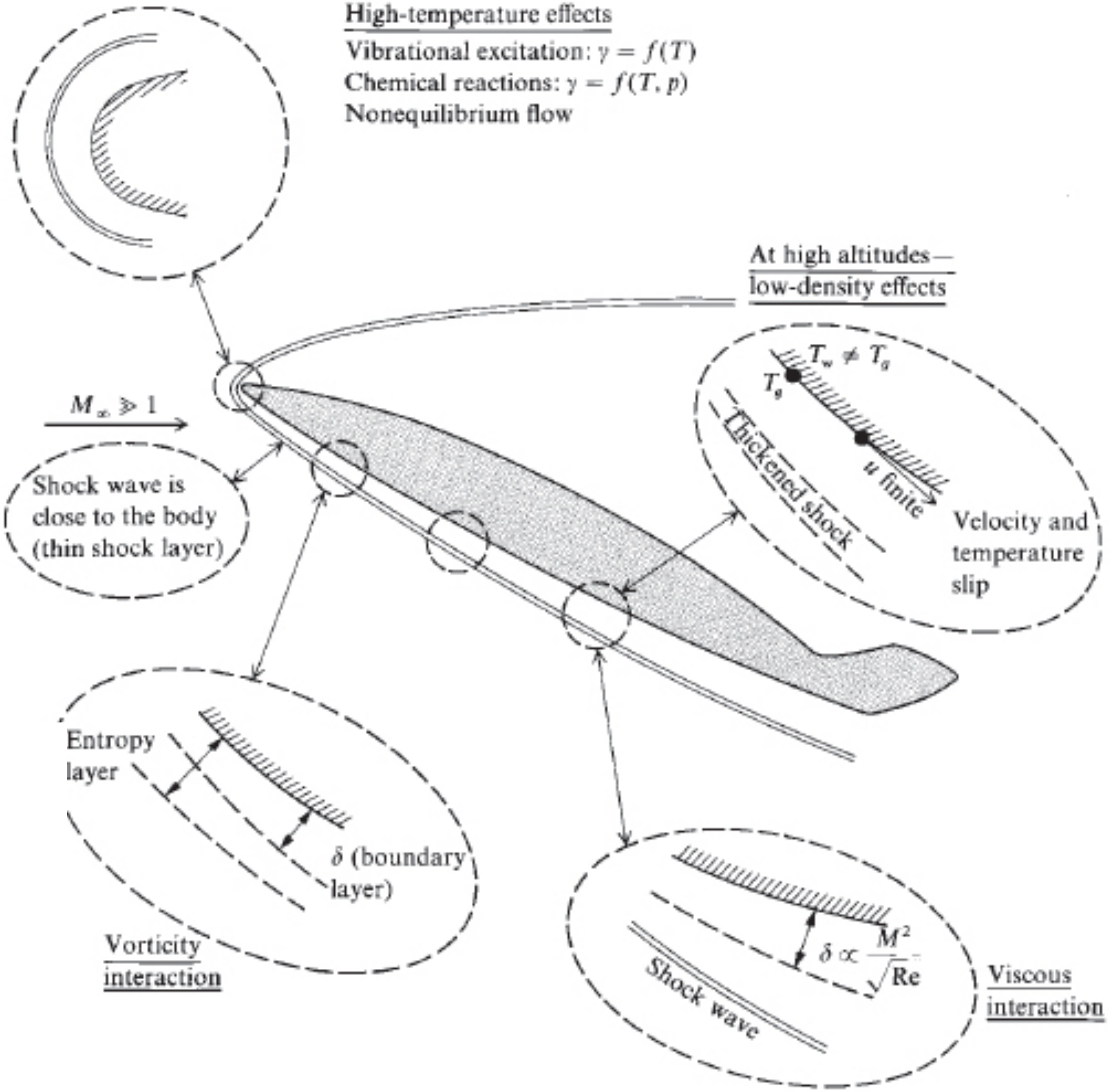
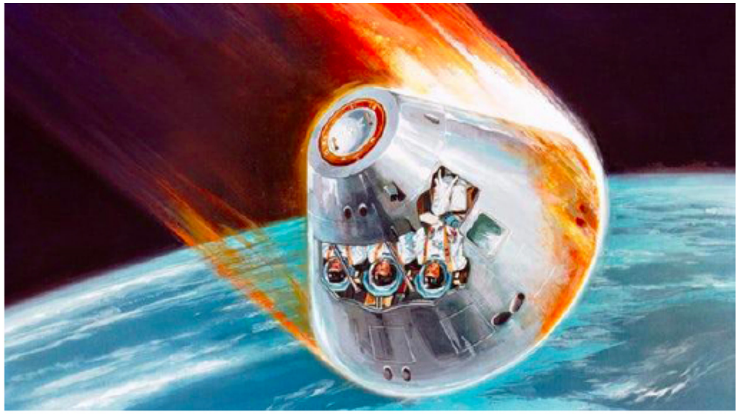


Fig. 1.20 Physical effects characteristic of hypersonic flow.



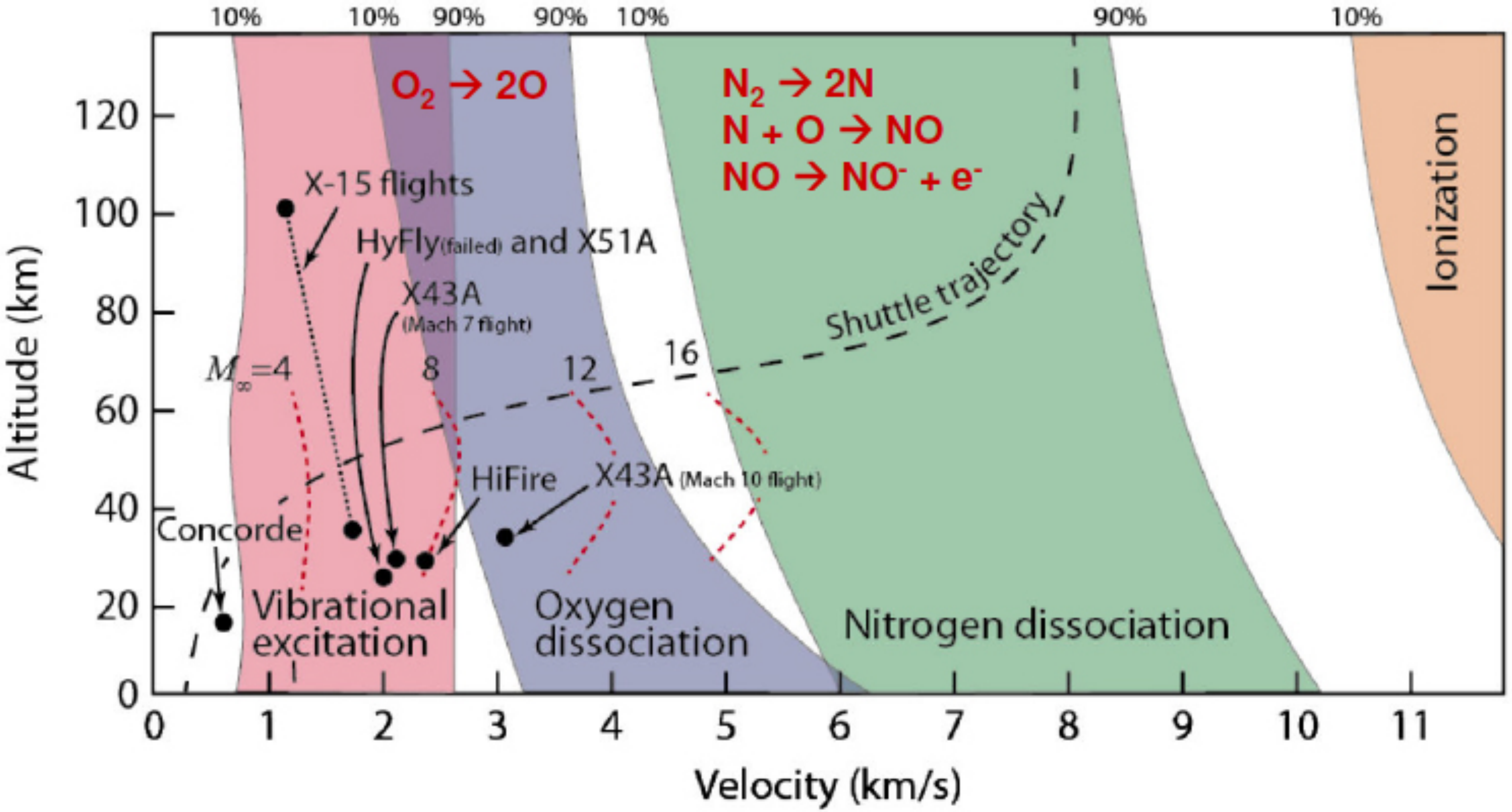
l. Rendering of Apollo command module with plasma sheath during reentry[a]

Chemical effects

At hypersonic speeds, shockwaves that heat and compress oncoming air are formed around the vehicle. These shockwaves can heat the air to such high temperatures that chemical reactions, vibrational excitation, molecular ionization, molecular disassociation, and other changes of the atmospheric particle state are induced.

These heat induced chemical reactions must be accounted for when designing any part of the vehicle with exposure to the flow field such as the structure, engine, thermal protection system, oxidation inhibitors, leading edges, and sensors.

chemical effects



In addition to Mach number, several non-dimensional parameters are necessary to describe hypersonic flow:

- Reynolds Re, a measure of the viscous flow time over the mean flow time
- Knudsen Kn, an indication of the collision path length relative to a flow scale
- Prandtl Pr, a measure of the thermal diffusion time relative to the viscous diffusion time
- Schmidt Sc, an indication of the species diffusion time relative to the viscous diffusion time
- Eckert E, indicates the relative magnitudes of kinetic and thermal energy for the flow
- Damkohler Da, the ratio of the characteristic flow time to a characteristic chemical reaction time, determining whether or not the flow is in equilibrium

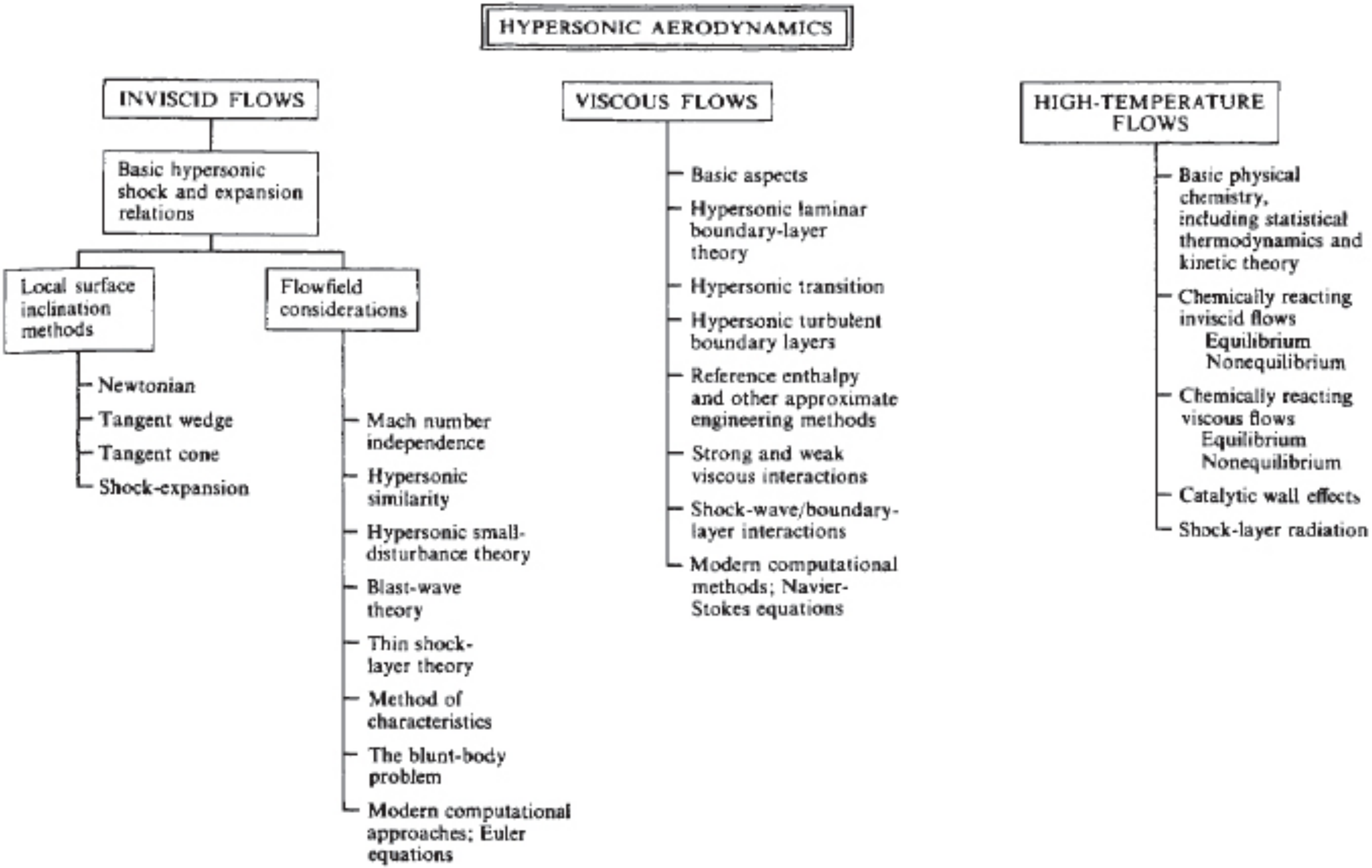
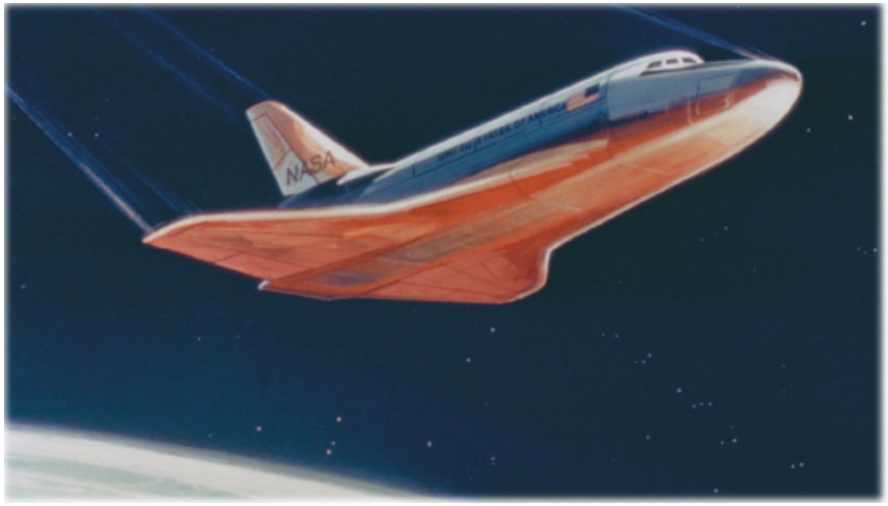


Fig. 1.24 Road map for our study of hypersonic and high-temperature flows.

Hypersonic vehicles

Hypersonic vehicles have aerodynamic features such as to create extremely high compression waves of great amplitude within which the density, pressure and speed of the fluid vary drastically (shock waves).

Over such shock waves hypersonic vehicles can glide for very long distances, receiving an upward lift which can lead them to perform "jumps" outside the atmosphere.



