Boost-Phase Intercept Systems for National Missile Defense

Scientific and Technical Issues

Report of the American Physical Society Study Group

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Report on the APS Study of Boost-Phase Intercept Systems

Goal: To help the country make the best possible choices about missile defense

- Questions addressed and the approach used
- Summary of the Study Group's findings
- Explanation of findings concerning
  - Systems using land-, sea-, or air-based interceptors
  - Systems using space-based interceptors
  - Systems using the Airborne Laser
- Other issues
  - Impact of possibly live munitions short of the target
  - Countermeasures to boost-phase intercept
- Summary of findings

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Why is There Interest in Boost-Phase Intercept?

- Midcourse intercept appears very challenging
- Boost-phase intercept has been described as easier
  - ICBMs are described as slowly-moving, fragile targets
  - ICBMs have bright exhaust plumes that are easy to track
  - An ICBM is a unitary target if it can be intercepted before it deploys its warheads
  - It is usually assumed that there are few if any effective countermeasures to boost-phase intercept
- It is therefore argued that boost-phase intercept . . .
  - Is an attractive alternative to midcourse intercept, or
  - Would reduce the challenge faced by the midcourse layer if it were the first layer of a layered defense

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Key Issues for Boost-Phase Intercept

- ICBM boost phases are short (4 min liquids, 3 min solids)
  - Defense has little time to decide whether to fire
  - Interceptors have little time to reach the ICBM
- ICBMs in powered flight accelerate unpredictably
  - Burn variations, energy management, programmed evasion
  - Interceptors would have to be fast and agile
- Geographical constraints require high interceptor speeds
  - Intercept points for ICBMs from North Korea and Iran are 500 to 1,000 km from potential interceptor basing locations
- A successful intercept is unlikely to destroy warheads
  - Live warheads could impact the United States or U.S. friends and allies ("shortfall management problem")

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The Study Group's Approach

- Relied on the threat assessments in recent National Intelligence Estimate summaries and Congressional testimony by NIC staff
- Considered a range of possible goals for the defense (defending all 50 states, only the largest cities, only one coast, only Hawaii, ...)
- Made generally optimistic assumptions about the performance of boost-phase defense systems:
  - Assumed the attacker would have only early-1960s technology
  - Assumed the defense would be able to deploy the most advanced technology available ten years from now
  - Set aside all battle management, communications, command, control, lethality, and reliability issues and countermeasures
- Constructed computer models of missiles, missile tracking systems, interceptors, and kill vehicles
- Carried out simulations to determine the performance that would be required for the systems we examined to work

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Why Solid-Propellant ICBMs Should Be Considered

- The two fundamentally different types of ICBMs (liquid- and solid-propellant) present different challenges
- Although North Korea might initially deploy liquid-propellant ICBMs, recent NIE summaries point to significant transfer of solid-rocket technology among North Korea, Iran, Pakistan, China, and other countries of concern
- According to the most recent U.S National Intelligence Estimate, countries of concern could deploy solid-propellant ICBMs within the next decade if they were able to purchase or acquire solid-propellant missiles or technology
- It would take at least a decade for the United States to field a boost-phase defense
- Therefore, a defense effective only against liquid-propellant ICBMs would risk being obsolete when deployed

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Why Our Results Differ From Other Studies

- Considered liquid-propellant ICBMs based on 40-year-old technology but did not assume they would have very long (300+ second) boost phases
- Considered solid-propellant ICBMs based on 40-year-old technology
- Did not assume the defense is "omniscient"
  - *Did* assume ICBM's performance characteristics are known exactly (but they may not be)
  - *Did not* assume knowledge of the attacker's intent
    - » Initial direction of flight and target unknown in advance
    - » ICBM's flight path not known in advance
- Carefully analyzed kill-vehicle performance required to intercept an accelerating ICBM
- Carefully examined technologies likely to be in hand in 10 years and their implications for interceptor and kill-vehicle performance

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Key Findings

- Defending the 50 states against *liquid-propellant* ICBMs from North Korea may be feasible, but would push the limits of what is possible physically, technically, and operationally
- Defending the 50 states against *liquid-propellant* ICBMs from Iran might be possible but would be much more challenging
- Defending the 50 states against *solid-propellant* ICBMs is unlikely to be practical when all factors are considered
- Defending only the West Coast against ICBMs from North Korea would be easier than defending all 50 states
- Defending only part of the United States against ICBMs from Iran would not be easier than defending all 50 states

