

Physics/Global Studies 280: Session 14

Plan for This Session

Questions

News

Module 5: Nuclear Weapon Delivery Systems

Module 5: Delivery Systems

Part 1: Overview of nuclear weapon delivery methods

Part 2: Aircraft

Part 3: Cruise missiles

Part 4: Ballistic missiles

Part 5: Technical and operational aspects

Part 6: Nuclear command and control

Nuclear Delivery Systems

Part 1: Overview

Basic Propulsion Mechanisms

- **None**
(examples: mines, depth charges)
- **Explosives**
(example: artillery shell)
- **Propellers**
(example: torpedo, speeds ~ 50 mph)
- **Jet engines**
(example: bomber, speeds ~ 600 mph)
- **Rocket motor**
(example: missile, speeds ~ 18,000 mph)
- **Unconventional**
(examples: barge, boat, Ryder truck, backpack, shipping container)

Examples of Weapon Delivery Methods

Air-breathing vehicles —

- Aircrafts (manned)
- Cruise missiles (unmanned aircraft)

Rocket-propelled vehicles —

- Land-based ballistic missiles
- Submarine-based ballistic missiles
- [Surface ship-based ballistic missiles]*
- [Space-based ballistic missiles]*
- Short range rockets (no guidance)

Other —

- Artillery/howitzers
- Land mines
- Torpedoes

* Never deployed by US or USSR/Russia for nuclear weapons

Important Attributes of Delivery Systems

- Range
- Speed
- Accuracy
- Recallability
- Reliability
- Payload/throw-weight
- Ability to penetrate defenses
- Survivability (at deployment base)
- Capital and operational costs
- Safety

Air-Breathing Vehicles

Aircraft (manned) —

- Long-range (“heavy”) bombers
(examples: Bear, Blackjack, B52, B-1, B-2)
- Intermediate-range bombers
(examples: B-29, FB-111, ...)
- Tactical aircraft
(examples: F-16, F-18, F-22, ...)

Cruise missiles (unmanned) —

- Air-launched cruise missiles (ALCMs)
- Sea-launched cruise missiles (SLCMs)
- Ground-launched cruise missiles (GLCMs)



Rocket-Powered Vehicles

Land-based ballistic missiles —

- Intercontinental-range ballistic missiles (ICBMs)
- Shorter-range ballistic missiles

Sea-based ballistic Missiles —

- Submarine-launched ballistic missiles (SLBMs)
- Surface-ship-launched ballistic missiles

Historical Examples of Other Nuclear Weapon Delivery Methods

Nuclear artillery shells:

- 16" naval guns
- 280 mm cannons (howitzer)

"Atomic Annie" 1953: 15-kt projectile to range of 17 miles



Operation Upshot/Knothole (1953)

Davy Crocket Nuclear Bazooka

- 76 lb., 10–250 t yield, 1.2–2.5 mile range
- Deployed 1961–1971; 2,100 produced

Atomic Demolition Munitions (ADMs)

Carried by back pack, 0.01 kt yield?

Nuclear-armed torpedoes



The U.S. Cold-War Strategic “Triad” – 1

Initially US nuclear weapons delivery systems were developed without an overall coherent plan, in the —

- Truman administration
- Eisenhower administration

Robert McNamara as President Kennedy’s Secretary of Defense changed this:

- Survivable basing
- Secure command and control
- Determine how much is enough by calculation!

Concluded 400 ‘effective’ megatons (EMT) would be “enough”

- The need to organize the roles for the USAF and the USN defined the “Triad” paradigm
- Established the SIOP (Single Integrated Operational Plan) for targeting

The U.S. Cold-War Strategic “Triad” – 2

Strategic nuclear delivery vehicles (SNDVs) —

The definition of “strategic” nuclear weapons was important for arms control but was controversial during the Cold War: the Soviet Union wanted to count weapons on its periphery whereas the U.S. did not want to count these:

- Systems with intercontinental range (U.S. def.)
- Systems able to strike directly the homeland of the adversary (Soviet def.)

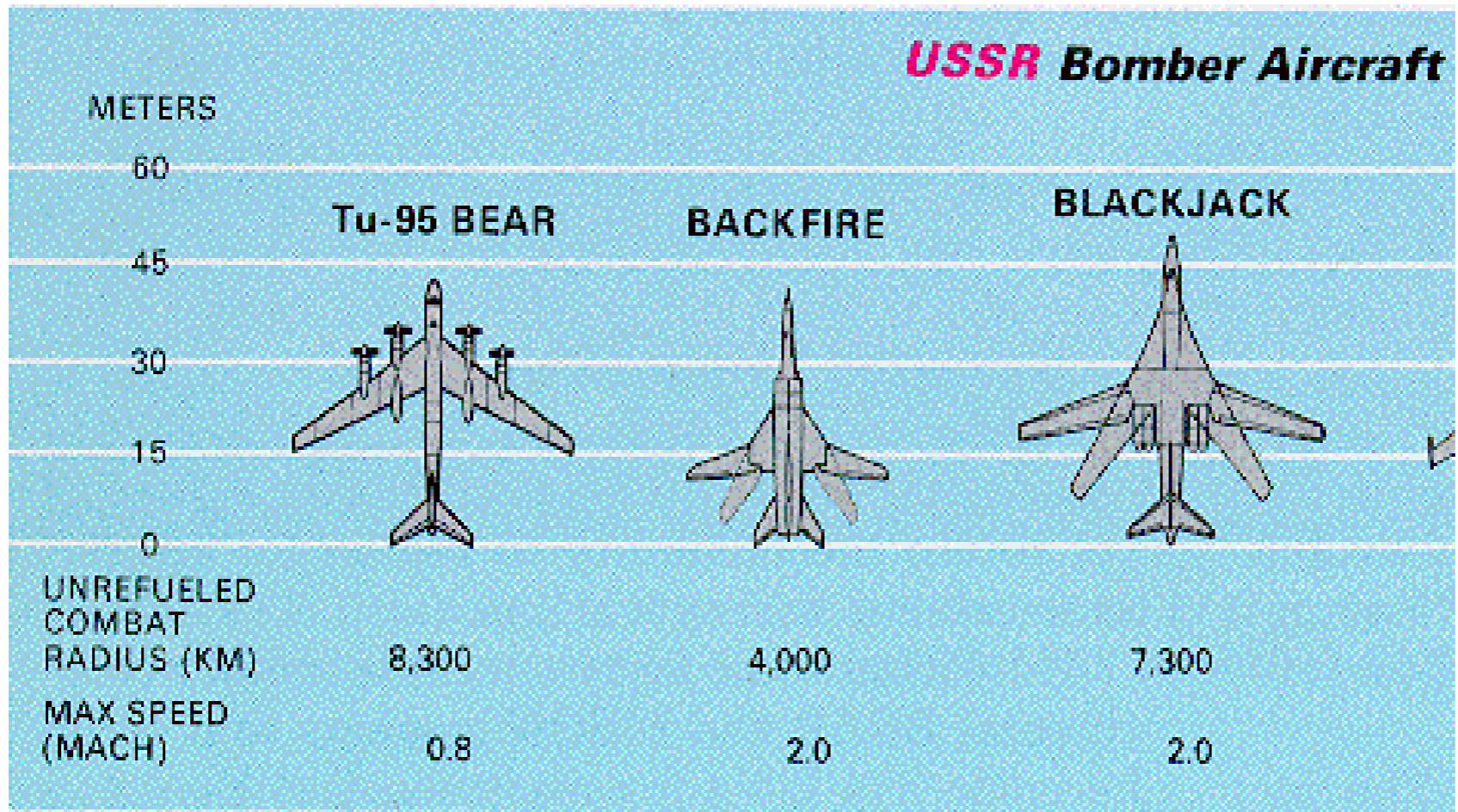
Systems in the Triad —

- Intercontinental-range bombers
- Intercontinental-range ballistic missiles (ICBMs)
- Submarine-launched ballistic missiles (SLBMs)

Module 5: Nuclear Delivery Systems

Part 2: Aircraft

Examples of Intercontinental Bombers – 1



Tu-95
65

Tu-22
160

Tu-160
16

Examples of Intercontinental Bombers – 2



U.S. B-2 Stealth Bomber

Speed: Mach 0.85

Altitude: 50,000 feet

Range: 7,000 miles

Refuel: 11,500 miles

Possible payloads:

- 16 B83 gravity bombs
- 20 B61 bombs
- 80 500 lb bombs

of B-2s 20



Currently Deployed U.S. and Russian Bombers

Current US bombers —

- B-52 carrying bombs, or cruise missiles
- B1 carry conventional armament
- B-2 each can carry 16 B83 bombs

Russian bombers* —

- Bear carrying bombs
- Blackjacks carrying bombs

*few are currently operational

Intercontinental Bomber Issues

Evolution of bomber missions —

- High-altitude bombing
- Low-altitude penetration and bombing
- As a stand-off launch platform for Air-launched cruise missiles (ALCMs)

Operational considerations —

- Launch, release to targets, and arming of weapons requires permission from the National Command Authority (NCA) (in the United States, the President or his designated successor)
- Can be recalled until weapons (e.g., bombs, cruise missiles, or air-to-surface ballistic missiles) are dropped or fired from the bomber
- The United States has substantial in-flight refueling capability; other countries have none

Attacking Iran's nuclear programme could drive it towards a bomb, experts warn

Julian Borger, Wed March, 4th, 2026

The Guardian is headquartered in London. The newspaper is center-left and has a readership of about 23 million each month. Borger is the Guardian's senior international correspondent based in London.

The US-Israeli onslaught against Iran is intended to resolve a 24-year standoff over Tehran's nuclear programme, but it runs the risk of backfiring and driving the regime towards making a secret bomb, proliferation experts have warned.

The regime in Tehran has long insisted that the programme is for civilian purposes and it has no intention of making a nuclear weapon. However, since two undeclared sites, for uranium enrichment and heavy water plutonium production, were discovered in 2002, the programme has been treated with intense suspicion.

Fears US-Israeli onslaught could lead regime to push for bomb or embolden other groups to steal uranium stockpile

● [Middle East crisis - live updates](#)



📷 A satellite image taken in 2020 of the Natanz uranium enrichment facilities, 300km south of Tehran. In June 2025, the US and Israel launched strikes on the site. Photograph: Maxar Technologies Handout/EPA

A nuclear deal in 2015 imposed severe limits and thorough inspections on Iran but when Donald Trump walked out of the agreement in 2018, triggering its collapse, Iran ramped up its work on enrichment and other aspects of the programme.

Most worryingly for the international community, Iran had by last summer produced a stockpile of just over 440kg of highly enriched uranium (HEU), of 60% purity. In terms of technical difficulty, once at 60%, it is a relatively easy step to reach 90% – weapons-grade uranium that can be used to make a compact warhead.

With further enrichment and conversion of the uranium from gas to metal form, Iran's 440kg stockpile would be enough to make more than 10 warheads.

The anxiety over this stockpile, accumulated since the torpedoing of the 2015 nuclear deal, was the motive for last June's US-Israeli strikes on Iran. The US role, Operation Midnight Hammer, was focused on dropping bunker-busting bombs on Iran's nuclear sites.

Trump claimed the bombardment had "obliterated" the nuclear programme, but it soon became apparent this was not true. The bombs had wreaked extensive damage, but deep underground sites, burrowed beneath mountains in two sites in particular, Isfahan and Natanz, could not be destroyed.

In response to the attacks, Iran excluded UN inspectors from the International Atomic Energy Agency (IAEA) from those and other sensitive sites, with the result that the watchdog lost track of what became of the 440kg HEU stockpile, and of what was being done in the deep tunnels in Isfahan and Natanz. In its latest report, the IAEA conceded it could not verify whether Iran had suspended all enrichment-related activities, or the size of its uranium stockpile at the affected nuclear facilities.

Despite that uncertainty, the IAEA director general, Rafael Grossi, said on Monday that “we don't see a structured programme to manufacture nuclear weapons”.

However, nuclear proliferation experts worry that might change in the aftermath of an attack aimed at destroying the regime that has ruled Iran for 47 years, and the killing of its supreme leader, Ali Khamenei, who had issued a religious edict, a fatwa, against the building of a bomb.

“That is what makes this such a tremendous roll of the dice,” said Jeffrey Lewis, a distinguished scholar of global security at the Middlebury Institute of International Studies at Monterey. “Because if the strike does not succeed in removing a regime, there remain thousands of people in Iran who are capable of reconstituting a programme like this.”

Lewis added: “The technology itself is decades old, and a vengeful Iran that survives this strike is likely to reach the same conclusion that North Korea reached, that it’s a dangerous world out there with the United States, and it’s better to go nuclear.”

Kelsey Davenport, the director for nonproliferation policy at the Arms Control Association, agreed that in the aftermath of the attack there would be greater motivation within the remnants of the regime “pushing Iran towards weaponisation no matter how this conflict ends, because of the nature in which it started”.

Davenport pointed out that if the regime collapsed or if a civil war broke out, the fate of Iran’s HEU stockpile would become a major global problem.

“If we end up in a scenario where we have regime implosion, where Iran becomes so internally destabilised that there is a real risk that material is diverted, that it is stolen ... there’s going to be a lot of pressure on the United States to put boots on the ground,” Davenport said.

“There’s a real nuclear terrorism risk to Trump’s regime change objective that I have not heard the administration acknowledging.”

What will it take to achieve Iran's surrender and regime change?

Difficult to know:

Air strikes have eliminated several important leaders, and significantly reduced military defensive and offensive capabilities. About 870 civilians have died.

Will decapitation force Iran into surrender or can Iran sustain a prolonged conflict?

Iran has a population of 92 million, for comparison the populations of Japan and Germany were 72 and 71 million in 1940. What did it take to force Japan and Germany into surrender?

The cost of WWII in the US was more than \$340 Billion (\$5.8 trillion in 2023 dollars). The Human cost is estimated to be between 40-50 million lives lost.

	country	killed, died of wounds, or in prison ¹	wounded	prisoners or missing ²	civilian deaths due to war	estimated total deaths
Allies	China ⁵	1,310,224	1,752,951	115,248		
	United States ¹¹	292,131	671,801	139,709	6,000	298,000
	U.S.S.R. ¹²	11,000,000			7,000,000	18,000,000
Axis	Germany ¹⁴	3,500,000	5,000,000	3,400,000	780,000	4,200,000
	Japan	1,300,000 ¹⁶	4,000,000	810,000	672,000	1,972,000

Module 5: Nuclear Delivery Systems

Part 3: Cruise Missiles

Introduction to Cruise Missiles – 1 (Important)

Cruise missiles (CMs) are pilotless vehicles powered by jet engines:

- Fly within the atmosphere
- Speeds are subsonic

Although cruise missiles were conceived 80 years ago, CMs did not become important until the late 1970s, when technological advances made them militarily useful. These advances were:

- Smaller and lighter nuclear warheads
- Efficient turbofan engines
- Highly capable miniaturized computers
- GPS, TERCOM (Terrain Contour Matching), and terminal guidance
- “Stealth” airframe technology

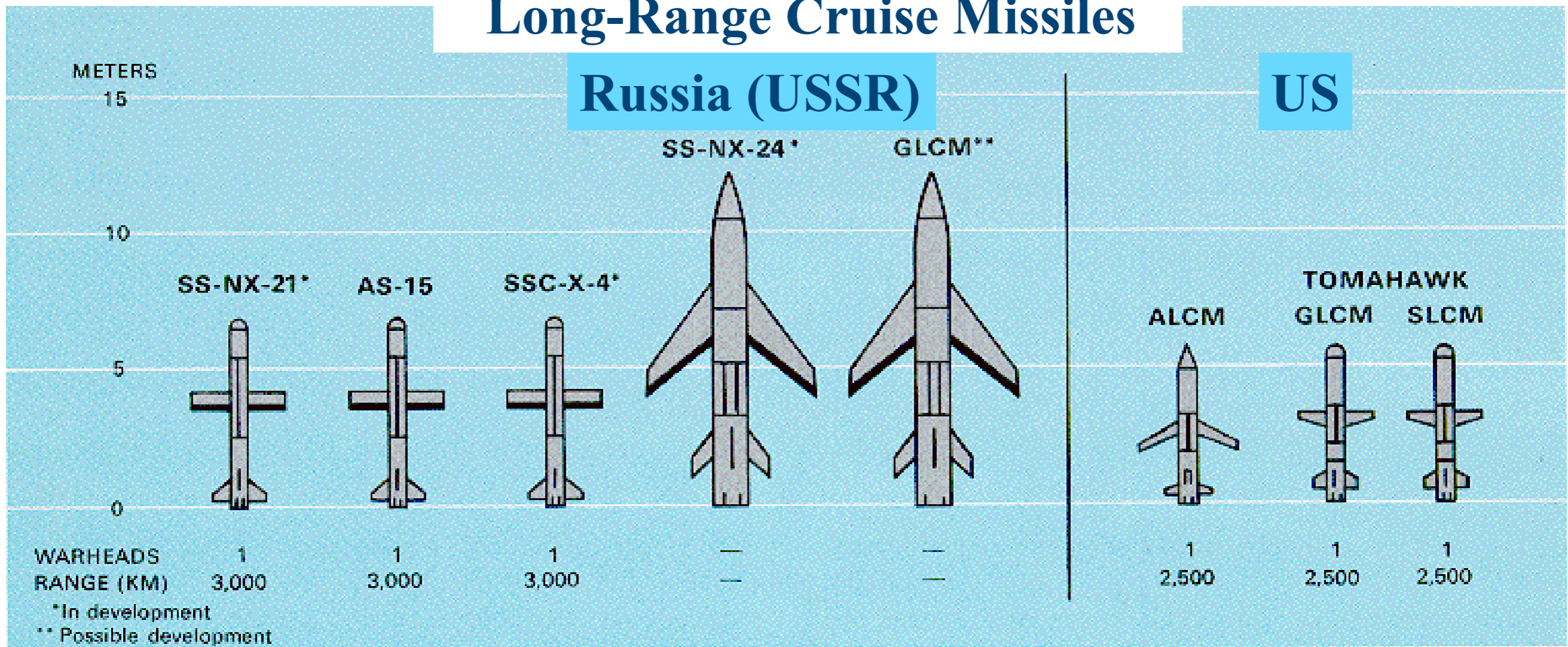
Introduction to Cruise Missiles – 2 (Important)

Key properties —

- Small
- Easily stored and launched
- Highly penetrating
- Versatile
- Highly accurate
- Very cheap (about ~ \$1 million per copy)