The friction with the atmosphere generates high quantities of heath: temperatures up to 2000 K are reached

Hypersonic vehicles

The high aerodynamic heating that an HV experiences creates difficulties in maintaining the temperature of the structure, leading edges, control surfaces, and internal components below the maximum allowable temperature limit.
These high temperatures, along with the thin structures that HVs are typically composed of to minimize mass, create high thermal gradients that can cause bending or warping of the HV.
Surface ablation, erosion, and oxidation of the leading edges can also change the shape of the HV.

While supersonic vehicles have almost cutting penetrating profiles, the front profile of the hypersonic ones are stocky in order to control overheating

$$Q_{total} \propto \int (\rho/Rnose)^{0.5}\, v^3\, dt$$

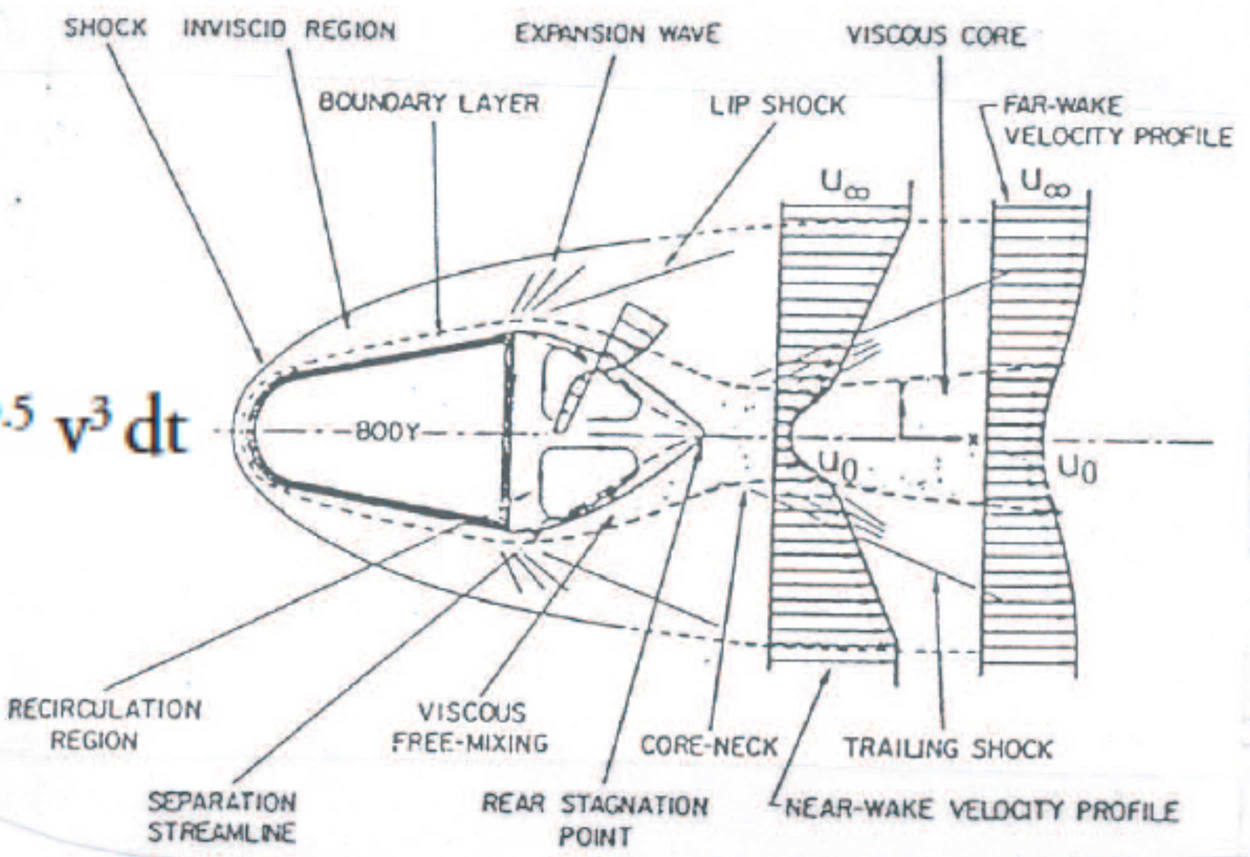
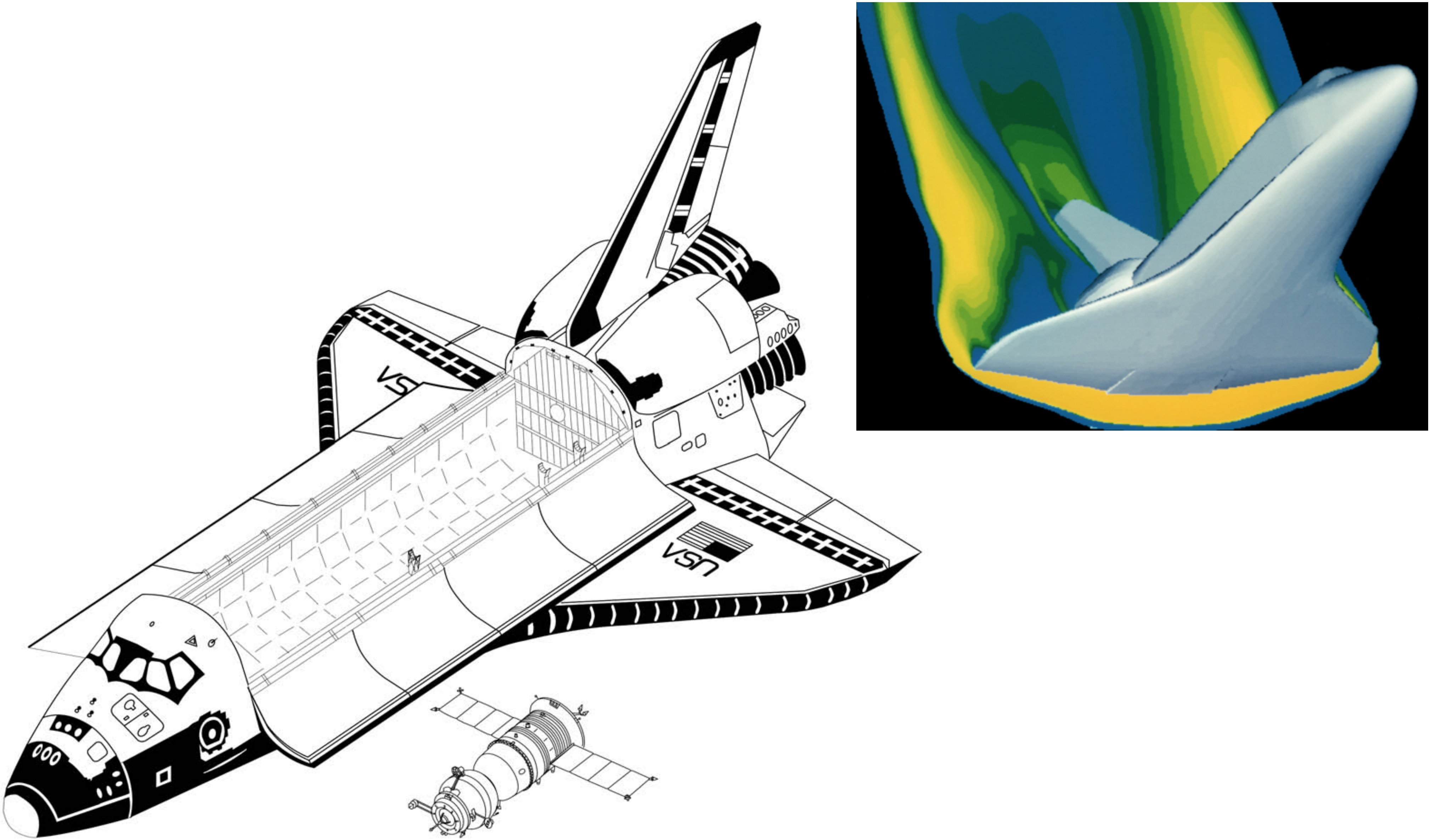


Fig. 1.2 Features of hypersonic flow around a blunt-nosed vehicle.

Space Shuttle, Mach 25 hypersonic vehicle



Characteristics of Environment	Effects on Vehicle
Aerothermodynamic	
Natural and forced boundary layer transition **Flow separation caused by shock-boundary layer interaction** **Shock-shock interaction heating** **Isolator shock trains** **Boundary layer re-laminarization (McClinton 2006)** **Non-equilibrium gas dynamics** **Molecular dissociations** **Wide range of Reynolds numbers** **High temperatures immediately behind the bow shock wave**	Difficulties in maintaining the temperature of the structure, leading edges, control surfaces, and internal components below the maximum allowable temperature limit (Speier et al. 2017). High thermal gradients, surface ablation, erosion, and oxidation cause bending, warping and other shape changes of the HV (Speier et al. 2017). Shape changes to the control surfaces of the HV cause different vehicle response than when controlled by undistorted surfaces.
Chemical/Radio Frequency (RF)	
Chemical reactions (heat induced) **Molecular ionization** **Molecular disassociation** **Vibrational excitation** **Plasma sheath around vehicle**	Degraded RF and GPS communications (Dolvin 2008; Starkey et al. 2002) characterized by: Signal attenuation Phase shift of the signal Signal noise Total loss of signal (Leslie and Marron 2009)

Aerodynamic efficiency

The fundamental parameter for gliding and slowing down is aerodynamic efficiency, the L/D ratio between lift and drag

- ▻ the maximum value of $L/D = 4 + 12/M$
- ▻ for subsonic aircraft ($M < 0.3$) L/D reaches 30-40
- ▻ for supersonic aircraft $L/D < 4.5$
- ▻ for hypersonic vehicles $L/D < 2.6$

for the Space Shuttle L/D ranged from 1 in hypersonic phase to 2 in supersonic phase and 4.5 in the landing phase

Hypersonic versus subsonic and supersonic airplane design philosophy

For subsonic and supersonic aircraft, the components for providing lift (the wings), propulsion (the engines), and volume (the fuselage) are not strongly coupled with each other. They are separate and distinct components; moreover, they can be treated as separate aerodynamic bodies with only a moderate interaction when they are combined in the total aircraft.

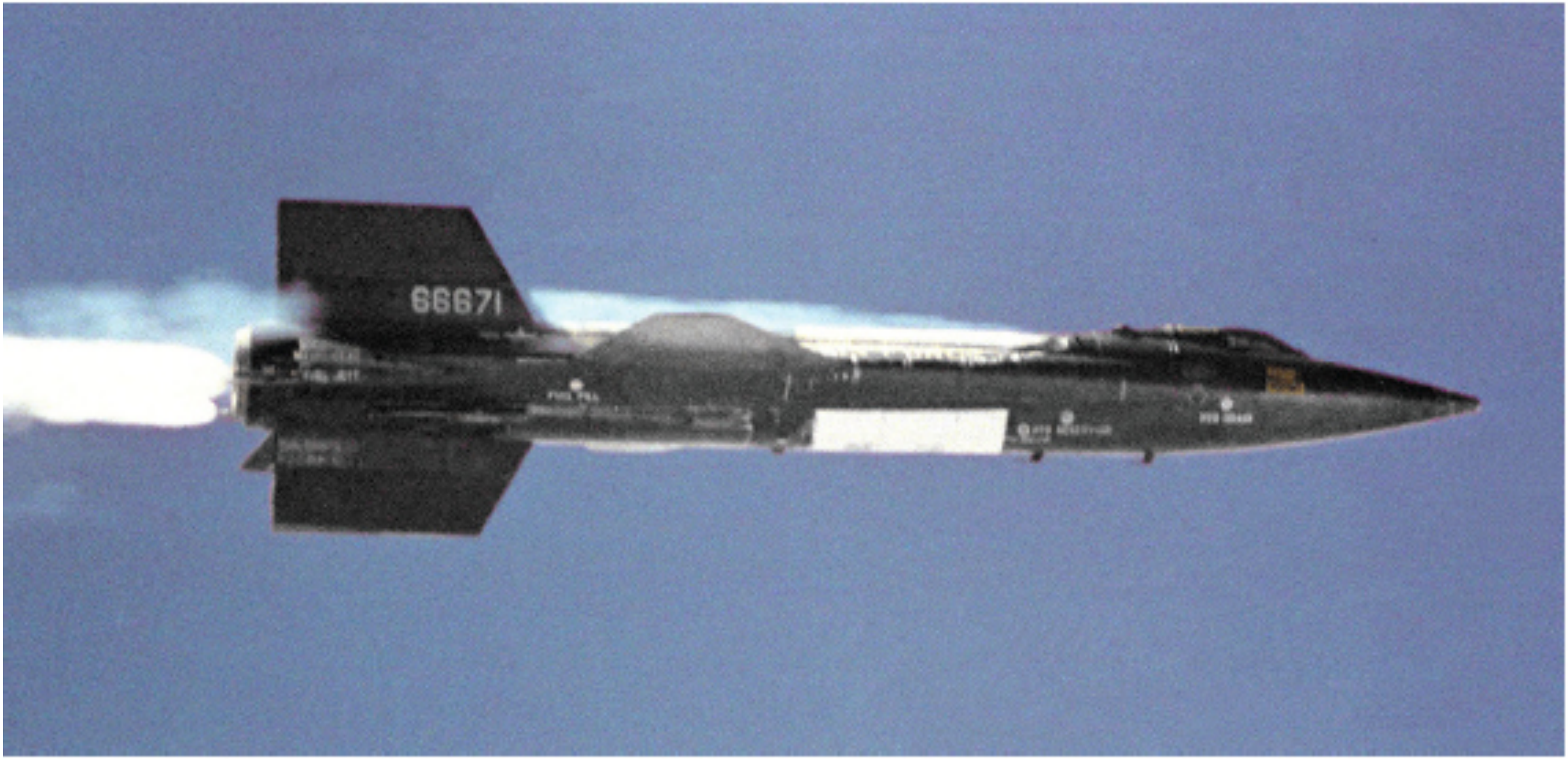
Modern hypersonic aerodynamic design is exactly the opposite, wherein the entire undersurface of the vehicle is part of the scramjet engine. Hence, the propulsion mechanism is intimately integrated with the airframe.

Moreover, most of the lift is produced by high pressure behind the bow shock wave and exerted on the relatively flat undersurface of the vehicle; the use of large, distinct wings is not necessary for the production of high lift.

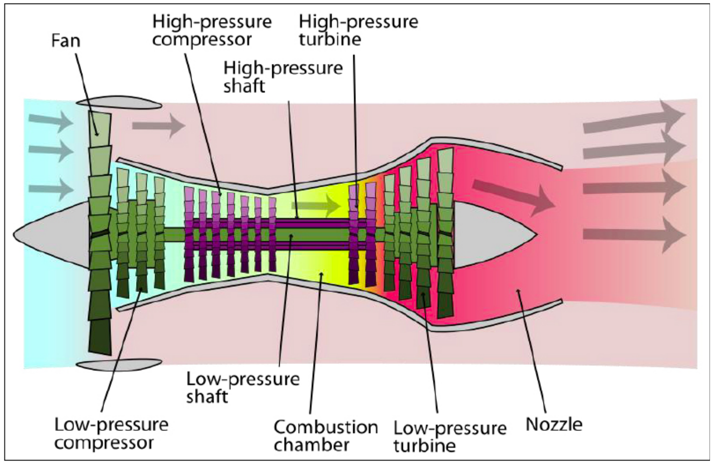
Finally, the fuel for airbreathing hypersonic airplanes is liquid H_2, which occupies a large volume.