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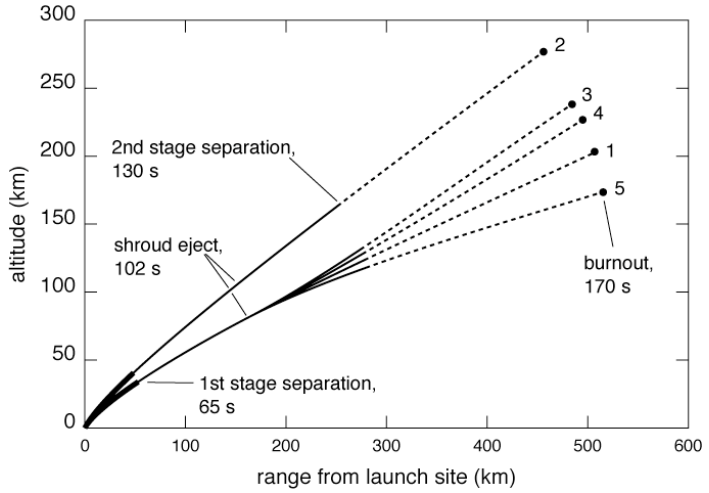
Hitting the ICBM

- Found no fundamental obstacle to developing adequate kill vehicles
- But kill vehicles would have to be very capable and therefore heavy (~100 kg)

ICBMs Fly in Unpredictable Ways



Hitting the ICBM Requires Highly Capable Kill Vehicles

- The kill vehicle must have sensors capable of tracking the missile body in the face of the very bright exhaust plume which is displaced from it
  - Passive infrared, optical, and UV sensors
  - Active sensors such as LIDAR
- The kill vehicle must be able to compensate fully for changes in the flight of the target missile
  - Adequate total divert capability (2.0 to 2.5 km/s)
  - Sufficient acceleration for the endgame (15 g)
  - Fast guidance and control and quick dynamic response (0.1 s or less total lag)
- Kill vehicles with these capabilities would be relatively heavy (90–140 kg)
  - Carrying out simulations to determine the performance that would be required to make a given system architecture work

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Reaching the ICBM

- Only 2 min (solids) or 3 min (liquids) would be available to achieve intercept even with a state-of-the-art space-based detection and tracking system
- Consequently the defense would have only seconds to decide whether to fire
- Even fast interceptors could have difficulty reaching ICBMs in time

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Feasibility Depends on ICBM Type and the Global and Regional Geography

- The time available to intercept depends strongly on whether the ICBM is a liquid-propellant or a solid-propellant missile
- Global geography determines how early the ICBM must be intercepted
- Regional geography determines how close to the ICBM's flight path interceptors could be based
- These three factors force interceptors to be based far from the intercept point, near the limits of their range (<5,000 km [solid] or <7,000 km [liquid]), and to intercept the ICBM at the last possible moment

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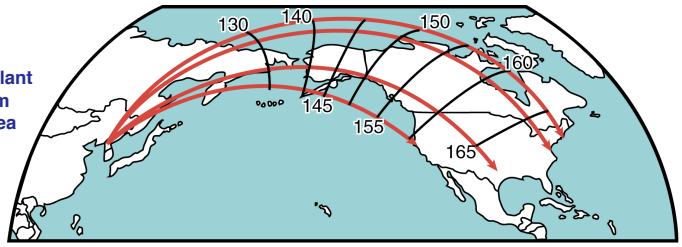
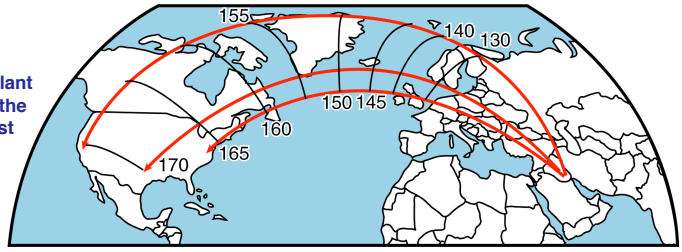
Global Geography Determines How Early the ICBM Must Be Intercepted