Long-Range Cruise Missiles – 1

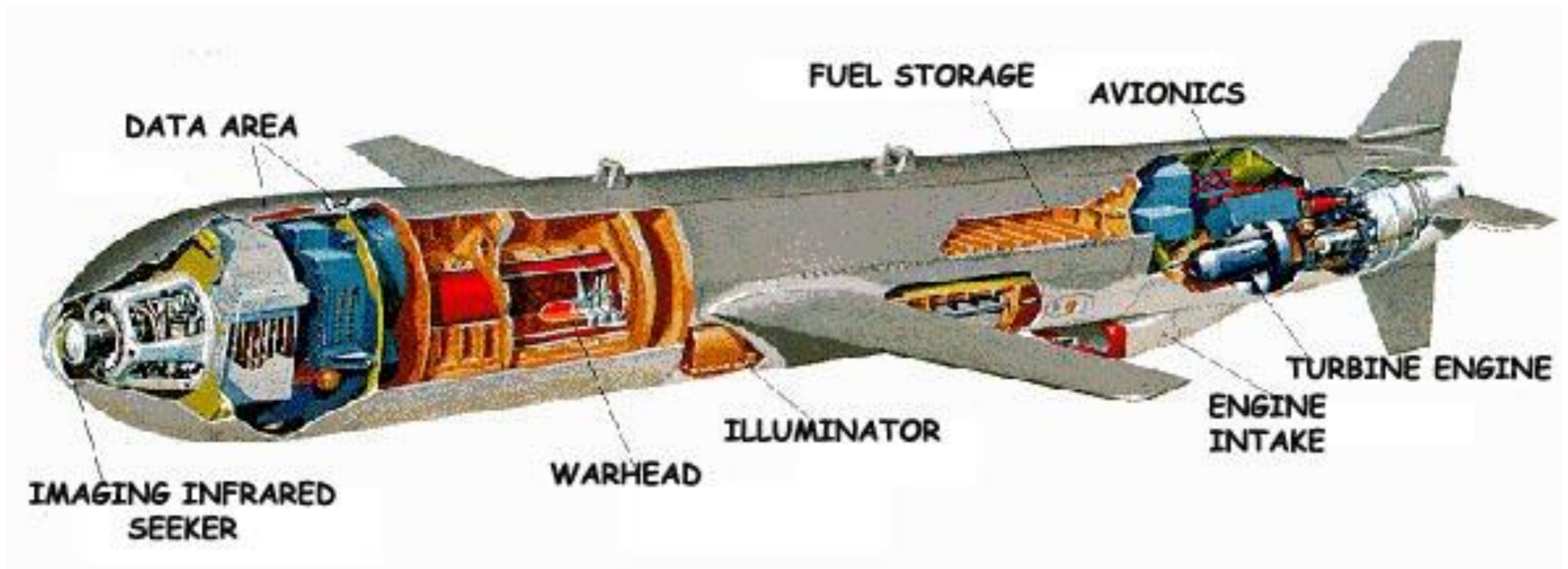
Long-Range Cruise Missiles



range : 1000 – 2000 miles

pay loads : 500 – 1200 lbs

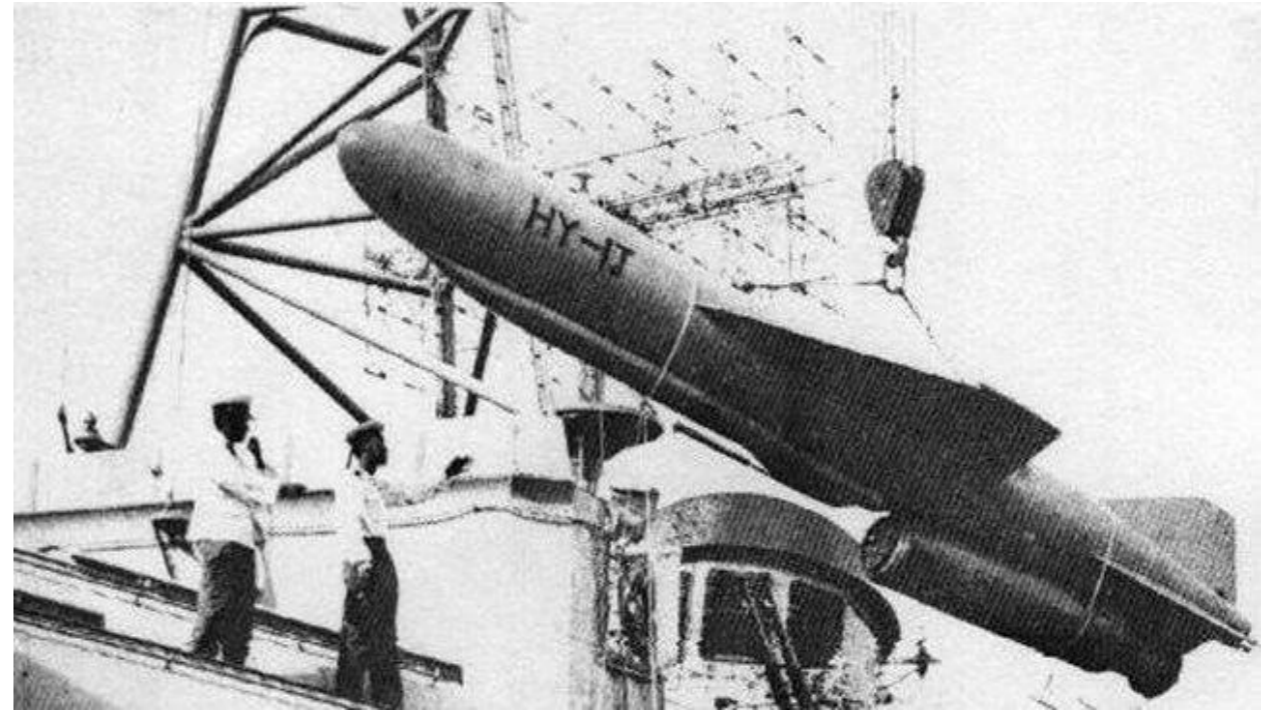
Long-Range Cruise Missiles – 2



Conventionally-Armed Tomahawk Cruise Missile

velocity: 550 mph
pay load: 1000 lbs
range : 1550 miles

Chinese Silkworm Anti-Ship Cruise Missile



Chinese CSS-C-2 SILKWORM / HY-1 / SY-1 Anti-Ship Cruise Missile

Velocity: 680 mph
payload: 660 lbs
range: 180 miles

Launching Cruise Missiles – 1



Launching Cruise Missiles – 2



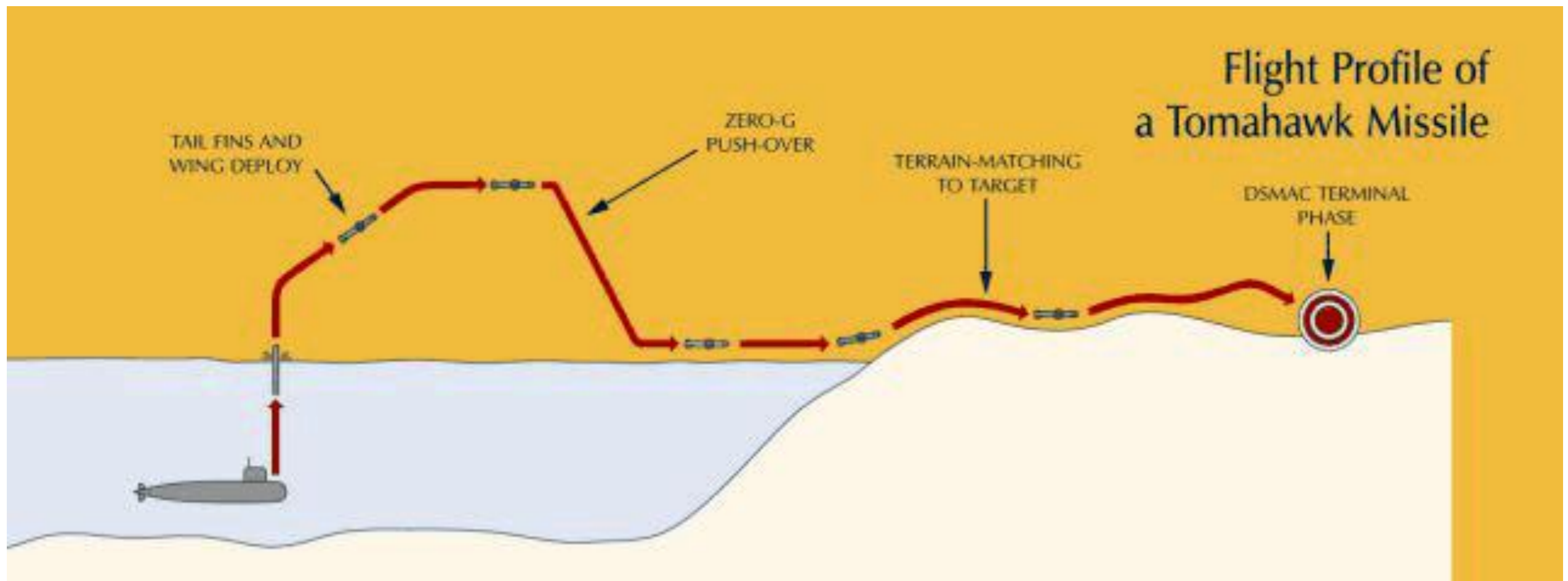
Cruise-Missile Guidance – 1



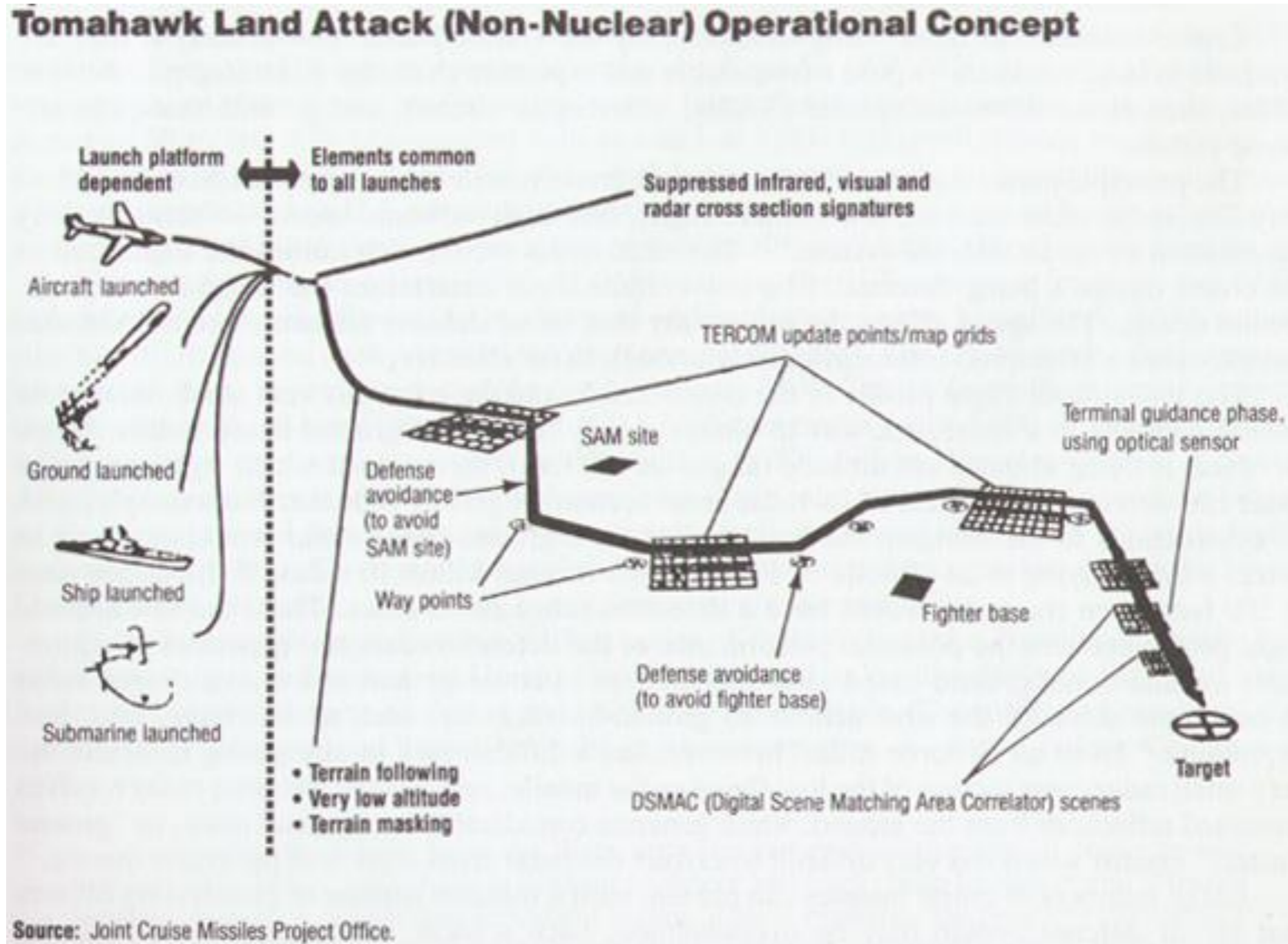
TERCOM: Terrain Contour Matching

DSMAC: Digital Scene Matching Area Correlation

Cruise-Missile Guidance – 2



Cruise-Missile Guidance – 3



Accuracy of Cruise Missiles



Physics/Global Studies 280: Session 15

Plan for This Session

News

RE3v2 due Wednesday at 10pm

Module 5: Nuclear Weapon Delivery Systems

Implications of Cruise Missiles – 1

The US developed and deployed CMs without coherent plan that considered the offensive, defensive, and long-range impact of their deployment.

Military history —

- Cruise missiles were the US countermeasure to the heavy Soviet investment in air defenses
- They capitalized on the temporary US lead in this technology
- However, the US is more vulnerable to CMs than Russia due to the proximity of potential targets to the sea shores.

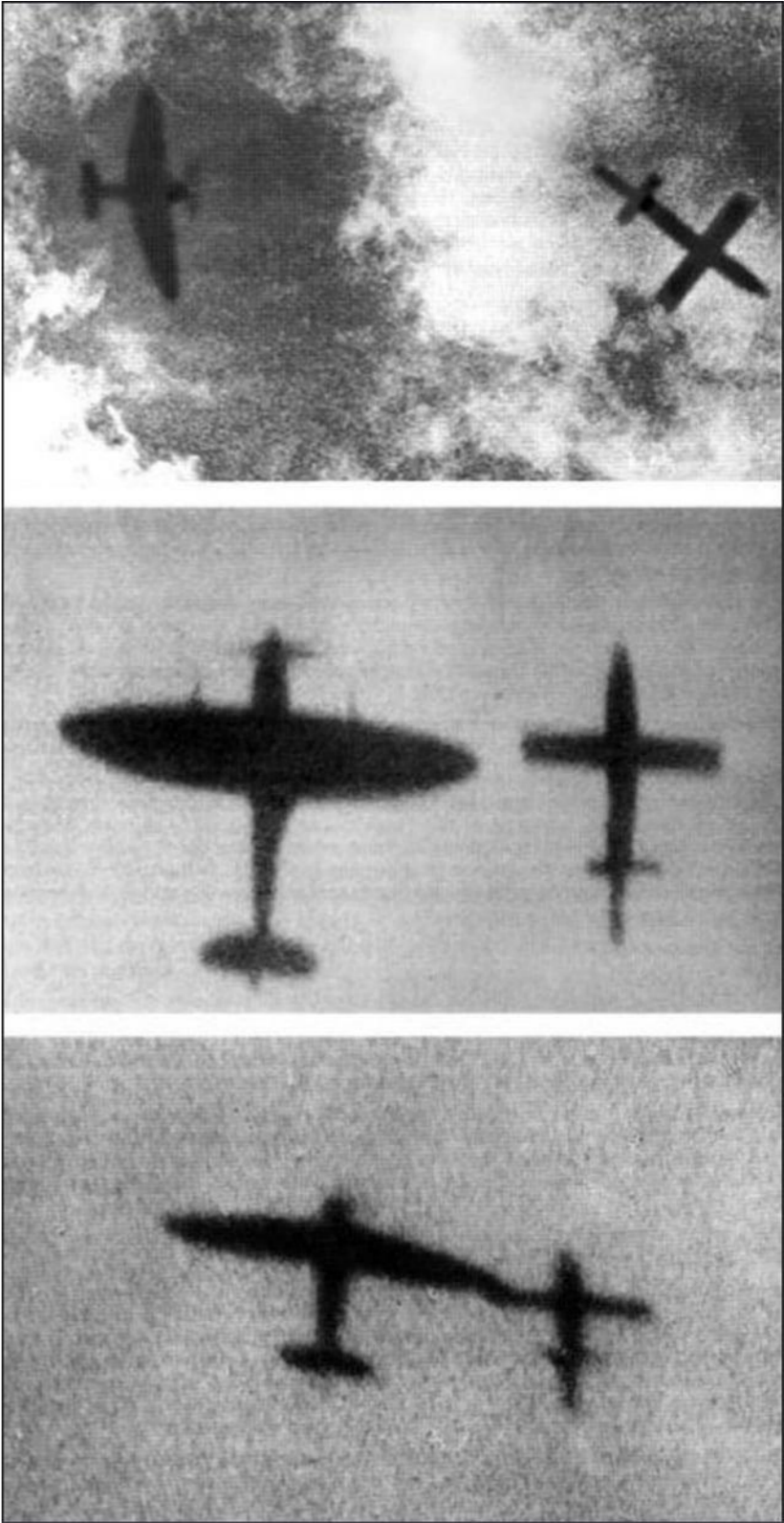
Implications of Cruise Missiles – 2

Implications for U.S. security—

- Very small (hard to find with National Technical Means)
- Can be based almost anywhere (hard to count)
- Dual capable (almost impossible to distinguish nuclear from high-explosive warhead)
- Cheap (can be produced in large numbers)

Several countries could develop a mechanism to launch SRBMs, MRBMs, or land-attack cruise missiles from forward-based ships or other platforms

Spitfire 'wingtipping' a V-1 Flying Bomb in WWII



TECH

Iran's Shahed drone: How 'the poor man's cruise missile' is shaping Tehran's retaliation

PUBLISHED THU, MAR 5 2026 5:12 AM EST | UPDATED FRI, MAR 6 2026 1:03 AM EST



Dylan Butts
@IN/DYLAN-B-7A451A107

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KEY POINTS

- Iran used low-cost Shahed-136 drones to overwhelm Gulf air defenses after U.S.-backed airstrikes.
- The drones are cheap and easy to produce, while interceptors can cost millions.
- Russia's wartime use in Ukraine helped prove the drones' battlefield effectiveness.

WATCH LIVES

[Prefer to Listen?](#)

NOW

UP NEXT

“ The Shahed ... has allowed states like Russia and Iran a cheap way to impose disproportionate costs

— Patrycja Bazylczyk ANALYST AT THE CENTER FOR STRATEGIC AND INTERNATIONAL STUDIE

Meanwhile, air defense systems used by Gulf states and Israel can cost [between \\$3 million and \\$12 million per interceptor](#), according to U.S. Department of Defense budget documents.

Analysts say the key to their effectiveness lies in the numbers. The drones are relatively cheap and easy to mass-produce, especially compared to the sophisticated systems used to defend against them.

Those factors make the drone ideal for swarming and overburdening aerial defenses, with each drone intercepted also representing a more valuable defense asset expended.

“The Shahed-136, among other unmanned aerial systems, has allowed states like Russia and Iran a cheap way to impose disproportionate costs,” said Patrycja Bazylczyk, analyst with the Missile Defense Project at the Center for Strategic and International Studies in Washington DC.

“They force adversaries to waste expensive interceptors on low-cost drones, project power, and create a steady psychological burden on civilian populations.”

Public estimates suggest individual Shahed drones can cost between \$20,000 and \$50,000. Ballistic and cruise missiles, by contrast, can cost millions of dollars each.

In that sense, the Shahed and its equivalents “basically serve as ‘the poor man’s cruise missile’ offering a way to strike and harass adversaries “on the cheap,” said Taleblu.



If cruise missiles were the “smart bombs” of the late 20th century, are drones merely the next step in that progression, or do they represent a new category of weapon entirely?

If cruise missiles were the “smart bombs” of the late 20th century, are drones merely the next step in that progression, or do they represent a new category of weapon entirely?

Cruise Missiles:

- *One-way weapon
- *Pre-programmed flight
- *Strike Only

Drone:

- *Some are reusable
- *Often have operators (AI???)
- *Recon/loiter capabilities

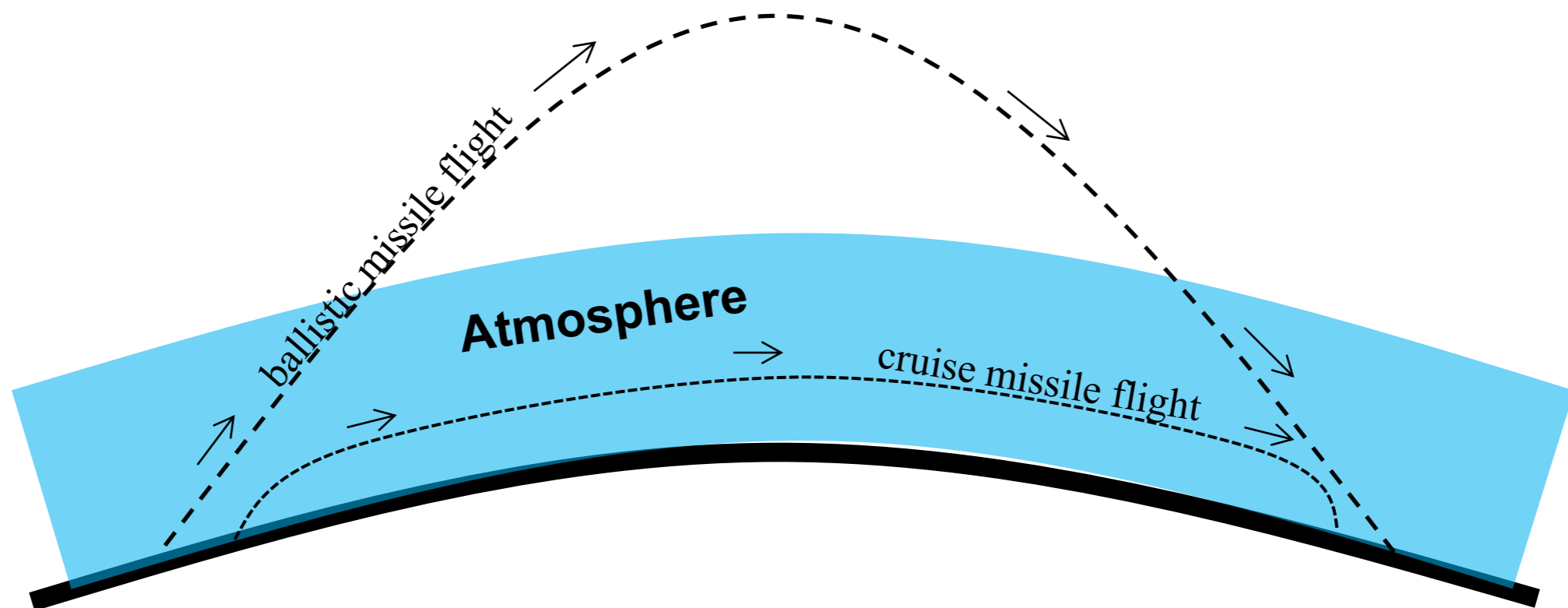
Air Breathing Delivery Systems (Bombers & Cruise Missiles) vs Ballistic Missiles

Air breathing systems:

- o carry the fuel on board but take the oxidizer from the atmospheres → operate endo-atmospheric

Ballistic missiles:

- o carry fuel and oxidizer → can operate exo-atmospheric



Attributes of Ballistic Missiles

Basing modes —

- Fixed (e.g., blast-hardened silos in the ground)
- Mobile (e.g., on railroad cars)

Propellants —

- Liquid (fuel and oxidizer are separate)
- Solid (fuel and oxidizer are mixed)

Payloads —

- Single warhead + penetration aids (“penaids”)
- Multiple warheads + penetration aids

Categories of Ballistic Missiles Based on Their Ranges (Important)

Short-range ballistic missiles (SRBMs) —

- Ranges under 1,000 km

Medium-range ballistic missiles (MRBMs) —

- Ranges between 1,000 km and 3,000 km

Intermediate-range ballistic missiles (IRBMs) —

- Ranges between 3,000 km and 5,500 km

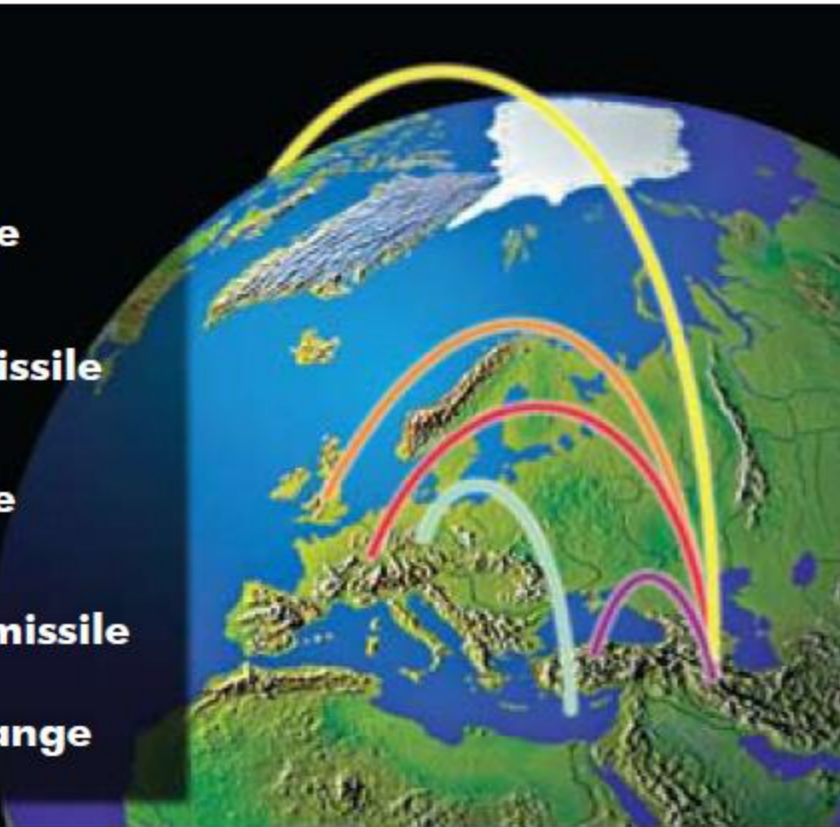
Intercontinental-range ballistic missiles (ICBMs, SLBMs) —

- Limited-range ICBMs (LRICBMs): 5,500 to 8,000 km
- Full-range ICBMs (FRICBMs): $> 8,000$ km
- Ranges of US and Russian ICBMs are $\sim 12,000$ km

These categories are not fluid, because they are based on the performance characteristics of the missile.

