Hypersonic Vehicles: State-of-the-Art and Potential Game Changers for Future Warfare

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Hypersonic flight is lacking a scientific definition, but is typically understood as flight within the atmosphere at speed around and beyond Mach 5. In this regime, dissociation of air starts to get significant and kinetic heating results in increasingly severe problems for a vehicle with increasing flight Mach number. Temperatures to be dealt with are about doubled between Mach 4 and 6 and quadrupled between Mach 4 and 9. Drag forces get huge and limit longer flight to altitudes within the stratosphere.

Today, long duration flight at Mach numbers beyond 5 poses technological challenges with regard to structural materials and design, cooling and insulation, aerodynamics and flight control as well as propulsion by SCRAMJET (supersonic combustion ramjet), which are well beyond actual operational technologies; thus being a topic of various current research activities.

Examples for hypersonic flight range from the X-15 experimental rocket plane of the 1960's, various reentry capsules and experimental vehicles, the Space Shuttle and a number of newer experimental programs with the USAF X-51 (Figure 1) as a most recent one. Hypersonic research is conducted by nations with highly developed R&D capabilities and adequate financial resources including the US, Australia, Russia, China, Europe and India.

Figure 1. An X-51A Wave-Rider hypersonic flight test vehicle is uploaded to an Air Force Flight Test Center B-52 for fit testing at Edwards Air Force Base on July 17, 2009. (U.S. Air Force photo/Chad Bellay)

Hypersonic applications may revolutionize the future of warfare from a military capability perspective and are therefore considered as game changing technologies. As adversaries push out the boundaries of contested areas with advanced air defense systems, hypersonics counters the trend and allows greater standoff operations for first strike.

Different future applications are conceivable for hypersonic flight vehicles in order to enable new or advanced military capabilities:

- Advanced un-powered (or less likely powered) maneuverable glide vehicles launched by a ballistic missile (BM).
  These vehicles will allow to increase the target footprint of a strategic or tactical BM significantly by a glide phase in the upper atmosphere and will be much more difficult to intercept than ballistic re-entry vehicles. The vehicles will have bigger size and higher mass than today's state of the art BM targetable re-entry warheads. Extreme peak dynamic pressures and temperatures (Mach 8 -12) will be a major challenge for the structural integrity of such vehicles. The Circular Error Probable (CEP) will depend on unresolved issues like navigation means and guidance/flight control precision. **Nevertheless, this is the most likely application in nearer future and is a major subject of research** (Falcon, HIFire, HSSW, WU-14).

- Powered (SCRAMJET) hypersonic cruise missile for long range force projection.
  Air launched expendable hypersonic vehicles may be used for tactical strike from standoff distances. Flight time (Mach 4 – 6+) is shorter or comparable to a BM up to about 1000 km, which might be an advantage for very time critical targets. The vehicles will be difficult to intercept during high altitude cruise and terminal dive. Long to global reach implies vehicle and propulsion endurance in the order of many minutes to even hours (achieved today < 3 minutes at Mach 5). Vehicles need rocket boost for acceleration and lift to high altitude, before using the SCRAMJET sustain propulsion. Widely unresolved issues relate to structural integrity (endurance and final dive), propulsion efficiency and endurance, military payload fraction as well as flight control and navigation resulting in a large and extremely costly vehicle. Recent research progress was gained by the US X-51 program, but operational readiness of such systems is very unlikely within the next ten years.

- Powered hypersonic interceptor missile (ground or air launched) for time sensitive and high value aerial targets.
  Typical range of such missiles will be in the range of hundreds of kilometers. These missiles will be difficult to intercept, but they need high precision guidance and flight control to hit the target. Flight time will be in the order of a few minutes alleviating the unresolved issues for propelled hypersonic flight. This military capability is likely to be achieved by a stepwise approach within ten to fifteen years , first using more mature technology for Mach 4 – 5 and conventional ramjet propulsion (subsonic combustion), like shown as a concept in Figure 2.