Solid-propellant ICBM from North Korea



Solid-propellant ICBM from the Middle East



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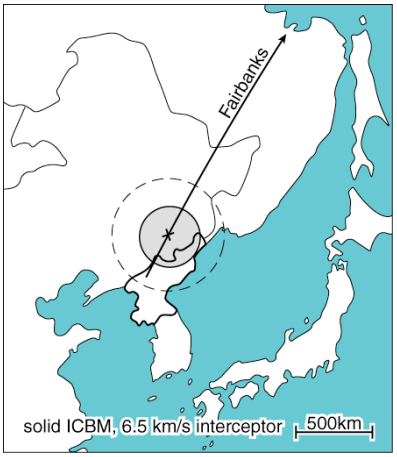
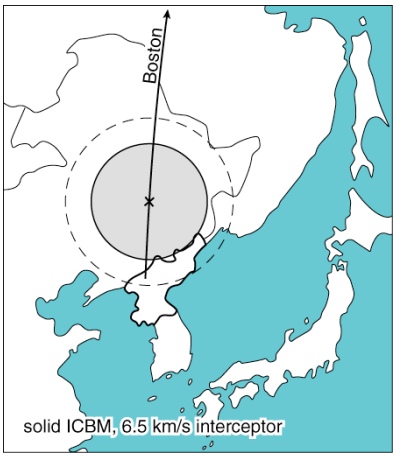
Regional Geography Determines How Close Interceptors Could Be Based



Basing areas for intercepting a solid-propellant ICBM from North Korea to Fairbanks



Basing areas for intercepting a solid-propellant ICBM from North Korea to Boston

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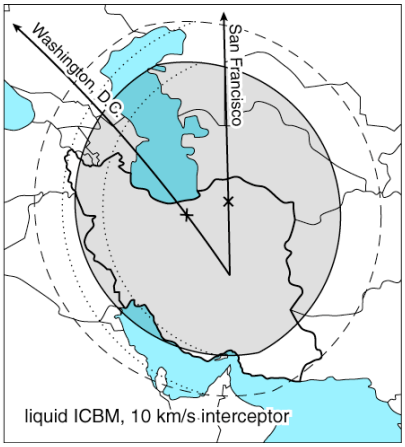
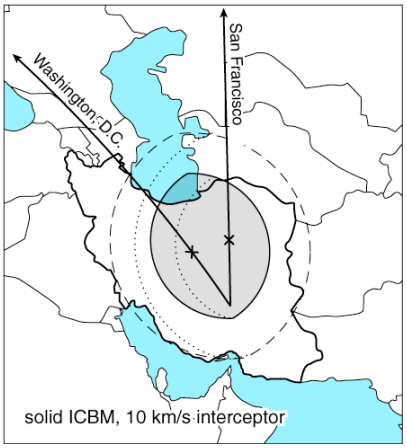
Regional Geography Determines How Close Interceptors Could Be Based



Basing areas for intercepting a liquid-propellant ICBM from Iran to the Lower 48 States



Basing areas for intercepting a solid-propellant ICBM from Iran to the Lower 48 States

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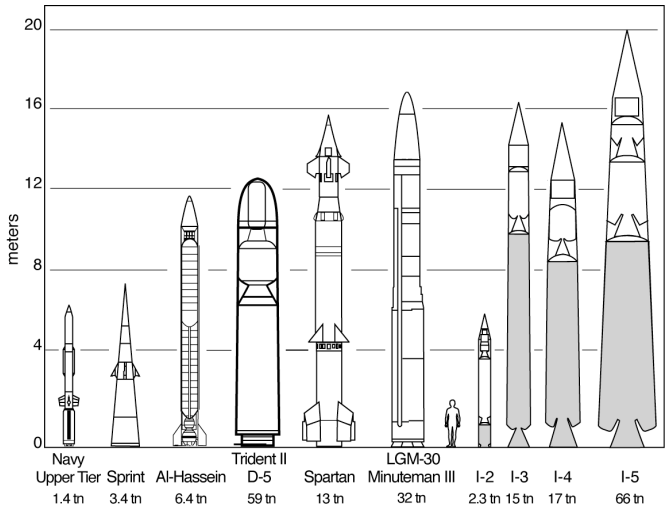
Reaching the Target Demands Large, Fast Interceptors



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Feasibility of Defending the U.S. Using Hit-to-Kill Interceptors

- Defending the 50 states against *liquid-propellant* ICBMs from North Korea may be feasible, but would push the limits of what is possible physically, technically, and operationally
- Defending the 50 states against *liquid-propellant* ICBMs from Iran might be possible but would be much more challenging
- Defending the 50 states against *solid-propellant* ICBMs is unlikely to be practical when all factors are considered
- Defending only the West Coast against ICBMs from North Korea would be easier than defending all 50 states
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Implications of Time Constraints

The very short time available to complete the intercept poses significant command-and-control issues—

- In some situations the decision whether to fire interceptors would have to be made within a few seconds after a firing solution was obtained
- There would generally be too little time to determine using the system's sensors whether the rocket is an attacking ICBM, a theater ballistic missile, or a rocket launching a satellite
- Consequently, interceptors would have to be fired whenever a large rocket in powered flight is detected, without waiting until the nature of the rocket or its trajectory is established
- Giving commanders the ability to divert or destroy interceptors in flight might extend the assessment time by 100 seconds or so