Categories of Ballistic Missiles Based on Their Ranges (Important)

	SRBM Short-range ballistic missile <1,000 km (621 mi)
	MRBM Medium-range ballistic missile 1,000-3,000 km (621-1,864 mi)
	IRBM Intermediate-range ballistic missile 3,000-5,500 km (1,864-3,418 mi)
	ICBM Intercontinental ballistic missile >5,500 km (3,418 mi)
	SLBM Submarine-launched ballistic missile Any ballistic missile launched from a submarine, regardless of maximum range



Source: national air and space intelligence center

“Ballistic and Cruise Missile Threat”, 2009

Intercontinental-range ballistic missiles (ICBMs, SLBMs) —

- Limited-range ICBMs (LRICBMs): 5,500 to 8,000 km
- Full-range ICBMs (FRICBMs): > 8,000 km
- Ranges of US and Russian ICBMs are ~ 12,000 km

These categories are not fluid, because they are based on the performance characteristics of the missile.

Phases of Flight of Intercontinental-Range Ballistic Missiles (Important)

Basic phases of flight of a (MIRVed) intercontinental ballistic missile (ICBMs and SLBMs) —

- Boost phase: rocket motors burning
- Post-boost phase (release of payload from bus)
- Midcourse phase: ballistic motion in space
- Terminal phase: re-entrance into atmosphere and passage through atmosphere

Phases of Flight of Intercontinental-Range Ballistic Missiles (Important)

PHASES OF BALLISTIC MISSILE TRAJECTORY



Categories of Ballistic Missiles Based on Their Purposes

Tactical ballistic missiles (TBMs) —

- For use on the battlefield (e.g., on a particular front)
- Usually have shorter ranges (SRBMs)

Theater ballistic missiles (TBMs) —

- For use in an entire theater of war (e.g., the Middle East)
- Usually have longer ranges than tactical missiles

Strategic ballistic missiles (an example of SNDVs – Strategic Nuclear Weapons Delivery Vehicle) —

- For attacking the homeland of the adversary
- May have longer, possibly intercontinental ranges

These categories are fluid, because they are based on the intent of the user at the time the missile is fired.

Missile Guidance Technologies

Inertial —

- Uses gyroscopes and accelerometers
- No contact with outside world

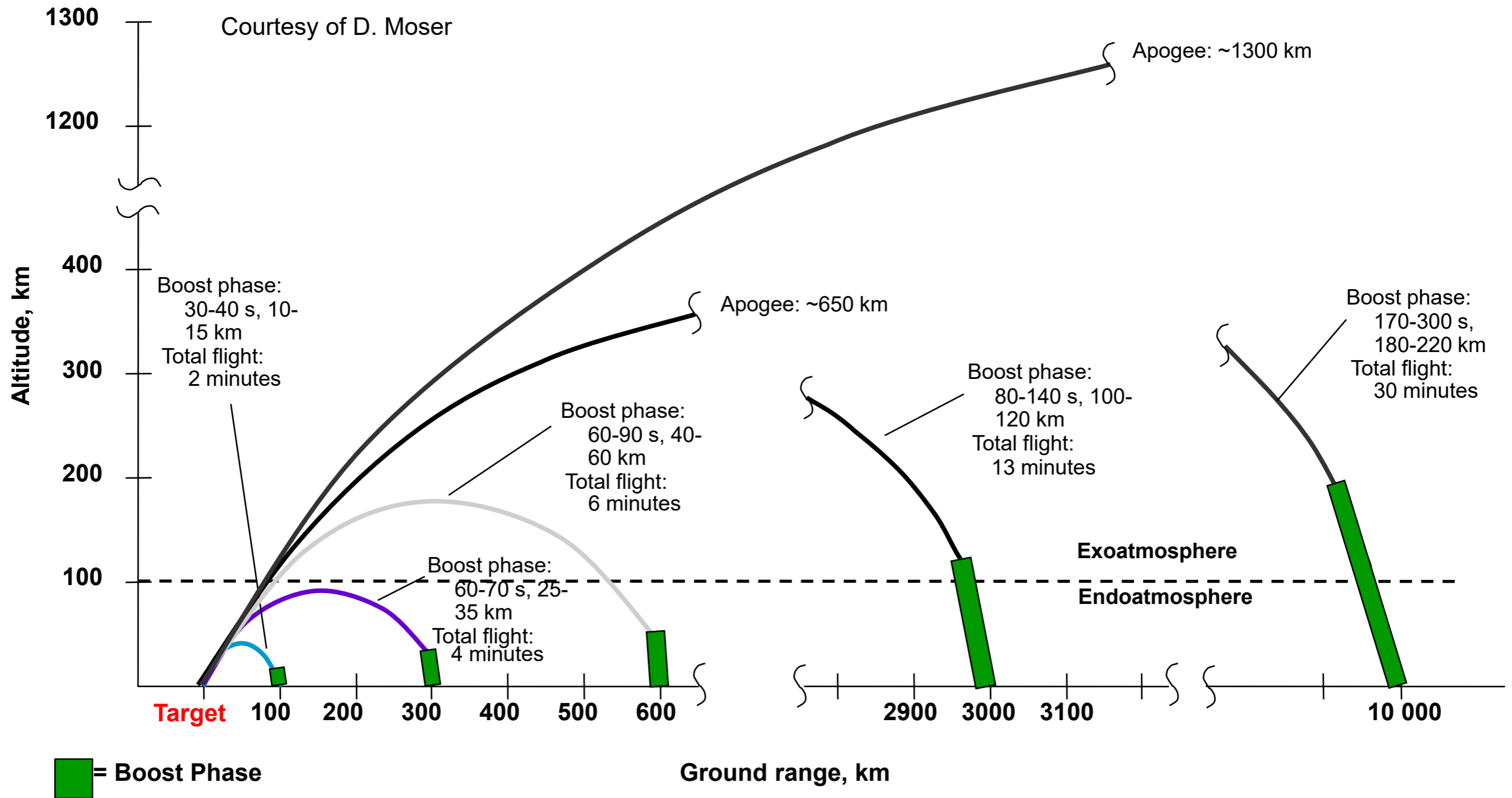
Stellar —

- Star trackers update inertial guidance system

Satellite —

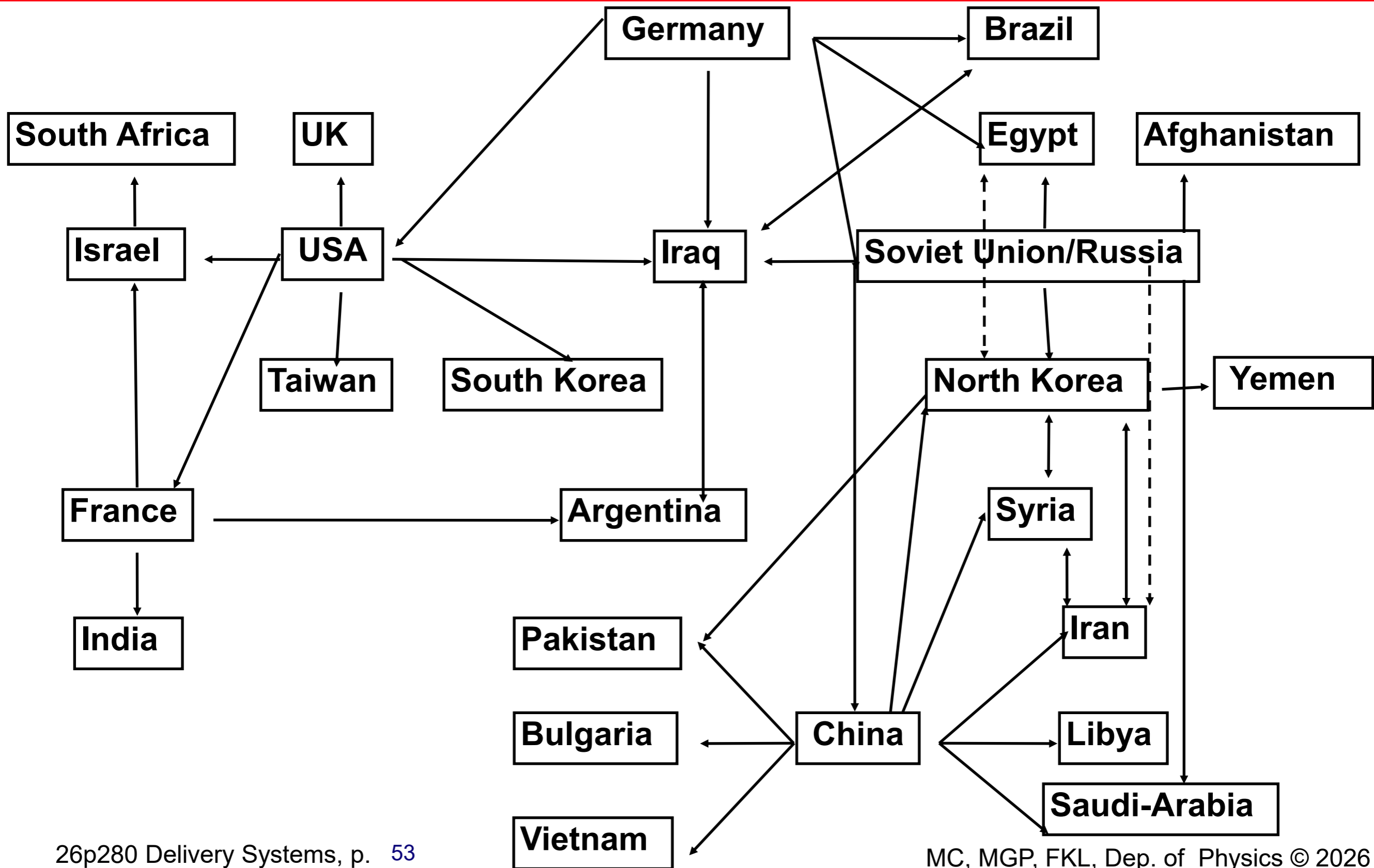
- Uses accurate (atomic) clocks on satellites
- Uses coded radio transmissions
- Uses sophisticated receivers
- Can determine both position and velocity very accurately using signals from 3 to 4 satellites

Trajectories and Phases of Flight of Missiles With Various Ranges

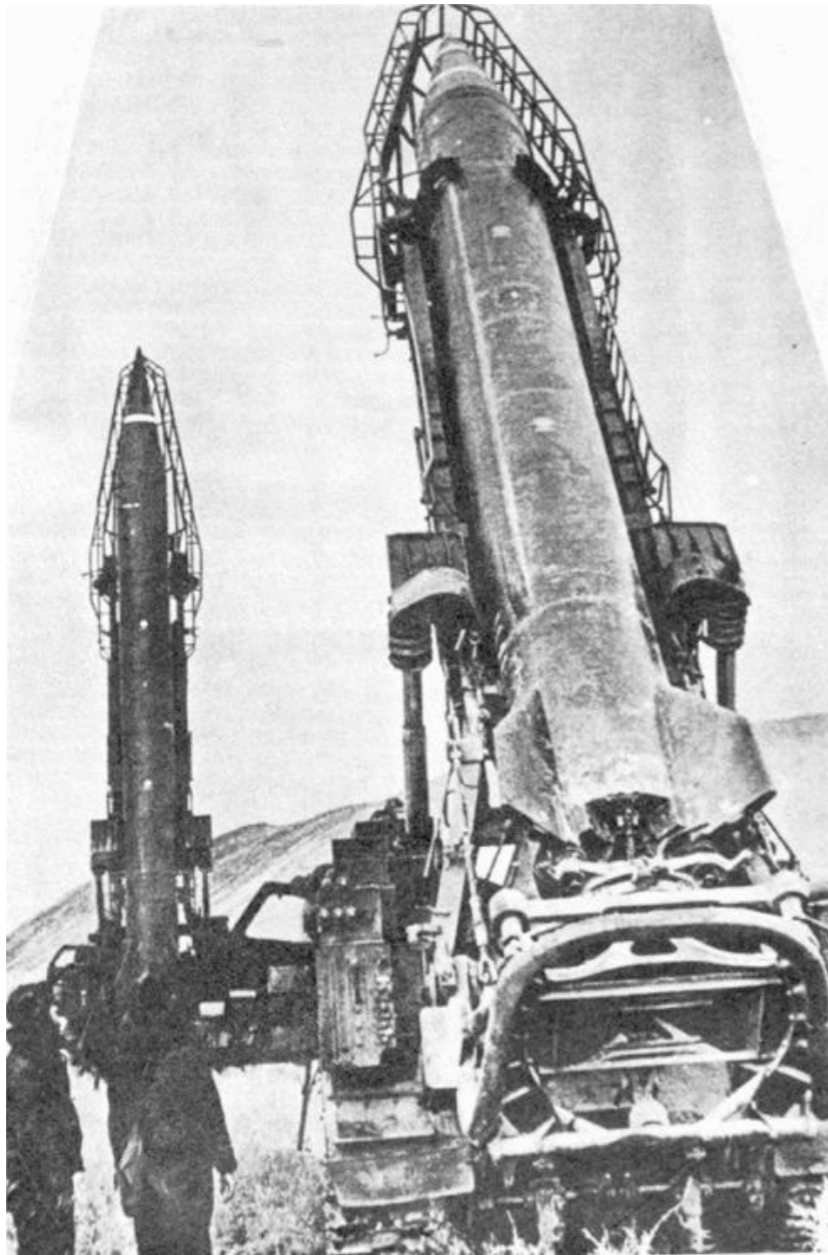


■ = Boost Phase

Proliferation of Ballistic Missile Technologies



Soviet Scud Missiles and Derivatives - 1

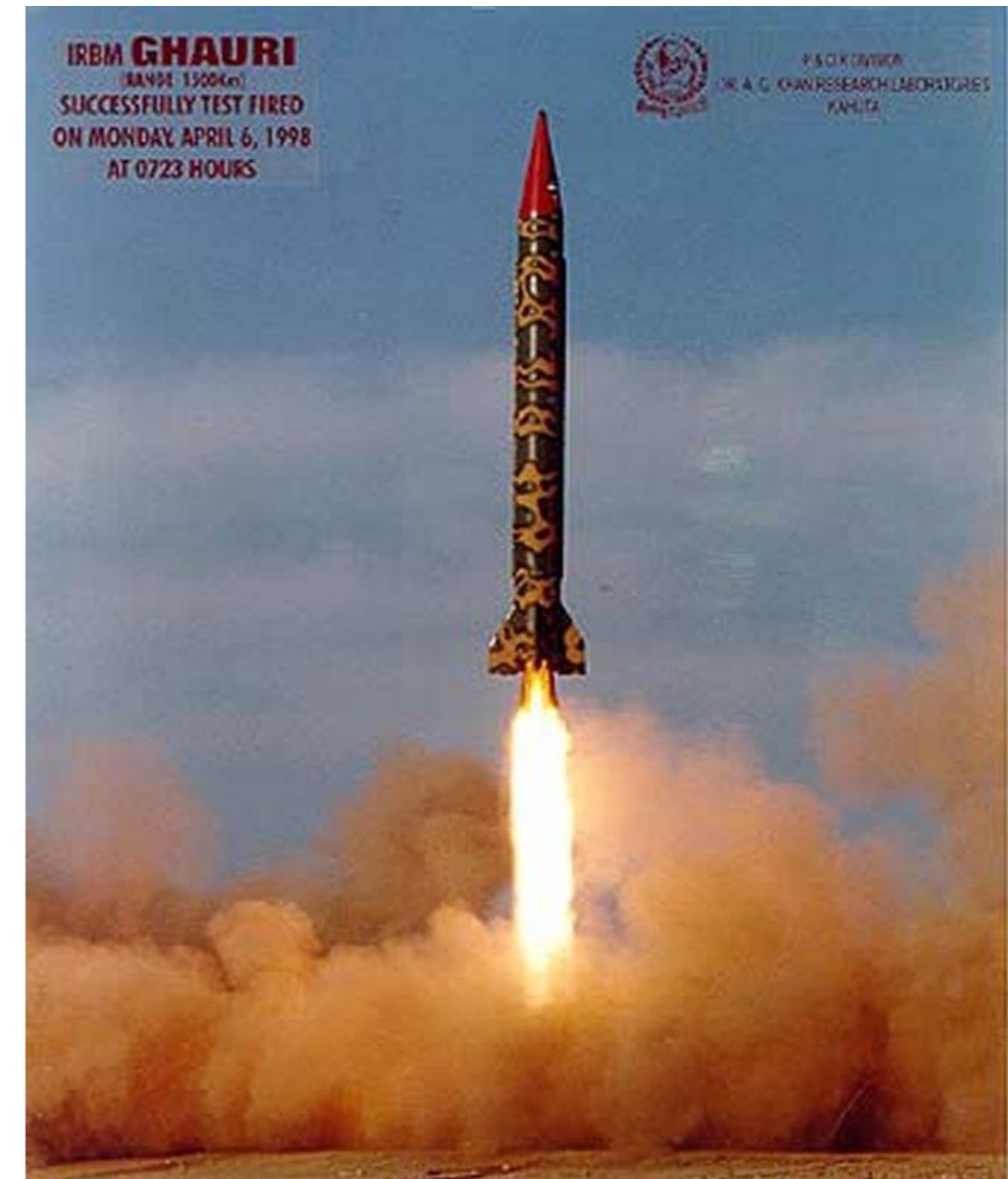


Soviet Scud-B Missile
(based on the German V2)
Range: 300 km



Iraqi Al-Hussein SRBM
Range: 600–650 km

Scud Missiles and Derivatives – 2

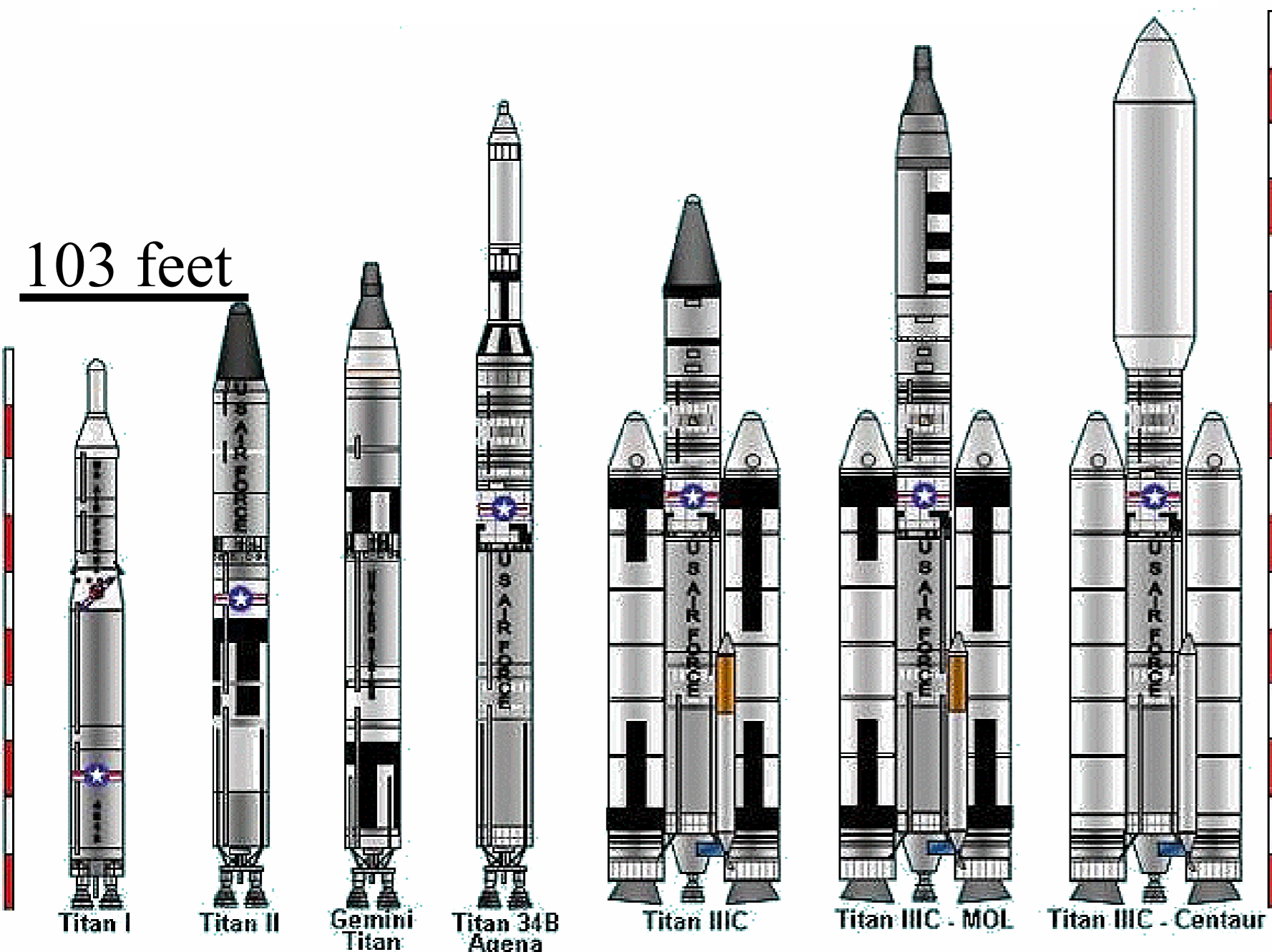


Pakistan's Ghauri MRBM and transporter (range 1,300 km). It is almost identical to North Korea's No Dong MRBM, which is based on Scud technology that North Korea got from Egypt in the 1970s.

