



Hypersonic Missiles *The Extreme Need for Speed*

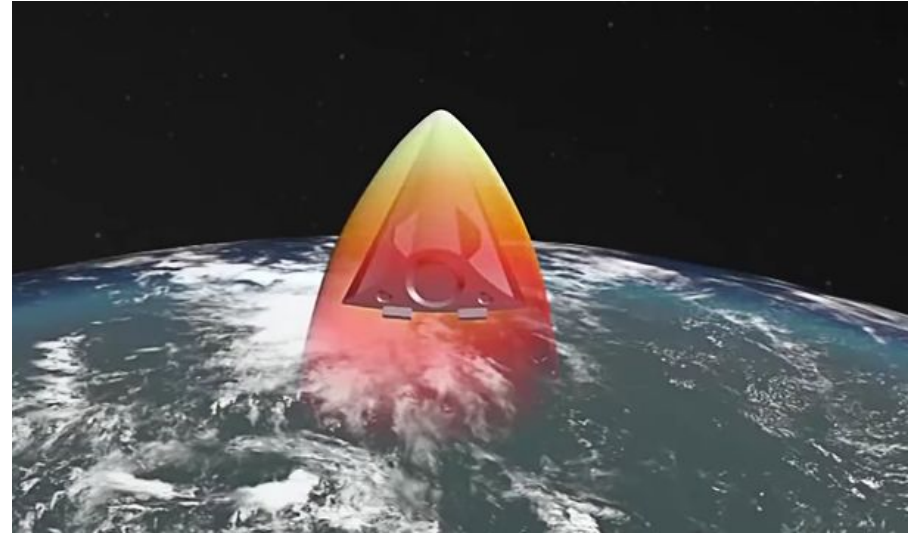
Chris Carlson
Cold Wars 2020

Admiralty Trilogy Seminar



Outline

- ◆ **Introduction**
- ◆ **Media Hype on Hypersonics**
- ◆ **What is Hypersonic?**
 - Define Mach number
- ◆ **Ballistic Missiles**
- ◆ **Hypersonic Glide Vehicles (HGV)**
- ◆ **Scramjet Missiles**
- ◆ **What does this extreme need for speed get you?**
- ◆ **How will *Harpoon V* handle hypersonic weapons?**
- ◆ **Questions**





Introduction

- ◆ **In the last five years there has been a considerable amount of talk on the developments in hypersonic weapons.**
 - **President Putin's address to the Russian Assembly on 1 March 2018.**
 - **China's 2019 National Military Parade.**

- ◆ **Multiple definitions of hypersonic weapons has also caused confusion.**
 - **A weapon that goes faster than Mach 5.**
 - **A weapon that goes faster than Mach 5 and can maneuver.**
 - **An air-breathing missile that goes faster than Mach 5.**

- ◆ **Media hype, and some poor reporting from a technical perspective, has fueled concern that warships are now completely vulnerable to being attacked and sunk.**



Media Hype on Hypersonic Missiles

Washington Examiner

How Russia got hypersonic missiles before the US

[Military.com](https://www.military.com)

Why Russia's Hypersonic Missiles Can't Be Seen on Radar

AP New Russian weapon can travel 27 times the speed of sound

The New York Times

Opinion

Hypersonic Missiles Are a Game Changer

No existing defenses can stop such weapons — which is why everyone wants them.

