An Air-Based Counterproliferation Campaign Against North Korean Nuclear Infrastructure

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17.483 *US Military Power*

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§1: Background

§1.1 History

The Democratic People's Republic of Korea (DPRK), also known as North Korea, is a small and impoverished country in East Asia. North Korea emerged to the global scene at the close of World War II with the division of the Korean peninsula at the 38th parallel, separating the Soviet Union in the North from the United States in the South. Since then, South Korea has symbolized an outpost of western allyship in East Asia akin to the relationship between the US and Japan since 1951[1].

Supreme Leader Kim-Jong Un, along with the rest of the DPRK government officials, stands accused of grave crimes against humanity. Human rights abuses[2] are rampant throughout the country, most notably including forced labor, enforced disappearances, a harshly administered suppression of free expression, and widespread severe economic insecurity.

The largest and most obvious obstacle to confrontation with North Korea is the DPRK's nuclear arsenal. It is estimated that North Korea is in possession of between 30 and 40 nuclear warheads, which, combined with the knowledge that it also possesses dozens of ballistic missiles, indicate

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[1] "U.S. Relations With Japan." n.d. *United States Department of State* (blog). https://www.state.gov/u-s-relations-with-japan/.

[2] Human Rights Watch. 2020. "North Korea: Events of 2020." In *World Report 2021*. https://www.hrw.org/world-report/2021/country-chapters/north-korea.

that the DPRK has the capacity to levy apocalyptic levels of damage against its neighbors and allies of the US.

In the era of nuclear deterrence, it is an interesting and necessary undertaking to investigate the strategic options at a nation's disposal to advance counterproliferation goals around the world. The rogue state of North Korea has gone to great lengths to boast its expansive arsenal of nuclear weapons. Between 1984 and 2022, the DPRK launched over 170 nuclear missile tests[3] and continues to organize massive parades brandishing nuclear weapons[4] in broad daylight.

§1.2 Scenario

It is May 2022 and North Korea has recently tested another intercontinental ballistic missile for the first time since 2017[5]. The United States and its allies have issued verbal warnings to the DPRK, but have indicated no explicit intention to commence a military strike of any kind against elements of the North Korean nuclear arsenal.

We introduce a nominal joint task force between the United States, South Korea, and Japan[6], known as the Coalition for East Asian Freedom (CEAF). Under the guise of routine practice drills and bilateral operations with the Japan Maritime Self-Defense Force, the USS Abraham

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[3] "The CNS North Korea Missile Test Database." n.d. *The Nuclear Threat Initiative* (blog). https://live-nuclear-threat-initiative.pantheonsite.io/analysis/articles/cns-north-korea-missile-test-database/.

[4] Johnson, Jesse. 2022. "North Korea's Kim Uses Massive Military Parade to Deliver Nuke Warning." The Japan Times. April 26, 2022. https://www.japantimes.co.jp/news/2022/04/26/asia-pacific/north-korea-parade-kim-nuclear/.

[5] "North Korea Fires First Suspected ICBM since 2017 - CNN." n.d. https://www.cnn.com/2022/03/24/asia/north-korea-missile-test-intl-hnk/index.html.

[6] In our operating assumptions, we impose a restriction on the involvement of Japan in this campaign

Lincoln is stationed in the Sea of Japan[7], carrying enough artillery for the US to launch a series of airstrikes against North Korea. The Japan-based US Seventh Fleet is also in proximity to the USS Abraham Lincoln, which serves as the forward base of operations (FOB). In reality, the US and South Korea are preparing to launch a stealthy, air-based campaign against various locations across North Korean soil at which missile launch sites and nuclear research facilities are situated.

The United States, with the backing of South Korea, is planning to launch a surprise air-based bombardment campaign of North Korea's nuclear facilities and missile launch sites. Through satellite imagery from the intelligence network, the US is aware of multiple missile launch sites across North Korean territory, many of which are linked to previous tests. It also possesses known locations of nuclear facilities in North Korea, including nuclear reactors and research centers.

The goal of the coalition will be to gather as much intelligence as possible on the locations of crucial targets in North Korea's nuclear infrastructure, and launch an overnight attack against those targets with the ultimate goal of crippling North Korea's inventory of weapons of mass destruction.