Titan Family of Missiles and Launch Vehicles

1959 – 2005 ICMB & civilian uses

103 feet



TIME Magazine, Monday September 29th 1980

Light on the Road to Damascus

Titan terror explodes in the Arkansas hills

Shortly after sunset one day last week, a maintenance worker on the third level of a silo housing a 103-ft. Titan II Intercontinental ballistic missile near Damascus, in the Arkansas hills north of Little Rock, dropped the socket of a wrench. The 3-lb. tool plummeted 70 ft. and punctured a fuel tank. As flammable vapors escaped, officials urged the 1,400 people living in a five-mile radius of the silo to flee. The instructions: "Don't take time to close your doors—just get out." And with good reason. At 3:01 a.m., as technicians gave up trying to plug the leak and began climbing from the silo, the mixture of fuel and oxygen exploded. Orange flames and smoke spewed out, lighting up the sky over Damascus. The blast blew off a 750-ton concrete cover. One worker was killed; 21 others were hurt.

Today: LGM-30G Minuteman III → 3 stage solid rocket fuel

Range: 11,000km +

Speed : 24,100 km/h or 6.7km/s (terminal phase)

Re-Entry Vehicles (RVs)

Basic types —

- MRV = multiple RV
 - Final stage carries more than 1 RV
 - Final stage has no propulsion
 - RVs are *not* independently targetable
- MIRV = multiple, independently targetable RV
 - Final stage carries more than 1 RV
 - Final stage has guidance package and propulsion
 - RVs are independently targetable
- MARV = maneuverable RV
 - RV has a guidance package
 - RV maneuvers during the terminal phase, using, e.g., thrusters or aerodynamic forces

MK21 re-entry vehicles on Peacekeeper MIRV bus



MIRV Technology



MX Peacekeeper MIRV



Soviet ICBM MIRV

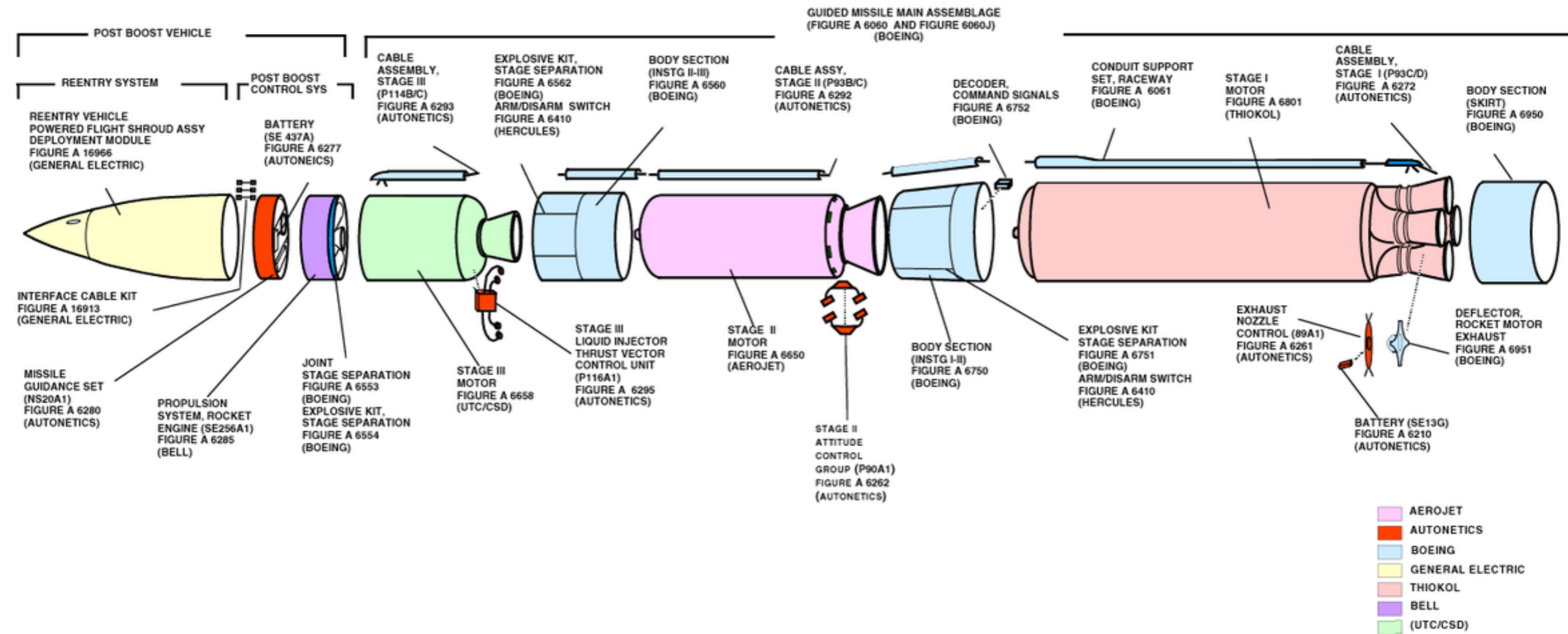
MIRV Technology



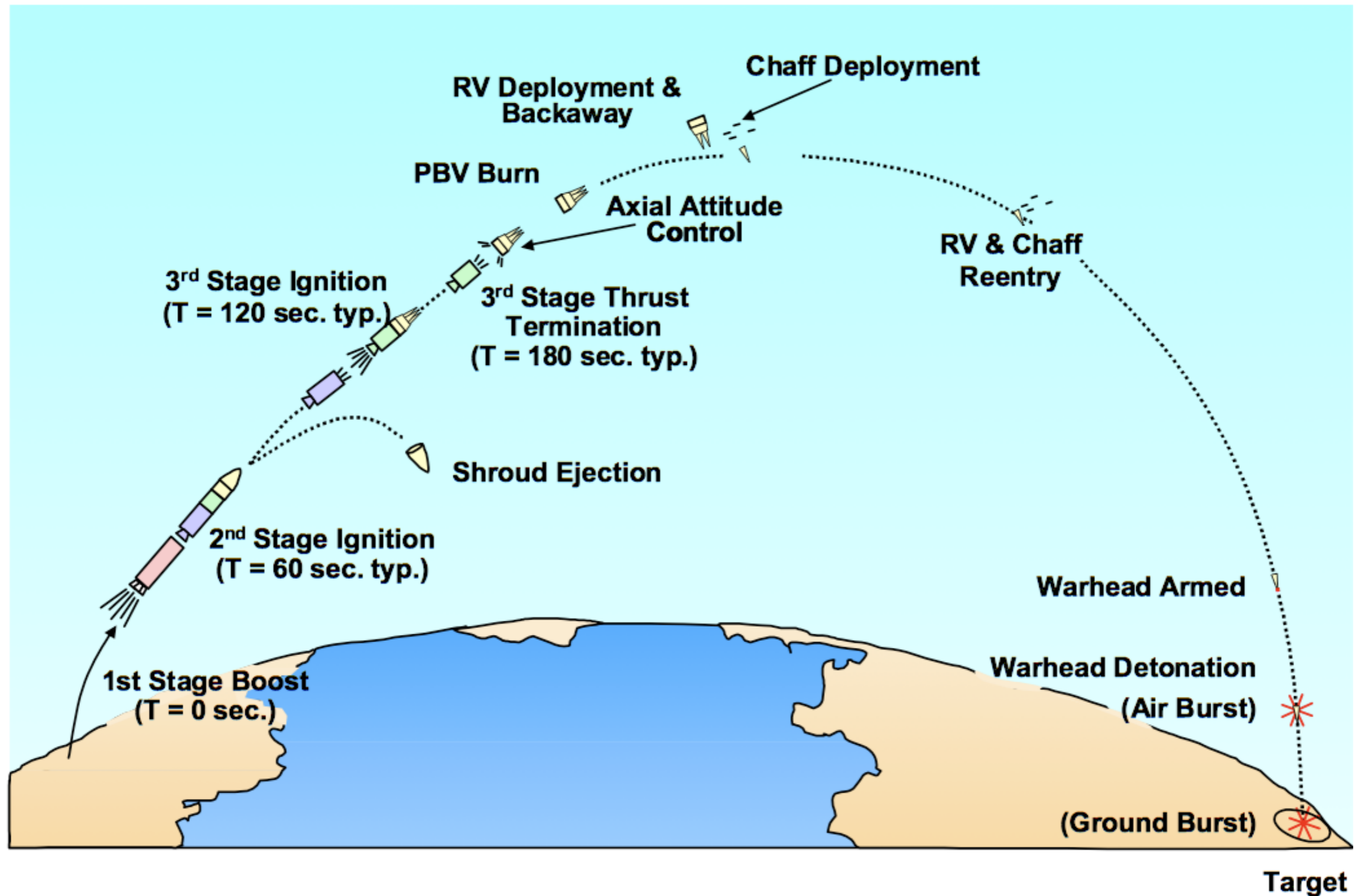
MX Peacekeeper missile tested at Kwajalein Atoll

Source: www.smdc.army.mil/kwaj/Media/Photo/missions.htm

Minuteman ICBM (Schematic)



Flight of a Minuteman ICBM (Schematic)



Flight of MIRV'd ICBMs

Four phases of the flight of an intercontinental-range missile armed with MIRVs (Multiple Independently Targetable Reentry Vehicles)—

- Boost phase (lasts about 1–5 min)
 - Rocket motors are burning
 - Missile rises through the atmosphere and enters near-Earth space
 - Stages drop away as they burn out
- Post-boost phase (lasts 5–10 min)
 - Bus separates from the final stage
 - Bus maneuvers and releases RVs
- Midcourse phase (lasts about 20 min)
 - RVs fall ballistically around the Earth, in space
- Terminal phase (lasts about 20–60 sec)
 - RVs re-enter the Earth's atmosphere and encounter aerodynamic forces
 - RVs fall toward targets, until detonation or impact

Examples of US and Russian ICBMs

Recent US ICBMs —

- MX Solid-propellant, range ~ 12,000 km, 10 warheads (Peacekeeper, retired 2005)
- MIII Solid-propellant, range ~ 12,000 km, Capability for 3 warheads (Minuteman) Presently deployed with 1 warhead

Recent Russian ICBMs —

- SS-24 Solid-propellant, range > 9,000 km
- SS-25 Solid-propellant, range > 9,000 km
- SS-27 Solid-propellant, range > 9,000 km

US ICBMs – 2

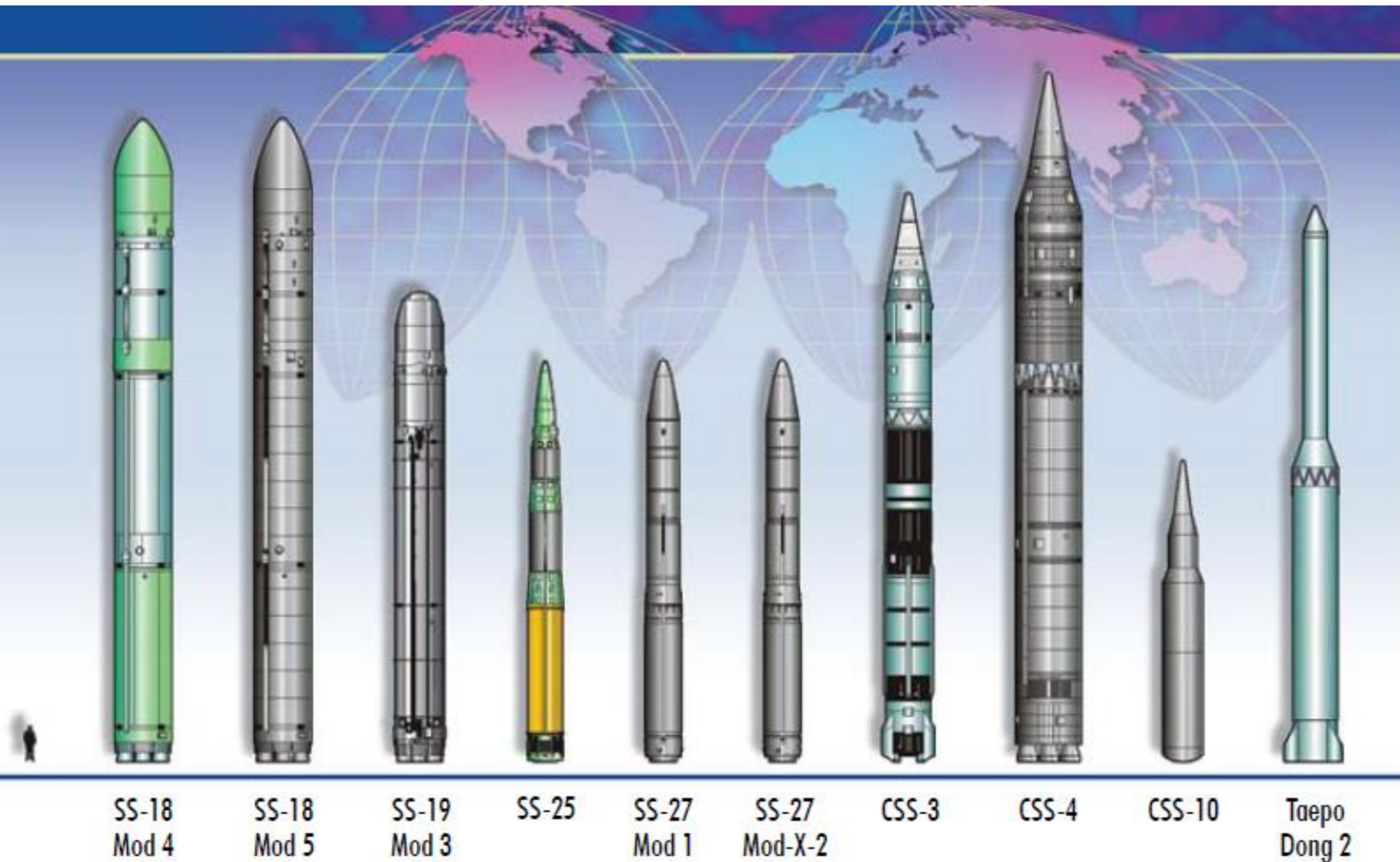


Launch of a Minuteman → [video!](#)



Launch of an MX

Russian, Chinese and North Korean ICBMs – 1



Source: national air and space intelligence center
“Ballistic and Cruise Missile Threat”, 2009

Russian, Chinese and North Korean ICBMs – 2

Missile	Number of Stages	Warheads per Missile	Propellant	Deployment Mode	Maximum Range* (miles)	Number of Launchers
Russia						
SS-18 Mod 4	2 + PBV	10	Liquid	Silo	5,500+	104
SS-18 Mod 5	2 + PBV	10	Liquid	Silo	6,000+	(total for Mods 4 & 5)
SS-19 Mod 3	2 + PBV	6	Liquid	Silo	5,500+	122
SS-25	3 + PBV	1	Solid	Road-mobile	7,000	201
SS-27 Mod 1	3 + PBV	1	Solid	Silo & road-mobile	7,000	54
SS-27 Mod-X-2	3 + PBV	Multiple	Solid	Silo & road-mobile	7,000	Not yet deployed
China						
CSS-3	2	1	Liquid	Silo & transportable	3,400+	10 to 15
CSS-4 Mod 2	2	1	Liquid	Silo	8,000+	About 20
CSS-10 Mod 1	3	1	Solid	Road-mobile	4,500+	Fewer than 15
CSS-10 Mod 2	3	1	Solid	Road-mobile	7,000+	Fewer than 15
North Korea						
Taepo Dong 2	2	1	Liquid	Undetermined	3,400+	Not yet deployed

Source: national air and space intelligence center
 “Ballistic and Cruise Missile Threat”, 2009

Physics/Global Studies 280: Session 16

Plan for This Session

Please turn in RE3v2 into 280 homework box in Loomis

News

- midterm will be Thursday March 23rd
- midterm will cover modules 1 to 5 + news
- old tests are available on course web-page
- review session during Wednesday office hours
on March 22nd

Module 5: Nuclear Weapon Delivery Systems



News Industry Sea

UK's Future SSBN is On Time and On Budget, Says MoD

Peter Felstead

8. March 2023

UK's Future SSBN is On Time and On Budget, Says MoD

The UK Ministry of Defence (MoD) published an update of its report to parliament on the status of programmes related to the United Kingdom's future nuclear deterrent on 8 March 2023.

The main sections of the report cover production of the Royal Navy's future fleet of four Dreadnought-class nuclear-powered ballistic missile submarines (SSBNs), upgrades to the submarine-launched ballistic missiles (SLBMs) that will arm them and the nuclear warheads these missiles will carry, and progress with infrastructure related to the delivery of the UK's future sea-based nuclear deterrent.

Post-introduction, the top line of the report states that the Dreadnaught SSBN programme “remains within its overall budget and on track for the first of class, HMS *Dreadnaught*, to enter service in the early 2030s”.

BAE Systems is building the four Dreadnaught-class boats to replace the Royal Navy's current fleet of four Vanguard-class SSBNs, which were commissioned from 1993 and currently provide the UK's continuous at-sea nuclear deterrent.

Construction of the first two SSBNs, *Dreadnaught* and *Valiant*, is currently underway, while BAE Systems announced on 9 February 2023 that work on construction of the third boat, to be called *Warspite*, had now begun.

Once the Dreadnaught class enters service with the Royal Navy it is due to operate for at least 30 years.

UK's Future SSBN is On Time and On Budget, Says MoD

In terms of costs the MoD report noted that the UK's 2015 Strategic Defence and Security Review estimated that the Dreadnaught programme is likely to cost a total of GBP 31 billion (including inflation) over its lifetime and set a contingency of GBP 10 Bn. "The programme remains within this overall budget," the report stated, "and, as of 31 March 2022, GBP 12.5 Bn had been spent on the concept, assessment, and early delivery phases of the Dreadnought programme.

Regarding the Dreadnaught class's armament, the UK is upgrading and life-extending both the current warheads and the SLBMs that will carry them while working on a new warhead design. In this area the MoD report said that the programme to replace the UK's sovereign nuclear warhead "has now entered its concept phase", while the "transition of the current warhead from Mark 4 to Mark 4A continues, addressing obsolescence to ensure that the UK has a safe, secure, and available stockpile until the UK Replacement Warhead is available in the 2030s."

The report further explained that the UK's in-service and future replacement warheads will "remain compatible with the Trident II D5 missile that is deployed on the Vanguard class and will be deployed on the new Dreadnought- class submarines", adding that the UK "is working with US partners on work to extend the life and replenish the Trident II D5 missiles to meet the future programme requirements of both nations".