METRO

Russia deploys 'world's first' unstoppable hypersonic nuclear weapon



US unable to defend against Russian and Chinese hypersonic weapons, report warns

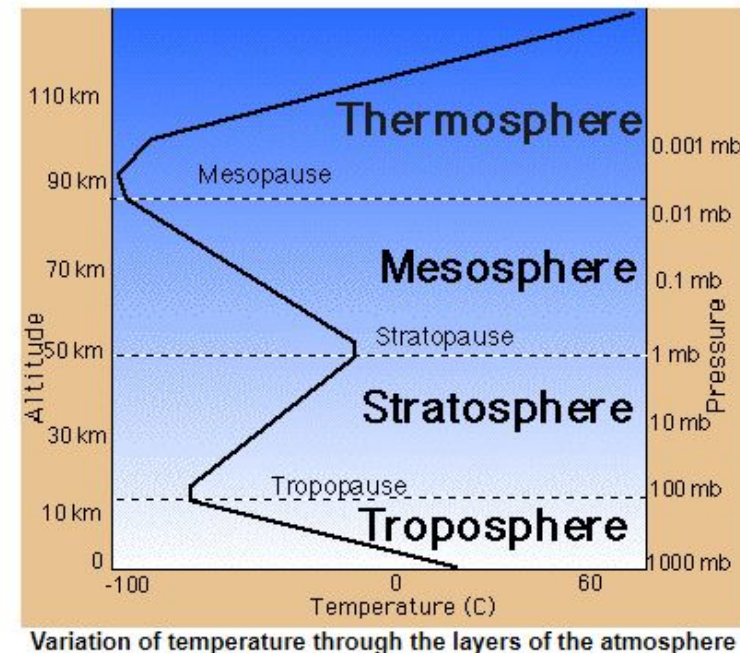


Mach Number

Speed of Sound Values in the Atmosphere of Earth

| | altitude 1000 m | Mach 1 | | | | altitude 1000 m | Mach 1 | | | | altitude 1000 m | Mach 1 | | | | | |
|--------------|--------------------|--------|--------|-------|------------|--------------------|--------|--------|--------|--------|--------------------|--------------|-------|-------|--------|-------|-------|
| | | km/h | m/s | kts | | | km/h | m/s | kts | | | km/h | m/s | kts | | | |
| Troposphere | -4 | 1279.2 | 355.3 | 690.7 | Strato-s | 40 | 1141.9 | 317.2 | 616.6 | Mes-p | 84 | 997.0 | 276.9 | 538.3 | | | |
| | -2 | 1252.4 | 347.9 | 676.2 | | 42 | 1154.4 | 320.7 | 623.3 | | 86 | 986.5 | 274.0 | 532.8 | | | |
| | 0 | 1225.0 | 340.3 | 661.5 | | 44 | 1166.8 | 324.1 | 630.0 | | 88 | 986.5 | 274.0 | 532.8 | | | |
| | 2 | 1197.1 | 332.5 | 646.4 | | 46 | 1179.1 | 327.5 | 636.6 | | 90 | 986.5 | 274.0 | 532.8 | | | |
| | 4 | 1168.5 | 324.6 | 631.0 | | S-p | 48 | 1187.3 | 329.8 | | 641.1 | Thermosphere | 92 | 986.8 | 274.1 | 532.8 | |
| | 6 | 1139.2 | 316.5 | 615.1 | | | 50 | 1187.3 | 329.8 | | 641.1 | | 94 | 988.8 | 274.7 | 533.9 | |
| | 8 | 1109.2 | 308.1 | 598.9 | | | 52 | 1183.7 | 328.8 | | 639.2 | | 96 | 992.9 | 275.8 | 536.1 | |
| | 10 | 1078.3 | 299.5 | 582.2 | | | 54 | 1171.5 | 325.4 | | 632.6 | | 98 | 999.3 | 277.6 | 539.6 | |
| | Tropopause | 12 | 1062.3 | 295.1 | | | 573.6 | 56 | 1159.2 | | 322.0 | | 625.9 | 100 | 1008.0 | 280.0 | 544.3 |
| | | 14 | 1062.3 | 295.1 | | | 573.6 | 58 | 1146.8 | | 318.6 | | 619.2 | 102 | 1019.4 | 283.2 | 550.4 |
| 16 | | 1062.3 | 295.1 | 573.6 | 60 | | 1134.3 | 315.1 | 612.4 | 104 | 1034.1 | | 287.2 | 558.4 | | | |
| 18 | | 1062.3 | 295.1 | 573.6 | 62 | | 1121.6 | 311.6 | 605.6 | 106 | 1053.0 | | 292.5 | 568.6 | | | |
| Stratosphere | 20 | 1062.3 | 295.1 | 573.6 | 64 | | 1108.8 | 308.0 | 598.7 | 108 | 1078.4 | | 299.6 | 582.3 | | | |
| | 22 | 1067.0 | 296.4 | 576.1 | 66 | | 1095.8 | 304.4 | 591.7 | 110 | 1082.8 | | 300.8 | 584.6 | | | |
| | 24 | 1071.8 | 297.7 | 578.7 | 68 | 1082.7 | 300.8 | 584.6 | 112 | 1087.1 | 302.0 | 587.0 | | | | | |
| | 26 | 1076.6 | 299.1 | 581.3 | Mesosphere | 70 | 1069.4 | 297.1 | 577.4 | 114 | 1091.4 | 303.2 | 589.3 | | | | |
| | 28 | 1081.4 | 300.4 | 583.9 | | 72 | 1056.4 | 293.4 | 570.4 | 116 | 1095.8 | 304.4 | 591.7 | | | | |
| | 30 | 1086.2 | 301.7 | 586.5 | | 74 | 1046.7 | 290.8 | 565.2 | 118 | 1100.1 | 305.6 | 594.0 | | | | |
| | 32 | 1090.9 | 303.0 | 589.0 | | 76 | 1036.9 | 288.0 | 559.9 | 120 | 1104.5 | 306.8 | 596.4 | | | | |
| | 34 | 1103.4 | 306.5 | 595.8 | | 78 | 1027.1 | 285.3 | 554.6 | 122 | 1108.8 | 308.0 | 598.7 | | | | |
| | 36 | 1116.4 | 310.1 | 602.8 | | 80 | 1017.1 | 282.5 | 549.2 | 124 | - | - | - | | | | |
| | 38 | 1129.2 | 313.7 | 609.7 | | 82 | 1007.1 | 279.8 | 543.8 | 126 | - | - | - | | | | |

Mach 1 vs. altitude in Metric Units



- ◆ A missile is “hypersonic” if it can attain a speed greater than Mach 5.
- ◆ Mach Number = Vehicle Speed/Speed of Sound.
 - Speed of sound is a function of altitude/temperature.
 - For purposes of this presentation, assume Mach 1 = 574 knots.



Ballistic Missiles

- ◆ **All ballistic missiles are hypersonic at some point in their flight.**
 - MRBMs – ICBMs are hypersonic during all phases of flight.
 - SRBM are usually hypersonic during boost phase and high supersonic during terminal phase.
 - V-2 (Sept 1944) was hypersonic during boost phase.
 - Boost: 5,760 km/hr – Mach 5.4
 - Impact: 2,880 km/hr – Mach 2.7
- ◆ **The Soviet Union deployed the first MRBM in 1953-55 and the first ICBM in 1960.**
 - U.S. started fielding similar weapons in 1958-59.
- ◆ **The majority of ballistic missiles are capable of hypersonic speeds throughout their flight trajectory and have been part of the defense landscape for over 65 years!**



Ballistic Missiles



R-5 [SS-3 Shyster]

