Plan for This Session

Questions

Announcement:

Midterm Exam, Thursday March 19th

- midterm will cover modules 1 to 5 + news
- old tests available for practice on course web-page
- 50% of problems will be from old exam
- will schedule review session next week

News

Module 5: Nuclear Weapon Delivery Systems
Iran nuclear deal 'very close' as Netanyahu brings negotiators together

American and Iranian diplomats find common ground rejecting Israeli leader’s combative approach to negotiations, but also agree serious hurdles remain to meeting March deadline

Julian Borger
Thursday 5 March 2015 10.31 EST

The long and convoluted negotiations over Iran’s nuclear programme adjourned on Wednesday amid talk of continuing progress towards a comprehensive deal but of tough political decisions still to be made.

The talks will resume on March 15, probably in Geneva, as the latest deadline for agreement looms at the end of the month.

Iran’s foreign minister, Mohammad Javad Zarif said a deal was “very close”, telling NBC that he and his team were prepared to carry on working through the Persian New Year celebration of Nowruz starting on March 21.

Zarif has frequently argued that the standoff over Iran’s nuclear ambitions is unnecessary and easy to solve, as Tehran has no intention of making a bomb and would therefore accept a great deal of transparency to reassure the international community.

Zarif’s American counterpart, the US secretary of state, John Kerry, emerged from their ten hours of talks in Montreux, Switzerland, with more of a focus on the half of the glass still empty, warning: “There are still significant gaps and important choices that need to be made.”
Concerns In Saudi Arabia and the Gulf States with Regards to a Possible P5+1 Accord with Iran

John Kerry, in Saudi Arabia, Reassures Gulf States on Iran Nuclear Talks

By MICHAEL R. GORDON    MARCH 5, 2015

RIYADH, Saudi Arabia — Secretary of State John Kerry on Thursday sought to reassure Saudi Arabia and other Gulf states that the negotiation of a nuclear accord with Iran would not lead the Obama administration to let down its guard against any Iranian interference in the region.

With the Saudi foreign minister by his side, Mr. Kerry said at a news conference here that the administration was committed to standing up to Iran’s “intervention.”

“We are not seeking a grand bargain,” Mr. Kerry said, offering the assurance that the administration was not pursuing a broader rapprochement with Iran that could come at the expense of its Arab rivals. “We will not take our eye off of Iran’s other destabilizing actions.”
Replacement of the Ohio-Class Submarines

Congressmen Rally Behind Ohio-Class Submarine Replacement

By Yasmin Tadjdeh

Navy “leg” of the Triad!

Congressmen gathered on Capitol Hill to tout the importance of replacing the nation’s aging ballistic missile equipped Ohio-class submarines.
Replacement of the Ohio-Class Submarines

Congressmen Rally Behind Ohio-Class Submarine Replacement

By Yasmine Tadjdeh

During a March 4 meeting sponsored by the Submarine Industrial Base Council, Rep. Rob Wittman, R-Va., chairman of the House Armed Services Committee’s subcommittee on readiness, said replacing the boats — also known as SSBNs — will be critical to the nation’s strategic outlook.

“We know how critical [the Ohio-class replacement] … is to our nation’s strategic position in the world and we want to make sure that SSBNs availability match Ohio-class retirement. Or make sure there is no gap in there,” he said.

The United States still “rules the undersea world,” Wittman said, but Congress needs to ensure it continues investing in submarine platforms.

The Navy’s 2016 proposed budget request asked for $1.4 billion toward research and development for the Ohio-class replacement program, also known as the SSBN(X). The program will replace 14 subs.
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
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

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

- Truman administration
- Eisenhower administration

McNamara (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 give roles to the USAF and the USN defined the “Triad” paradigm
- Established the SIOP (Single Integrated Operational Plan) for targeting
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 BEAR**: 8,300 km, 0.8 MACH
- **BACKFIRE**: 4,000 km, 2.0 MACH
- **BLACKJACK**: 7,300 km, 2.0 MACH
- **M-TYPE BISON**: 5,600 km, 0.85 MACH
- **Tu-16 BADGER**: 3,100 km, 0.85 MACH
- **Tu-22 BLINDER**: 2,900 km, 1.4 MACH