All of these considerations combine in a hypersonic vehicle in such a fashion that the components to generate lift, propulsion, and volume are not separate from each other; rather, they are closely integrated in the same overall lifting shape, in direct contrast to conventional subsonic and supersonic vehicle design.

The US Air Force X-15 vehicle reached Mach 6.7 on its final flight on 22 August 1963 at a height of 11,620 m. X-15 was also used to test a hypersonic scramjet engine

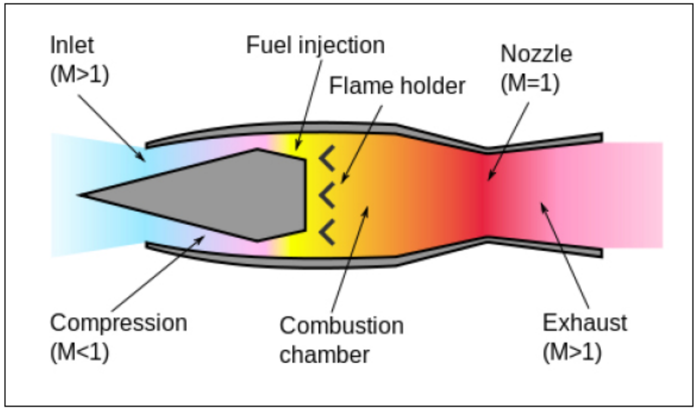


Engines



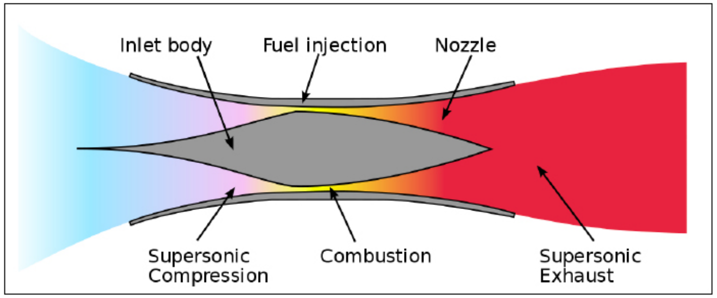
a. turbojet

the incoming flow must be compressed for combustion



b. ramjet

the incoming supersonic flow is made subsonic for the combustion



c. scramjet

ramjet with a supersonic combustion

in order to start the scramjet engine the vehicle must reach hypersonic velocities by means of a rocket or a turbine-based combine cycle (inlet-turbine-ramjet)

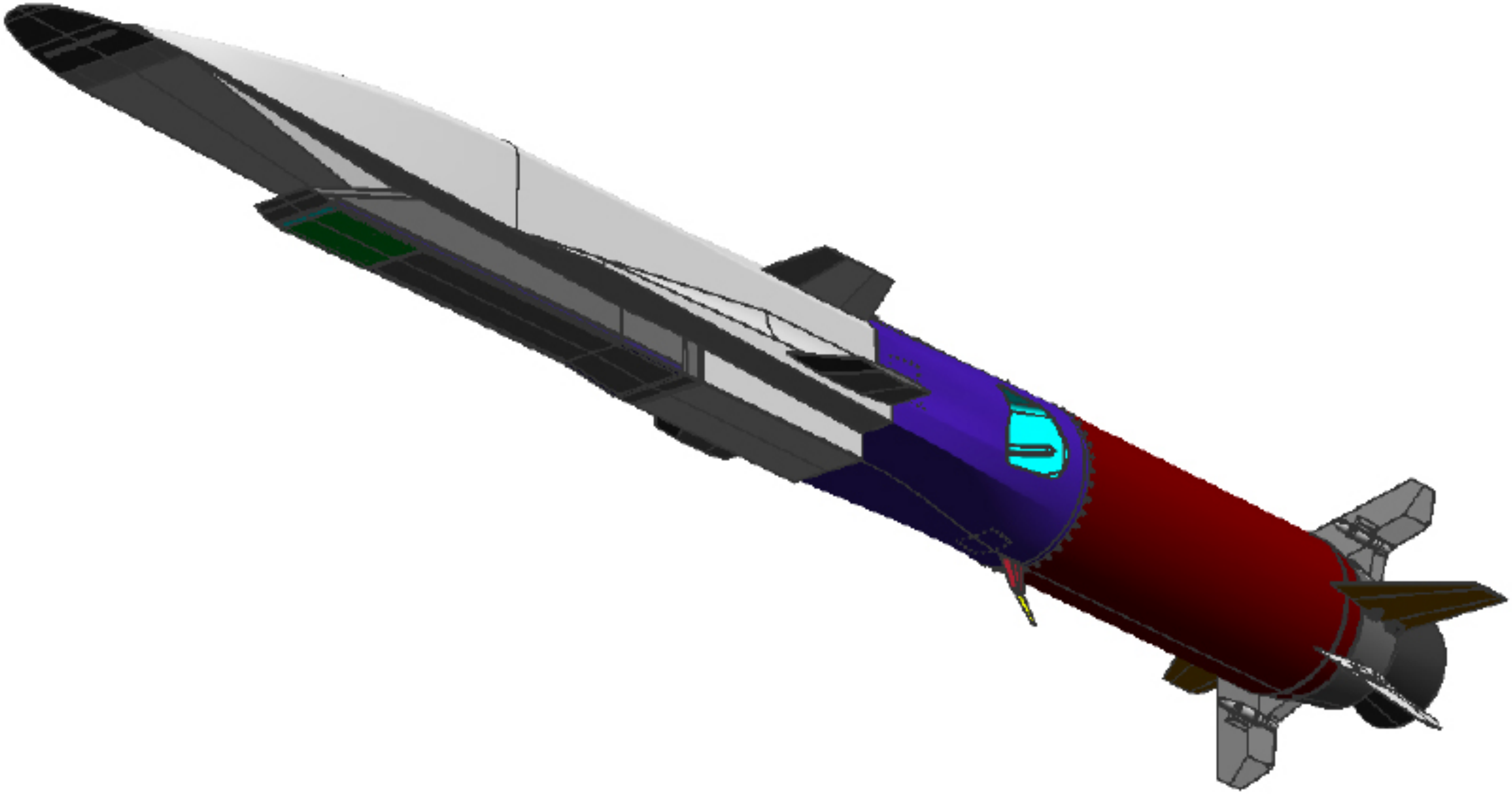
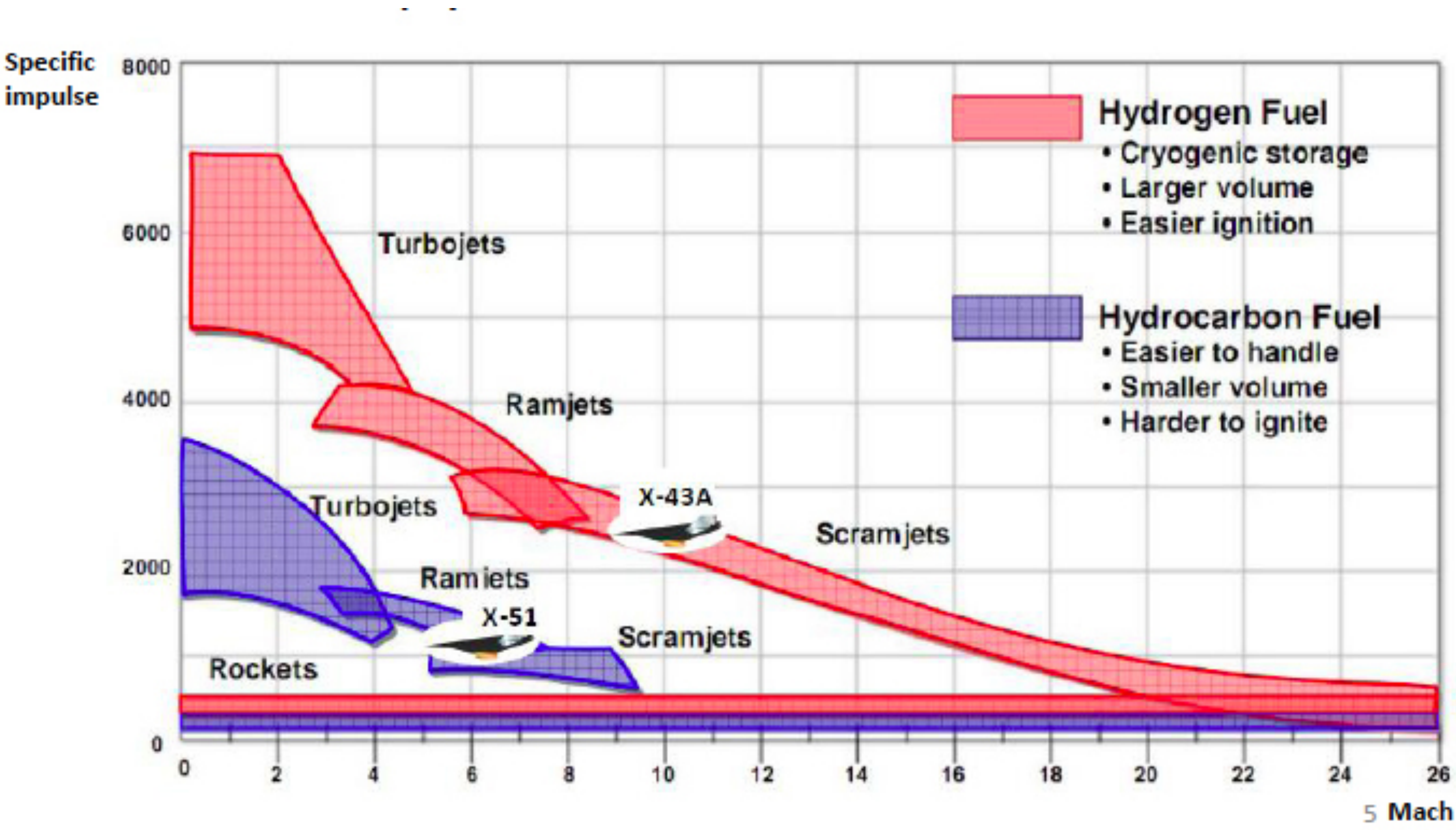


FIGURE 1. The USAF X-51 flight test vehicle. Forward (grey) part is the scramjet-powered test vehicle; rear (red) segment is a solid rocket motor for initial acceleration to scramjet speeds.

specific impulse for liquid fuels



hypersonic weapons

Hypersonic weapons

Ideas that are being considered or developed for militarization in various countries include:

- **supersonic aircraft with high-speed capability,**
- **hypersonic bombers,**
- **hypersonic air-launched ballistic missiles (ALBM),**
- **hypersonic cruise missiles (HCM),**
- **hypersonic glide vehicles (HGV),**
- **high-speed intelligence, surveillance, and reconnaissance (ISR) aircraft**

the most advaced hypersonic weapons belong to two primary categories (designed for one-time use)

- Hypersonic glide vehicles (HGV)
- Hypersonic cruise missiles (HCM)

Unlike ballistic missiles, hypersonic weapons

▻ do not follow a ballistic trajectory

▻ can maneuver en route to their destination

They can be nuclear or conventionally armed

Note:

manoeuvring at high-speed comes at a price:

- **loss of speed (loss of energy)**
- **loss of speed = loss of range**

- **high speed = high G-force**
- **high speed = high turning force**
- **high G-loading = strong airframe**
- **strong airframe = more weight**

Hypersonic glide vehicles (HGV)

HGVs are launched from a rocket into a sub-orbital trajectory before re-entering the atmosphere at high altitude (80-90 km) and glide at Mach 20-25 velocity towards a target 8-10 thousands km away

HGV maintain near constant velocity by trading altitude for speed and then deplete their energy gradually

Hypersonic cruise missiles (HCM)

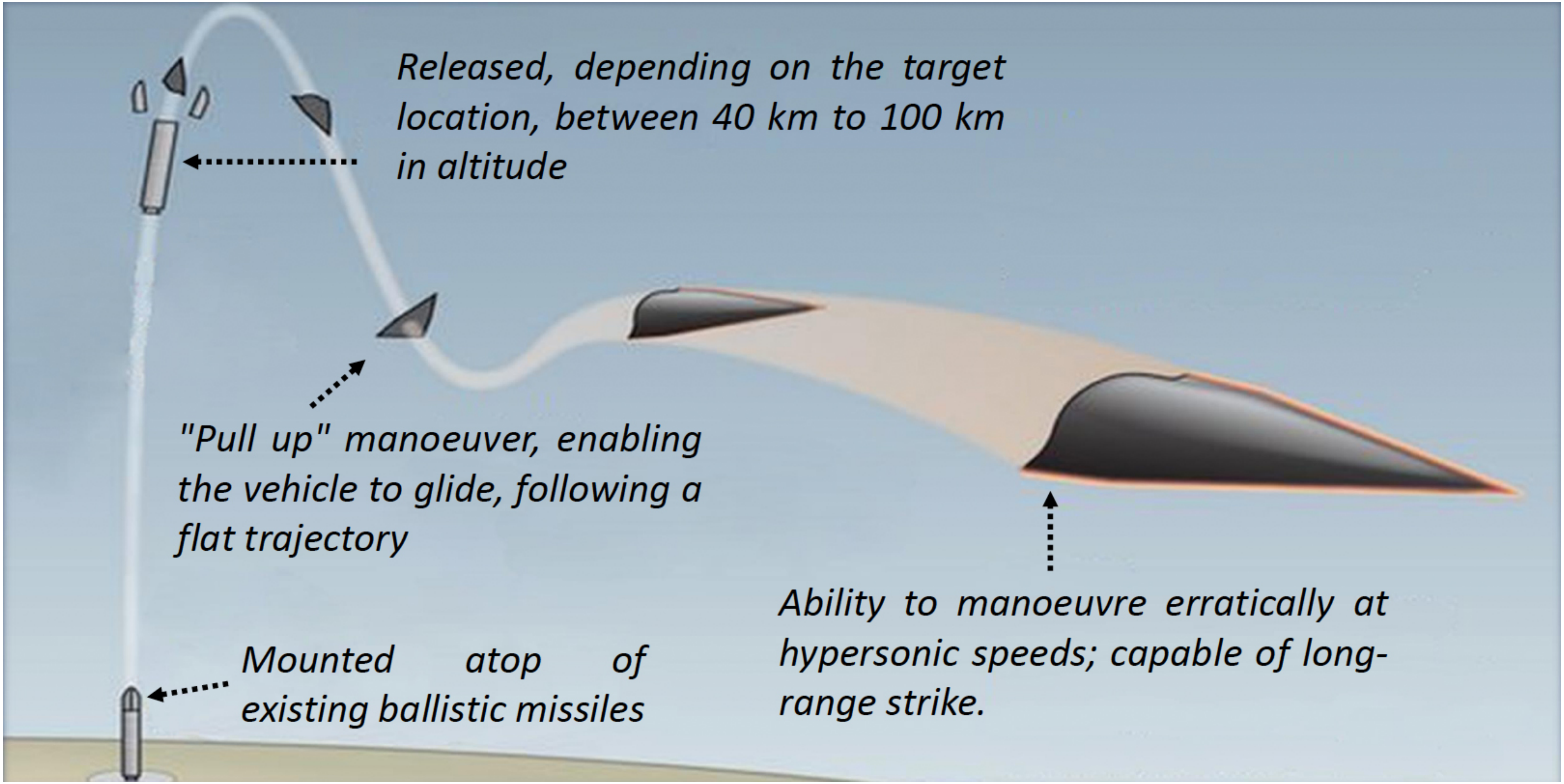
HCM are launched from a rocket or an aircraft at 20-30 km altitude; they are powered by high-speed, air-breathing scramjet engines up to Mach 10 velocity towards their target, some 1-3 thousands km away