IOC: 1953-55

Type: MRBM

Range: 1,200 km

Speed: 10,771 km/hr

(Mach 10-10.5)



R-7 [SS-6 Sapwood]

IOC: 1960

Type: ICBM

Range: 8,000 km

Speed: 15,358 km/hr

(Mach 26-27)



Russian Kinzhal



- ◆ **Kh-47 M2 Kinzhal air-launched ballistic missile.**
 - Likely based on the ground-launched 9K720 Iskander [SS-26 Stone] SRBM.
 - Reported range: 2,000 km from MiG-31K aircraft.
 - Reported speed: 12,250-14,700 km/hr (Mach 11-14).
- ◆ **SRBMs are not necessarily hypersonic throughout their entire flight, SS-26 max speed is Mach 6.8 during boost, however, being launched from a Mach 2.0-2.5 aircraft from 25,000 meters is a big help.**



Russian Kinzhal



- ◆ **10 MiG-31K deployed on “Experimental Combat Duty” to the Southern Military District in May 2018 (red X).**
- ◆ **Kinzhal has no demonstrated capability to attack ships, no evidence of a terminal seeker, missile speed too fast for a homing radar to function.**
- ◆ **Kinzhal missile designed to target NATO ground-based BMD facilities in Romania and Poland.**



DF-21D ASBM

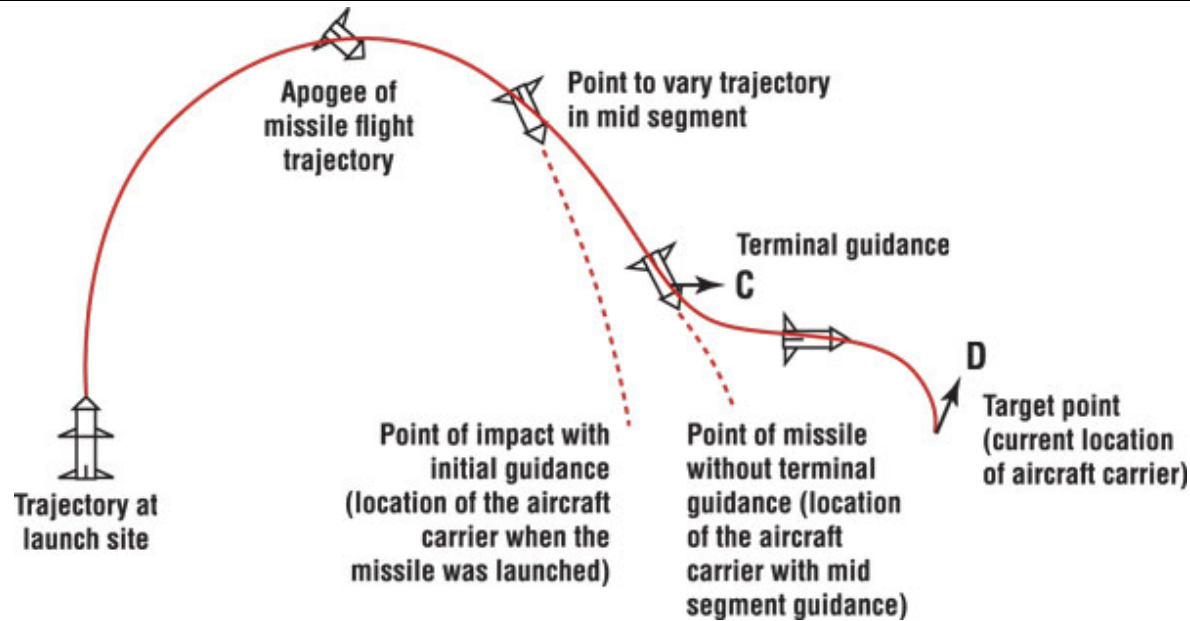


- ◆ Ballistic missiles can be designed to attack ships, the Chinese DF-21D and possibly the DF-26 are examples.
- ◆ Hypersonic throughout their flight trajectory.