**USSR Bomber Aircraft**
Examples of Intercontinental Bombers – 2

<table>
<thead>
<tr>
<th>Bomber Aircraft</th>
<th>Unrefueled Combat Radius (km)</th>
<th>Max Speed (Mach)</th>
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<tbody>
<tr>
<td>FB-111</td>
<td>1,480</td>
<td>2.5</td>
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<tr>
<td>B-1B</td>
<td>7,500</td>
<td>1.25</td>
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<tr>
<td>B-52G/H</td>
<td>8,000</td>
<td>0.9</td>
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</tbody>
</table>
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
Currently Deployed U.S. and Russian Bombers

Current US bombers —
  • B-52 Hs, carrying bombs, or cruise missiles
  • B1-s, each can carry 16 B83 bombs
  • B-2, each can carry 16 B83 bombs

Russian bombers* —
  • Bear-H16s, carrying bombs
  • Bear-H6s, carrying bombs
  • Blackjacks, carrying bombs
  *Very 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
Which one of the following is *not* one of Richardson’s “Three Goals of Terrorists”?

(A) Revenge

(B) Reaction

(C) Resources

(D) Renown
iClicker Question
Which one of the following is not one of Richardson’s “Three Goals of Terrorists”?

(A) Revenge
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Which one of the following delivery vehicles was not considered a leg of the Cold War nuclear “Triad”?

(A) Submarine-launched ballistic missiles
(B) Ship-launched ballistic missiles
(C) Land-based intercontinental ballistic missiles
(D) Land-based intercontinental bombers
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(B) **Ship-launched ballistic missiles**
(C) Land-based intercontinental ballistic missiles
(D) Land-based intercontinental bombers
Module 5: Nuclear Delivery Systems

Part 3: Cruise Missiles
Cruise missiles (CMs) are pilotless vehicles powered by jet engines:

- Fly within the atmosphere
- Speeds are subsonic

Although cruise missiles were conceived 60 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
Key properties —

• Small
• Easily stored and launched
• Highly penetrating
• Versatile
• Highly accurate
• Very cheap (about ~ $1 million per copy)
Long-Range Cruise Missiles

Russia (USSR)

- SS-NX-21
- AS-15
- SSC-X-4

US

- ALCM
- TOMAHAWK
- GLCM
- SLCM

**Range**: 1000 – 2000 miles

**Pay Loads**: 500 – 1200 lbs
Long-Range Cruise Missiles – 2

**Conventionally-Armed Tomahawk Cruise Missile**

- **velocity**: 550 mph
- **payload**: 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 – 3

Tomahawk Land Attack (Non-Nuclear) Operational Concept

- Launch platform dependent
- Elements common to all launches
- Suppressed infrared, visual and radar cross section signatures
- TERCOM update points/map grids
- Terminal guidance phase, using optical sensor
- SAM site
- Defense avoidance (to avoid SAM site)
- Way points
- Defense avoidance (to avoid fighter base)
- DSMAC (Digital Scene Matching Area Correlator) scenes
- Terrain following
- Very low altitude
- Terrain masking
- Fighter base
- Target

Source: Joint Cruise Missiles Project Office.
Accuracy of Cruise Missiles
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 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”

– Foreign Missile Developments and the Ballistic Missile Threat Through 2015, Unclassified Summary of a National Intelligence Estimate, December 2001
Physics 280: Session 15

Plan for This Session

Vote on schedule for Midterm Review Session
  (a) Sunday March 15th 6-8pm
  (b) Tuesday March 17th 7-9pm
  (c) Wednesday March 18th 7-9pm

Midterm Exam, Thursday March 19th, 2.00-3.20pm

Module 5: Nuclear Weapon Delivery Systems
Part 4: Ballistic Missiles
Air Breathing Delivery Systems (Bombers & Cruise Missiles) vs Ballistic Missiles

Air breathing systems:
- carry the fuel on board but take the oxidizer from the atmospheres \(\Rightarrow\) operate endo-atmospheric

Ballistic missiles:
- carry fuel and oxidizer \(\Rightarrow\) 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 ~ 12,000 km

These categories are not fluid, because they are based on the performance characteristics of the missile.
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Source: national air and space intelligence center
“Ballistic and Cruise Missile Threat”, 2009
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)

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

PHASES OF BALLISTIC MISSILE TRAJECTORY

- Launch Site
- Ascent Phase Engagement
- Exit Earth’s Atmosphere
- Boost Burn Out
- Midcourse
- Apogee
- Descent Phase Engagement
- Re-entry
- Terminal Phase Engagement
- Target
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