Common problems of hypersonic missiles

The persistent high speed and long atmospheric flight time of hypersonic vehicles result in an extremely severe operating environment requiring advanced new systems, components, materials, design tools, and test facilities

- thermal management and materials
- air vehicle and flight control
- propulsion for HCMs
- testing and modeling
- the necessary integration of many critical and complicated subsystems, the failure of each of them leading to the failure of the global system

Trajectory of a HGV



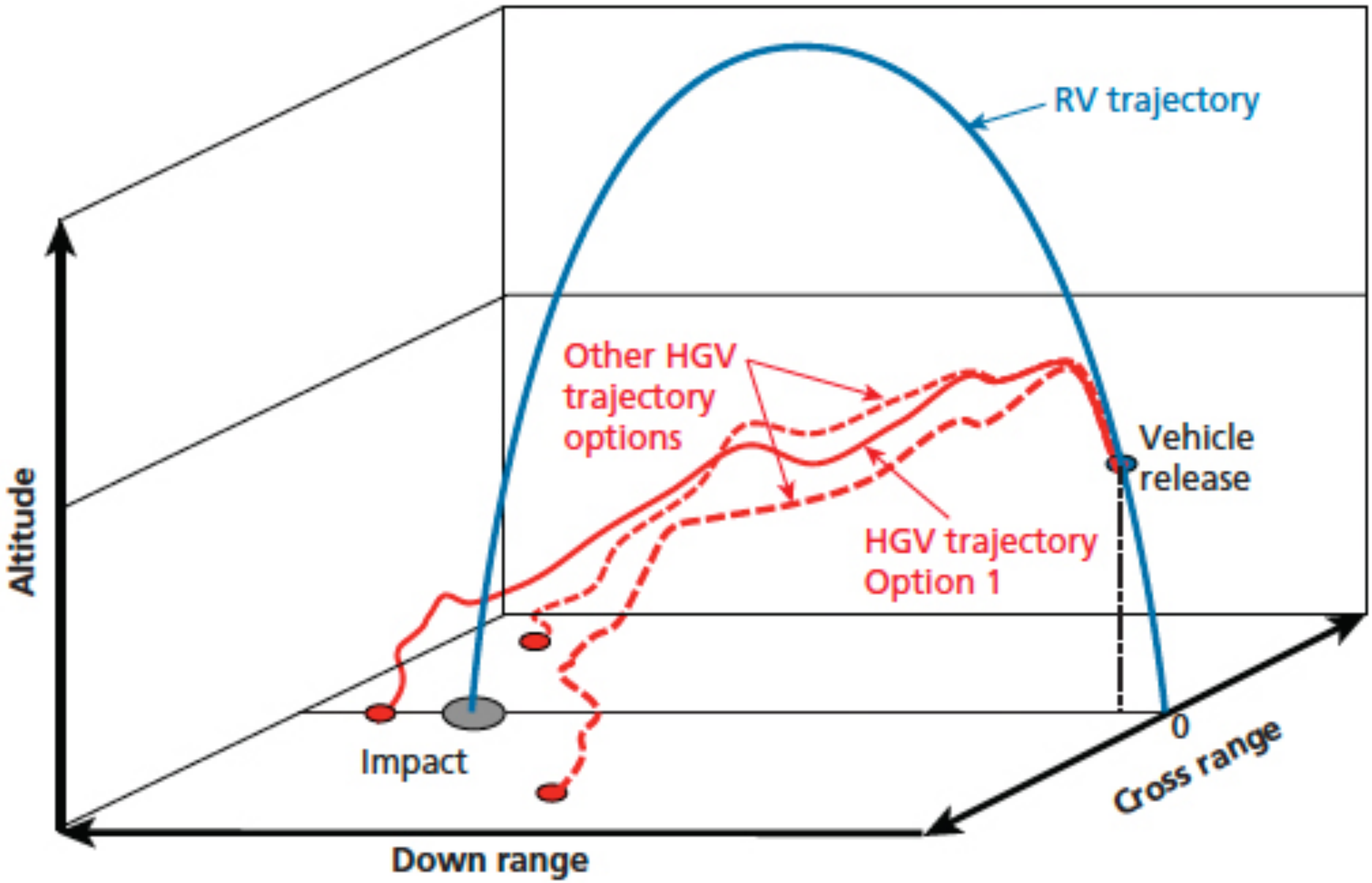
Released, depending on the target location, between 40 km to 100 km in altitude

"Pull up" manoeuver, enabling the vehicle to glide, following a flat trajectory

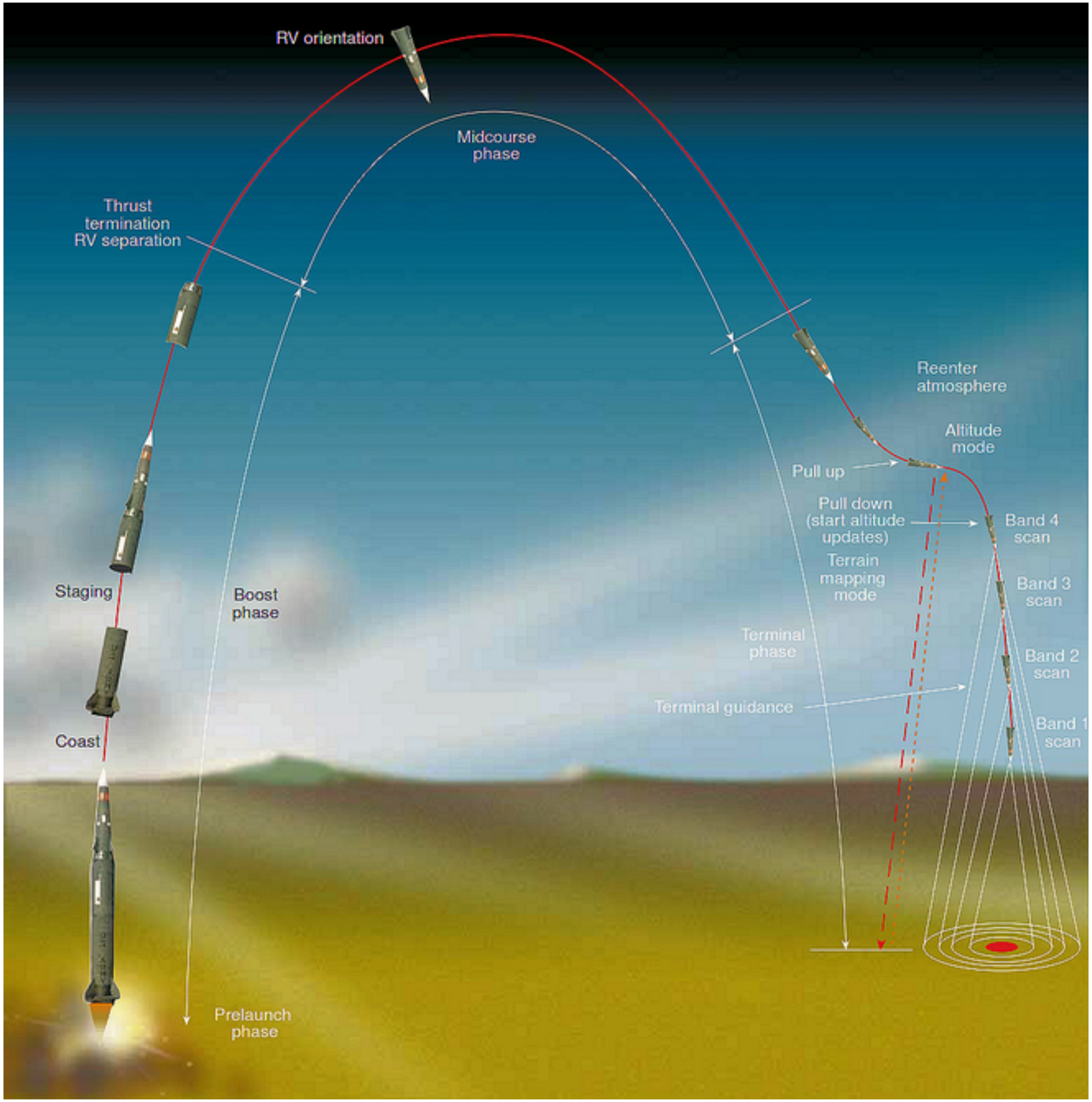
Ability to manoeuvre erratically at hypersonic speeds; capable of long-range strike.

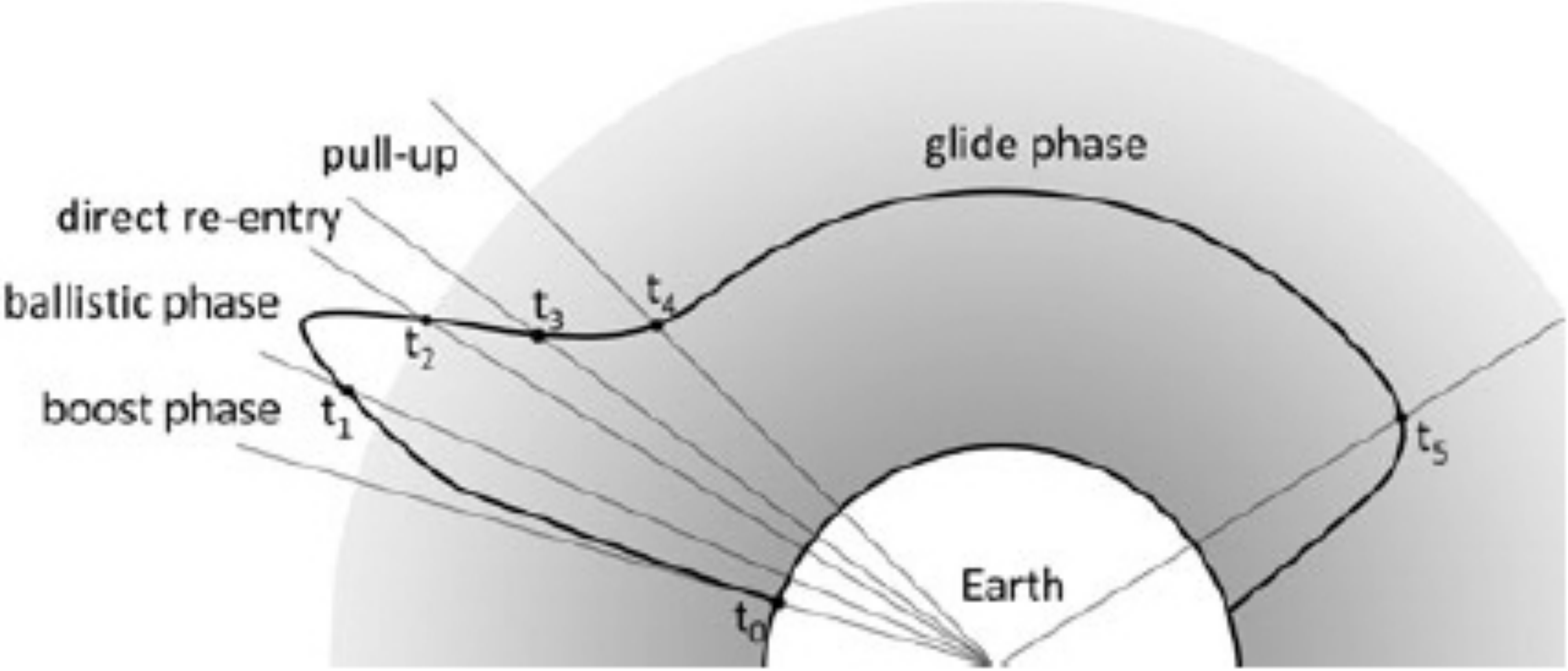
Mounted atop of existing ballistic missiles

Comparison of ballistic and HGV trajectories



MARVs modify their trajectory in the terminal phase only





Flight phases: **1. Boost phase, 2. Exo-atmospheric phase, 3. Direct re-entry, 4. Pull-up, 5. Equilibrium gliding**

Range of a glider

$$l_{GLIDE} = -\tfrac{1}{2}\, R\ L/D\ \ln[1 - (v_i/v_s)^2]$$

R = radius of the Earth

$v_s = (g\,R)^{½}$ = speed of a satellite in low Earth orbit ≈ 7.8 km/s

v_i = glider's initial speed

for v_i = 6.6 km/s (Mach 20) L/D = 2.6

$l_{GLIDE} \approx 10400$ km

HGV problems

- ensuring stability in the long-glide regime, not yet fully understood and difficult to simulate in wind tunnels
  - ▻ massive aerodynamic forces
  - ▻ chemical alterations of the air flow

- dissipation of the very high amount of heat due to the friction with the atmosphere; it damages the vehicle and interferes with aerodynamic properties

These variables need to be managed not only to maintain the structural integrity of the vehicle, but also to ensure that the on-board instrumentation and payload remain functional.

HGV problems

- **ensuring accurate guidance and control of navigation in order to achieve the target with the high precision required to make the use of conventional weapons effective**
  - ▻ **inertial systems are not sufficient**
  - ▻ **connection to the GPS may fail as a result of the ionization generated by the hypersonic flow**

The development of advanced materials is necessary for hypersonic glider applications

The principal advantages of a HCM: speed and maneuverability

Combined, these would provide a very responsive and flexible offensive weapon that could, for example, aim targets within a 1,000 km radius of the launch aircraft, and strike these targets within several minutes.

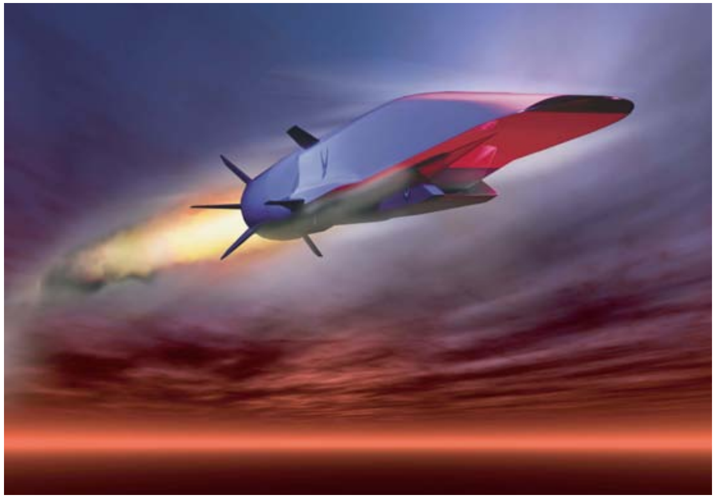
Cruise missiles are difficult to defend against because of their unpredictable trajectories.

The additional speed provided by a HCM would further complicate defense system timelines, and be more effective against missile interceptors.