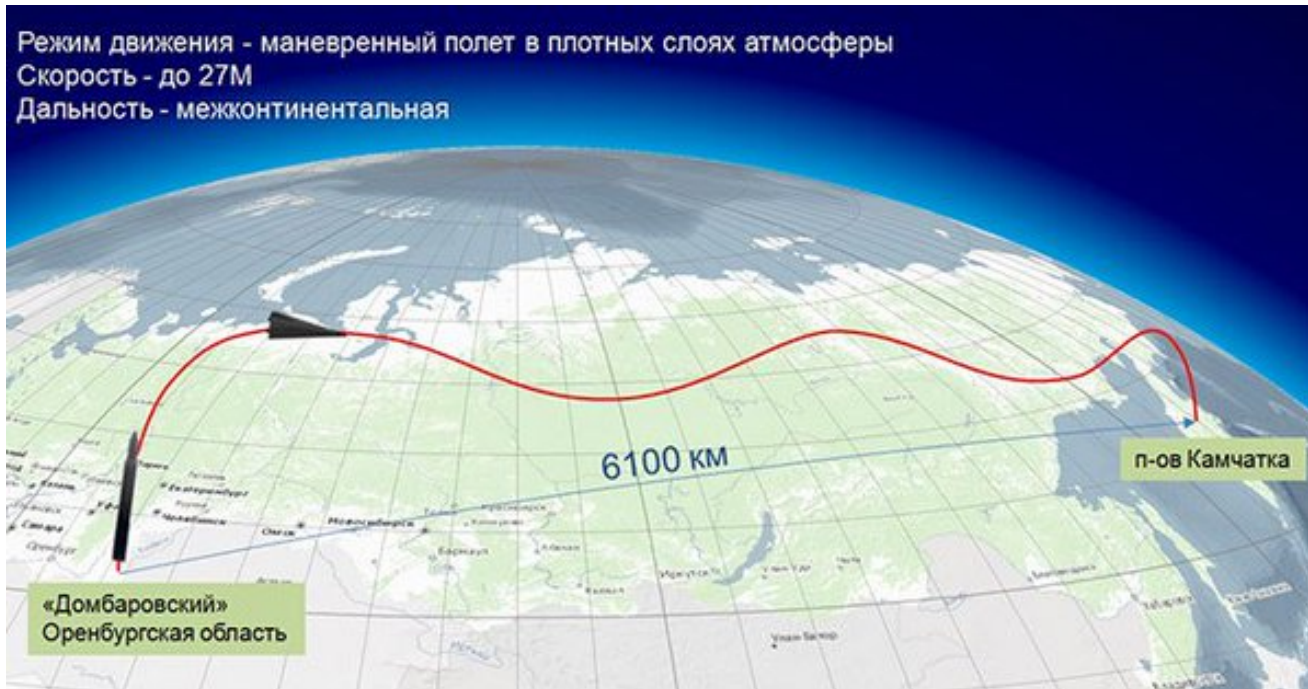
DF-21D ASBM



- ◆ **Missile has to dramatically slow down if the radar seeker is to be able to function properly.**
 - Speeds greater than Mach 10 create an ionized plasma field around the re-entry vehicle that greatly interferes with radar transmissions.
- ◆ **The pull up maneuver, illustrated in all Chinese documents, is to slow the missile down - not an evasion maneuver. Similar to the Pershing II that the DF-21D/26 is likely based on.**
- ◆ **Difficult, but not impossible to counter.**



Hypersonic Glide Vehicles



- ◆ **Ballistic missile payload.**
- ◆ **Instead of following a predictable ballistic trajectory, the glide vehicle is released and stays relatively low - about 80,000 km.**
- ◆ **Uses aerodynamic control surfaces to execute maneuvers.**
- ◆ **Both the lower trajectory and ability to maneuver greatly complicates the problem for ballistic missile defenses.**



Hypersonic Glide Vehicles



◆ Russia's Avangard (Object 4202/Yu-71)

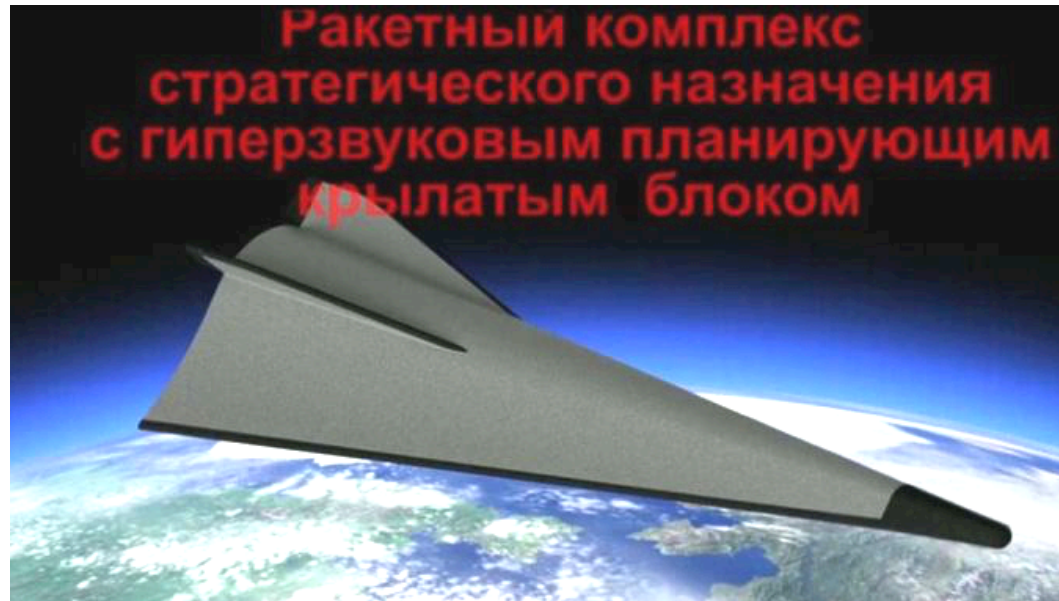
- Tested on a UR-100NUTTkH [SS-19 Mod 4 Stiletto] ICBM.
- Claimed to be operational on 27 December 2019.

◆ China's DF-17 (DF-ZF/Wu-14)

- Payload on a DF-16B SRBM.
- Could be operational, shown at 2019 National Military Parade.