In our study, we ask the question: *Could a coalition task force between the United States and South Korea successfully execute an air-based counterproliferation mission against North Korean nuclear infrastructure?*

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[7] "Carrier USS Abraham Lincoln in Sea of Japan Ahead of Key North Korean Anniversaries." 2022. *USNI News* (blog). April 12, 2022. https://news.usni.org/2022/04/12/carrier-uss-abraham-lincoln-in-sea-of-japan-ahead-of-key-north-korean-anniversaries.

§2: Mission Objectives

§2.1 Operating Assumptions

In order to effectively model our campaign, we establish a set of constraints on the degrees of freedom involved in the conflict at large:

- ❖ There exists a joint counterproliferation force known as the Coalition for East Asian Freedom which has agreed to undertake a military strike on North Korea's armaments
- ❖ Japan, though part of the coalition, will not join the US and South Korea in the fighting, but remains at risk of retaliation from North Korea
- ❖ The People's Republic of China will not intervene militarily in the conflict
- ❖ South Korea's involvement in the campaign is relegated to intelligence and reconnaissance before and after the operation

§2.2 Tactical Requirements

The operation must also proceed conditioned on a set of methodology constraints in order to limit the risk of retaliation and minimize collateral damage. We outline the following requirements:

- ❖ The coalition force should execute the operation with the intent to limit their footprint as much as possible, so as to prevent the immediate possibility of a pointed retaliation as well as to avoid alerting the adversaries of other target sites

- The operation to disable key nuclear facilities must be carried out within a narrow time frame; specifically, the coalition should aim to neutralize all target sites within a timeframe of 2.5 hours overnight
- The operation should be conducted in a manner that allows for verification of neutralization of the various targets, and such that these sites can be searched or surveilled beforehand to provide intelligence on North Korean nuclear capabilities

The above conditions indicate that the mission requires a high speed, stealthy, powerful artillery approach. We will see in the section on coalition capabilities which force structure is most appropriate for this set of goals.

§2.3 Strategic Avenues

In principle, the Coalition for East Asian Freedom is equipped with enough overall firepower that it can commence a broad array of potential military operations against North Korea. The requirements and assumptions outlined in the sections above will rule out many of these approaches, but we comment on some of the major campaign archetypes.

Stratagem:

- <u>Airstrikes on known existing facilities:</u> This option is contingent on there being a majority of nuclear facilities and launch sites which are confirmed with high confidence to exist, as well as those sites being conventional, and not heavily guarded (e.g. in reinforced silos) as is common for nuclear weapons.[8] This strategy is the primary focus of this paper, so we will defer further comments on it to the rest of this paper's sections.

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[8] Keir A. Lieber, Daryl G. Press; The New Era of Counterforce: Technological Change and the Future of Nuclear Deterrence. *International Security* 2017; 41 (4): 9–49. doi: https://doi.org/10.1162/ISEC_a_00273

- ❖ Conventional grounds-force approach: This option is the least appropriate for this mission, because while it allows for more intimate interaction with nuclear targets, it is vulnerable to strong retaliation or insurgency by the adversaries and can catalyze a much larger conflict that will inevitably point towards the US and its allies. This would prevent other targets from being neutralized in a timely fashion, and likely instigate heavy collateral damage in the Korean peninsula. In this scenario, the US 7th fleet would advance westward through the Sea of Japan and launch an amphibious assault on North Korea's eastern coast. For the purposes of this analysis, we do not consider this option.
- ❖ Direct-action raids: This option would involve special operations forces planning and carrying out a chain of covert operations to secure and neutralize nuclear facilities. It allows for a more sensitive approach to the mission (e.g. civilian considerations, intelligence gathering, etc.) but requires an equally sensitive preparation scheme (prior intelligence gathering, very careful entrance and extraction to cover US footprint, etc.) The results of this strategy could also precipitate the first option (airstrikes), but would most likely be conducted in conjunction with an air-based approach, allowing ground operators to serve as strike air controllers. We also do not consider this option in our analysis.

§3. Campaign Planning

§3.1 Threat Analysis

North Korea's Missile Capabilities

North Korea has tested countless missiles of different kinds and at different ranges in recent years, the most significant of which is the ballistic missile. A ballistic missile[9] is a ranged weapon immediately after whose launch is guided and powered by a specific type of fuel, but eventually continues its parabolic trajectory acted upon only by gravity until falling on its target.