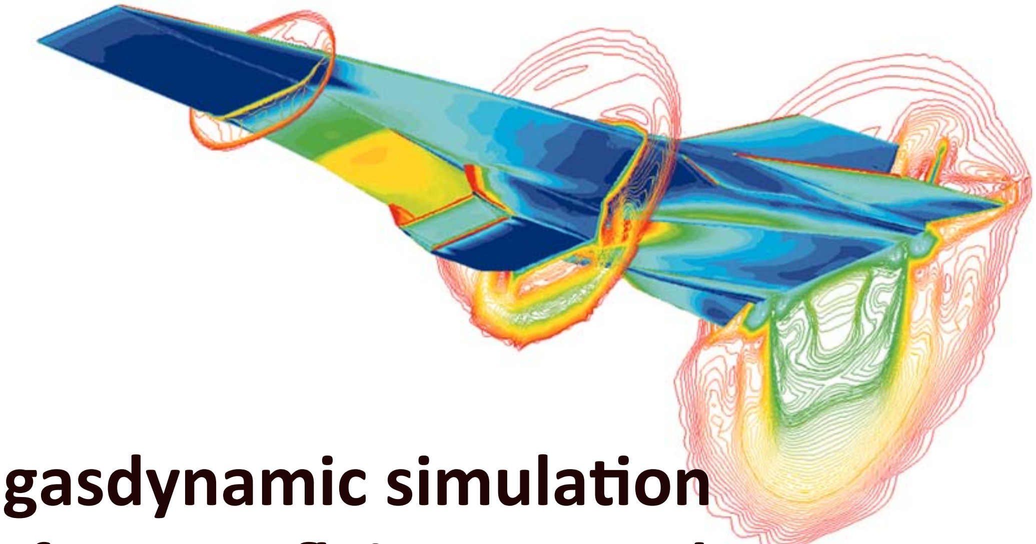
HCMs would fly at altitudes higher than most current surface-to-air missile systems are capable of reaching.

HCM problems

- formation and control of the supersonic air flow for the scramjet engine to ensure a stable combustion
- the very high temperatures of the air passing through the engine: at Mach 6 the incoming flow can reach 1500 °C and the expelled one 2400 °C



BOING X- 51 Waverider



gasdynamic simulation of a HCM flying at Mach 7

Armaments

✦ indicative useful load:
  ≈ 1000 kg for HGV
  ≈ 500 kg for HCM

- nuclear warhead
- conventional armaments
  - ▻ high explosive (tritonal) against missile silo or underground targets
  - ▻ UAV against mobile systems
  - ▻ fast ammunition to disperse over distributed targets
  - ▻ kinetic energy projectiles

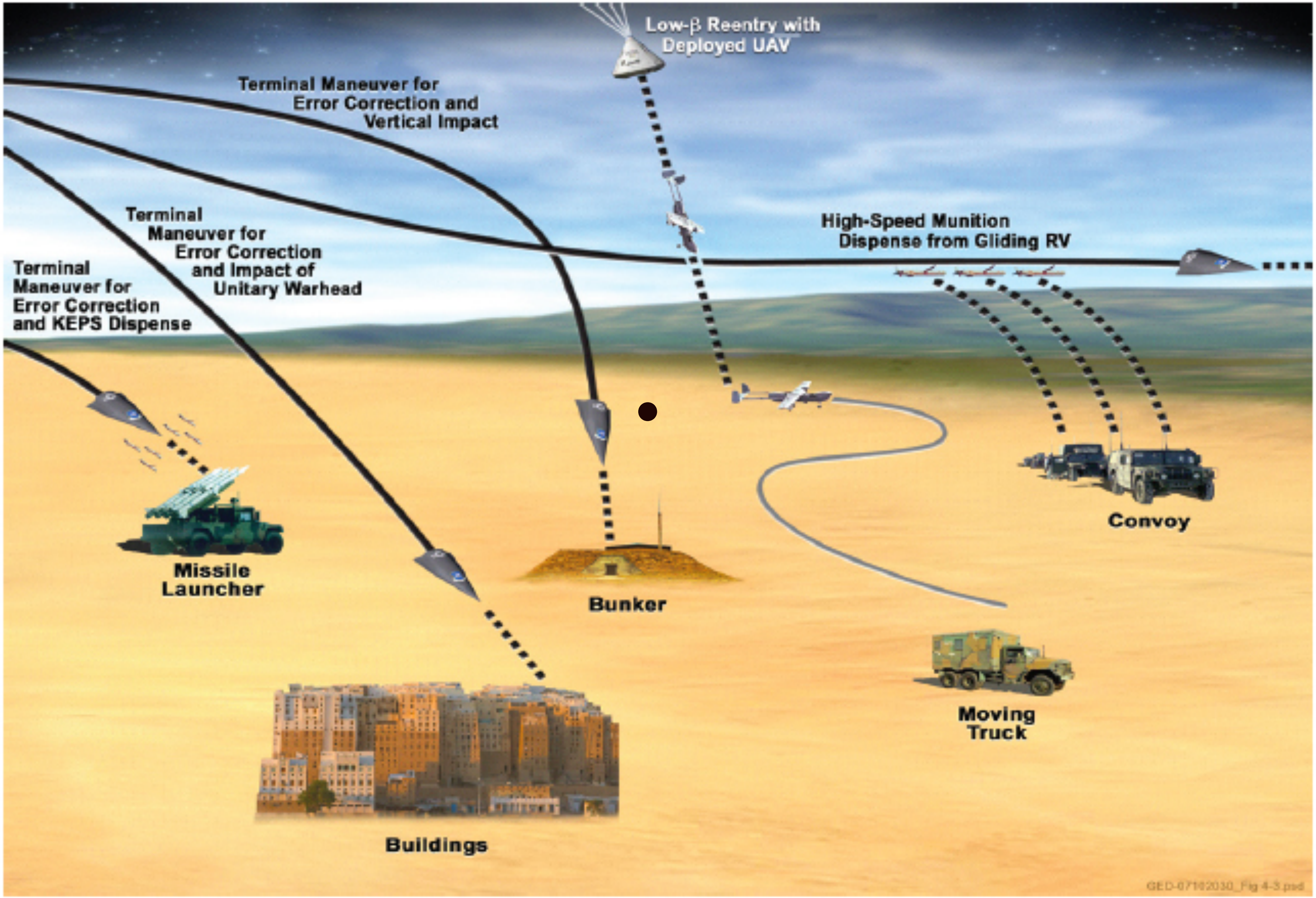
Kinetic energy armaments

- kinetic energy projectiles (KEP): a rose of 750 g tungsten cylinders (shock darts) with the energy of 1.5 MJ each (≈ 360 g of TNT) (impact speed 2 km/s)

- kinetic energy particles: 4000 particles of 75 g mass with energy 150 kJ each (impact speed 2 km/s)

* a 20 kJ bullet seriously damages an airplane

Attack forms



Conventionally-armed hypersonic weapons are counter-force weapons

Critical operating points

- need for extremely precise information on the objectives
- maintenance of command and control
- verification of damage
- comparison with other conventional means
- cost/result analysis

hypersonic weapon programs

Present military programs

- advanced
  - USA
  - Russia
  - China
- in development
  - France
  - India

Today's hypersonic weapon programs appear to be driven at least in part by developments in technology rather than specific military objectives.
This creates a dynamic in which development in one country provides impetus for others to follow suit even if military applications of the system under development have yet to be clearly understood.
By all indications this reinforcing effect between different programs will continue.
The secrecy surrounding these programs also fuels exaggerated threat perceptions, leading the arms racing dynamic.

The United States began work on HGVs in the early 2000s, as part of its Conventional Prompt Global Strike program.
This effort probably helped renew interest in the technology in Russia, which revived an old Soviet program.
Similar considerations may have played a role when China decided to invest in hypersonic boost-glide systems as well.
The Russian and Chinese programs have in turn become major factors sustaining interest in hypersonic systems in the United States

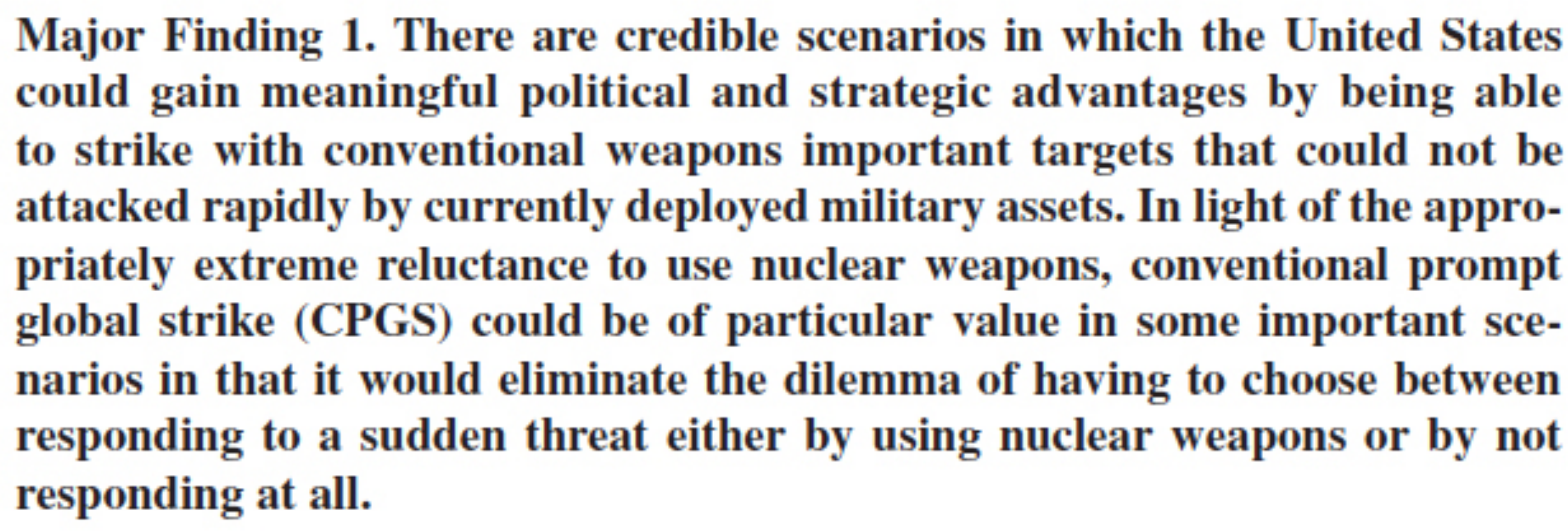
USA: the Propt Global Strike (PGS)

In 2003, the Department of Defense (DOD) identified a new mission—prompt global strike (PGS)—that sought to provide the United States with the ability to strike targets anywhere on Earth with conventional weapons in as little as an hour, without relying on forward-based forces.

This capability would bolster US efforts to deter and defeat adversaries by providing the United States with the ability to attack high-value targets or "fleeting targets" that might be visible for only a short amount of time promptly, at the start of or during a conflict. At the same time reduce the American bases abroad.

DOD has considered a number of systems: bombers, cruise missiles, ballistic missiles, and boost-glide.

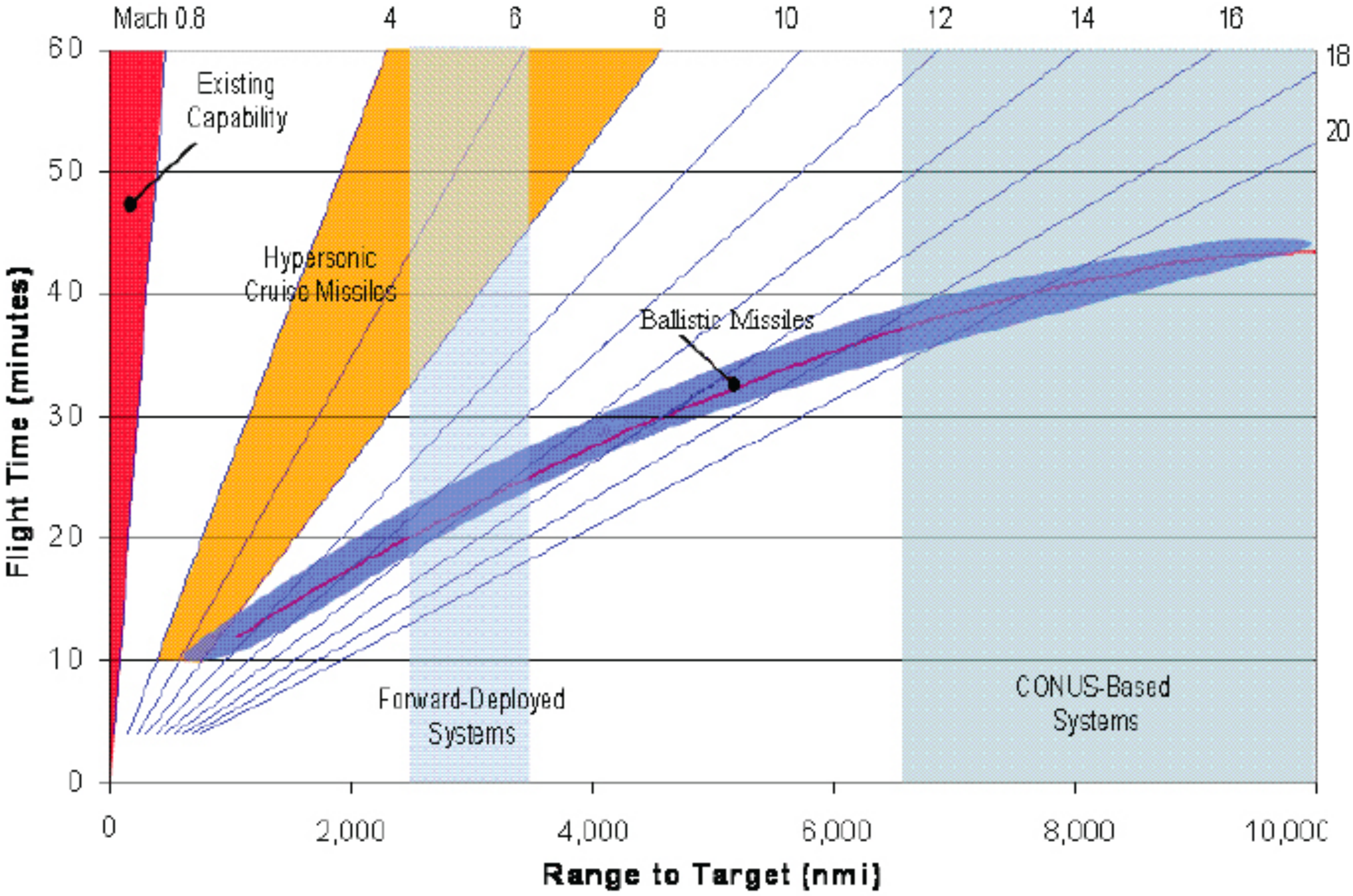
CPGS rationale



Major Finding 1. There are credible scenarios in which the United States could gain meaningful political and strategic advantages by being able to strike with conventional weapons important targets that could not be attacked rapidly by currently deployed military assets. In light of the appropriately extreme reluctance to use nuclear weapons, conventional prompt global strike (CPGS) could be of particular value in some important scenarios in that it would eliminate the dilemma of having to choose between responding to a sudden threat either by using nuclear weapons or by not responding at all.

Committee on Conventional Prompt Global Strike Capability, Naval Studies Board, and Division on Engineering and Physical Sciences, the National Research Council of the National Academies (2008)

time and distance



Scenarios that require CPGS

- attack a short-term meeting of terrorists in a specific location and disrupting terrorist operations
- attack the transfer of weapons of mass destruction between one vehicle and another or when the weapons remain for a short time in a specific depot, in situations where no local forces can be counted on
- denying a new nuclear proliferator the ability to employ its nuclear arsenal
- destroying or disabling antisatellite capabilities
- countering anti-access/area-denial capabilities
- immediate or preventive response to an imminent attack, to avoid serious damage or loss

According to open-source reporting, the United States has a number of major offensive hypersonic weapons and hypersonic technology programs in development:

- **U.S. Navy—Intermediate Range Conventional Prompt Strike Weapon (IR CPS)**
- **U.S. Army—Land-Based Hypersonic Missile (also known as the Long Range Hypersonic Weapon)**
- **U.S. Air Force—Hypersonic Conventional Strike Weapon (HCSW, pronounced “hacksaw”)**
- **U.S. Air Force—AGM-183A Air-launched Rapid Response Weapon (ARRW, pronounced “arrow”)**
- **DARPA—Tactical Boost Glide (TBG)**
- **DARPA—Advanced Full-Range Engine (AFRE)**
- **DARPA—Operational Fires (OpFires)**
- **DARPA—Hypersonic Air-breathing Weapon Concept (HAWC, pronounced “hawk”).**

These programs are intended to produce operational prototypes, as there are currently no programs of record for hypersonic weapons

Among other various possible CPGS systems, the United States have tested two hypersonic HGV systems: the Hypersonic Technology Vehicle-2 (HTV-2) of the Air Force and the Advanced Hypersonic Weapon (AHW) of the army.
The wedge-shaped HTV-2, planned for a range of 17,000 km, was tested in April 2010 and August 2011; both tests failed and the program was canceled.