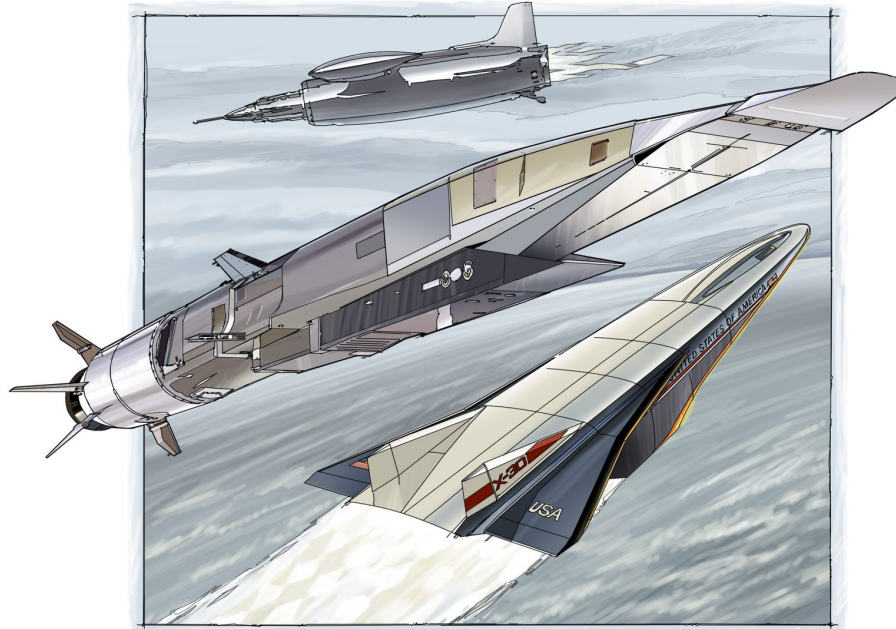
Hypersonic Glide Vehicles



- ◆ **Hypersonic glide vehicles sacrifice a lot of speed to gain the ability to maneuver.**
 - **Avangard max boost speed is on the order of Mach 27, however, while gliding atmospheric drag reduces the speed to Mach 15 – 20.**
 - **China's DF-17 reportedly glides at Mach 10.**
- ◆ **Unlikely a threat to naval vessels at sea. HGVs are not that maneuverable and the high speed preclude terminal homing.**



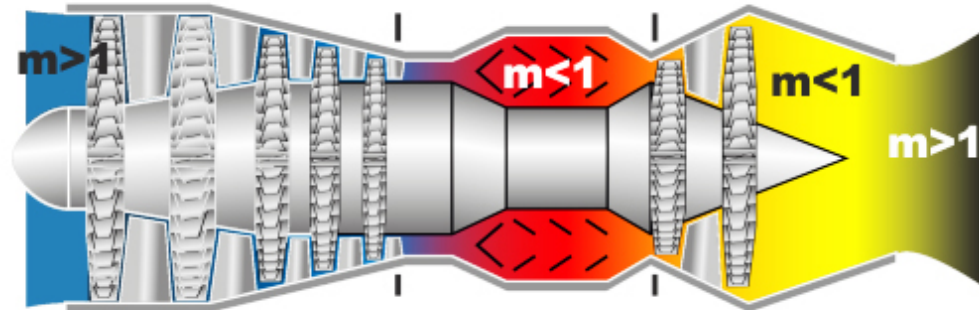
SCRAMJET Missiles



- ◆ **A SCRAMJET missile uses an air-breathing propulsion system to obtain speeds of Mach 5 or greater.**
 - Not a rocket with a solid fuel motor or a liquid fuel + oxidizer engine.
 - Oxygen for combustion is obtained from the atmosphere.
- ◆ **SCRAMJETs have been a hot topic in aeronautical research and development since the early 1960s.**
 - First flight tests of scramjet propelled vehicles took place in the 1990s.

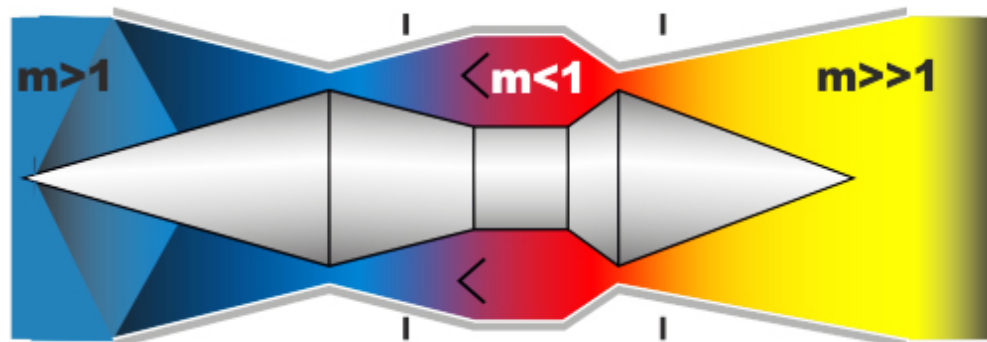


What is a SCRAMJET?