<table>
<thead>
<tr>
<th>Ground range, km</th>
<th>Altitude, km</th>
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</thead>
<tbody>
<tr>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>400</td>
<td>400</td>
</tr>
<tr>
<td>1200</td>
<td>1200</td>
</tr>
<tr>
<td>1300</td>
<td>1300</td>
</tr>
</tbody>
</table>

- **Boost phase:** 30-40 s, 10-15 km
- **Total flight:** 2 minutes
- **Apogee:** ~650 km

- **Boost phase:** 60-90 s, 40-60 km
- **Total flight:** 6 minutes
- **Apogee:** ~1300 km

- **Boost phase:** ~80-140 s, 100-120 km
- **Total flight:** 13 minutes
- **Apogee:** ~1300 km

- **Boost phase:** 170-300 s, 180-220 km
- **Total flight:** 30 minutes

Thank you to D. Moser for the graphics.
Proliferation of Ballistic Missile Technologies

Diagram showing the flow of technology from various countries:

- South Africa
- UK
- USA
- Iraq
- Germany
- Brazil
- Egypt
- Afghanistan
- Soviet Union/Russia
- North Korea
- Yemen
- Syria
- Iran
- Libya
- Saudi-Arabia
- China
- Vietnam
- Bulgaria
- Pakistan
- Argentina
- South Korea
- Taiwan
- Israel
- France
- India

Countries in the network include:
- Germany
- Brazil
- Egypt
- Afghanistan
- Soviet Union/Russia
- North Korea
- Yemen
- Syria
- Iran
- Libya
- Saudi-Arabia
- China
- Vietnam
- Bulgaria
- Pakistan
- Argentina
- South Korea
- Taiwan
- Israel
- France
- India
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

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)
Which one of the following technologies was not crucial in developing militarily useful cruise missiles?

A. Light carbon fiber materials for the airframes
B. More efficient engines
C. Much smaller and more capable computers
D. GPS and other methods for more accurate guidance
E. “Stealth” technologies to make them harder to detect
iClicker Question
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iClicker Question

Which one of the following delivery vehicles was not considered a leg of the Cold War nuclear “Triad”?

A. Submarine-launched ballistic missiles
B. Ship-launched ballistic missiles
C. Land-based intercontinental ballistic missiles
D. Land-based intercontinental bombers
iClicker Question
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Which one of the following strategic nuclear delivery vehicles can be recalled after launch?

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B. Land-based intercontinental ballistic missiles
C. Land-based intercontinental bombers
iClicker Question
iClicker Question

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C. Land-based intercontinental bombers
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
MIRV Technology

MX Peacekeeper MIRV

Soviet ICBM MIRV
MX Peacekeeper missile tested at Kwajalein Atoll

Source: [www.smdc.army.mil/kwaj/Media/Photo/missions.htm](http://www.smdc.army.mil/kwaj/Media/Photo/missions.htm)
Minuteman ICBM (Schematic)
Flight of a Minuteman ICBM (Schematic)

- 1st Stage Boost (T = 0 sec.)
- 2nd Stage Ignition (T = 60 sec. typ.)
- 3rd Stage Ignition (T = 120 sec. typ.)
- 3rd Stage Thrust Termination (T = 180 sec. typ.)
- RV Deployment & Backaway
- Shroud Ejection
- RV & Chaff Reentry
- Chaff Deployment
- Axial Attitude Control
- PBV Burn
- Warhead Armed
- Warhead Detonation (Air Burst)
- (Ground Burst)
- Target
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 —

- **MMIII** Solid-propellant, range ~ 12,000 km, 3 warheads (Minuteman)
- **MX** Solid-propellant, range ~ 12,000 km, 10 warheads (Peacekeeper, retired 2005)

Recent Russian ICBMs —

- **SS-18** Liquid-propellant (storable), range ~ 12,000 km, 12 to 18 warheads
- **SS-24** Solid-propellant, range > 9,000 km
- **SS-25** Solid-propellant, range > 9,000 km
US ICBMs – 1

Current land based US ICBMs

- **Titan II**
  - Meters: 30
  - Number Deployed Warheads: 4
  - Max Range (KM): 12,000 Hot