They are also developing hypersonic cruise missiles

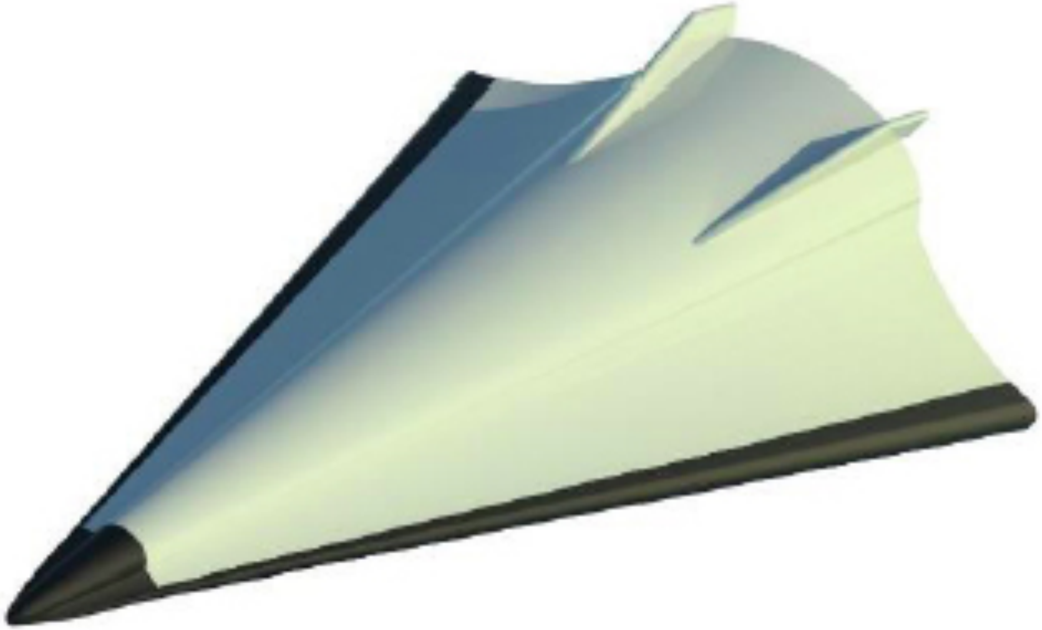
The conical AHW, equipped with a high-precision navigation system, with a maximum range of about 8,000 km (and therefore a “non” global CPGS) had a positive test in 2011 with a glide flight of 2,400 km, while a test in 2014 failed due to carrier missile problems; at the end of October 2017 a positive test was carried out with a launch from a submarine. In 2018, the Defense department required the army, navy and aeronautics to work together to develop a common AHW operating at the early 2020s.

Russia

- long experience with space re-entry vehicles
- activity resumed after the US withdrawal from the ABM treaty
  - ▻ objective: to create strategic forces that cannot be intercepted by American ABMs
- the system in advanced development is Avangard, a nuclear armed HGV that can be maneuvered:
  - ▻ more than a dozen flight tests carried out
  - ▻ President Putin declared (27 December 2019) that the first Avangard regiment (6 missiles) is operational at the Dombarovsky base

Avangard (Project 4202 o Yu-74)

released at its apogee (about 100 km height) from a ballistic missile like the SS-19 (UR-100NUTTH) and in the future from the R-28 “Sarmat”, then it should glide for over 6,000 km at speeds up to Mach 20 (almost 7 km/s)



3M22 Tsirkon (NATO SS-N-33)

Tsirkon is believed to be a maneuvering, winged hypersonic anti-ship cruise missile with a lift-generating center body.

A booster stage with solid-fuel engines accelerates it to supersonic speeds, after which a scramjet motor with liquid-fuel in the second stage accelerates it to hypersonic speeds.

The missile's maximun range is estimated to be 1000 km.

Tsirkon can travel at a speed of Mach 8–Mach 9 (3 km/s).

Such high speeds would likely create a cloud of plasma around the missile, absorbing any radio waves and making the missile virtually invisible to radars.

Kh-47M2 Kinzhal (“dagger”)

The Kinzhal is a nuclear-capable air-launched ballistic missile (ALBM).

It has a claimed range of more than 2,000 km, Mach 10 speed, and an ability to perform evasive maneuvers at every stage of its flight.

It can carry both conventional and nuclear warheads and can be launched from Tu-22M3 bombers or MiG-31K interceptors. It has been deployed at airbases in Russia’s Southern Military District.

It is capable of attacking fixed and movable targets such as aircraft carriers.

The missile accelerates to hypersonic speed within seconds of launch.

China

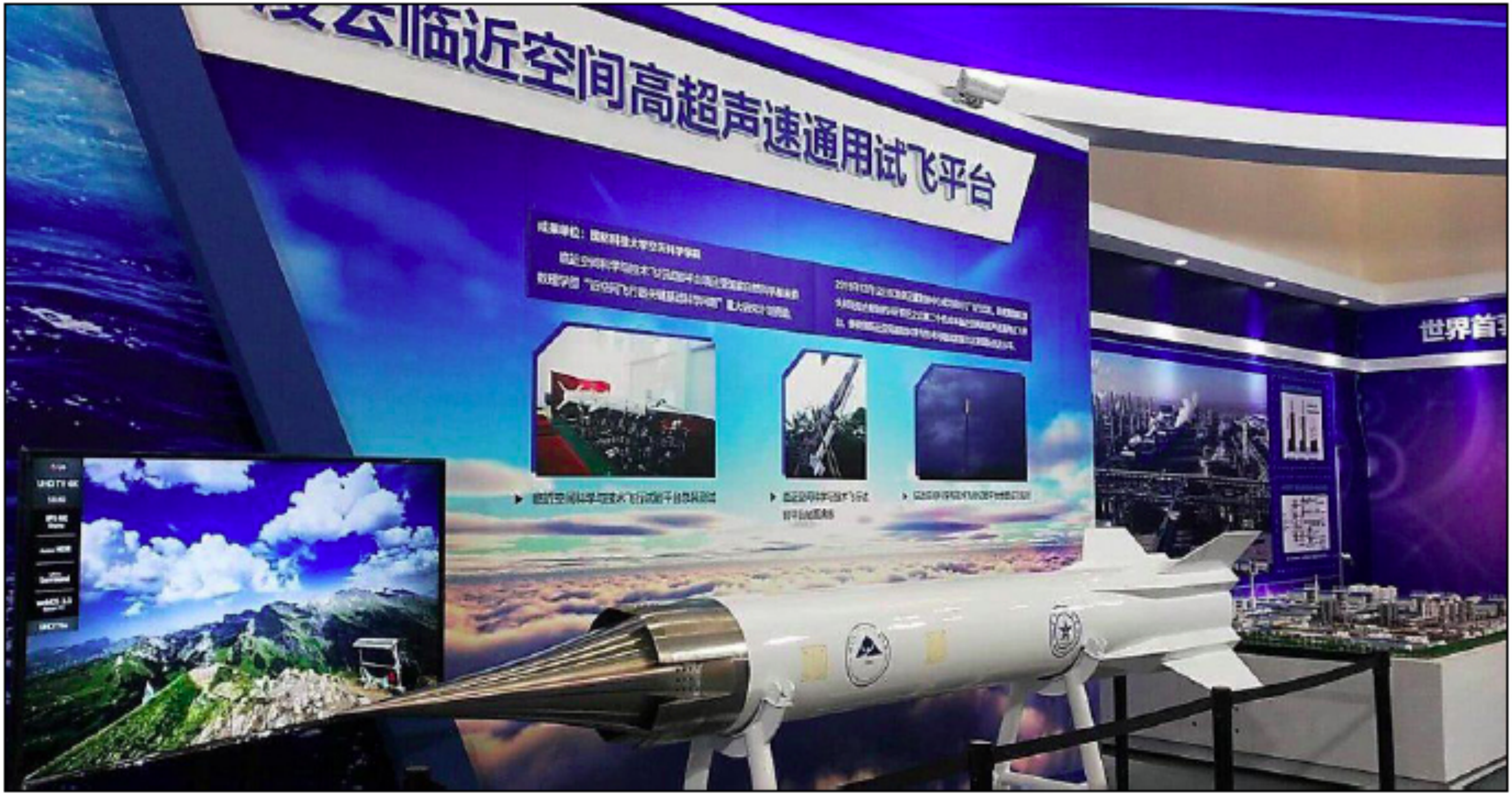
Chinese HGVs with conventional armament are considered anti-ship force, to control the Chinese seas, and as a system to strengthen their A2/AD (anti-access/ denial area) capabilities in the Asia-Pacific area, ie to prevent operations of the opponent in an exclusive area adjacent to her own territory by means of a combination of sensors and long-range vectors in anti-aircraft, anti-ship and land-based anti-missile function. Possible HGV with nuclear weapons on intercontinental vectors can contribute to deterrence vis-a-vis the US with their penetrability of anti-missile systems.

HGV Dong Feng (East wind) or DF-DZ or WU-14

China

- strong commitment to the development of HM
- most advanced HGV: Dong Feng vehicle (East wind) for speeds exceeding Mach 10
  - ▻ between 2014 and 2016 at least 7 tests launched by short and medium-range missiles
  - ▻ on November 2017 two tests using the DF-17 vector, an intermediate-range missile developed for HGV
- on August 2018 test of XINGKONG-2 or Starry Sky-2, an HGV with wedge-shaped fuselage and advanced thermal protection systems; with Mach 5.5 speed at 29 km altitude it reached the target after extensive maneuvers

Figure 3. Lingyun-1 Hypersonic Cruise Missile Prototype



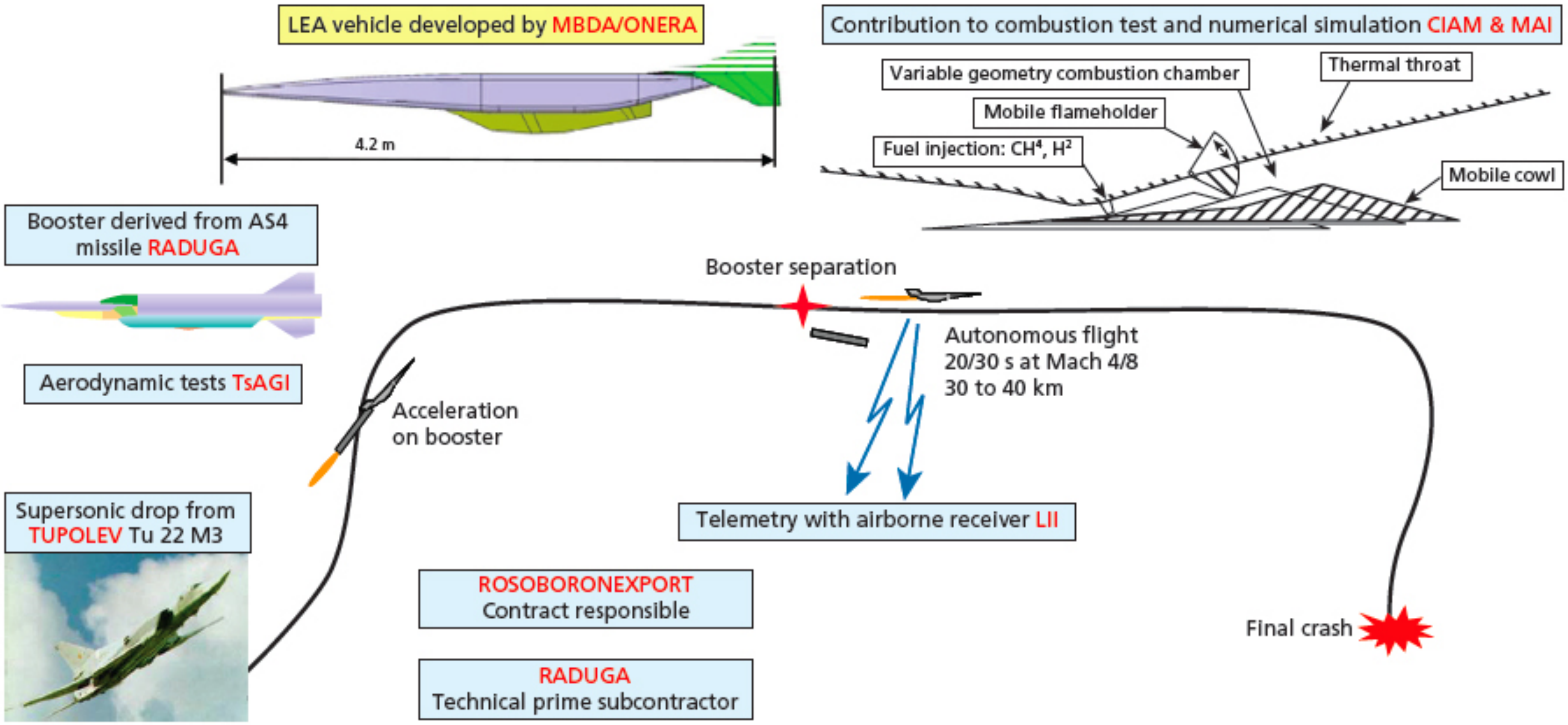
China’s JF-12 hypersonic wind tunnel

France

France sees hypersonic missile development largely as the next stage of modernization for her nuclear arsenal and essential to maintaining technical parity with the United States.
Over the past decade, she has invested a considerable amount into R&D efforts and defense acquisitions.
There are two companies principally responsible for the development of French hypersonic systems and technology: the European contractor MBDA Missile Systems and France's national aerospace research center, ONERA.

French programs for HCM

Figure 3.1
French LEA



SOURCE: Francois Falempin and Laurent Serre, "French Flight Testing Program LEA Status," Washington, D.C.: NATO Research and Technology Organisation, RTO-EN-AVT-185, undated, p. 17-5, Figure 5.

RAND *RR2137-3.1*

India

Indian-Russian BrahMos II

India’s Defense Research and Development Organization (DRDO) currently has two parallel programs in hypersonic development, each making considerable strides toward being operational.

Her research program, BrahMos II, is a joint venture with Russia.

India's possible hypersonic boost-glide system Shourya (also spelled Sharuya)

There is very little publicly available information. According to one source, it is a two-stage solid-fuel missile, capable of carrying a conventional or nuclear warhead. There are reports of test flights in 2004, 2008, 2011 and 2016, with the most recent test involving manoeuvring and successfully impacting its target. The version of the Shourya tested to date apparently has a range of only 700 km, but there are reports of possible plans to develop a variant with a range of 1,000 km.

Japan

Japan’s 2019 defence budget request includes plans to develop an HGV called the Hyper Velocity Gliding Projectile (HVGP).

Japan reportedly plans to develop two variants of the HVGP, Block I to be deployed in 2026 and Block II, capable of higher speeds and more manoeuvrability, to be deployed around 2033.