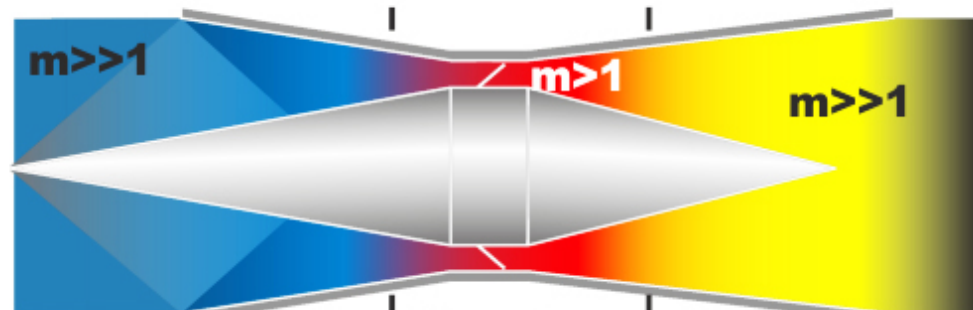
TURBOJET/TURBOFAN

**Theoretical
Max Speed:
≈ Mach 3.5**



RAMJET

3.0 < Mach < 5.5

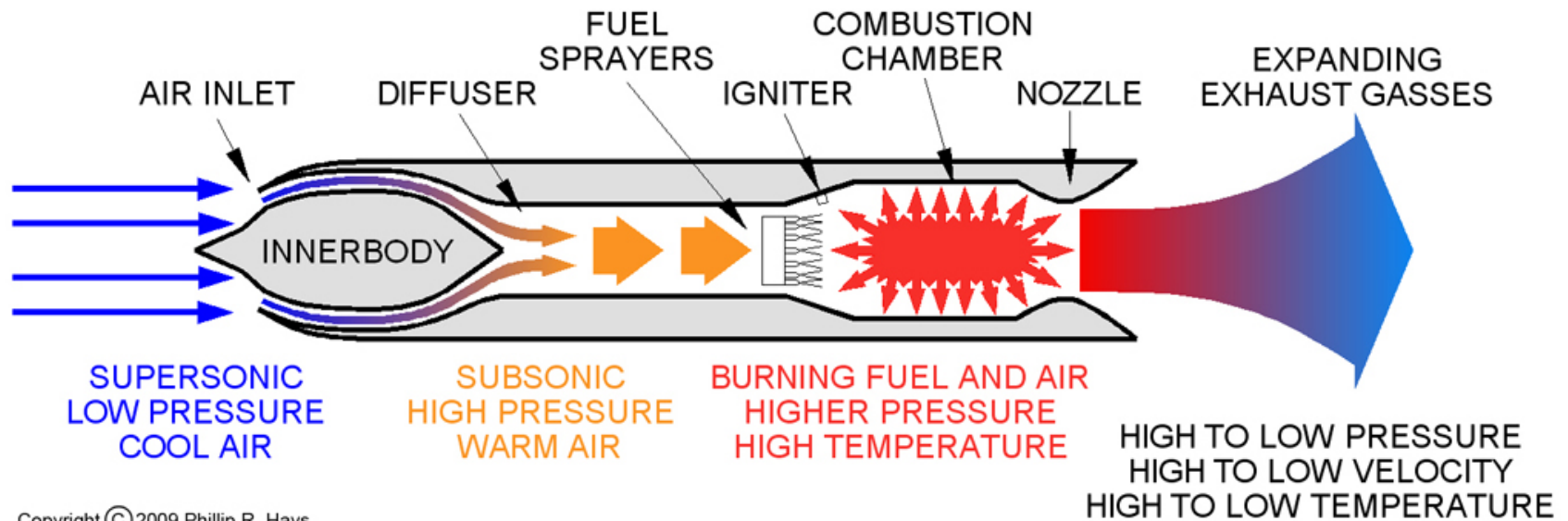


SCRAMJET

5.0 < Mach < 15.0?



What is a SCRAMJET?

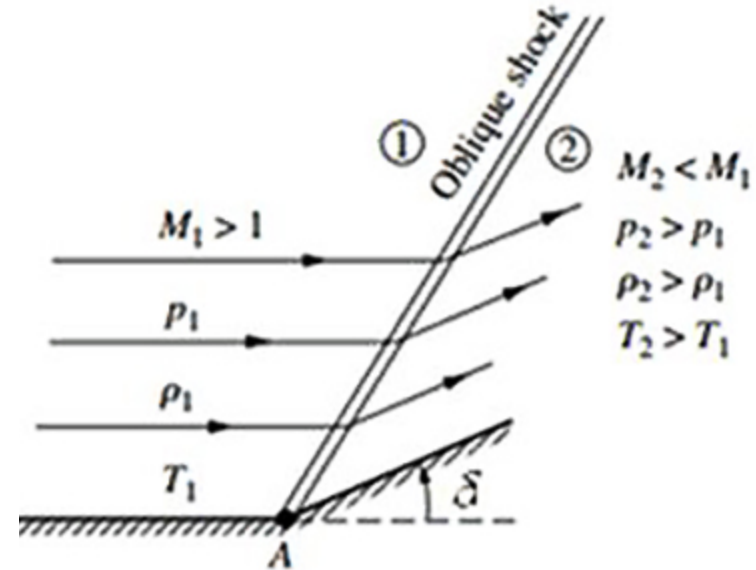
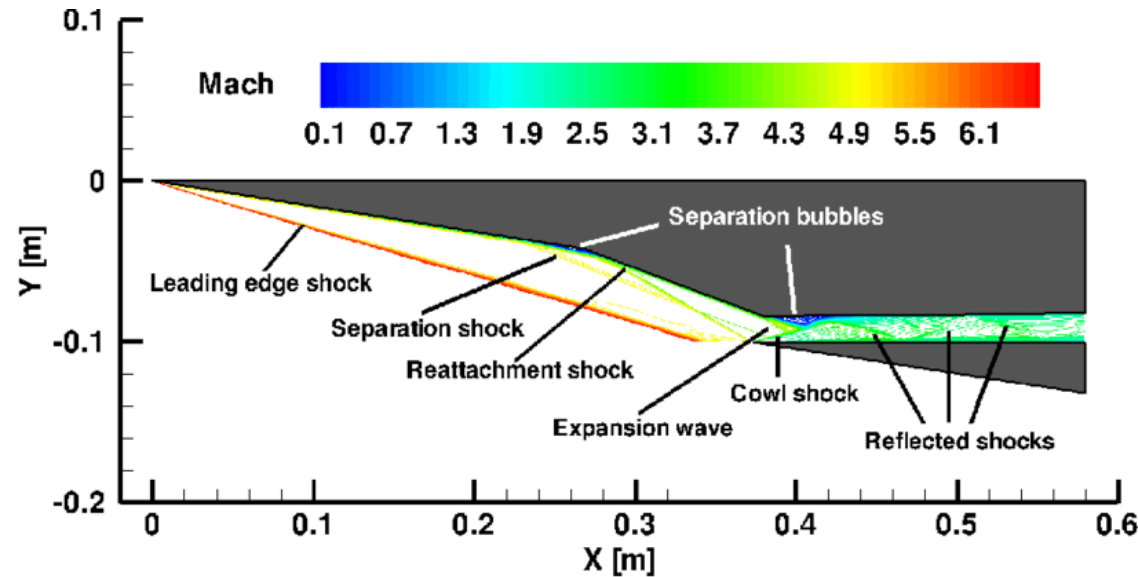