Published on 4 March 2026

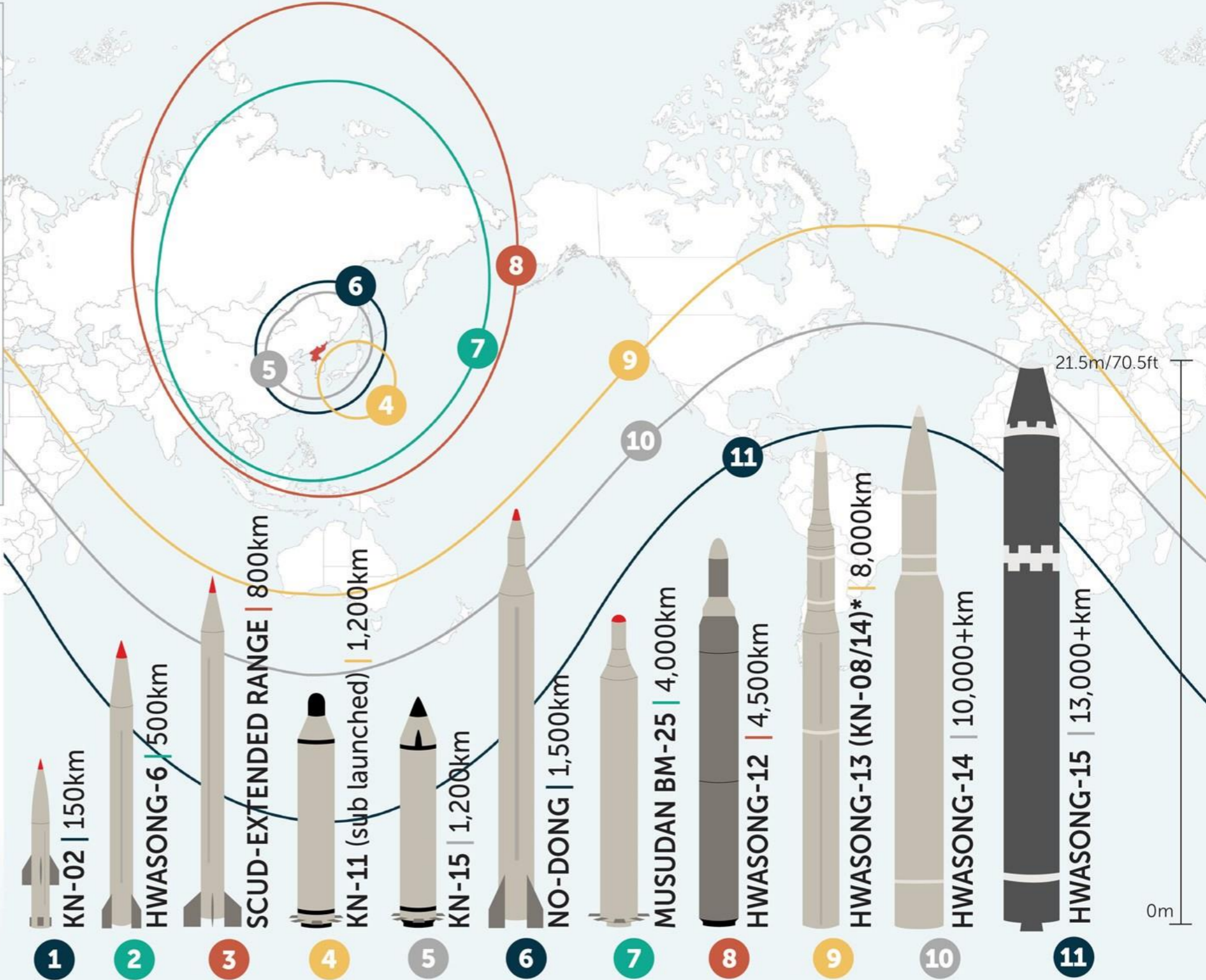
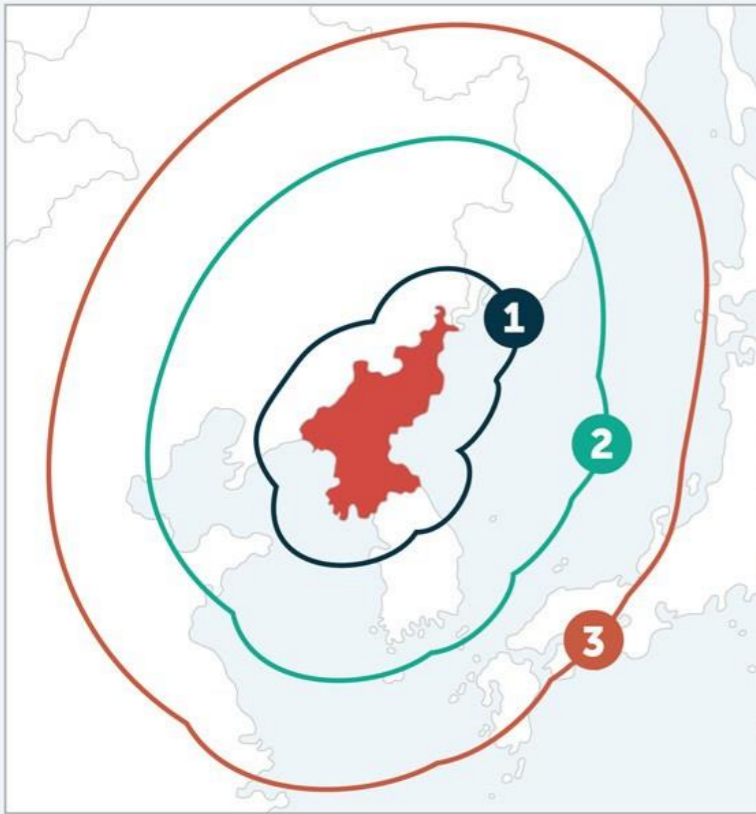
President delivers speech on France's nuclear deterrence

During a visit to the Ile Longue operational base, Emmanuel Macron says we are currently at a geopolitical tipping point fraught with risks and that France's deterrence is robust and effective.





NORTH KOREA'S BALLISTIC MISSILES



North Korea's ballistic missile program is one of the most rapidly developing threats to global security. In recent years, an unprecedented pace of missile testing has included new and longer range missiles, sea-launches, and the orbiting of satellites. The most notable of these advances has been North Korea's development of two new intercontinental ballistic missiles, the Hwasong-14 and -15, which can likely reach the continental United States.

*Not yet flight tested.

Russian, Chinese and North Korean ICBMs – 4



The Russian Dnepr space launch vehicle is based on the SS-18 ICBM.



Chinese CSS-10 Road-Mobile Launcher



Russian SS-27 Road-Mobile Launcher

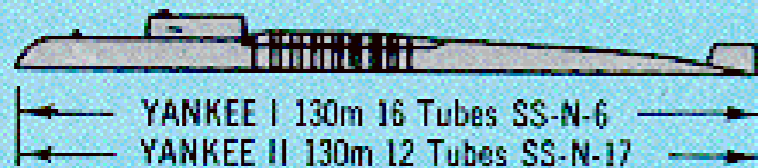
US and Russian SSBNs

Nuclear-Powered Ballistic Missile Submarines

USSR

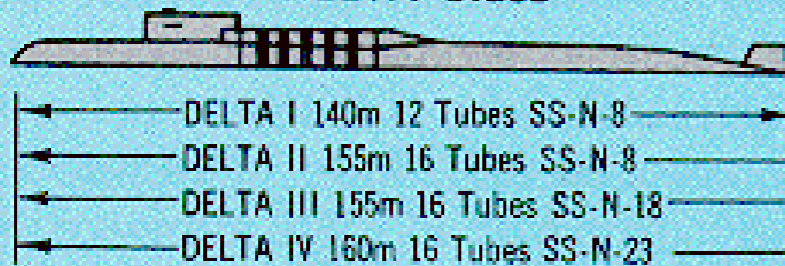
US

YANKEE-Class



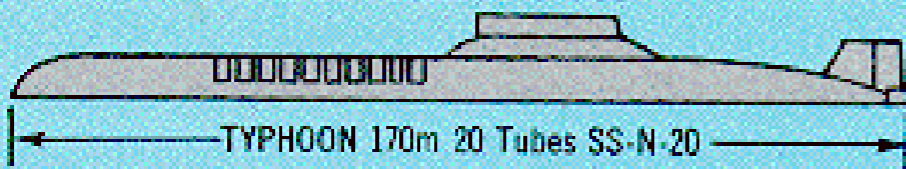
Decommissioned
~1988-1995

DELTA-Class



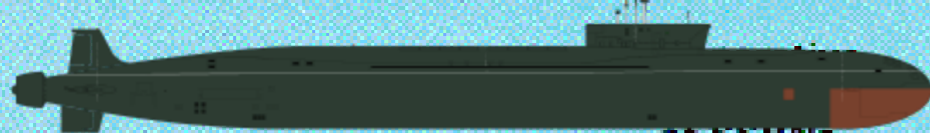
Delta I + II retired
Delta III 1 left
Delta IV 6 left

TYPHOON-Class



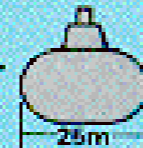
1 left

Borei-Class



170 m, 20 Tubes

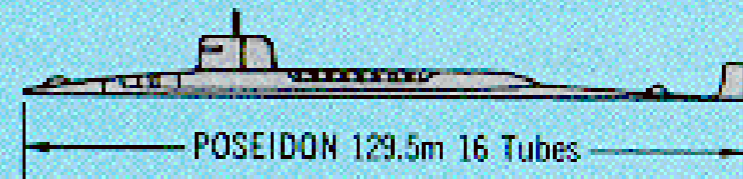
TYPHOON-Class



OHIO-Class

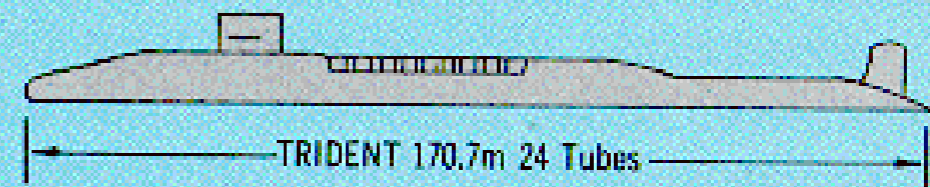


POSEIDON SSBN



retired 1992

TRIDENT (OHIO-Class) SSBN



US Trident SSBN (14 SSBNs, 4 SSGNs)



Trident Missile Tubes
With Covers Open

24 Trident C4 SLBMs
8 MIRVs with 100kt W76
→ up to 192 targets
SLBM range 7400 km

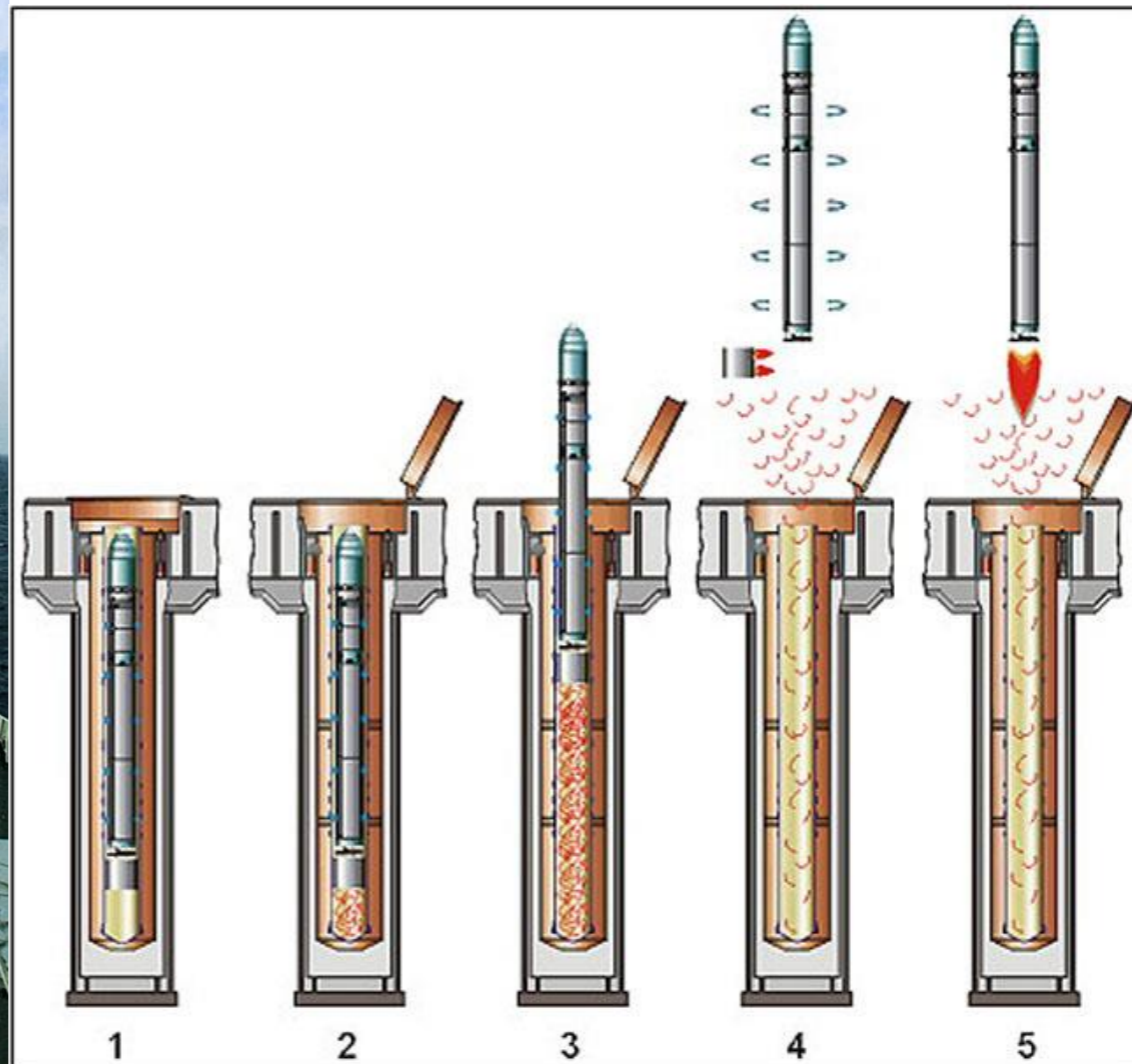


Trident Submarine Underway

speed : 20 knots
SSBN range : unlimited
deployment : 70-90 days, two rotating crews
Displacement : 16500 tons
Length : 170 m
width : 13 m

Cold Launch Mode

Missile is ejected with high pressure steam before rocket engines are started: “Cold Launch”



US Trident SSBN



TRIDENT I FLIGHT TEST

Launch video

Submarine-Based Missiles

US SLBMs —

- Trident C4 missiles carried 8 MIRVs each (solid propellant, range 7400 km)
- Trident D5 missiles carry 8 MIRVs each (solid propellant, range 7400 km)

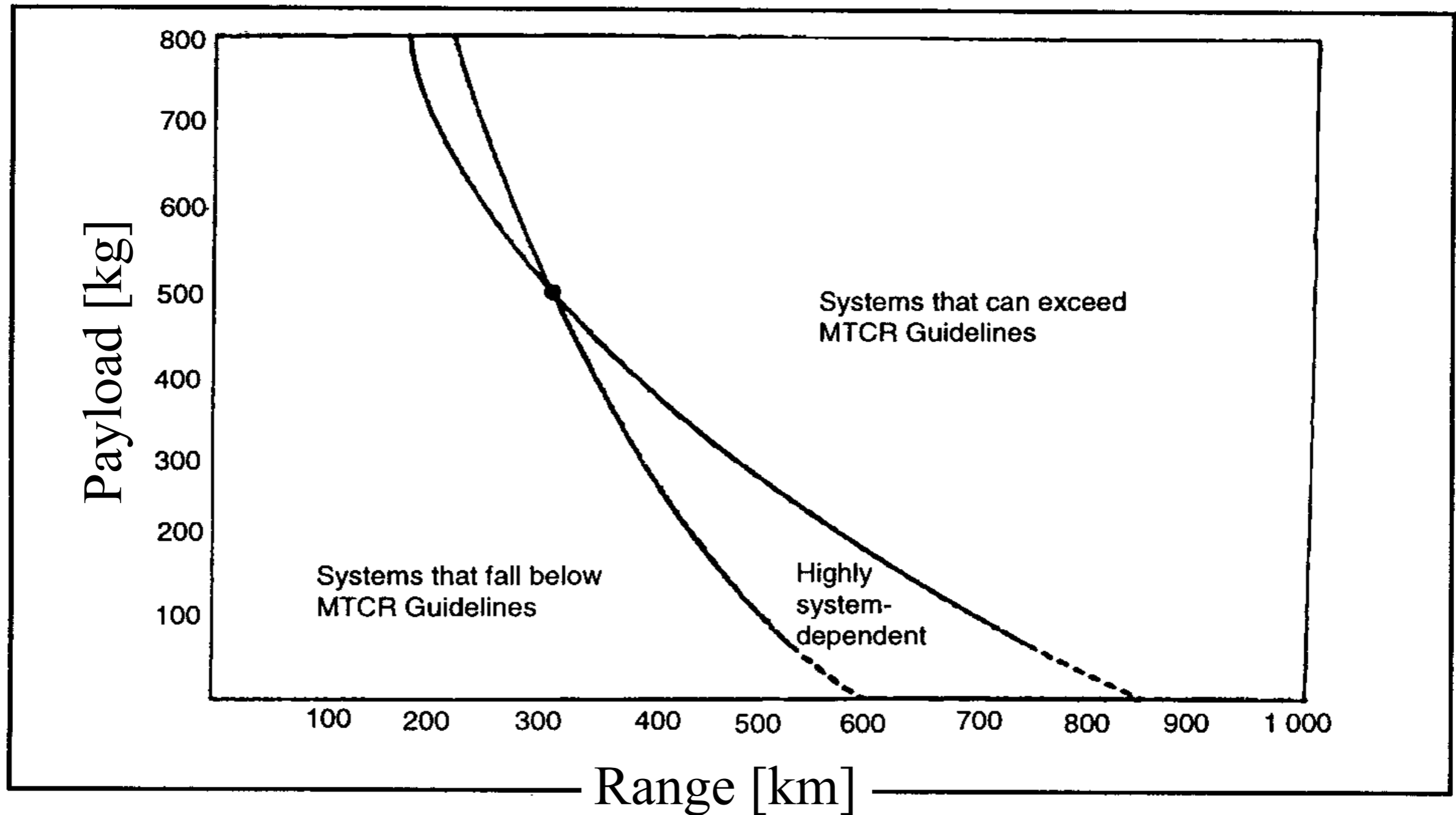
Russian SLBMs —

- SS-N-8 missiles carried 1 warhead each (range 9100 km)
- SS-N-18 missiles carried 3 warheads each (liquid propellant, range 6500 km)
- SS-N-20 missiles carried 10 warheads each (solid propellant, range 8300 km)
- SS-N-23 missiles carried 4 warheads each (liquid propellant, range 8300 km)

Module 5: Nuclear Delivery Systems

Part 5: Technical and Operational Aspects

MTCR: Range-Payload Limits



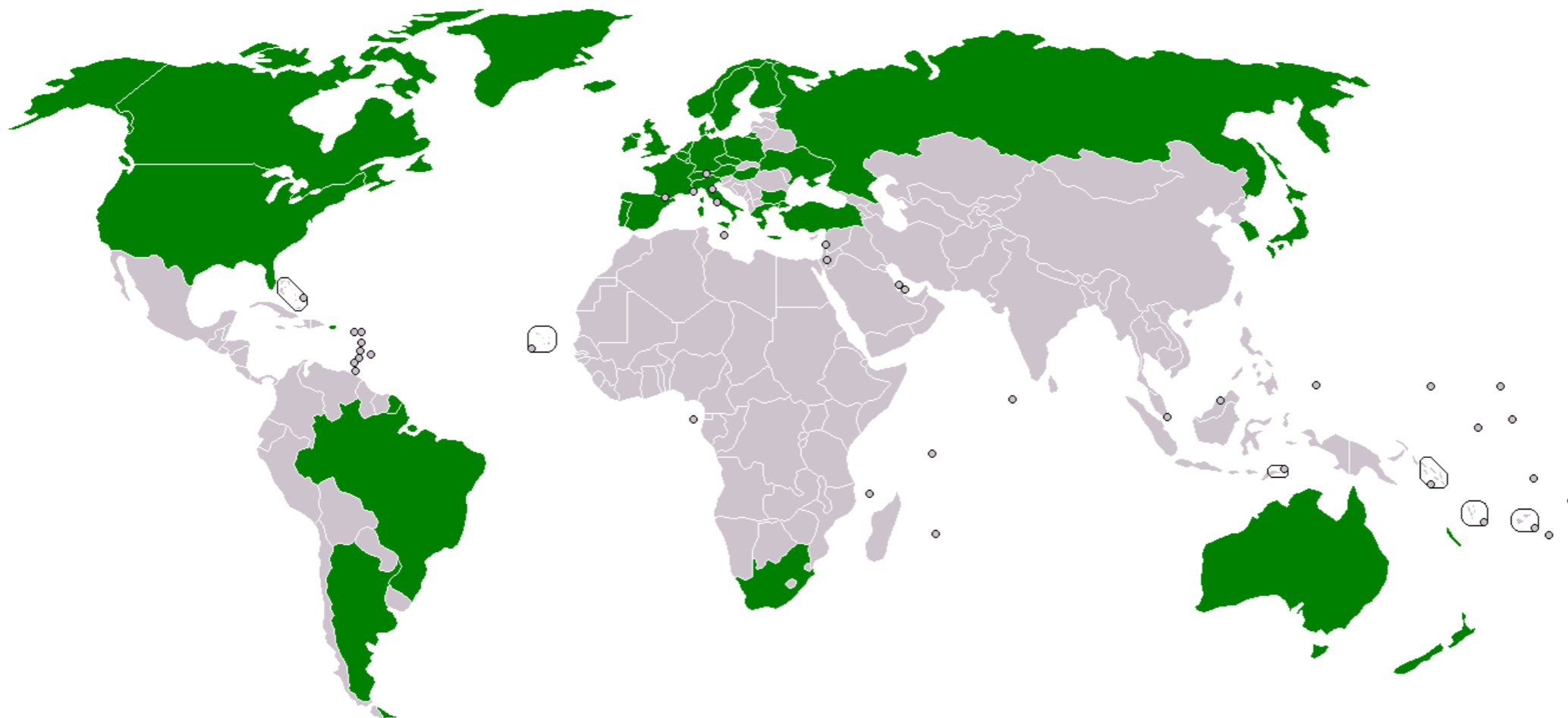
MTCR is the 1987 Missile Technology Control Regime to restrain missile exports