While it is understood that North Korea possesses many of these ballistic missiles, it is not well known how many exactly, nor of which type. First, we outline the conventional classification of North Korea's ballistic missiles[10], which groups the missiles into four kinds:

- Short range ballistic missiles (SRBM)
- Medium range ballistic missiles (MRBM)
- Intermediate range ballistic missiles (IRBM)
- Intercontinental ballistic missiles (ICBM)

It is important to note that of the four kinds listed above, the first three are most threatening to the security of territories in the proximity of the DPRK, namely allies like Japan, South Korea, or territories like Guam. The fourth kind possesses the greatest range, and is thereby the type which presents the greatest threat to the continental US.

[9] https://armscontrolcenter.org/wp-content/uploads/2017/04/Ballistic-vs.-Cruise-Missiles-Fact-Sheet.pdf
[10] United States and Defense Intelligence Agency. 2021. *North Korea Military Power: A Growing Regional and Global Threat.* https://purl.fdlp.gov/GPO/gpo172971.

For each system class, North Korea operates various modifications of the missile type with slightly varying properties. It is largely unknown how each system class of missiles is distributed across the country's numerous launch sites and storage facilities.

§3.2 Target Selection

There are numerous research facilities, storage centers, missile launchers, and nuclear testing grounds scattered across North Korea, all of which contribute in different ways to the country's outward nuclear threat. The goal of this section is to identify targets that are crucial to the North Korean nuclear infrastructure, and subsequently prioritize the targets according to a scheme commensurate with the ambitions of the United States and CEAF.

To prioritize targets, we first divide the set of all potential targets across North Korea into equivalence classes, i.e. groups of targets serving similar purposes. We then execute a qualitative prioritization of these classes at a high level. Once the target classes are prioritized, we proceed to select targets that pertain to each class and rank the importance of each individual target to the mission according to a quantitative scheme.

Our two equivalence classes of targets are:

1. Missile launch sites
2. Nuclear research & development facilities

Missile Launch Sites

Numerous launch sites populate different regions of North Korean territory, many of which are undeclared by the DPRK. Analysts estimate that up to 19 undeclared launch sites exist in North Korea[11]. For this study, we select 6 launch sites identified via satellite imagery as targets.

Target launch sites:

- Tongchang-ri: ICBM launch site
- Sino-ri: undeclared missile base
- Sangnam-ni: undeclared missile base
- Tonghae
- Hoejung-ni
- Yusang-ni

Data on the inventory of North Korea's ballistic missiles is scarce, and even more so for the capacity of individual launch sites. In order to rank the sites, we consider the following factors:

- distance of the target from the forward operating base (FOB)
- relative size (as a proxy for missile capacity) of the facility
- Complexity, based on factors such as terrain and civilian proximity

For each factor, we assign a score and compute weighted sums to determine an overall priority score, according to the following equation:

$$\pi = \vec{w} \cdot \vec{x} = \sum_i w_i x_i$$

[11] Ballistic and Cruise Missile Threat (2020)

π is the priority score of each location, and the normalized weights vector $\vec{w}$ reflects the choices of the modeler to reflect which factors x_i are most important when incorporated into the sum over all i factors.

For our analysis, we choose the weights vector to be $\vec{w} = (0.05, 0.45, 0.35, 0.15)$. The priority scores for each target are collected below:

Site Name	**FOB Distance**	**Capacity**	**Collateral**	**Terrain**	**Score**
Hoejung-ni	2	3	3	2	2.80
Tonghae	3	2	2	3	2.20
Sangnam-ni	3	1	3	1	1.80
Sino-ri	1	2	2	2	1.95
Sohae	1	2[12]	2	3	2.10
Yusang-ni	1	3	1	3	2.20

Figure 1: Attribute scores and overall priority scores for six missile launch sites

Target priority ranking:

1. Hoejung-ni
2. Tonghae (tied for 2)
3. Yusang-ni (tied for 2)
4. Sohae
5. Sino-ri
6. Sangnam-ni

[12] Could also use 3, but apparently this base was partially dismantled

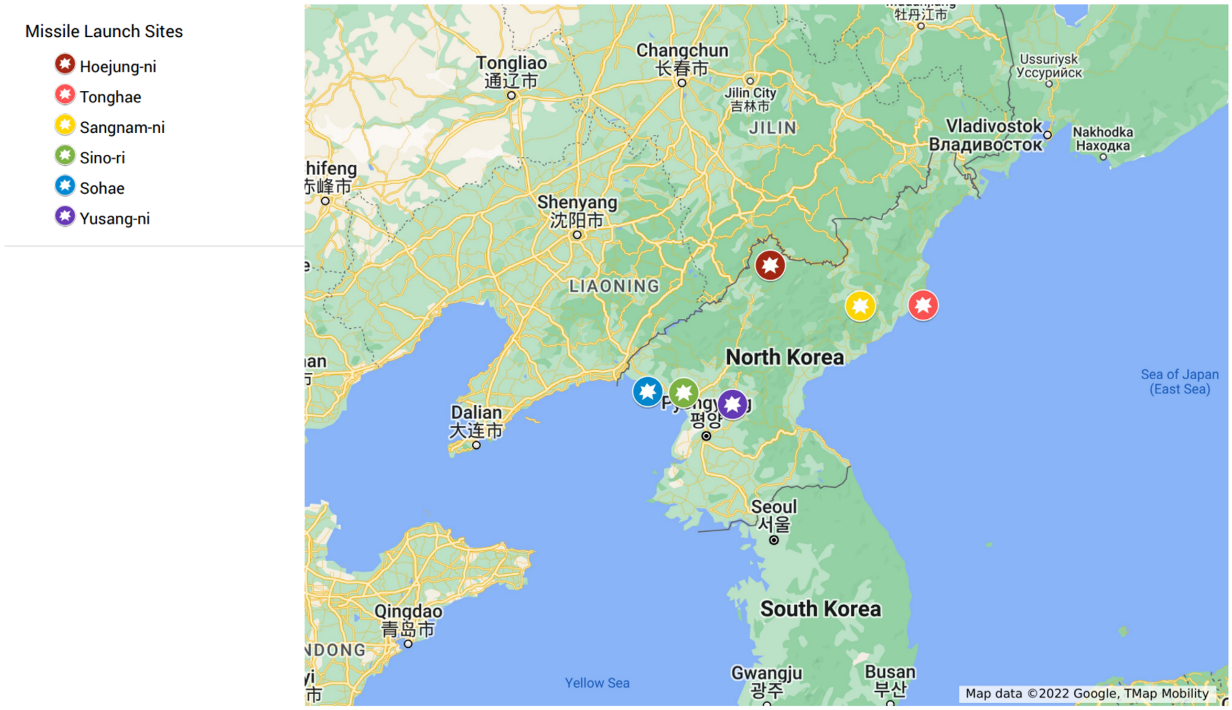

Figure 2: Map[13] of the six selected missile launch sites

Nuclear R&D Facilities

The next class of targets we consider is the nuclear facilities harbored in different parts of North Korea, forming a critical part of the country's nuclear infrastructural backbone. We select six prominent nuclear facilities, organized alphabetically below:

- Kangson covert uranium enrichment site
- Pakch'on Atomic Energy Research Center
- Punggye-ri underground nuclear test site
- Pyongyang Institute of Nuclear Physics
- Taecheon Nuclear Power Plant
- Yongbyon nuclear reactor, power plant, and research facilities

[13] Made available by the author via Google maps here

The factors we consider for deciding which targets to prioritize are now as follows:

- Collateral damage
- Terrain viability
- Research and/or energy output

This time, we let the weights vector be $\vec{w} = (0.05, 0.40, 0.40, 0.15)$ to reflect the slightly lower level of urgency to address progressing research compared with already-existing weapons of mass destruction, and the greater attention to collateral damage. With the same methods as for the missile launch sites, we assign values and weights to each attribute, computing the weighted sum to arrive at overall priority scores for each target:

Facility	FOB Distance	Output	Collateral	Terrain	Score
Kangson	1	3	1	1	1.80
Pakch'on	1	1	3	3	2.10
Punggye-ri	3	2	2	2	2.05
Pyongyang	1	3	1	2	1.95
Taecheon	1	1	2	1	1.40
Yongbyon	2	3	2	2	2.40

Figure 3: Attribute scores and overall target priority scores for six nuclear sites

Target priority ranking:

1. Yongbyon
2. Pakch'on
3. Punggye-ri

4. Pyongyang
5. Kangson
6. Taecheon

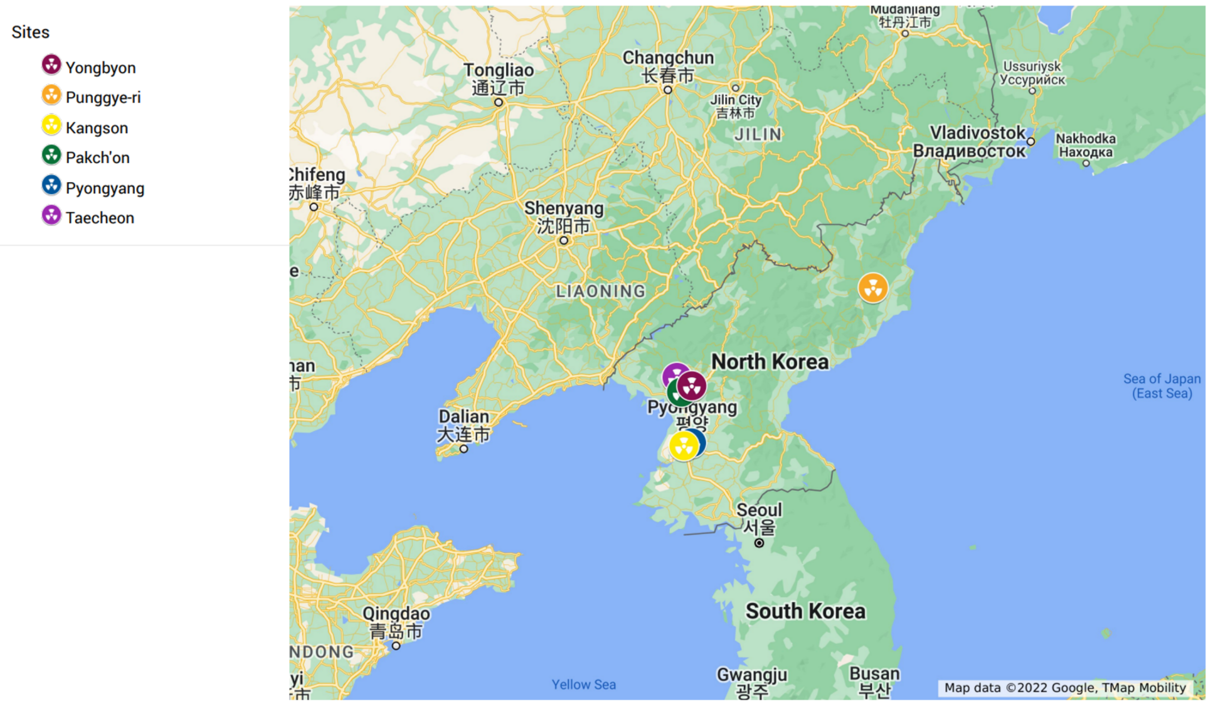

Figure 4: Map[14] of six selected nuclear facilities in North Korea

§3.3 Coalition Capabilities

As per the mission objectives, the goal is to execute an unannounced airstrike against elements of the North Korean nuclear infrastructure while limiting the footprint of the United States in the attack. Given the conditions, stealth bomber aircrafts are most suited to this mission.

In this section we will outline the capabilities available to the coalition, and delineate roles for each of the operators according to a force structure.

[14] Available by author online here

Overview of Available Airpower

The B-2 bomber

The B-2 Spirit is a highly capable stealth bomber. The B-2 has a substantially high probability of evading North Korea's detection technology due to its reduced infrared, acoustic, and electromagnetic signatures[15]. Additionally, the B-2 will be most useful in penetrating the more heavily defended targets in North Korea's nuclear arsenal, such as those underground or encased in concrete silos. The B-2 has a range of 6000 kilometers, which will not present any difficulties given the proximity of the forward operating base to the targets. The B-2 has a top speed of 628 mph, and has the capacity to carry up to 40000 pounds of weapons. There are currently twenty B-2s in operation in the US Air Force.

It can carry the following bombs:

- Up to 16 joint directed attack munition (JDAMs) satellite-guided 2000 lb bombs
- Up to two 30,000 pound Massive Ordnance penetrator (MOP) bombs for attacking hardened targets

The B-1 Bomber

The B-1B is an intercontinental, multipurpose, long range bomber. It possesses electronic jamming equipment[16], also enabling it to disrupt North Korean air defense technology to some degree. It is capable of flying lower and faster while carrying a larger payload[17]; the B1-B has a

[15] "B-2 Spirit." n.d. Air Force. https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104482/b-2-spirit/.

[16] "B-1B Lancer." n.d. Air Force. https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104500/b-1b-lancer/.

[17] "B-1B Lancer - United States Nuclear Forces." https://nuke.fas.org/guide/usa/bomber/b-1b.htm.

top speed of 670 mph and can carry up to 15 500-pound GBU-38 JDAMs. There are currently 62 active B-1Bs in the US Air Force.