- **Minuteman II**
  - Meters: 20
  - Number Deployed Warheads: 450
  - Max Range (KM): 12,500 Hot

- **Minuteman III**
  - Meters: 10
  - Number Deployed Warheads: 540
  - Max Range (KM): 11,000+ Hot

- **Peacekeeper**
  - Meters: 0
  - Number Deployed Warheads: Up to 10
  - Max Range (KM): 11,000+ Cold

As of early 1987
US ICBMs – 2

Launch of a Minuteman

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

<table>
<thead>
<tr>
<th>Missile</th>
<th>Number of Stages</th>
<th>Warheads per Missile</th>
<th>Propellant</th>
<th>Deployment Mode</th>
<th>Maximum Range* (miles)</th>
<th>Number of Launchers</th>
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<tr>
<td><strong>Russia</strong></td>
<td></td>
<td></td>
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<td>SS-18 Mod 4</td>
<td>2 + PBV</td>
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<td>Liquid</td>
<td>Silo</td>
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<td>SS-18 Mod 5</td>
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<td>Silo</td>
<td>6,000+</td>
<td>(total for Mods 4 &amp; 5)</td>
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<td>2</td>
<td>1</td>
<td>Liquid</td>
<td>Silo &amp; transportable</td>
<td>3,400+</td>
<td>10 to 15</td>
</tr>
<tr>
<td>CSS-4 Mod 2</td>
<td>2</td>
<td>1</td>
<td>Liquid</td>
<td>Silo</td>
<td>8,000+</td>
<td>About 20</td>
</tr>
<tr>
<td>CSS-10 Mod 1</td>
<td>3</td>
<td>1</td>
<td>Solid</td>
<td>Road-mobile</td>
<td>4,500+</td>
<td>Fewer than 15</td>
</tr>
<tr>
<td>CSS-10 Mod 2</td>
<td>3</td>
<td>1</td>
<td>Solid</td>
<td>Road-mobile</td>
<td>7,000+</td>
<td>Fewer than 15</td>
</tr>
<tr>
<td><strong>North Korea</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taepo Dong 2</td>
<td>2</td>
<td>1</td>
<td>Liquid</td>
<td>Undetermined</td>
<td>3,400+</td>
<td>Not yet deployed</td>
</tr>
</tbody>
</table>

Source: national air and space intelligence center
“Ballistic and Cruise Missile Threat”, 2009
Russian, Chinese (and North Korean) ICBMs – 3

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

Russian SS-27 Road-Mobile Launcher

Chinese CSS-10 Road-Mobile Launcher
US and Russian SSBNs

- **USSR**
  - **YANKEE-Class**
    - YANKEE I: 130m, 16 Tubes SS-N-6
    - YANKEE II: 130m, 12 Tubes SS-N-17
  - **DELTA-Class**
    - DELTA I: 140m, 12 Tubes SS-N-8
    - DELTA II: 155m, 16 Tubes SS-N-8
    - DELTA III: 155m, 16 Tubes SS-N-18
    - DELTA IV: 160m, 16 Tubes SS-N-23
  - **TYPOHOON-Class**
    - TYPHOON 170m, 20 Tubes SS-N-20

- **US**
  - **POSEIDON SSBN**
    - POSEIDON 129.5m, 16 Tubes
  - **TRIDENT (OHIO-Class) SSBN**
    - TRIDENT 170.7m, 24 Tubes

**Timeline**
- **YANKEE-Class**: retired 1991
- **DELTA-Class**: phased out 2012
- **TYPOHOON-Class**: phased out 2012
- **POSEIDON SSBN**: retired 1992
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
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)
US and Russian SLBMs

Nuclear Submarine-Launched Ballistic Missiles

<table>
<thead>
<tr>
<th>Metric</th>
<th>USSR</th>
<th>US</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range (km)</td>
<td>SS-N-6: 1, 2, 3 MRVss 2,400, 3,000, 3,000</td>
<td>SS-N-18: 1, 2, 3 MRVss 1, 3,900, 6,500</td>
</tr>
<tr>
<td></td>
<td>SS-N-8: MOD</td>
<td>SS-N-20: 2, 1, 7 MRVss 8,000, 6,500, 8,300</td>
</tr>
<tr>
<td></td>
<td>SS-N-17: MOD</td>
<td>SS-N-23: 3 MRVss 6,9 MRVss 8,300</td>
</tr>
<tr>
<td></td>
<td>POSEIDON SLBM C-3: 10 MRVss 4,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TRIDENT SLBM C-4: 8 MRVss 7,400</td>
<td></td>
</tr>
</tbody>
</table>
Plan for This Session