A. Karp, Ballistic Missile Proliferation, sipri, 1996, p. 157

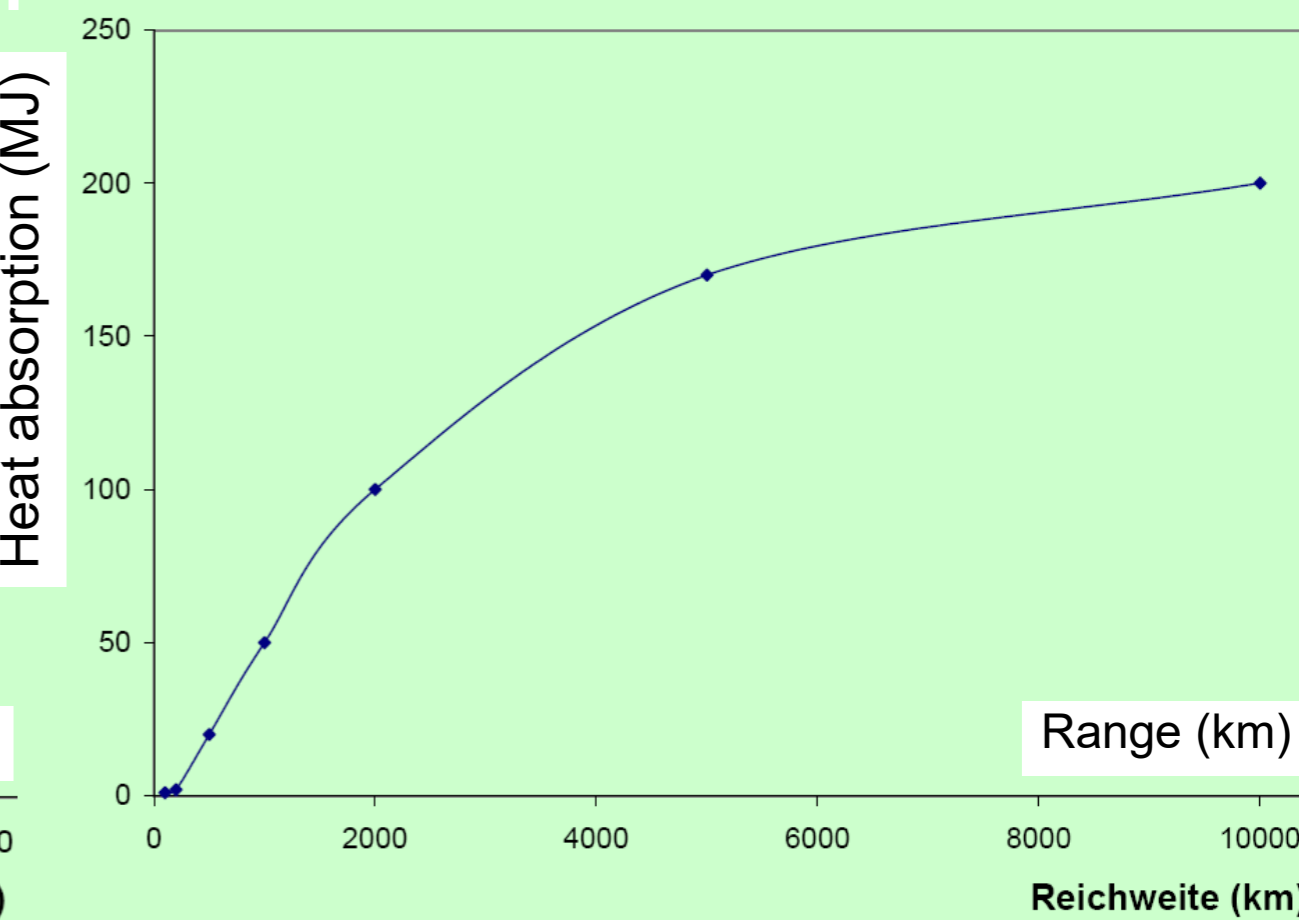
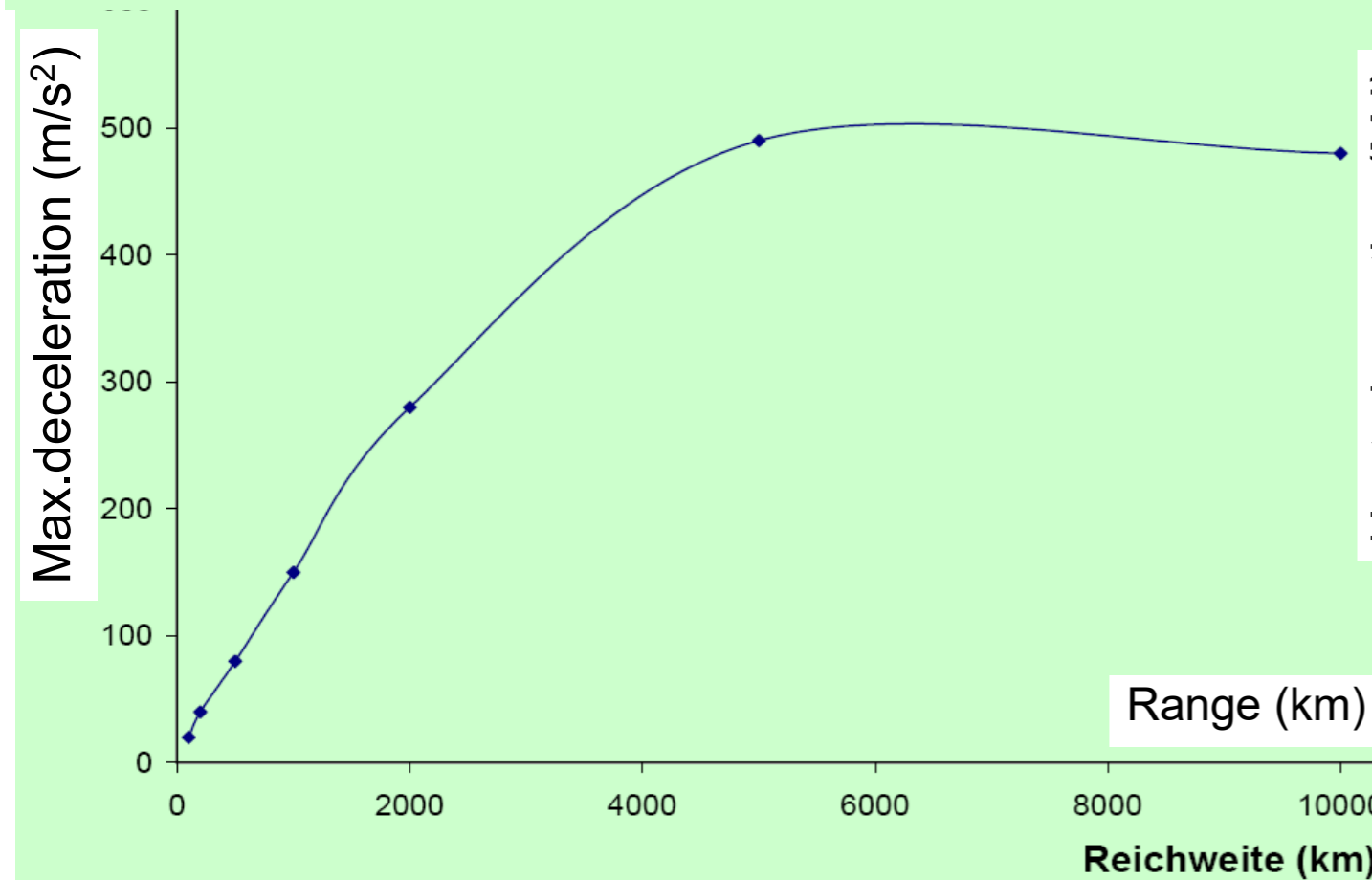
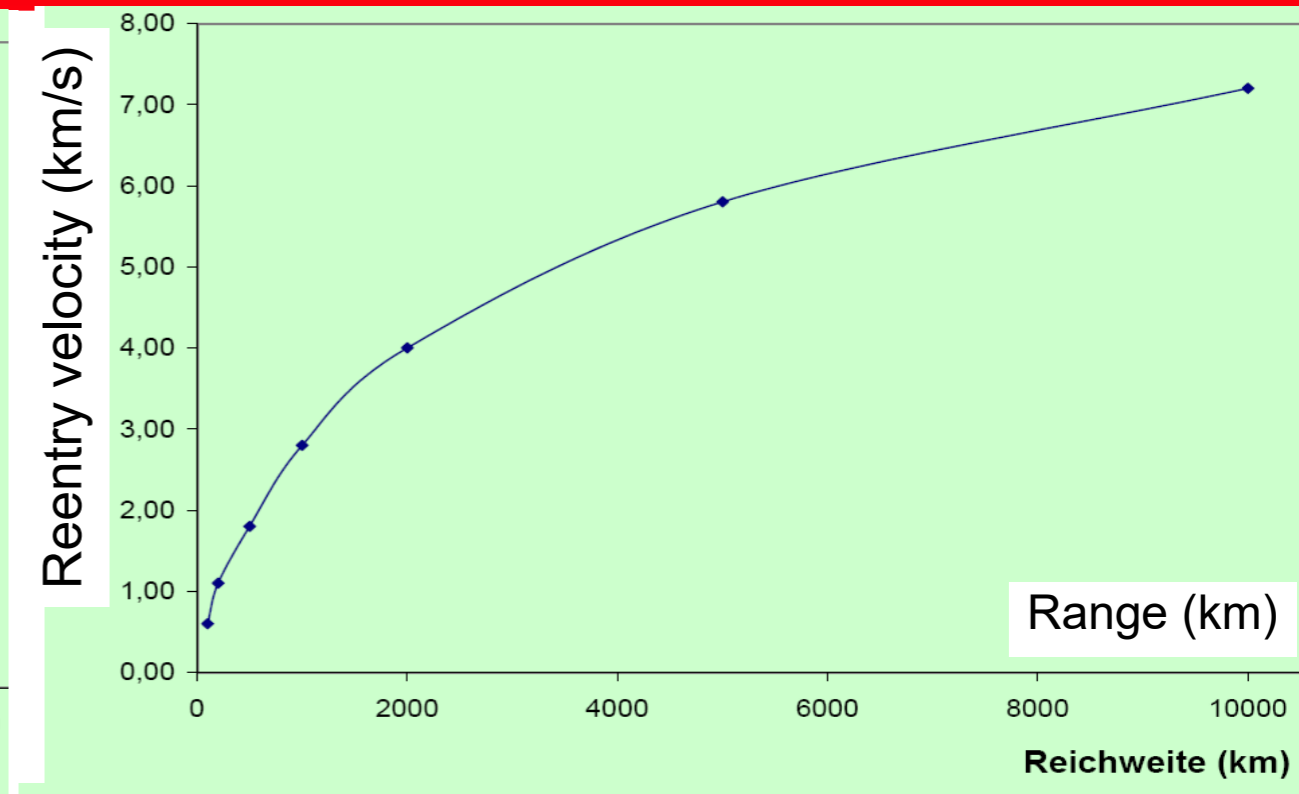
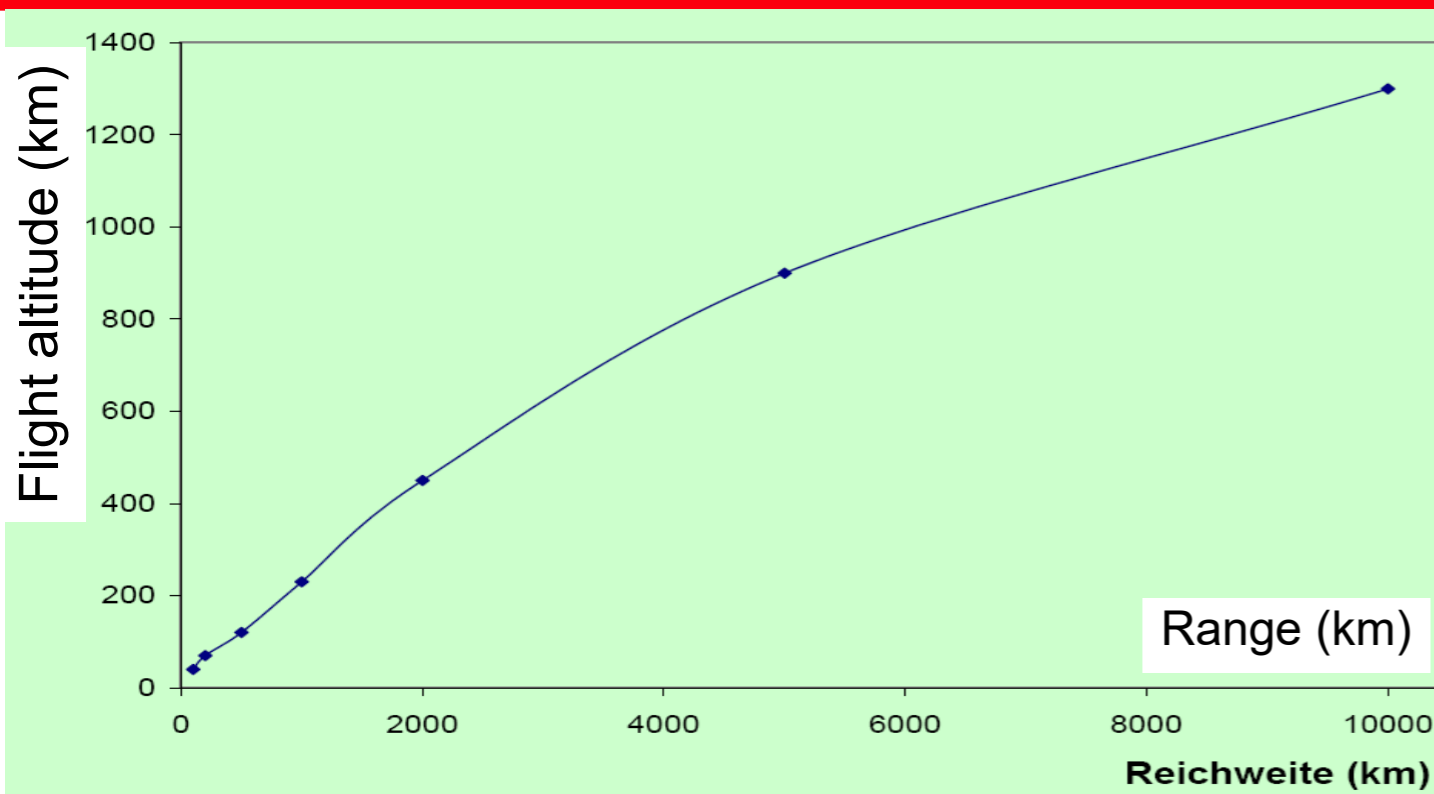
1987 Missile Technology Control Regime

34 member countries (the leading missile producing countries have agreed to restrict missile exports).

China and Israel are not members but have agreed unilaterally to adhere to the provisions of the agreement.



The Performance Required for Missile Warheads Increases Greatly with Increasing Missile Range



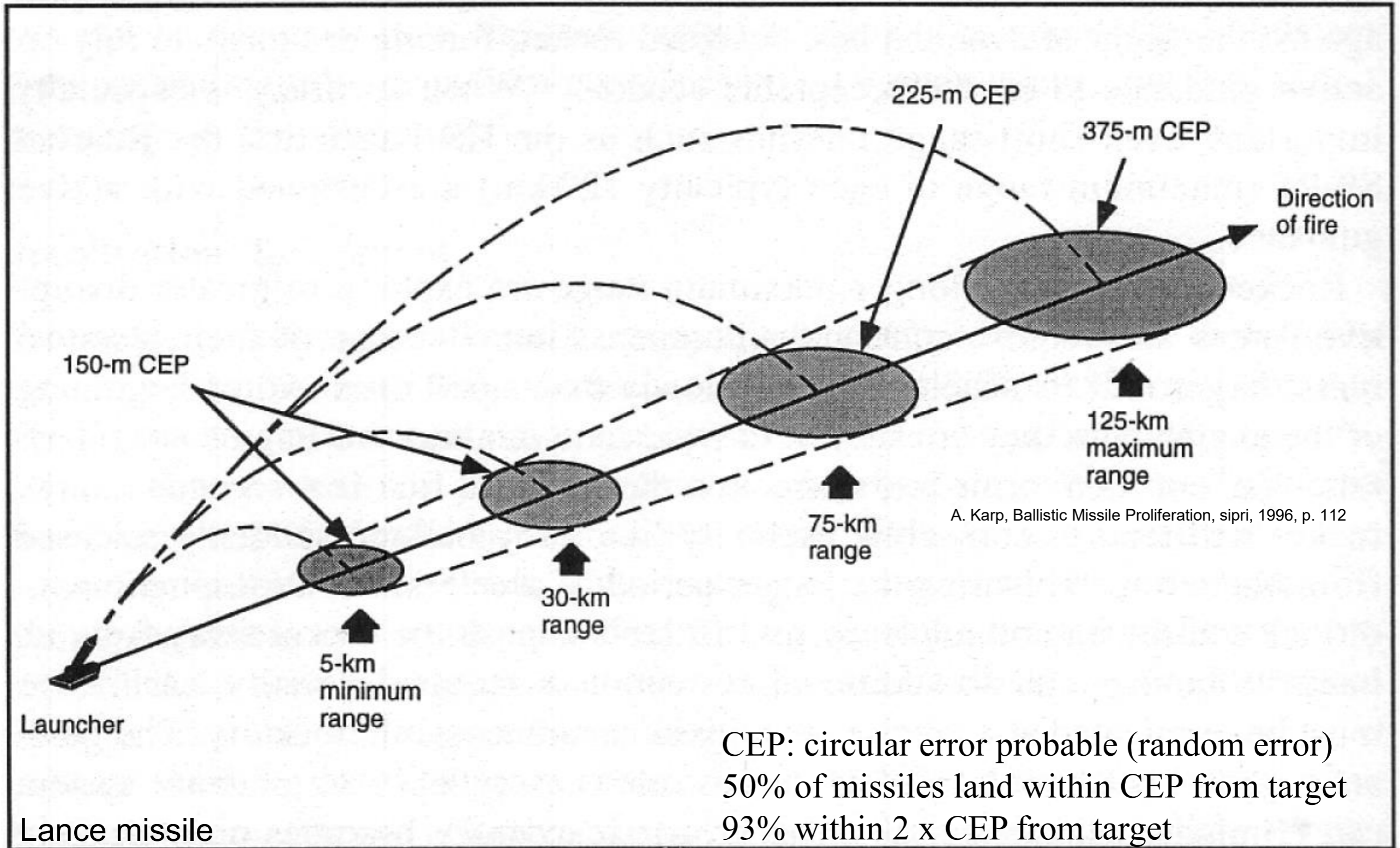
How Does this Translate into Challenges During Re-Entry into the Atmosphere?



Large frictional forces on re-entry lead to

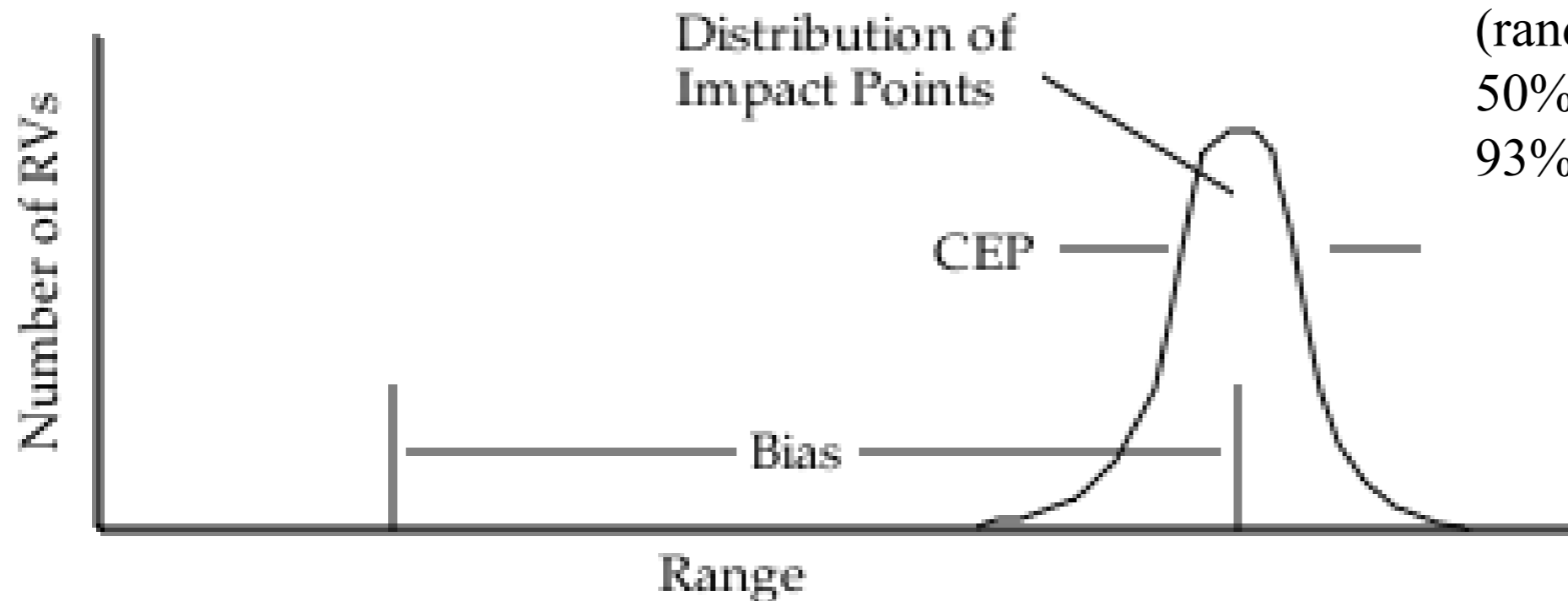
- ➔ deceleration up to $500 \text{ m/s}^2 = 51 \text{ g}$
~ car with 70mph into concrete wall
g-forces can be lethal if $> 25 \text{ g}$
- ➔ 200 MJ of energy is enough to heat
W76 warheads to the melting temperature
of iron $\sim 1540 \text{ C}$!

Missile Range–Accuracy Tradeoff



Ballistic Missile Accuracy

Distribution of RV impact points —



CEP: circular error probable
(random error)
50% of missiles land within CEP,
93% within 2 x CEP from target

Ballistic Missile Accuracy

The accuracy of a ballistic missile—like the value of *any* physical quantity—can only be specified *statistically*.

Important concepts:

- D = total miss distance
- CEP = “circular error probable” (random error)
- B = Bias (systematic error)

Relation —

$$D = (B^2 + CEP^2)^{1/2}$$

CEP is *not* a measure of the miss distance. The miss distance is *at least as large* as the CEP, but can be *much larger* if there is significant bias.

Ballistic Missile Accuracy

Published CEPs for some ICBMs and SLBMs

	Missile	CEP
US	MMIII	220 m
	Trident II	100 m
Russia	SS-18	450 m
	SS-27	350 m
	SS-27 Sickle B	200 m

ICBM Accuracy & Vulnerability

Missile accuracy steadily improved during the Cold War as the result of technological innovation.

As ICBMs become more accurate, they become more vulnerable to attack by the adversary, increasing crisis instability.

Each ICBM and each SLBM was armed with more and more warheads during the Cold War.