F-35 and F-22

The F-35 Lightning II is a high performance, stealth-enabled multirole fighter. The most valuable feature of the F-35 is its extensive range of electronic warfare (EW) capabilities. The F-35 is equipped with radio-frequency and infrared countermeasures[18], and its ability to operate efficiently within signal-dense environments empowers the F-35 to serve effectively as a surveillance aircraft when necessary.

The F-22 Raptor, like the F-35, also possesses robust EW capabilities. The primary difference between these two aircrafts is that the F-22 is able to operate at higher altitude and higher speed[19]. In our model, these two aircrafts will complement one another in the field of EW and battlefield surveillance.

Overview of Available Naval Capabilities

The USS Abraham Lincoln

The USS Abraham Lincoln is a nimitz-class nuclear-powered aircraft carrier. USS Abraham Lincoln can carry 90 aircraft models[20], allowing it to easily accommodate a reasonable inventory

[18] "AN/ASQ-239 F-35 EW Countermeasure System." n.d. BAE Systems | International. https://www.baesystems.com/en/product/an-asq-239-f-35-ew-countermeasure-system.

[19] "F-22 Raptor." n.d. Air Force. https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104506/f-22-raptor/.

[20] "USS Abraham Lincoln - Nimitz Class Aircraft Carrier." n.d. *Naval Technology* (blog). https://www.naval-technology.com/projects/abraham-lincoln-nimitz-class-aircraft-carrier/.

of the aircrafts outlined in the previous sub-section. The vessel can also accommodate up to 5,680 people.

Intelligence Capabilities of the South Korean Military

As per our operating assumptions, South Korea's role in the campaign is limited to providing intelligence support. Given the nature of the mission, this means that South Korea would provide surveillance in the weeks leading up to the assault, and perhaps afterwards in the event that North Korea's retaliation is prolonged.

The importance of pre-operation reconnaissance cannot be understated, and an airstrike against North Korea is a mission for which surveillance is crucial to preparation. In selecting targets, we made the implicit assumption that those sites we chose are the only six operating in North Korea; however, there are known to be many more undeclared sites. If such sites are overlooked when planning a counterproliferation mission, then if even one site slips through detection, North Korea has all it needs to levy a catastrophic counterattack.

Post-operation reconnaissance is significant insofar as a relatively gentle retaliation follows in the wake of the campaign. If North Korea retaliates by launching a ballistic missile at Seoul, for instance, then South Korea will be in no position to send surveillance equipment into North Korea, nor would there be any point.

Nonetheless, we list some of the intelligence equipment[21] South Korea possesses:

[21] "Republic of Korea Air Force (2021)." n.d. https://www.wdmma.org/republic-of-korea-air-force-south-korea.php.

- RQ-4 Global Hawk
    - High-altitude, remotely-piloted recon and surveillance aircraft
- RC-800 Geumgang
- RF-16 Saemae
    - KF-16 based recon aircraft

§3.4 Mission Course of Action

In this section we explain the force structure necessary to complete the operation. We outline the task delineation for the forces involved, and provide a timeline estimate of the mission's course.

Force Structure

The aircrafts to be deployed in this operation, as well as their respective armaments, are listed below.

- B2-Spirit stealth bombers (6x)
    - Utilizing MOP (2x each)
- B-1B bombers (6x)
    - Utilizing GBU-38 JDAM (5x each)
- F-35 Lightning II (4x)
    - Utilizing built-in EW and surveillance equipment
- F-22 Raptor (2x)
    - Utilizing built-in EW equipment

Mission Tasks & Timeline

The first wave of the mission will begin with all six B-2 bombers taking off from USS Abraham Lincoln at 02:00 Seoul time. The B-2s will fly over the Sea of Japan towards each of their respective targets, and collectively arrive at their target sites approximately 1.25 hours after departing the FOB. Once at the targets, the B-2 bombers will each deploy their two MOPs on the launch sites and quickly exfiltrate North Korean airspace. Wave 2 finishes upon the return of all B-2 bombers to FOB, estimated to occur at 04:35.