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- ◆ **Ramjet compresses air with shock waves, no mechanical compressor.**
- ◆ **Shock waves slow the airflow, increases pressure and temperature.**
- ◆ **Airflow into the combustor is subsonic (<Mach 1).**
- ◆ **Ramjets are effective to about Mach 4.5 – 5, higher speeds require more compression and this causes temperature to rise beyond what the burning process and engine material properties can support.**



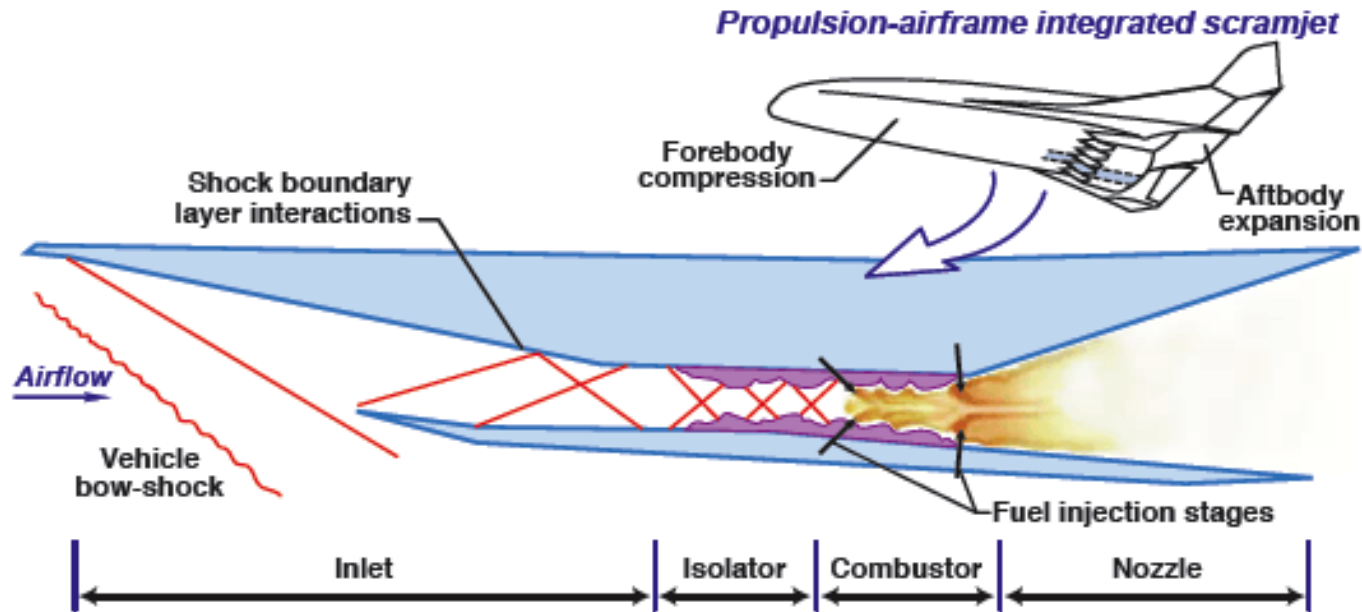
SCRAMJET



- ◆ **Supersonic combustion ramjet = Scramjet**
- ◆ **Scramjets work exactly like ramjets, but the air flow is always at supersonic speeds – even in the combustor.**
- ◆ **Air is directed, compressed, and slowed by a series of oblique shock fronts. Once in the inlet reflected shocks stabilize the flow.**



SCRAMJET



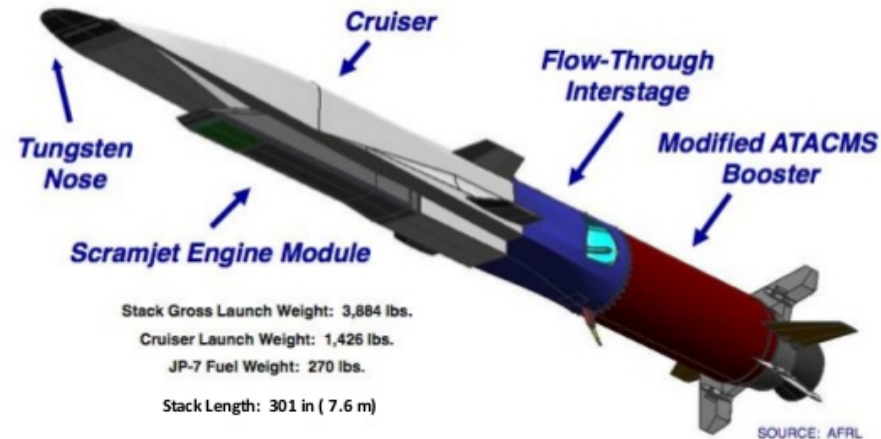
- ◆ **Theoretical potential for speeds as high as Mach 15.**
 - Speeds above about Mach 9 will likely require hydrogen fuel.
 - Hydrocarbon fuels can possibly support speeds up to about Mach 7-8.
 - Most vehicles are currently in the Mach 5-6 range.
- ◆ **A very complex and technically challenging endeavor.**
 - Described as: “Lighting a match in a hurricane and keeping it burning.”