As each missile was armed with more warheads, it became a greater threat to the nuclear forces of the adversary and a more attractive target for a pre-emptive or first strike, increasing crisis instability.

Silo-Based Missiles

Vulnerable to attack

- Silo locations are known very accurately
- MIRVed missiles make it possible to launch several warheads against an array of silos

Effect of silo hardness

- Hardening is expensive
- US assumes its silos can withstand 2,000 psi (5 psi will completely destroy a brick house)
- US assumes Russian silos can withstand 5,000 psi (example of 'worst-case' analysis)
- To destroy a silo this hard, a 300 kt warhead would have to land within 100 m

Silo-Based Missiles

Effect of missile accuracy

- Theoretically, missile survival is very sensitive to the miss distance D of incoming warheads
- An an example, assume
 - 1,000 Minuteman silos are hardened to 2,000 psi
 - Two 1.5 MT warheads are targeted to explode at ground level on each silo
- Computations predict
 - If $D = 300$ ft, then 20 missiles survive (60 if 5,000 psi)
 - If $D = 500$ ft, then 200 missiles survive (600 if 5,000 psi)

Sources of Systematic Error

- Gravitational field variations
- Atmospheric drag variations

Gravitational Field Variations

Some possible causes —

- Bumps on the Earth (mountains)
- Mass concentrations (masscons)
- Gravitational pull of the Moon

(Motion of the Moon changes g by 3 ppm. An error in g of 3 ppm introduces a bias of 300 ft.)

The Earth's gravitational field is carefully measured over US and R (E-W) test ranges —

- US: Vandenberg to Kwajalein
- R: Plesetsk to Kamchatka and Tyuratam to Pacific

But wartime trajectories would be N-S over pole.

Atmospheric Drag Variations

Some possible sources —

- Jet streams
- Pressure fronts
- Surface winds
(30 mph surface wind introduces a bias of 300 ft.)

Density of the atmosphere —

- Is a factor of 2 greater in the day than at night
- Varies significantly with the season
- Is affected by warm and cold fronts

Data from military weather satellites and from models of weather over SU targets were reportedly used to update US warheads twice per day

Uncertainties on Silo-Based Missiles

Fundamental uncertainties

- Missile accuracy
- Warhead yield
- Silo hardness

Operational uncertainties

- System reliability
- Wind and weather
- Effects of other warheads (fratricide)
- Extent of 'collateral damage'
('digging out' missiles creates enormous fallout)

Effects of Explosive Yield, Missile Accuracy, and Silo Hardness on Land-Base Missile Vulnerability

Probability of destroying (“killing”) a missile silo: $P_K = 1 - e^{-K/f(H)}$

- A 10-fold increase of warhead yield Y increases the kill factor K by about a factor of 5.
- A 10-fold decrease in the warhead miss distance D increases the kill factor K by 100.
- For a kill factor of 20, a 10-fold increase in the silo hardness from 300 psi to 3000 psi reduces the probability of silo destruction from about 85% to about 35%.

Counterforce Capabilities

U.S. ICBMs: $K = 107,000$

U.S. Trident II D5: $K = 475,000$

Russia ICBMs: $K = 131,000$

Russia SLBMs: $K = 9,500$

Submarine-Based Missiles

Operational considerations

- Vulnerability depends on size of operational areas, ASW threat, counter-ASW capability
- Ability to survive
- US SSBNs are quieter than Russian SSBNs (but Russia is improving rapidly)
- US leads in anti-submarine warfare (ASW) capability and access to high seas
- Fraction of forces on-station (duration of patrols, time required for repairs)
- System reliability
- Effectiveness of command and control

Submarine-Based Missiles

Effective number of warheads (example) before New START

- United States

$$\begin{array}{ll} 2688 & \text{[SLBM warheads]} \\ \times 0.75 & \text{[fraction typically on-station]} \\ \times 0.90 & \text{[estimated reliability]} \\ = 1,814 & \text{[effective number of warheads]} \end{array}$$

- Russia

$$\begin{array}{ll} 2384 & \text{[SLBM warheads]} \\ \times 0.25 & \text{[fraction typically on-station]} \\ \times 0.70 & \text{[estimated reliability]} \\ = 447 & \text{[effective number of warheads]} \end{array}$$

These examples show that many factors *other than just the number of warheads* are important in comparing the effectiveness of nuclear forces.

Module 5: Nuclear Delivery Systems

Part 5: Nuclear Command and Control

Nuclear Command and Control – 1

C3I: Command, Control, Communication, Intelligence

Specific goals—

- Provide strategic and tactical warning
- Provide damage assessments
- Execute war orders from National Command Authority before, during, and after initial attack
- Evaluate effectiveness of retaliation
- Monitor development of hostilities, provide command and control for days, weeks, months

Nuclear Command and Control – 2

Some important aspects and implications —

- Organizational structure of command and control
- Available strategic communications, command, control and intelligence (C³I) assets
- Vulnerability of strategic C³I assets to attack

Alert levels — (Defensive Readiness Condition)

DEFCON 5 Normal peacetime readiness

DEFCON 4 Normal, increased intelligence and strengthened security measures

DEFCON 3 Increase in force readiness above normal readiness intelligence and strengthened security measures

DEFCON 2 Further Increase in force readiness

DEFCON 1 Maximum force readiness.

Nuclear Command and Control – 3

Satellite systems

- Early warning
- Reconnaissance
- Electronic signals
- Weather
- Communication
- Navigation

Response Times for Attack or Breakout



The Threat of Accidental Nuclear War – 20 Dangerous Incidents

- 1) November 5, 1956: Suez Crisis Coincidence
- 2) November 24, 1961: BMEWS Communication Failure
- 3) August 23, 1962: B-52 Navigation Error
- 4) August-October, 1962: U2 Flights into Soviet Airspace
- 5) October 24, 1962- Cuban Missile Crisis: A Soviet Satellite Explodes
- 6) October 25, 1962- Cuban Missile Crisis: Intruder in Duluth
- 7) October 26, 1962- Cuban Missile Crisis: ICBM Test Launch
- 8) October 26, 1962- Cuban Missile Crisis: Unannounced Titan Missile Launch
- 9) October 26, 1962- Cuban Missile Crisis: Malstrom Air Force Base
- 10) October, 1962- Cuban Missile Crisis: NATO Readiness

Source: www.nuclearfiles.org/kinuclearweapons/anwindex.html

The Threat of Accidental Nuclear War

20 Dangerous Incidents

- 11) October, 1962- Cuban Missile Crisis: British Alerts
- 12) October 28, 1962- Cuban Missile Crisis: Moorestown False Alarm
- 13) October 28, 1962- Cuban Missile Crisis: False Warning Due to Satellite
- 14) November 2, 1962: The Penkovsky False Warning
- 15) November, 1965: Power Failure and Faulty Bomb Alarms
- 16) January 21, 1968: B-52 Crash near Thule
- 17) October 24-25, 1973: False Alarm During Middle East Crisis
- 18) November 9, 1979: Computer Exercise Tape
- 19) June , 1980: Faulty Computer Chip
- 20) September, 1983: Russian False Alarm
- 21) November, 1983 Able Archer
- 21) January, 1995: Russian False Alarm (Norwegian research missile)

Source: www.nuclearfiles.org/kinuclearweapons/anwindex.html

January, 1995: Russian False Alarm

On January 25, 1995, the Russian early warning radar's detected an unexpected missile launch near Spitzbergen. The estimated flight time to Moscow was 5 minutes. The Russian President, the Defense Minister and the Chief of Staff were informed. The early warning and the control and command center switched to combat mode. Within 5 minutes, the radar's determined that the missile's impact would be outside the Russian borders.

The missile was Norwegian, and was launched for scientific measurements. On January 16, Norway had notified 35 countries including Russia that the launch was planned. Information had apparently reached the Russian Defense Ministry, but failed to reach the on-duty personnel of the early warning system.

Possible Risk Reduction Measures

- Put ballistic missiles on low-level alert
- Reduce number of warheads on missiles
- Remove warheads to storage
- Disable missiles by having safety switches pinned open and immobilized
- Allow inspections and cooperative verification

Source: B. Blair, H. Feiveson, F. von Hippel, Taking Nuclear Weapons off Hair-Trigger Alert, Scientific American, November 1997

GPS jamming: The invisible battle in the Middle East

3 days ago

Share Save

Chris Baraniuk
Technology Reporter



GPS jamming is making ships near the Iranian coast appear to be on land

News

Hundreds and hundreds of ships. But they're all in the wrong place. "Oh my goodness," says Michelle Wiese Bockmann, senior maritime intelligence analyst at Windward, a maritime AI company, as she checks the live positions broadcast by commercial vessels in waters off Iran, the United Arab Emirates and Qatar.

"I'm up to... 35 different clusters," she says, looking at a map of the Strait of Hormuz and surrounding areas.

The clusters she mentions are weird circles of icons layered over the map, with each icon representing a real ship.

But ships don't bunch together in tight, unnaturally perfect circles. And they also don't hover over land – which is where some of the clusters appear. No, their GPS coordinates have been disrupted, obfuscating their true location.

Wars are not just fought with bullets and bombs. Electromagnetic waves also do battle. Invisible to the naked eye, GPS jamming can cause significant disruption, hampered communications – and potentially deadly accidents.

In recent years, GPS jamming has affected aircraft in Europe, including a plane used by the President of the European Commission. And it is a daily feature of the war in Ukraine. Now that conflict has erupted in the Middle East, electronic warfare is spilling over yet more territory.

The interference currently affecting ships in and around the Strait of Hormuz is far from the first time that Bockmann has observed GPS jamming impacting vessels' Automatic Identification Systems (AIS).

The same thing happened in this region last year during the 12-day war between Israel and Iran, and electronic interference has also troubled vessel navigators in the Baltic Sea. But, she says, "This is next-level."

"We can't over-estimate the huge danger this places to maritime navigation and safety," adds Bockmann. The National Hydrographic Office Pakistan has also warned about interference affecting shipping in the region.

Ships use AIS partly to avoid one another. It takes a long time for a 300m-long tanker carrying hundreds of thousands of tonnes of oil to turn or come to a stop – and vessels can travel potentially many kilometres before they fully adjust their course.

If you can't be sure about where nearby vessels are, the risk of a collision goes up, especially at night or in poor visibility.

"That's the problem," says Alan Woodward at the University of Surrey. "Not you knowing where you're going – it's not knowing where everybody else is going."

There is no official confirmation as to who is behind the jamming but military analysts strongly suspect Iran of causing disruption to vessels. Iran has also threatened to attack any ship attempting to pass through the Strait of Hormuz.

Global Navigation Satellite System (GNSS) or GPS jamming tools used by Iran are likely to be domestically produced or made with equipment sourced from Russia or China, says Thomas Withington, associate fellow at the Royal United Services Institute, a think tank.

He also suggests that US forces in the region are using jamming systems to protect their bases, personnel and vessels from drones and GNSS-guided weapons.

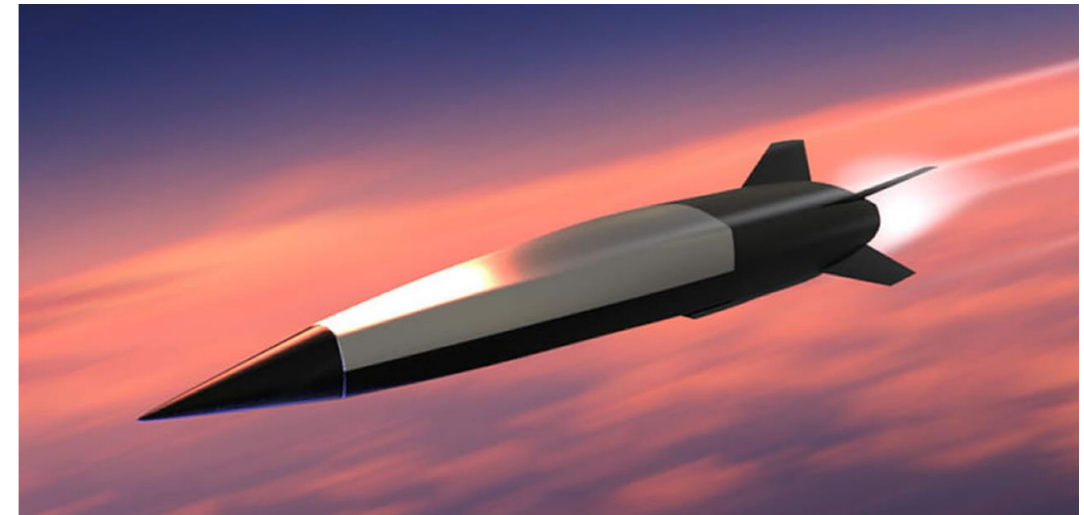
When approached, the US Department of War told the BBC: "Due to operations security we are not going to comment on the status of specific capabilities in the region."

<https://www.bbc.com/news/articles/c3ewwlx9e1xo>

End of Module 5

Introduction to Hypersonics

Hypersonic weapons: Missiles that travel faster than Mach 5 and have maneuverability capability. Can carry conventional and nuclear payloads.



Mach system: ratio of object's speed to the speed of sound (Mach 1 = speed of sound, Mach 2 = twice the speed of sound, etc)

- Below Mach 1: subsonic
- Mach 1 - Mach 5: supersonic
- Above Mach 5: hypersonic

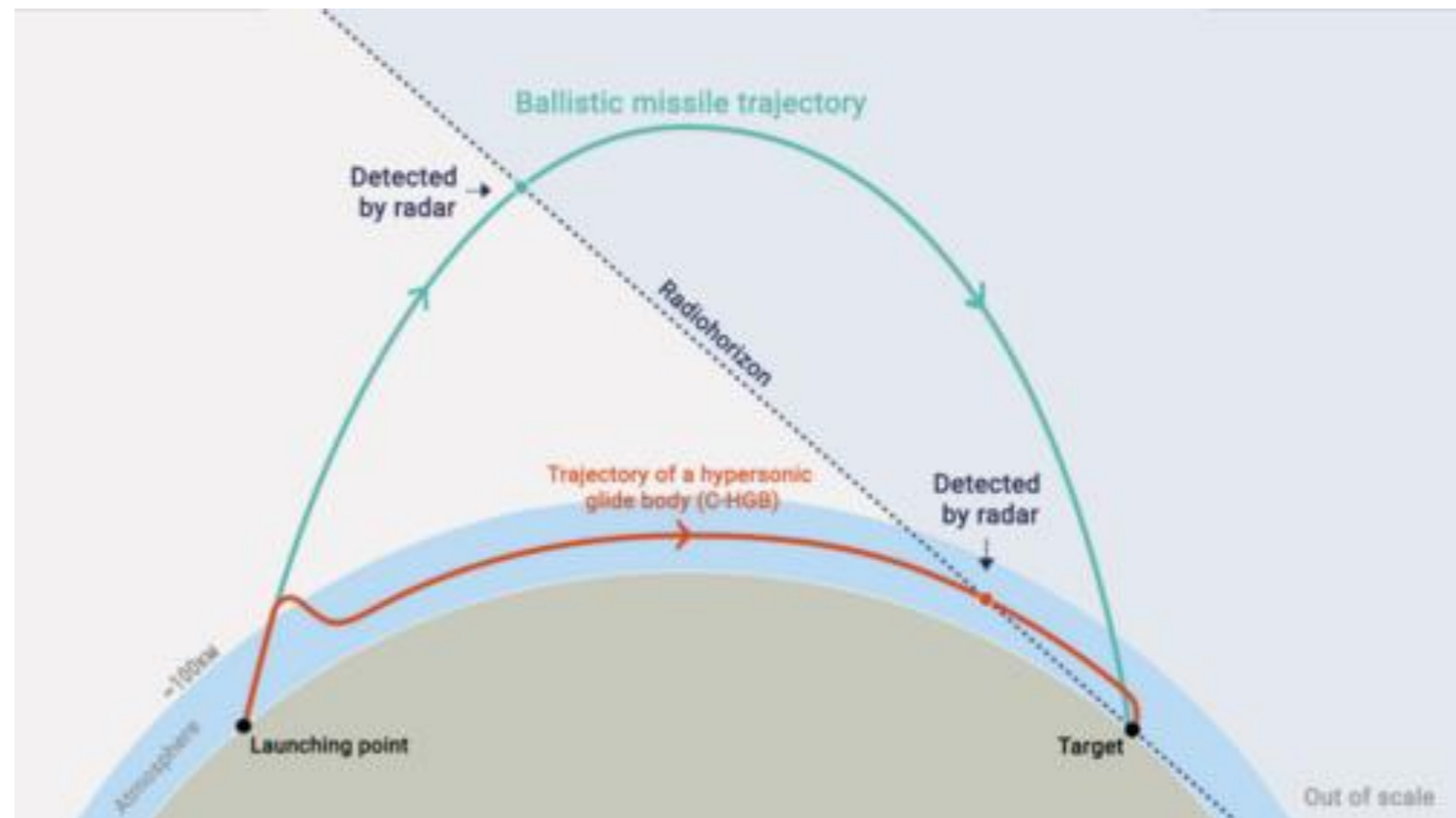
Speed of sound: depends on the properties of the medium it propagates through (air, water, etc); altitude affects the speed of sound (higher altitude = lower speed of sound), so changing the height at which a missile is flying could change whether or not it is hypersonic

Introduction to Hypersonics

Important: hypersonic missiles are maneuverable during flight.

They don't have a fixed path like an ICBM, and travel within the atmosphere instead of above.

- Harder to detect by radar
- Increased survivability against missile defense systems (evasion)



Introduction to Hypersonics

Three Main Types:

- 1) Boost-glide: launched on ICBM/SLBM and released during final stages into Low-Earth Orbit, where it glides along the top of the atmosphere
- 2) Air-breathing: require an initial rocket/launch vehicle to reach Mach 5, then begins to use a scramjet engine (combusts fuel in the stream of supersonic air)
- 3) Gun-launched (Railgun): use an electromagnetic pulse to launch projectiles; development has been slow, but Japan successfully tested a railgun launcher in 2025



A boost-glide hypersonic weapon relies on a rocket to launch it into a low-Earth orbit, where the hypersonic projectile then detaches and glides on top of the atmosphere to its target. This design of the Air-Launched Rapid Response Weapon (ARRW) shows the rocket and projectile in low-Earth orbit prior to detachment. *Source: Lockheed Martin Corporation*



Airbreathing hypersonic missiles would likely be carried by aircraft and employed like conventional cruise missiles. In this design, the US Air Force's experimental X-51 Waverider, shown here under the wing of a B-52 Stratofortress, is set to demonstrate hypersonic flight. Powered by a Pratt & Whitney Rocketdyne SJY61 scramjet engine, it is designed to ride on its own shockwave and accelerate to about Mach 6. *Source: US Air Force graphic <https://www.af.mil/News/Photos/igphoto/2000360694/>*



While often discussed separately from boost-glide and airbreathing hypersonic weapons, railgun weapon systems can achieve hypersonic speeds and may be valuable in supporting air and missile defense in the future. Source: General Atomics Electromagnetic Systems <https://www.ga.com/railgun-weapon-systems>

Introduction to Hypersonics

New hypersonic missiles unveiled for fighter planes, ground systems

By Zita Ballinger Fletcher

Wednesday, Feb 25, 2026



Introduction to Hypersonics



“The U.S. will soon have the ability to deploy a new type of hypersonic missile that can be shot from fighter planes, bombers, ground-based launchers — and can even be fired from space.

Ursa Major, a Colorado-based defense manufacturer, debuted the HAVOC missile system on Tuesday.

The medium-range hypersonic system is powered by a liquid rocket engine, is able to alter its speed in flight and can be adapted for use with a wide variety of rocket motor systems from warplanes to vertical launch systems.

Additionally, the system can be deployed outside of Earth’s atmosphere, according to the company.”

Introduction to Hypersonics

DefenseNews

“Keeping pace with our adversaries requires more than exquisite systems. It requires speed to delivery, affordability, and the ability to build at scale,” Chris Spagnoletti, CEO of Ursa Major, said in a statement.

“The Ursa Major HAVOC Missile System delivers a highly capable hypersonic weapon designed from the start to be produced rapidly and in quantity, giving the warfighter a credible and adaptable capability.”

The system has a core module that makes it suitable for striking hypersonic targets as well, the company adds.”

Introduction to Hypersonics

“Hypersonic missiles, which fly at roughly five times the speed of sound, have become a priority across all U.S. military [branches](#).

The Army, Air Force and Navy are all developing hypersonic missile programs, including: the Army’s Long-Range Hypersonic Weapon; the Air Force’s Hypersonic Attack Cruise Missile; and the Navy’s Conventional Prompt Strike programs. While the services have aimed for hypersonic weapons since the early 2000s, development has lagged while Russia and China have gained advantages in this arena.”

Introduction to Hypersonics



“In a notable divergence, Russian and Chinese hypersonic missiles are designed to field nuclear warheads, while U.S. hypersonics are not.

“Most U.S. hypersonic weapons, in contrast to those in Russia and China, are not being designed for use with a nuclear warhead,” according to a Congressional Research Service [report](#) published last August.

The report predicted that U.S. hypersonics would “likely require greater accuracy and will be more technically challenging to develop than nuclear-armed Chinese and Russian systems,” while also noting that Russian and Chinese systems would have a potential advantage since nuclear weapons can inflict devastating damage without need for accuracy.”

Introduction to Hypersonics



“China has a robust hypersonic program and has conducted up to 20 times as many hypersonic missile tests than the U.S., and is also investing in underground facilities, per the report.

“Analysts disagree about the strategic implications of hypersonic weapons,” the report notes, adding that Congress has previously restricted funding due to concerns of nuclear escalation.

“Differences in threat perception and escalation ladders could thus result in unintended escalation,” the report concluded.”