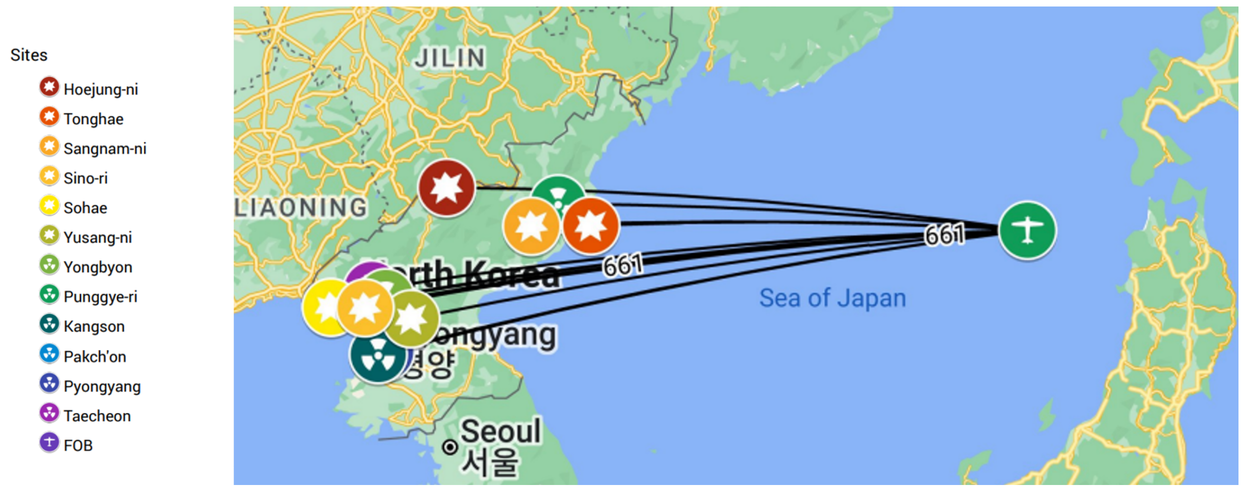

Figure 5: A map[22] of all targets, showing connected paths from FOB to each

Wave 2 commences ten minutes after the B-2s have departed, with a squadron of four F-35s departing the FOB and proceeding across the Sea of Japan. The squadron of F-35s separates into two groups of two units, with each group assuming the role of battle damage assessment of a set of three of the six targets. The F-35s will use their advanced sensory capabilities to assess the damage wrought by the kinetic weapons deployed by the B-2s. To support the F-35 squadron, two F-22s will take off immediately after the F-35s, accelerating to a greater velocity and ascending to a higher altitude. After overtaking the F-35s, the paths of the F-22s diverge,

[22] Online map available here

allowing each unit to approach two separate clusters of target sites: the greater Pyongyang region, and the northern frontier of North Korea (encompassing the four northernmost targets on the map). The F-22s will then descend to an appropriate altitude so as to detect enemy radars, geolocating them for the F-35s which are en route to employ their offensive electronic capabilities. The F-35 pairs will each enter their regions of operation and jam the signals of adversarial satellites and air defenses before returning to the FOB.

Finally, wave 3 begins with six B-1 bombers taking off from the FOB and proceeding to their nuclear site targets. Their deployment in the final wave reflects the lower priority of this target class as compared to the missile launching sites. It is expected that by the time the B1-Bs cross over into North Korean airspace, the DPRK will already be aware of the attack underway. However, with successful results from team 2, the B1-Bs will be largely unencumbered by North Korean air defenses or detection technologies, as these will have been largely disabled by the F-35 squadron beforehand. Upon arrival over their respective targets, the B-1Bs will launch five GBU-38 JDAMs at their targets before retreating to the FOB.

A clearer timeline providing clarity on the overlaps between the timeframes of the different operator teams is presented in the table below.

TIME	TEAM 1	TEAM 2 (A|B)	TEAM 3
0200	depart FOB	-	-
0210	in transit	depart FOB	-
0215	in transit	in transit	depart FOB
0315	strike target sites	in transit	in transit
0320	depart target site	geolocate | in transit	in transit

0325	in transit	in transit | EW	in transit
0330	in transit	in transit	strike target sites
0435-0450	return to FOB	return to FOB	return to FOB

Figure 6: Timeline of strike team courses of action; time given in GMT +9 (Seoul local time)

§4. Modeling the Campaign

To study the feasibility and effects of the proposed course of action, we implement a parameterized, data-generative computational model to track the results of multiple iterations of the campaign. The model is parameterized by many factors governing the intrinsic properties of the equipment used as well as the terrain being advanced upon. We execute our model construction using Python code[23].