Its range is likely in the order of hundreds of kilometres.

australia

Australian–U.S. HIFiRE Scramjet

SOURCE: Australian Hypersonics Initiative at the University of Queensland, Australian Defence Science and Technology Group, and U.S. Air Force Research Laboratory.

The Australian government has sponsored several projects and collaborations with U.S. agencies in the field of hypersonics.

risks of proliferation

Civilian programs

Hypersonic technology has a dual-use character; it can be used for nonmilitary purposes including space launch, spacecraft retrieval, and civilian transport of passengers and cargo.
The current situation sees hypersonic research openly disseminated and widely spread among governments, industries, and universities.

The technology can be imported or exported, short-circuiting the slow route of indigenous development.

Several countries are active in the field in Europe, Australia, Brazil, Canada, South Corea, Iran, Israel, Japan, Pakistan, United Kingdom, Singapore, Taiwan ...

Japan has developed a conceptual model for a hypersonic aircraft capable of cruising at Mach 4.5 and traveling trans-Pacific routes in just a few hours, using dual precooled liquid hydrogen-fueled turbojets.

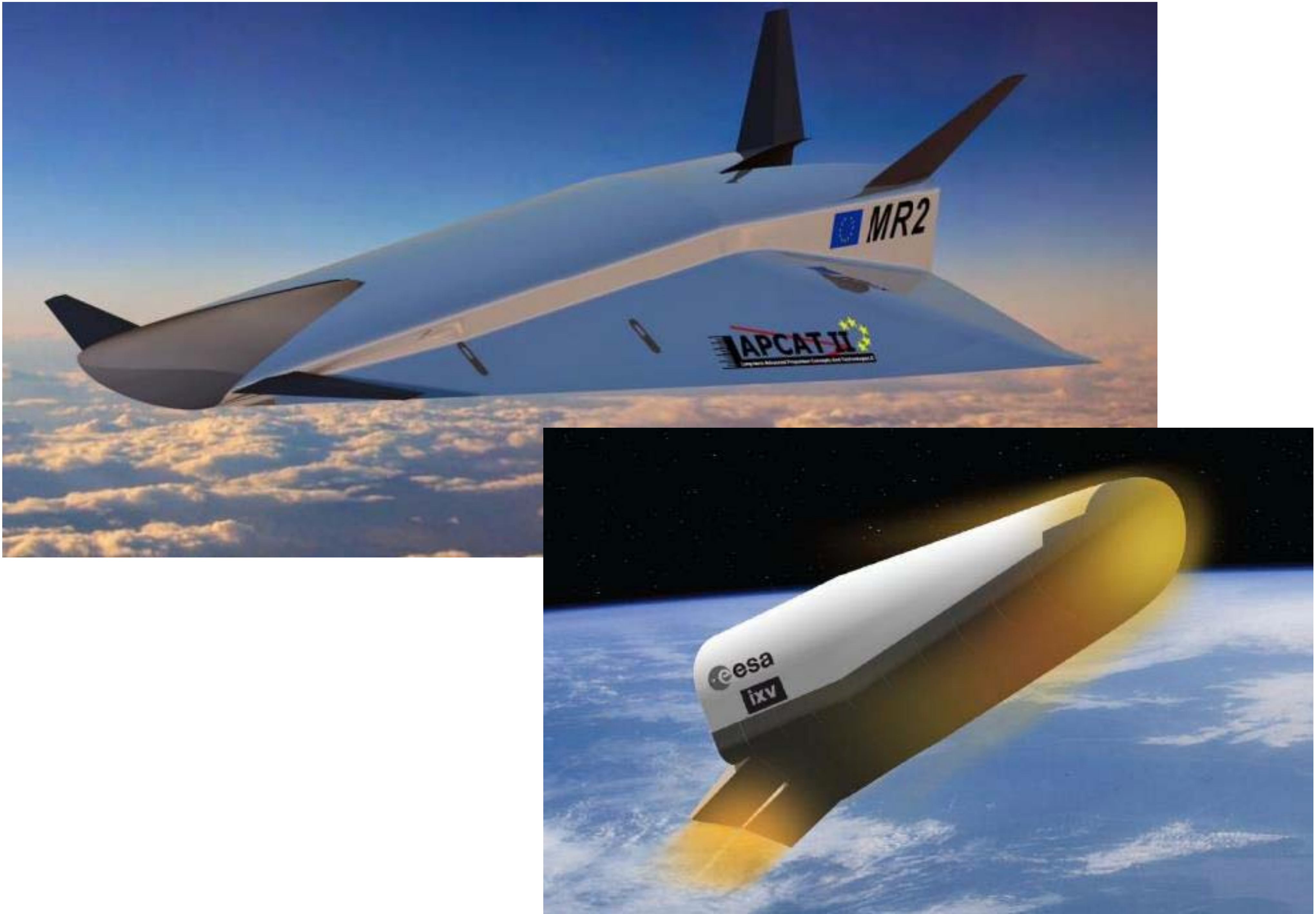
The European Union

The EU has primarily invested in three R&D programs using hypersonic technology, involving several countries.

The LAPCAT II project is intended to develop a civilian Mach 5 transport airplane, using a hybrid turbo-scramjetengine.

IXV is an experimental suborbital RV designed to test atmospheric reentry conditions from (hypersonic) orbital speeds and trajectories. It is intended to be a reusable satellite launch vehicle that is able to reenter the Earth's atmosphere after reaching a maximum altitude of 256 miles.

The European Union is currently finalizing the Meteor Missile, a ramjet-powered air-to-air missile capable of traveling at speeds of up to Mach 4 with a range of more than 100 km.


MR2
APCAT II
esa
ixv

Italian programs

Italian activities are essentially civilian, with little state participation and little military interest. In addition to participation in European projects, research is carried out using ptototypes, plasma studies, re-entry vehicles and feasibility studies of high-altitude flights.

They involve various industries and the universities of Naples and Rome and the Turin Polytechnic. The main Italian center is the private consortium CIRA (Italian aerospace research center), which runs two wind tunnels for hypersonic plasma studies in Capua.

SEZIONE ROMADUE LUIGI BROGLIO
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Risks of proliferation

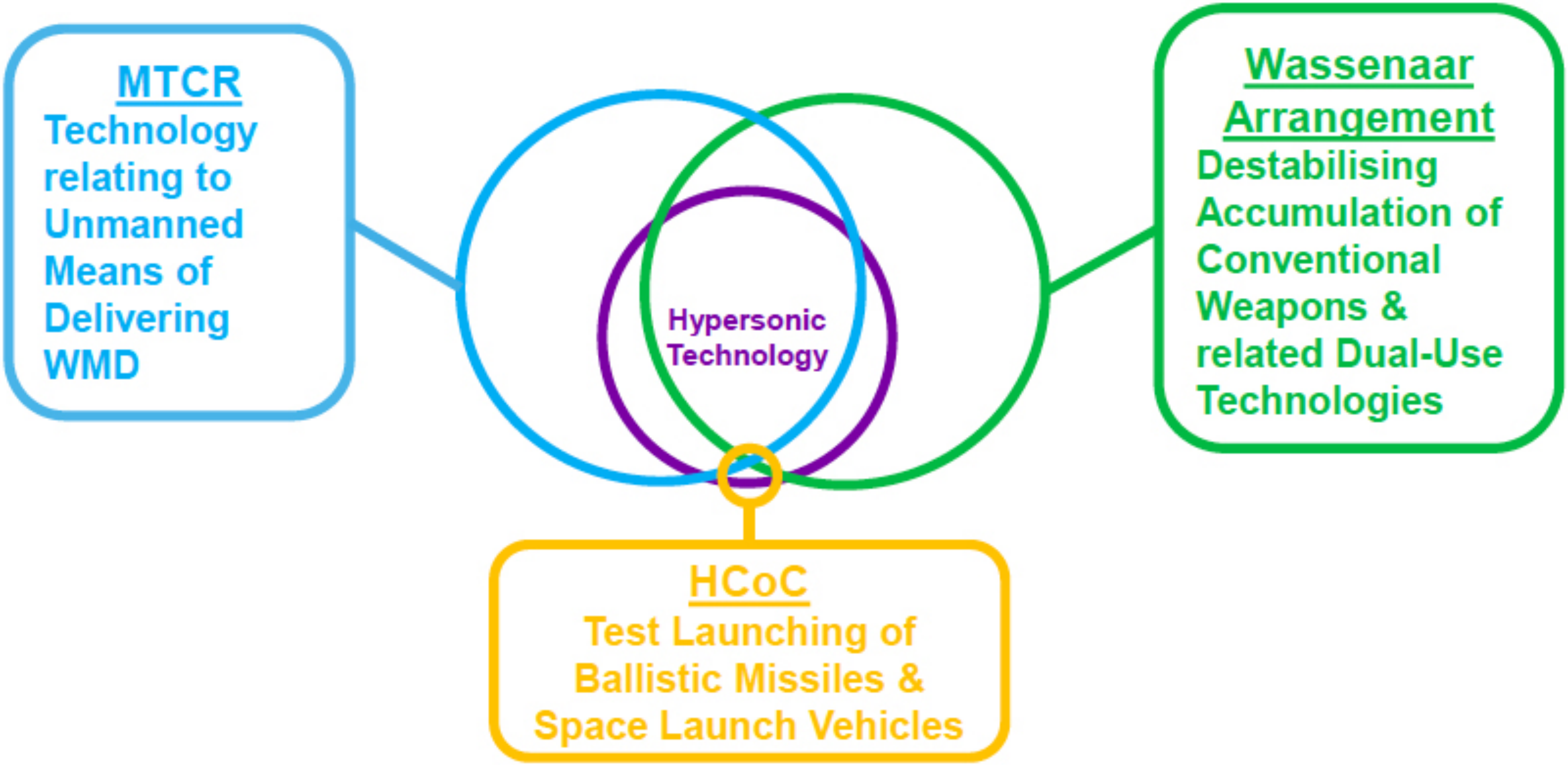
The enormous military capabilities of HMs could make the acquisition of hypersonic technology a desirable goal for new countries, also with a view to achieving a deterrent force against the major powers.

Current activities aim at scientific objectives and civil applications, however, once a state acquires hypersonic technology, its intentions may change, particularly in competitive situations or in delicate security issues, when even serious economic uncertainties on the market of commercial applications are overcome by military needs.

Given the still inadequate level of current civil research in the face of enormous difficulties for the full mastery of military hypersonic technology, the proliferation of HM could be prevented by a regime of export controls, modeled on the Missile Technology Control Regime (MTCR), which already incorporates some controls on hypersonic related technologies.

In any case, China, Russia and the United States cannot expect to impose constraints on the proliferation of HM if they do not commit themselves in the first place to stopping their dangerous race for these weapons.

Multilateral Export Control Regimes (MECRs)



MTCR
Technology relating to Unmanned Means of Delivering WMD

Hypersonic Technology

Wassenaar Arrangement
Destabilising Accumulation of Conventional Weapons & related Dual-Use Technologies

HCoC
Test Launching of Ballistic Missiles & Space Launch Vehicles

N.B. Hague Code of Conduct (HCOC) isn't technically one of the MECRs

strategic implications

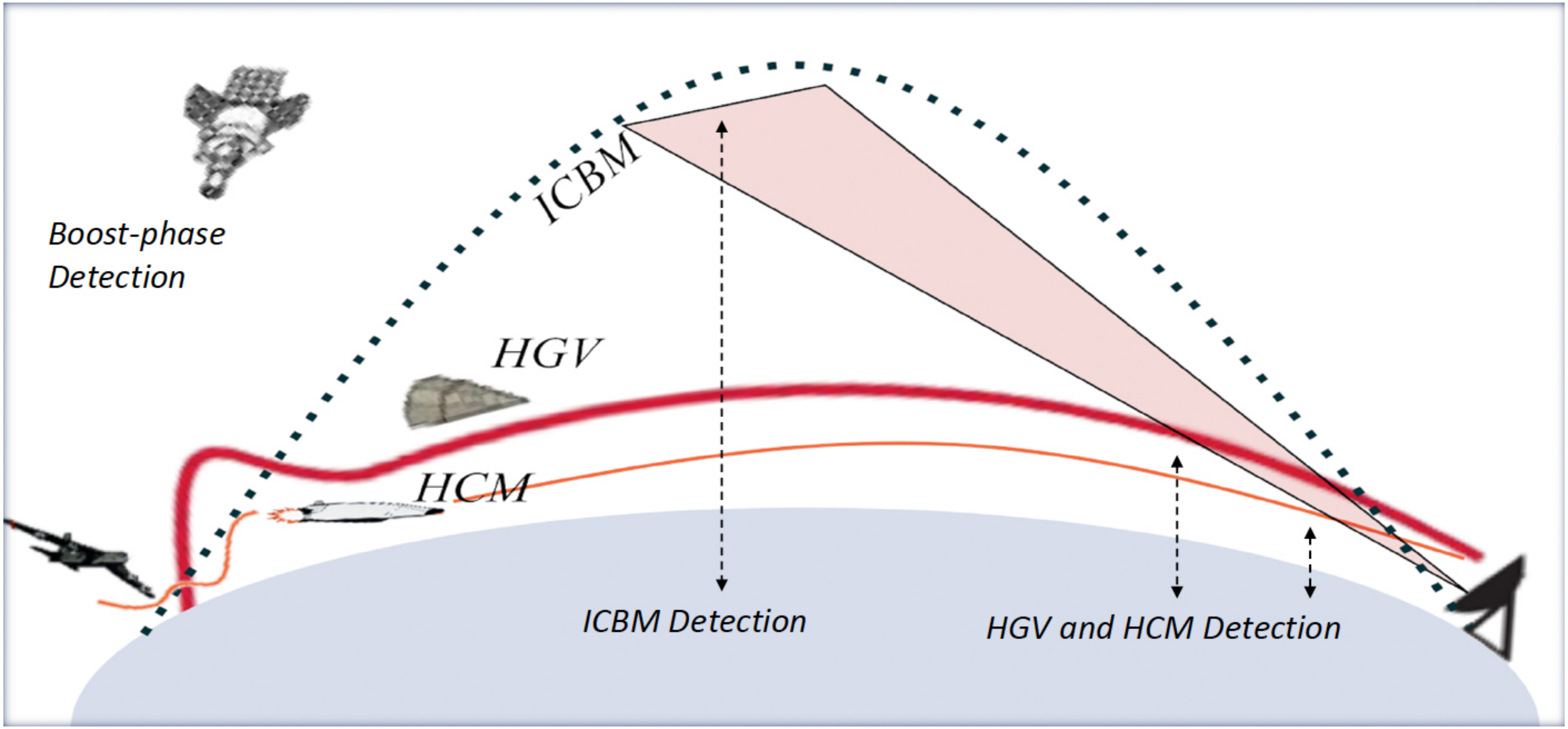
Strategic implications of hypersonic weapons

Hypersonic missiles create new challenges to global security.

Hypersonic missiles, if used against nations with limited strategic forces, might disarm target forces before they can react.
This prospect can lead the target nations to set up their strategic forces for “launch on warning” — creating many forms of crisis instability.

Because of the difficulties of defending against hypersonic missiles, relatively small hypersonic forces can pose threats against major powers’ forward-projected forces, or even deterrent threats against the homelands of major powers.