X-51A Waverider



Cruiser Length: 168 in (4.26 m), Max. Width: 23 in (0.58 m)



Stack Gross Launch Weight: 3,884 lbs.

Cruiser Launch Weight: 1,426 lbs.

JP-7 Fuel Weight: 270 lbs.

Stack Length: 301 in (7.6 m)

Pratt & Whitney Rocketdyne Scramjet
SJY61, Ethylene and JP-7 Fuel

- ◆ U.S. prototype for a Mach 5-6 vehicle
 - Hydrocarbon fuel (modified JP-7)
- ◆ Four flight tests from 2010 – 2013.
- ◆ Last flight test on 1 may 2013 achieved Mach 5.1 for 210 seconds.



3M22 Zircon



- ◆ **Russian hypersonic anti-ship cruise missile.**
 - Decilin-M hydrocarbon fuel with aluminum nanoparticles.
- ◆ **Claimed speed of Mach 8-10 and a range of 500 km are high.**
- ◆ **Best estimate is Mach 5-6 and 340-350 km (184-189 nmi).**
- ◆ **Claimed that it will be in production by 2022.**



3M22 Zircon



- ◆ Designed to fit in the UKSK universal vertical missile launchers on Russian surface ships and submarines.
- ◆ Experiencing development problems and delays have been suggested by Russian Navy officials.



Pros and Cons of Extreme Speed

- ◆ **Really high speeds is one way to reduce the amount of time that an air defense system has to react – stealth is the other option.**
 - **Weapon covers a lot more distance while the computers chew on the sensor data and calculates an intercept solution.**
 - **Weapon covers more distance during a combat system's kill assessment time, this means fewer engagement opportunities.**
 - **Hypersonic speed may negate some defensive systems, largely older slower systems, because they don't have sufficient time to react.**

- ◆ **Due to their very high speed, hypersonic missiles maybe more susceptible to electronic countermeasures.**

- ◆ **Hypersonic weapons are technically challenging and can be rather expensive – scramjets have sucked up a lot of R&D money.**



U.S. Navy Counters



- ◆ **U.S. Navy ships are not defenseless against hypersonic missiles.**
 - Aegis combat system originally designed to counter the high flying, Mach 3-4 Soviet Kh-22 [AS-4] air-launched ASCM.
 - Updates have continued to improve the Aegis combat system's software (Baseline 10/BMD 6.0), surface-to-air missiles (SM-6), and electronic countermeasures.
- ◆ **Hypersonic weapons are not invisible, not invincible, nor are they un-engageable. They are, however, a difficult threat to counter.**



Harpoon V and Hypersonic Missiles

- ◆ **Harpoon V** air defense model has been expanded to account for hypersonic missiles.
- ◆ Anti-ship ballistic missiles and ship ballistic missile defense capabilities have been added.
- ◆ Air defense combat system capabilities are now directly modeled to include system reaction time and kill assessment time.
- ◆ Greatly expanded the range of aircraft/missile speed modifiers on surface-to-air probability of hit.

| TARGET MODIFIERS | | | | | | |
|------------------|------------|-------|------|------|-----------------|---------|
| Target Speed | | | | | | |
| Speed | Speed | Delta | Mach | Mach | Descriptor | SAM |
| Low (kts) | High (kts) | | Low | High | | ATA Mod |
| | 500 | | | 0.8 | Subsonic | +1 |
| 501 | 750 | 249 | 0.8 | 1.2 | Transonic | 0 |
| 751 | 1525 | 774 | 1.2 | 2.5 | Low Supersonic | -1 |
| 1526 | 2300 | 774 | 2.5 | 3.8 | Med Supersonic | -2 |
| 2301 | 3075 | 774 | 3.8 | 5.0 | High Supersonic | -3 |
| 3076 | 4100 | 1024 | 5.0 | 6.7 | Low Hypersonic | -4 |
| 4101 | 5125 | 1024 | 6.7 | 8.3 | Med Hypersonic | -5 |
| 5126 | 6150 | 1024 | 8.3 | 10.0 | High Hypersonic | -6 |



Conclusions

- ◆ **Hypersonic missiles exist...and have been around for over 60 years.**
 - **Ballistic missiles are hypersonic by definition.**
- ◆ **Ballistic missiles are a threat to ships mostly in port, but attacks at sea are under development.**
 - **Still some debate that the Chinese DF-21D has reached IOC.**
 - **Targeting anti-ship ballistic missiles is a very big question.**
- ◆ **Hypersonic glide vehicles, while exciting, really haven't change the strategic nuclear deterrence concept from the Cold War.**
 - **Russia compensating for U.S. BMD developments.**
 - **Not likely a threat against ships at sea.**
- ◆ **Scramjet development is close to making Mach 5-6 missiles a reality, with the potential for Mach 7-8 in the near future.**
 - **Faster speeds would need hydrogen fuel.**
 - **This will increase the threat to ships and complicate defenses.**
 - **U.S. Navy ships are not defenseless.**



Conclusions





Questions?