Questions

Midterm Review, Sunday, March 15\textsuperscript{th}, 6-8pm

Midterm Exam, Thursday March 19\textsuperscript{th}, 2-3.20pm

News and discussion

Module 5: Nuclear Weapon Delivery Systems
Module 5: Nuclear Delivery Systems

Part 5: Technical and Operational Aspects
MTCR is the 1987 Missile Technology Control Regime to restrain missile exports

A. Karp, Ballistic Missile Proliferation, sipri, 1996, p. 157
The Performance Required for Missile Warheads Increases Greatly with Increasing Missile Range.
Missile Range–Accuracy Tradeoff

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

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

$CEP$ 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

<table>
<thead>
<tr>
<th>Missile</th>
<th>CEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>US MMIII</td>
<td>220 m</td>
</tr>
<tr>
<td>Trident I</td>
<td>450 m</td>
</tr>
<tr>
<td>Trident II</td>
<td>100 m</td>
</tr>
<tr>
<td>Russia SS-18</td>
<td>450 m</td>
</tr>
<tr>
<td>SS-N-18</td>
<td>600 m</td>
</tr>
</tbody>
</table>
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 each silo or 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 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)
Probability of destroying ("killing") a missile silo:

- 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%.

\[ P_K = 1 - e^{-K/f(H)} \]
Counterforce Capabilities in 1985

U.S. ICBMs: \[ K = 107,000 \]
U.S. SLBMs: \[ K = 48,000 \]
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
Effective number of warheads (example) before New START

• United States

  2688 [SLBM warheads]
  x 0.75 [fraction typically on-station]
  x 0.90 [estimated reliability]
  = 1,814 [effective number of warheads]

• Russia

  2384 [SLBM warheads]
  x 0.25 [fraction typically on-station]
  x 0.70 [estimated reliability]
  = 447 [effective number of warheads]

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
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
Some important aspects and implications —

• Organizational structure of command and control
• Available strategic communications, command, control and intelligence (C^3I) assets
• Vulnerability of strategic C^3I 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.
Satellite systems

• Early warning
• Reconnaissance
• Electronic signals
• Weather
• Communication
• Navigation
Response Times for Attack or Breakout

Risk of accidental nuclear war

- Automatic launch
- Launch on warning
- Launch under attack
- Launch after attack
- De-alerting
- Arms control
- Disarmament

Time for decision-making

seconds  minutes  hours  days  weeks  months  years
The Threat of Accidental Nuclear War – 20 Dangerous Incidents

1) November 5, 1956: Suez Crisis Coincidence

2) November 24, 1961: BMEWS Communication Failure


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) January, 1995: Russian False Alarm

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

Flight of a MIRV’d ICBM (Schematic)
Flight of a MIRV’d ICBM (Schematic)

1. The missile launches out of its silo by firing its 1st stage boost motor (A).
2. About 60 seconds after launch, the 1st stage drops off and the 2nd stage motor (B) ignites. The missile shroud is ejected.
3. About 120 seconds after launch, the 3rd stage motor (C) ignites and separates from the 2nd stage.
4. About 180 seconds after launch, 3rd stage thrust terminates and the Post-Boost Vehicle (D) separates from the rocket.
5. The Post-Boost Vehicle maneuvers itself and prepares for re-entry vehicle (RV) deployment.
6. The RVs, as well as decoys and chaff, are deployed during backaway.
7. The RVs and chaff re-enter the atmosphere at high speeds and are armed in flight.
8. The nuclear warheads detonate, either as air bursts or ground bursts.
Schedule Midterm Review

Please click

A if “can’t make time”
B if “can make time but inconvenient”

(1) Saturday, March 15, 5-7pm
(2) Saturday, March 15, 6-8pm
(3) Saturday, March 15, 7-9pm

A B

(4) Sunday, March 16, 5-7pm
(5) Sunday, March 16, 6-8pm
(6) Sunday, March 16, 7-9pm

A B

(7) Tuesday, March 15, 5-7pm
(8) Tuesday, March 15, 6-8pm
(9) Tuesday, March 15, 7-9pm