Detection of ICBMs and HM



the HGV and HCM are weapons of surprise: with satellite systems it is possible to identify the launch of the missile that releases an HGV, but the radars can see it again only a few minutes before arriving on the target

The speed of war: faster weapons, shorter reaction times

The pace of technological change in hypersonic flight vehicles in conjunction with areas such

- robotics and uninhabited land, sea and air vehicles
- quantum cryptography and quantum computing
- artificial intelligence and autonomuos control
- nanosciences and material science
- space militarization
- directed energy

will accelerate the speed of battle, making conflict faster and more complex.

It raises the demand for yet quicker weapons.

Compression of the entire time line for detection, control and reaction to a HM attack

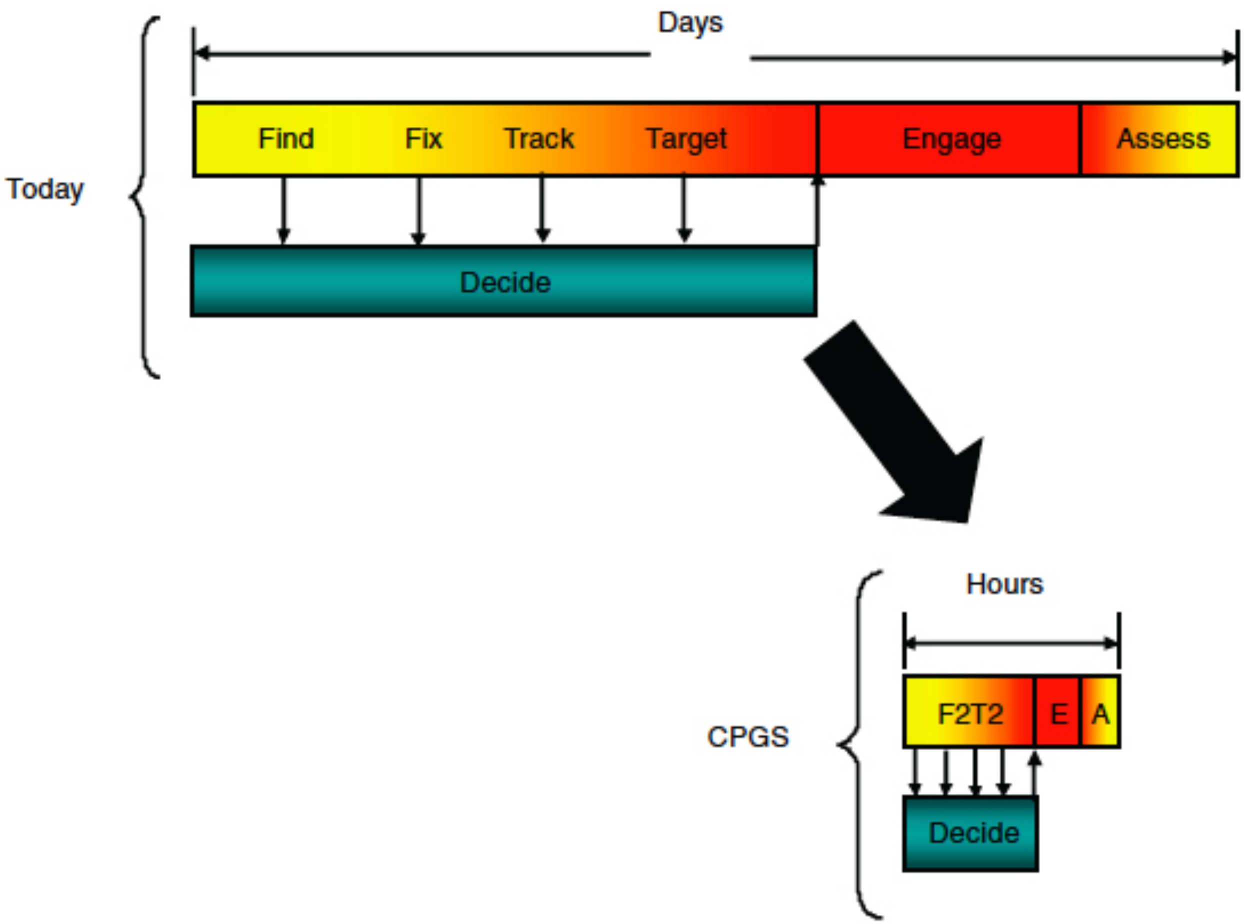


FIGURE 4-4 Conventional prompt global strike (CPGS) will require compression of the time line across the entire Find, Fix, Track, Target, Engage, and Assess (F2T2EA) strike process. With strategic warning and preparation, key aspects of this process can be accomplished in advance. For those portions of the process that need to occur inside the compressed time, technical means for seamlessly integrating systems that are currently not interoperable will need to be developed.

Strategic implications of hypersonic weapons

An arms race for hypersonic weapons presents many destabilizing aspects for the present (already precarious) global strategic balance, increasing the uncertainties and risks of escalation of military confrontation in case of conflict:

- **warhead ambiguity**
- **destination ambiguity**
- **origin ambiguity**
- **target ambiguity**
- **crisis instability**

Warhead ambiguity

the attacked country can erroneously misinterpret the launch of a vehicle with conventional weapons and conclude that the missile carries nuclear weapons instead, thus suggesting the need for a nuclear response.

However, as a United Nations report notes, “even if a State did know that an HGV launched toward it was conventionally armed, it may still view such a weapon as strategic in nature, regardless of how it was perceived by the State firing the weapon, and decide that a strategic response was warranted.”

Ambiguity of destination

hypersonic weapons, due to their high maneuverability, can induce a country observing a HM launch to mistakenly conclude that it is the real target of the attack, while the HM vehicle is destined for another country. Destination ambiguity could exacerbate warhead ambiguity and introduce other risks.

Prompt, global attack capabilities could prove destabilizing, when nations might have incomplete information about the nature of an attack and too little time to gather more information and plan an appropriate response. Faced with these circumstances, a nation who was not an intended target might choose to respond quickly, rather than to wait for more information.

Origin ambiguity

in the case of non-detecting the launch of an HM, an attacked country may not know which is the attacking state and therefore react against the wrong opponent; the problem becomes acute in the case of proliferation of hypersonic weapons

Target ambiguity

a state can mistakenly believe that its nuclear forces are threatened, while the objective are conventional systems; the risk is all the greater given the increasing integration of nuclear and conventional command and control systems

Crisis instability

The real or perceived ability of HM to hold a country's nuclear or strategic conventional capabilities at risk creates pressures to use (or threaten to use) weapons out of concern that they lacked survivability.

HMs thus increase fears of a disarming attack, encouraging to devolve command and control of strategic forces to low-level officials and to disperse forces, in an alert posture during a crisis. These extremely destabilizing measures lower the threshold for military actions.

Operative implications of hypersonic weapons

Faster weapons and faster C_4ISR systems (command, control, communication, computers, intelligence, surveillance and reconnaissance) will change the way military leaders operate on the battlefield as well as how they plan and execute missions. They will also allow a broader range of targeting options than hitherto, with hypersonic weapons allowing more fleeting targets to be engaged than was previously possible.

The increasing speed of weapons and of the decision making cycle will challenge military professionals.

New technologies will enable even more sophisticated and disruptive “grey zone” operations

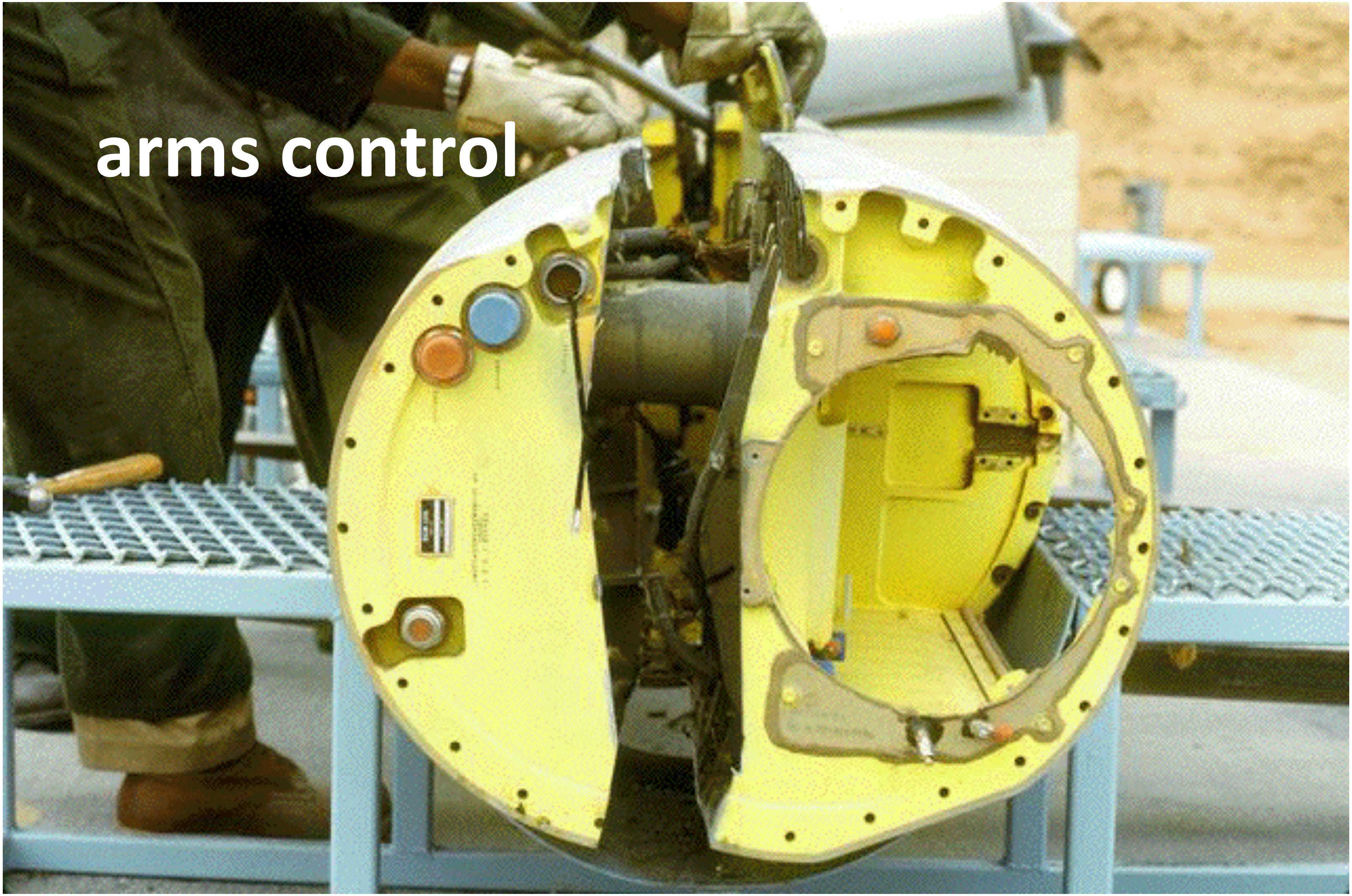
A geopolitical consequence of faster weapons

The present technological progress in hypersonic flight in conjunction with other advanced areas is eroding Westner military dominance across land, sea, air, space and in electromagnetic spectrum.

Advanced military capabilities are proliferating and systems previously monopoly of Western states are increasingly operated by others.

There is now contestation in all domains, and the pace is accelerating, also because competing countries are able to adapt, innovate and integrate change with a shorter decision process and greater flexiblity.

arms control



Arms control

At the moment there are no treaties or conventions limiting the development of HGV or HCM with conventional armament.

During the New START negotiations, Russia raised the issue of high precision conventional weapons, which she still considers a threat to strategic stability.

Hence, land-based ballistic missiles armed with conventional warheads would count under the limits in New START if (par. 6 of Part One of the Treaty Protocol) the missile “has a ballistic trajectory over most of its flight path” and a range greater than 5,500 kilometers.

So conventional HGV or HCM systems remain excluded.

Under the definitions in New START, the boost-glide systems would qualify as new kinds of strategic offensive arms.

Article V of the treaty indicates that, “when a Party believes that a new kind of strategic offensive arm is emerging, that Party shall have the right to raise the question of such a strategic offensive arm for consideration in the Bilateral Consultative Commission.”
As a result, a party would have the opportunity to question the other party on whether the boost-glide systems should count under the treaty. But the second party would not have to delay the development, testing, and deployment of these systems while the discussions proceeded.

Nuclear hypersonic weapons

The nuclear hypersonic weapons fall generically under the dictates of the article VI of the Non-proliferation treaty, in particular if they are triggering a new arms race.

The matter could be discussed during the next review conference.

Given the inherentdestabilizing nature of hypersonic weapons and the fact that they have not yet reached full and effective operation, it would be in the common interest if China, Russia and the United States to find a key to negotiate a ban on such weapons, or at least reach an agreement for the moratorium on their development

Arms control for hypersonic weapons

Some analysts have proposed negotiating a new international arms control agreement that would institute a moratorium or ban on hypersonic weapon testing. These analysts argue that a test ban would be a “highly verifiable” and “highly effective” means of preventing a potential arms race and preserving strategic stability.

Other analysts have countered that a test ban would be infeasible, as “no clear technical distinction can be made between hypersonic missiles and other conventional capabilities that are less prompt, have shorter ranges, and also have the potential to undermine nuclear deterrence.”

These analysts have instead proposed international transparency and confidence-building measures, such as exchanging weapons data; conducting joint technical studies; “providing advance notices of tests; choosing separate, distinctive launch ocations for tests of hypersonic missiles; and placing restraints on sea-based tests.”

Reasons for flight testing:

1. Generate information unique to flight test environment that cannot be obtained on the ground
2. Use the data to anchor/validate models and to verify ground test data
3. Validate system performance in its operational environment and/or for system certification
4. Identify unanticipated problems
5. Reduce risk and demonstrate technology in flight
6. Provide political messaging

the initial five are vital to the development and fielding of HVs, both civilian and military

Arms control and hypersonic weapons

The present military posture increasingly requires weapons that can travel faster, farther and with greater precision.

This leaves no space and hopefor either arms control or confidence-building measures

A modest proposal

if the only perceived additional value of hypersonic weapons is the possibilty to penetrate ABM ystems, why not consider negotiating a new ABM ban treaty, that has proven so useful for the cointanement of the nuclear arm race 40 years ago?

a few sources

- James M. Acton (2013) *Silver Bullet? Asking the Right Questions About Conventional Prompt Global Strike*, Carnegie Endowment for International Peace, Washington DC
- James M. Acton (2015) Hypersonic Boost-Glide Weapons, *Science & Global Security* 23, 191–219.
- James M. Acton (2015) Russia and Strategic Conventional Weapons: Concerns and Responses, *The Nonproliferation Review* 22(2), 141-154.
- John D. Anderson (2000) *Hypersonic and High Temperature Gas Dynamics,* American Institute of Aeronautic and Astronautics, Washington DC.
- Committee on Conventional Prompt Global Strike Capability, Naval Studies Board, and Division on Engineering and Physical Sciences, the National Research Council of the National Academies (2008) *U.S. Conventional Prompt Global Strike: Issues for 2008 and Beyond,* National Academies Press, Washington DC.
- Joshua H. Pollack (2015) Boost-glide Weapons and US-China Strategic Stability, *The Nonproliferation Review* 22(2), 155-164.
- Richard H. Speier, George Nacouzi, Carrie A. Lee, Richard M. Moore (2017) *Hypersonic Missile Nonproliferation. Hindering the Spread of a New Class of Weapons*, RAND Corporation, Santa Monica CA.
- Amy F. Woolf (2019) *Conventional Prompt Global Strike and Long-Range Ballistic Missiles: Background and Issues*, Updated August 14, 2019, Congressional Research Service, Washington DC.

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