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Assumptions for the SBI Results Presented Here

- SBI orbits have 45° inclinations
- Required a high probability that one interceptor is within range of a single ICBM for launch sites between 35° and 45° north latitude (on average, two interceptors are within range of a launch site)
- Interceptors are stationed at an altitude of 300 km
- The missile is a solid-propellant ICBM similar to our model SS2
- The interceptor is fired with zero decision time (45 sec after ICBM launch)
- The last chance to intercept is 5 sec before burnout
- Intercepts take place at an altitude of 200 km

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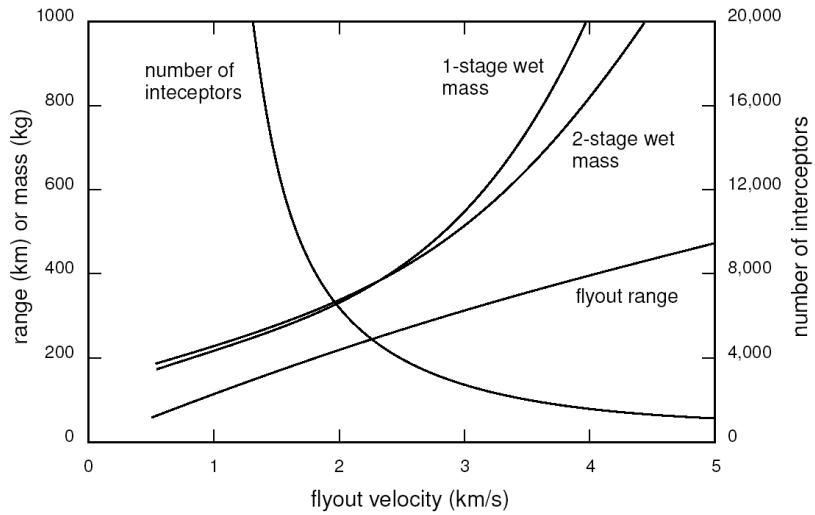
BPI Mass, Range, and Constellation Size as Functions of Flyout Velocity



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Tradeoff Between Flyout Velocity, Decision Time, and Constellation Size

Table 6.2. Number of Interceptors as a Function of v_{flyout}, Decision Time, and Geography against Solid-Propellant ICBM S1[a]

	Baseline case		Defend U.S. from Iran	
v_{flyout} (km/s)	Zero Decision time	30-second delay	Zero Decision time	30-second delay
3	2,800	6,100	3,700	12,400
4	1,600	3,600	2,000	5,700
5	1,100	2,600	1,400	3,700

[a]The number of SBIs required to intercept solid-propellant ICBM S1 as a function of flyout velocity and decision time for two different cases: the baseline case where the ICBM is intercepted 5 s before burnout, and the case where it is intercepted 10 s before burnout, which is what would be required to defend the entire United States against an attack by Iran. In all cases, the interceptor has an average flyout acceleration of 10 g.

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Tradeoff Between Flyout Velocity, Decision Time, and Mass-In-Orbit

Table 6.3. Mass-in-Orbit as a Function of v_{flyout}, Decision Time, and Geography against Solid-Propellant ICBM S1[a]

v_{flyout} (km/s)	Baseline case: Zero decision time	Baseline case: 30-second delay	Defend U.S. from Iran: Zero decision time	Defend U.S. from Iran: 30-second delay
3	2,200	4,700	2,900	9,700
4	2,000	4,500	2,500	7,000
5	2,300	5,200	2,700	7,500

[a]The mass in tonnes of SBIs required to intercept solid-propellant ICBM S1 as a function of flyout velocity and decision time for two different cases: the baseline case where the ICBM is intercepted 5 s before burnout, and the case where it is intercepted 10 s before burnout, which is what would be required to defend the entire United States against an attack from Iran. In all cases, the interceptor has an average flyout acceleration of 10 g.

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Space-Based BPI Would Require Many Large Satellites

- **Placing interceptors in space would avoid geographic restrictions on basing, but global geographic constraints would still determine when ICBM must be intercepted**
- **To counter *solid-propellant ICBMs*, at least 1,600 interceptors would be required, each at 840 kg, for a minimum mass in orbit of 2,000 tonnes**
  - **Would require a 5- to 10-fold increase in annual U.S. space launch capability**
- **To counter *liquid-propellant ICBMs*, roughly half as many interceptors and space launches would be required**
  - **However, designing a defense for only such missiles runs risk of early obsolescence**

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The Airborne Laser Would Have Limited Range Against ICBMs