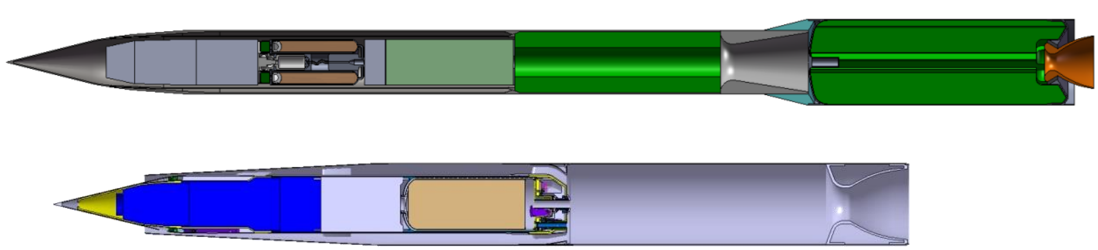

Figure 2. Concept for ground launched endo-atmospheric interceptor (Mach 5); top: launch configuration with tandem booster and integral booster in the ramjet combustor case; bottom: cruise configuration with throttle able ducted rocket propulsion. (Bayern-Chemie GmbH)

- Limited life reconnaissance or weapon delivery by partially re-usable/refurbishable powered hypersonic vehicle (SR-71 ++).

  This weapon system would be an UAV flying at Mach 5+ to perform long range (>1000 km) tactical strike or ISR of deep high value targets and to return after its mission. Potentially, such a system could be more flexible than satellite reconnaissance and offer lower operating costs than fully expendable weapon. All issues of a hypersonic cruise missile apply for this system increased by the complexity of a re-usable vehicle. Used for ISR, hypersonic speed and external aerothermal effects will pose severe problems for picture resolution and data link bandwidth as well as data transmission. Stepwise approach may occur with UAV's flying up to Mach 4 with a more limited range. Operational capability may be considered in the mid-term by 2035+.

- Payload delivery into space by recoverable single or multistage launch vehicle.

  This mission is under research for military and civil applications. It is almost state-of-the-art as the USAF mini-shuttle with rocket launch (USAF X-37, cf. Figure 3).

  A fully re-usable long life air platform will be much more ambitious with a single or first stage taking off from a runway like a conventional aircraft. Shorter flight through the atmosphere may slightly alleviate hypersonic issues as quoted for the cruise missile. Widely unresolved problems relate to complex propulsion concepts like combined cycle engines - different cycles for different Mach number regimes or e.g. precooled hybrid air-breathing rocket (SABRE). Such a system is unlikely to occur until the long-term of more than 25 years.

Figure 3. X37B at ground testing (USAF)

In the mid to long term future, hypersonic flight may offer important advantages with regard to flexibility of long range force projection in highly contested environments and penetration of enemy defense. The cost effectiveness of hypersonic vehicles will remain to be judged, based on the progress in the wide area of unresolved technical issues today. Only maneuverable re-entry glide- vehicles are likely to get operational on a somewhat mid-term (next decade) time line. There is no doubt that other missions will go into the direction of higher speed for shorter time to target and defense penetration. Current military research and development plans show a stepwise approach staying below the hypersonic regime and allowing for a near term development using evolved materials and technologies like ramjets, but for the longer term allowing for incorporation of more capable hypersonic scramjet capabilities.

Research and development for hypersonic flight is very expensive, due to the variety of complex challenges, the limited capability of ground testing even in highly specialized costly facilities and the high effort for flight experiments. Therefore, research is often carried out in international collaboration like the USA/AUS/DEU HIFiRE and HIFEX programs investigating fundamental hypersonic phenomena and advancing component technology and instrumentation. (Figure 4).

Figure 4. USA/AUS HIFiRE 5 test vehicle (left), German (DLR) SHEFEX II test vehicle (USAF release)

In the past, funding of high speed/hypersonic research in NATO nations was not always purposeful and very discontinuous leading to fluctuations in the TRL level. This implies that decision makers must develop a roadmap which is clearly followed with sustained funding (nationally or internationally). This is paramount to stay sufficiently ahead in technology considering the increasing efforts of potential red force nations, where e.g. China appears to massively invest in this technology.