Satellites and ASATs

US Nuclear Command, Control, and Communications network (NC3): 'detection, warning and attack characterization, adaptive nuclear planning, decision-making conferencing, receiving and executing presidential orders, and enabling the management and direction of forces'

Requires a high level of survivability

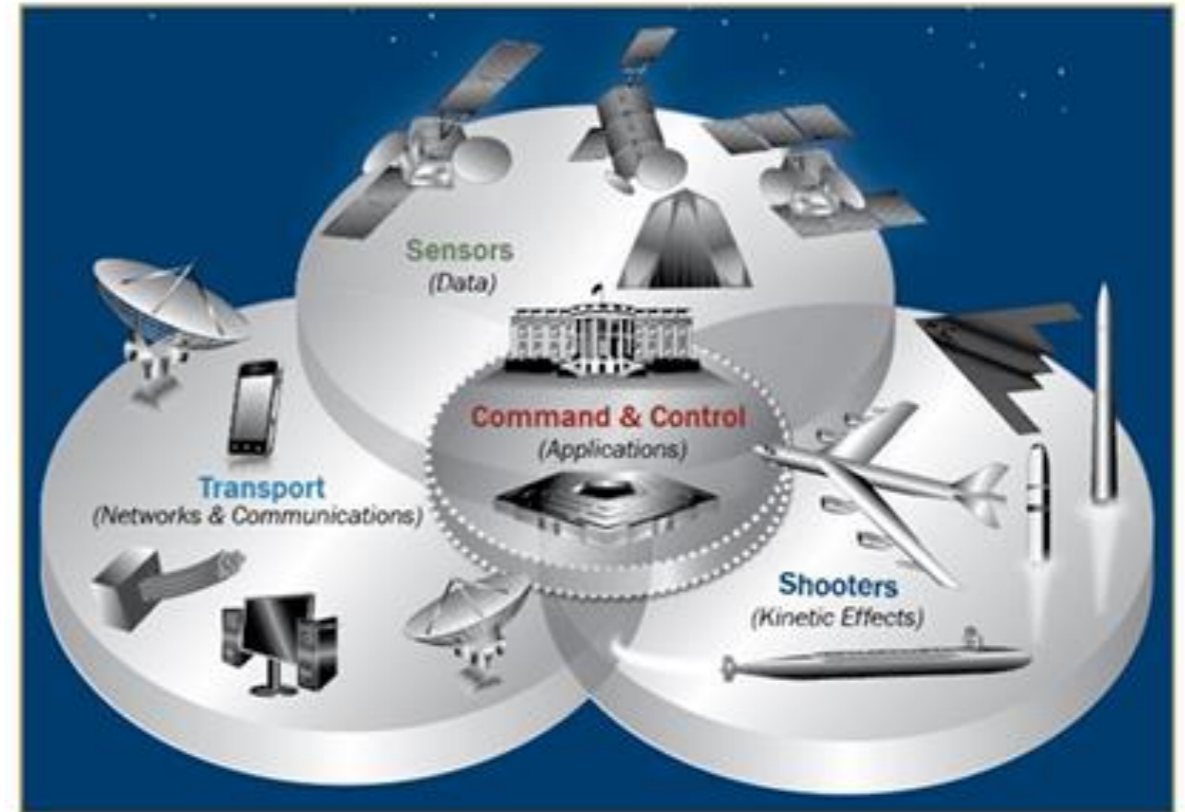


Figure 1: Space-Based Nuclear Command & Control.

Source: "Nuclear Matters Handbook 2020 [Revised]," Chapter 2, <https://www.acq.osd.mil/ncbdp/nm/NMHB2020rev/chapters/chapter2.html>

Satellites and ASATs

Space-based component of NC3 is essential: communications, intelligence, surveillance, and reconnaissance (ISR), missile launch early warning, and positioning, navigation, and timing elements (PNT)

In addition to satellites' importance for nuclear stability and military use, satellites support crop monitoring, disaster response, Internet access, and other communications in remote areas.

Creation of Russia's Space Forces in 1992 and US Space Force in 2019 reflect trend of 'space militarization'

Nuclear deterrence depend on satellite intelligence and early-warning systems to understand an adversary's capabilities and intentions.

Satellites and ASATs

Satellites are inherently vulnerable because they have fixed orbits

Anti-Satellite Weapons (ASATs): any weapon that aims to disrupt or destroy satellites

Kinetic ASATs: physically destroy/blow up satellites; dual-use (missile defense and ASAT capabilities)

Non-kinetic: disrupt a satellite's function (Electronic Warfare, lasers ('blind/dazzle' the satellite), cyber)



Satellites and ASATs

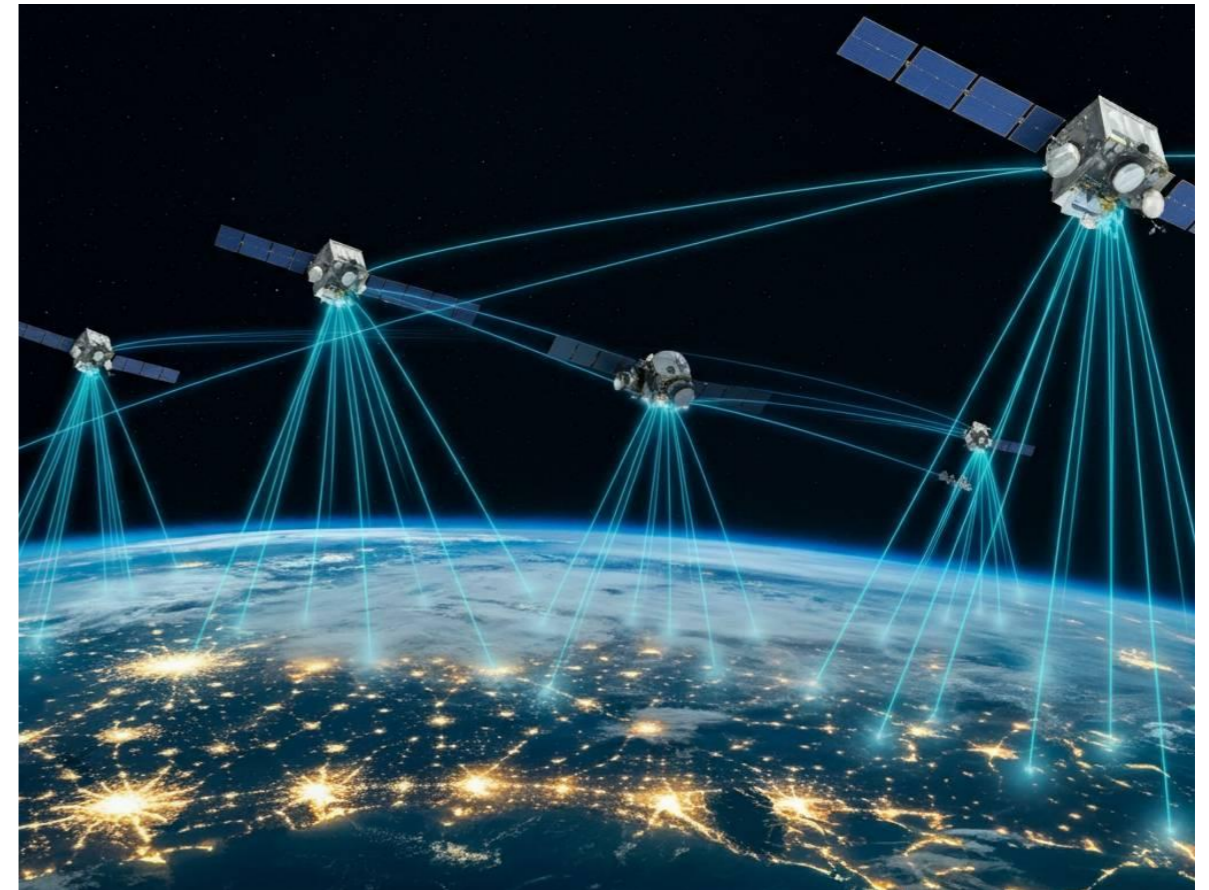
Kinetic ASAT:



Satellites and ASATs

Atmospheric Nuclear Detonation: detonating a nuclear bomb in space. The resulting EMP pulse would destroy hundreds of satellites and space debris could make the orbit unusable for years. (1967 Outer Space Treaty)

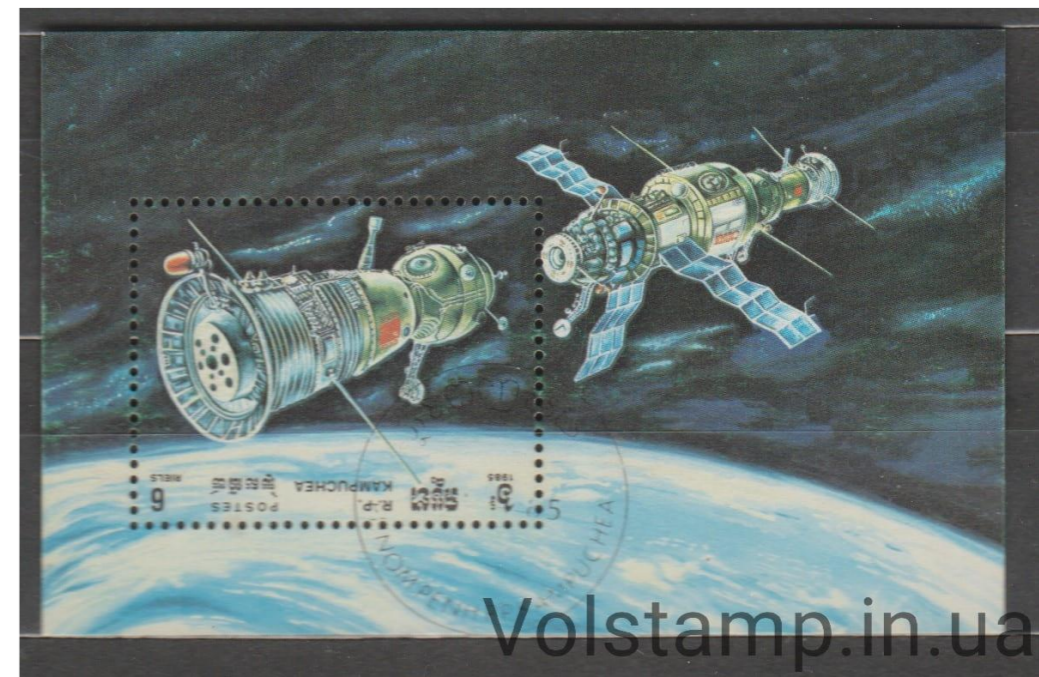
US Satellite Doctrine: historically, the US focused on building a few expensive and very capable satellites, but a single kinetic ASAT could destroy about 20% of American early-warning satellites. Currently, the US is creating a network of smaller, cheaper satellites in low-earth orbit. This network reduces the risk of a kinetic ASAT attack, but an atmospheric nuclear detonation would be very effective at wiping out the entire network



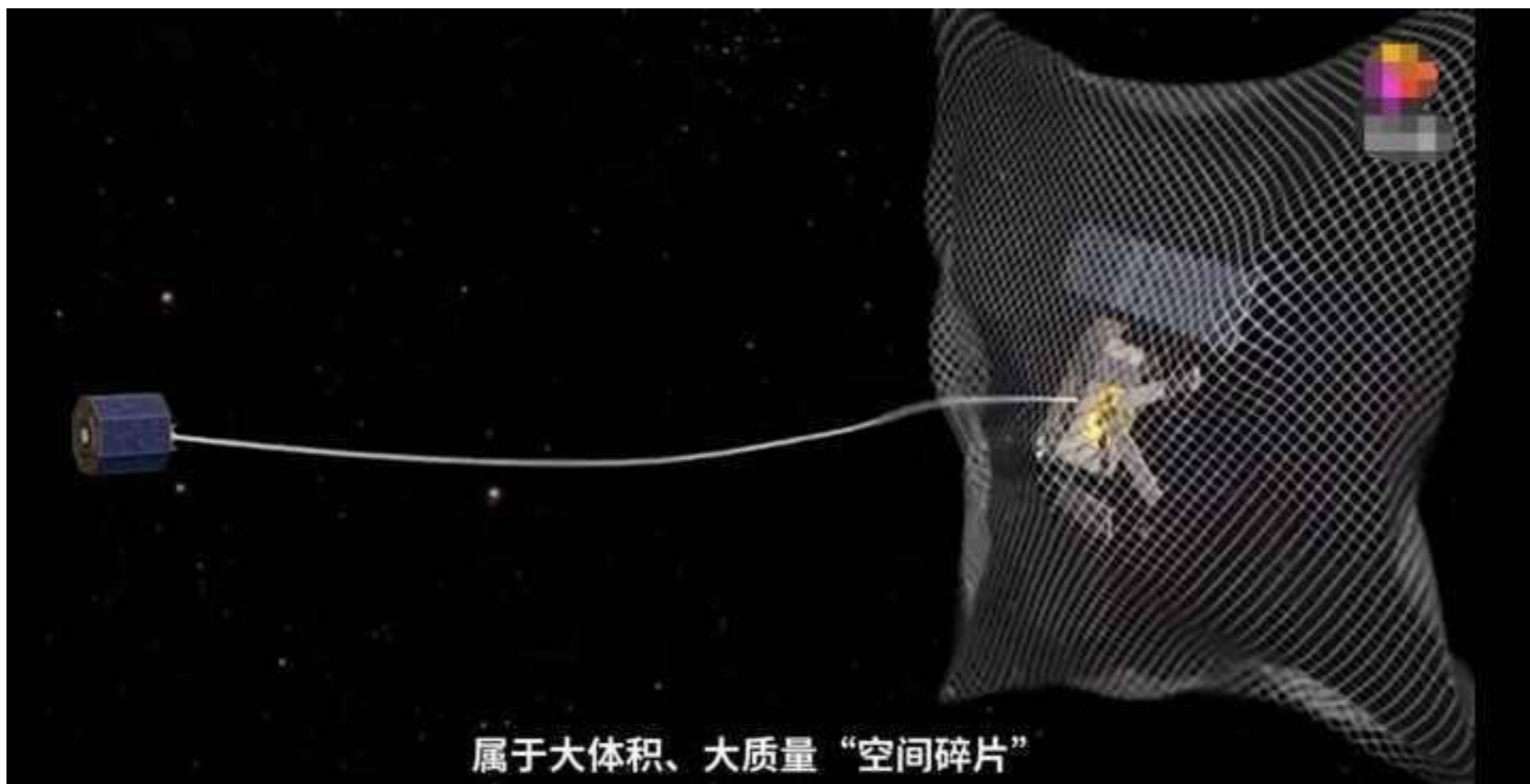
Satellites and ASATs

Inspector Satellites: maneuver close to other satellites; observing and repairing capabilities. Provide intelligence about other countries' space and technology capabilities

Dual-use: Inspector satellites can carry ASATs such as electronic warfare systems, lasers, projectiles, and robotic mechanisms. It is impossible to distinguish between peaceful/civilian use from weaponized satellites.



Satellites and ASATs



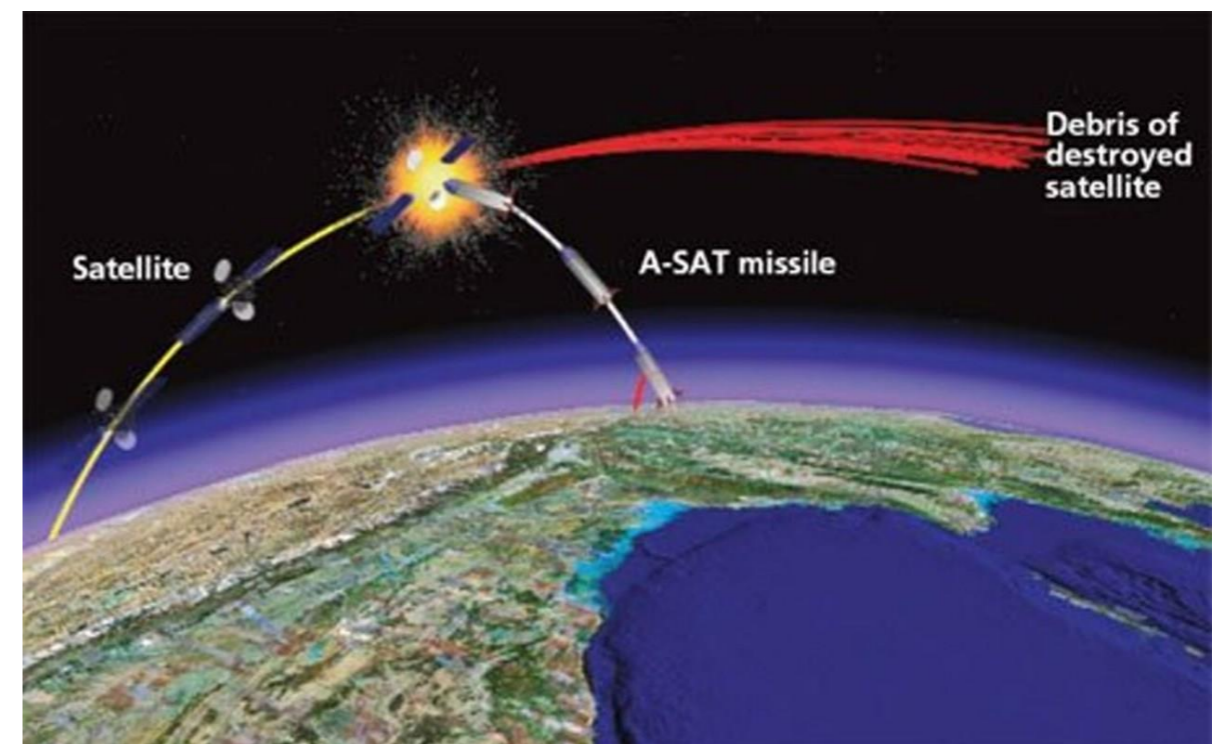
Satellites and ASATs

The US relies on satellites more than any other state, encouraging other states to develop ASATs.

Since satellites play such an important role in nuclear stability through intelligence gathering, **early warning systems**, communications, etc, ASATs threaten the stability of deterrence.

If a satellite stops transmitting, this may signal the beginning of a ballistic missile attack.

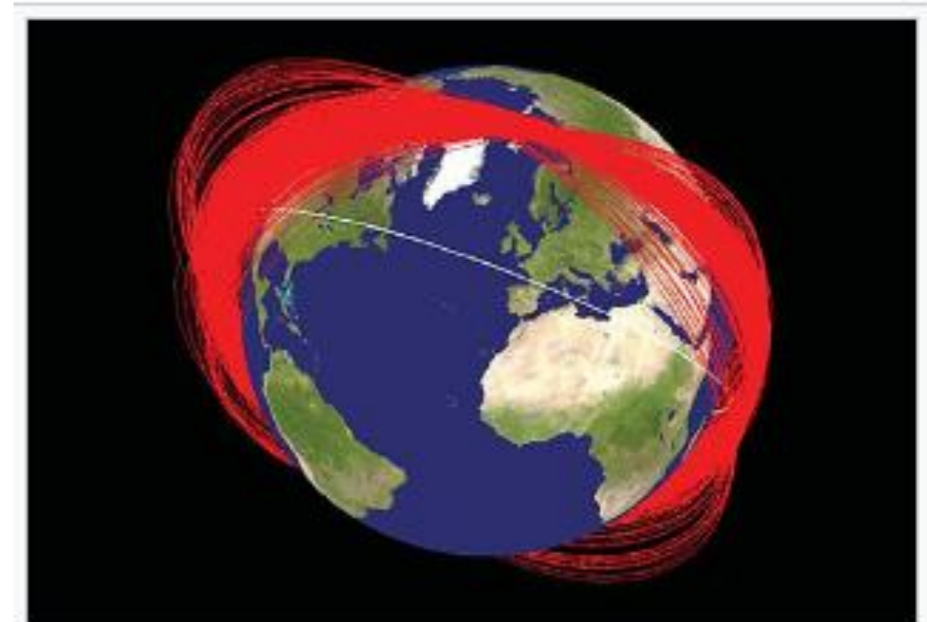
Treaties: difficult because most ASATs are dual-use



Satellites and ASATs

China, Russia, the United States and India have successfully tested ASATs

ASAT tests create space debris which remains in orbit (doesn't fall back down to earth). The satellite becomes thousands of pieces of space junk; their velocity in the explosion becomes a small spread in orbital velocities, so they spread out. The two rings correspond to the two objects that collide.



Known orbit planes of Fengyun-1C debris one month after its disintegration by the Chinese ASAT (orbits exaggerated for visibility)

Satellites and ASATs

Date	Country	Anti-satellite weapon	Target	Altitude	Ref.
1958–1962	 <i>United States</i>  <i>Soviet Union</i>	Various <i>high-altitude nuclear test</i> missiles	None; various satellites unintentionally disabled	See <i>artificial radiation belts</i>	
1968–1982	 Soviet Union	Istrebitel Sputnikov co-orbital interceptors	Istrebitel Sputnikov targets	~100–2,300 km	[12]
13 September 1985	 United States	ASM-135 ASAT	Solwind P78-1	555 km	[18][72]
11 January 2007	 China	SC-19	FY-1C	865 km	[73]
21 February 2008	 United States	RIM-161 Standard Missile 3	USA-193	247 km	[74]
27 March 2019	 India	PDV Mark-II	Microsat-R	283 km	[75]
15 November 2021	 Russia	A-235 PL-19 Nudol	Kosmos 1408	~465 km	[76]

Satellites and ASATs

"Although no ASAT system has yet been utilized in warfare, a few countries (China, India, Russia, and the United States) have successfully shot down their own satellites to demonstrate their ASAT capabilities in a show of force. ASATs have also been used to remove decommissioned satellites."

Space junk poses a risk because it can kill other satellites- space junk is therefore a nuclear security risk because damage to EWSs can be interpreted as the first step in a nuclear exchange by an adversary (i.e. space junk can accidentally start a nuclear war!).

Likewise, technology to clean space junk and reduce this risk has dual purpose use as an antisatellite weapon- if you have the ability to use a net to capture and deorbit a dead satellite, you also have the ability to destroy functional military satellites.