- ABL range would not be limited by time, but by the distance a focused beam could be propagated through the atmosphere
- In principle, the ABL could be used against ICBMs, if the laser works as advertised
- The ABL would have a range up to 600 km against a liquid-propellant ICBM
  - Would work against North Korea, but not Iran unless ABL aircraft could fly over lower Caspian Sea or Turkmenistan
- The ABL would have a range of only 300 km against a solid-propellant ICBM
  - Would not be effective in any of the scenarios we examined

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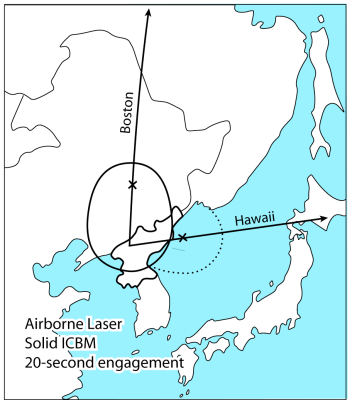
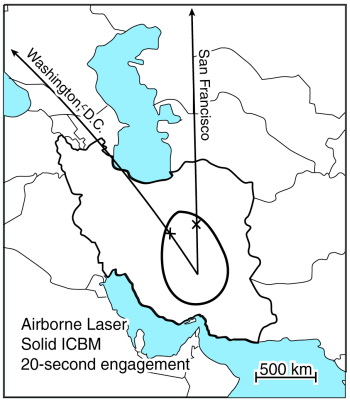
The Airborne Laser Would Have Limited Range Against ICBMs

Basing areas for intercepting a solid-propellant ICBM from North Korea



Basing areas for intercepting a solid-propellant ICBM from Iran



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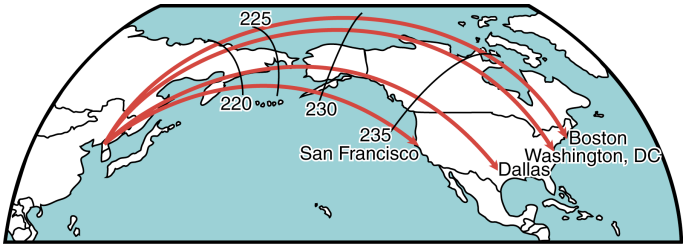
Shortfall Would Be Difficult to Manage



- A problem inherent in boost-phase defense is that preventing a missile's munitions from impacting their target could cause live nuclear, chemical, or biological weapons to impact populated areas short of their target, in the United States or other countries
- Timing intercepts accurately enough to avoid causing this would be very difficult, if it's possible at all
- An alternative would be to design the interceptor to destroy all warheads or submunitions, but this is likely to be difficult

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Possible Countermeasures to Boost-Phase Intercept

- A boost-phase defense would not be susceptible to some of the proposed countermeasures to a midcourse defense, but it would face countermeasures
- Some countermeasures to both hit-to-kill and the ABL
  - Launch several ICBMs nearly simultaneously
  - Deploy solid-propellant ICBMs
- Some countermeasures to hit-to-kill
  - Deploy payload during powered flight
  - Program evasive maneuvers
  - Deploy decoys and jammers
  - Deploy fast-burn boosters with multiple upper stages
  - Mask the kill-vehicle aim point (to defeat warhead kill)
- Some countermeasures to the ABL
  - Attack the airframe
  - Roll the ICBM
  - Use ablative coating
  - Change the optical properties of the ICBM

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Where Boost-Phase Defense Could Be Effective

- Intercepting short- and medium-range ballistic missiles launched from ships off the coast of the United States
  - Could use interceptor similar to existing Standard Missile 2 launched from Aegis ships
  - Would require the ship carrying interceptors to stay within 400 km or so of the threatening ship
- Providing an incomplete first layer for a multi-layered defense against ICBMs
  - Could intercept some ICBMs before they deployed their warheads and midcourse countermeasures
  - Might provide increased protection for some areas of the United States, but not others (one coast or the other)
  - Would require the midcourse system to handle the unpredictable debris generated by a boost-phase intercept. Such a capability remains to be studied or proven

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Summary of Findings

- Hit-to-kill interceptors could potentially defend the United States against liquid-propellant ICBMs launched from some countries
- Boost-phase defense against solid-propellant ICBMs is unlikely to be practical during the next decade, when all factors are considered
- A boost-phase defense against short-or medium-range missiles launched from platforms off U.S. coasts appears feasible
- Space-based BPI unlikely to be feasible until kill-vehicle masses could be reduced substantially
- The ABL's range is likely to be too short for it to be useful except against liquid-propellant ICBMs from North Korea
- Countermeasures are possible and should be expected

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