§4.1 Formulating the Model

For our purpose of simulation, we ignore all but phase one of Operation Hadronic Storm, in which B-2 bombers launch a stealth bombardment against six missile launch facilities across North Korea. In future studies, the other components of this operation can be implemented in the model and explored as well.

To begin formulating our simulation, we create simple representations of the B-2 bombers. The main quantity parameterizing our aircrafts is the accuracy with which they launch precision-guided missiles at targets. In our case, the B-2 bombers are each equipped with two Massive Ordnance Penetrator (MOP) bombs. We take the accuracies of the two bombs to be

[23] I have made public the repository of code I wrote to simulate this campaign.

independent random variables, each distributed normally with a mean of 93% and a standard deviation within 1%. These numerical choices are somewhat arbitrary but are meant to reflect the precision of the B-2 bomber. Another variable we introduce is the average speed of the bomber, which we take to be normally distributed around a mean of 620 miles per hour and with a standard deviation 5 miles per hour. There are many other parameters we can set for the aircrafts as well as various probability distributions from which to choose to estimate parameters, but for simplicity we proceed from here.

The next component of our model is to establish the targets, which are the same six targets enumerated earlier in the paper. For each of these targets, we assign three numerical parameters:

- **Margin** = the area over across which a target's main facilities are spread, expressed as a percentage of a unit-radial area
- **Population** = a very rough estimate of the population in areas inside and surrounding the target's vicinity, extrapolated from terrain and proximity to towns
- **Distance** = the number of miles between a target and the forward operating base

The distance above is computed nearly exactly using online maps. The former two quantities are crude estimates meant only to stand in as numbers for our toy model, but are still chosen to reflect differences among targets in the level of precision required to successfully strike them and the degree to which they are populated. To estimate these, we use the same criteria outlined in the section on target prioritization.

With aircrafts and targets in place, each with appropriate attributes, we move on to modeling the battle plan sequentially. We first model the procedure by which a B-2 bomber leaves base and travels to its target. The speed of the bomber is given by

$$v = v_0 + \epsilon$$

where ϵ is a Gaussian noise term centered around 0 representing uncertainties in the aircraft's actual average speed. Neglecting time spent directly over the target and changing direction, the expected time elapsed t_e between the bomber's departure and its return back to the carrier is calculated kinematically according to the equation

$$t_e = 2\Delta x / v_0$$

where Δx is the target's distance from FOB. We establish a time limit T specific to each target for the corresponding aircrafts to complete their missions, which will serve later on as a metric for evaluating the mission performance as a whole.

For each target, we subsequently allow the aircraft to deploy both of its bombs. We measure whether the target was successfully hit by the bombs based on a simple metric calculated from the accuracies of the two bomb drops. We define an effective destruction range to be the maximum of the two bomb accuracies. We choose a threshold of accuracy (e.g. 93.5%), above which the maximum of the bomb accuracies must be in order for the strike to be considered a successful hit.

This model also takes collateral damage into account, making use of the population estimates defined for each target. The initial number of casualties is modeled as a normal random variable centered around 5% of the population. After this, we compute the additional casualties via the following steps:

- Define an impact spillover rate by the difference in bomb 1's accuracy and the region margin
- Multiply this rate by the remaining population to get the next round of casualties
- Define bomb 2's impact spillover rate the same way
- Multiply bomb 2's spillover rate by the remaining population and add this quantity to the total casualties

For each target, we defer computing a mortality rate until considering the entire campaign, as this percentage will be more meaningful when weighted by the number of residents in each region. The last quantity of interest is the timeframe fidelity, measuring how well each operator stays within their allotted mission time. Lower time elapsed results in better performance, and vice versa. The timeframe fidelity rate is computed as follows:

$$tf = \frac{1}{T}\max(T - t_e, 0)$$

which therefore imposes a hard cutoff for operators who fail to remain under the allotted time.

From the above target airstrike model, we are able to complete the model of the campaign's first phase. We allow the above steps to proceed simultaneously for each of the six targets, and compute the overall mortality rates mr, strike success (hit) rates hr, and timeframe fidelities tf across all of the airstrikes.

To measure the success of our campaign as presented in the model, we define a mission score:

$$MS = 0.4(1 - mr) + 0.5hr + 0.1tf$$

Once again, the weights in the above formula are free to be chosen to reflect a modeler's priorities and values.

§4.2 Interpreting Results

We run 1000 simulations of the campaign with our model, collecting values and computing mission scores for each trial.

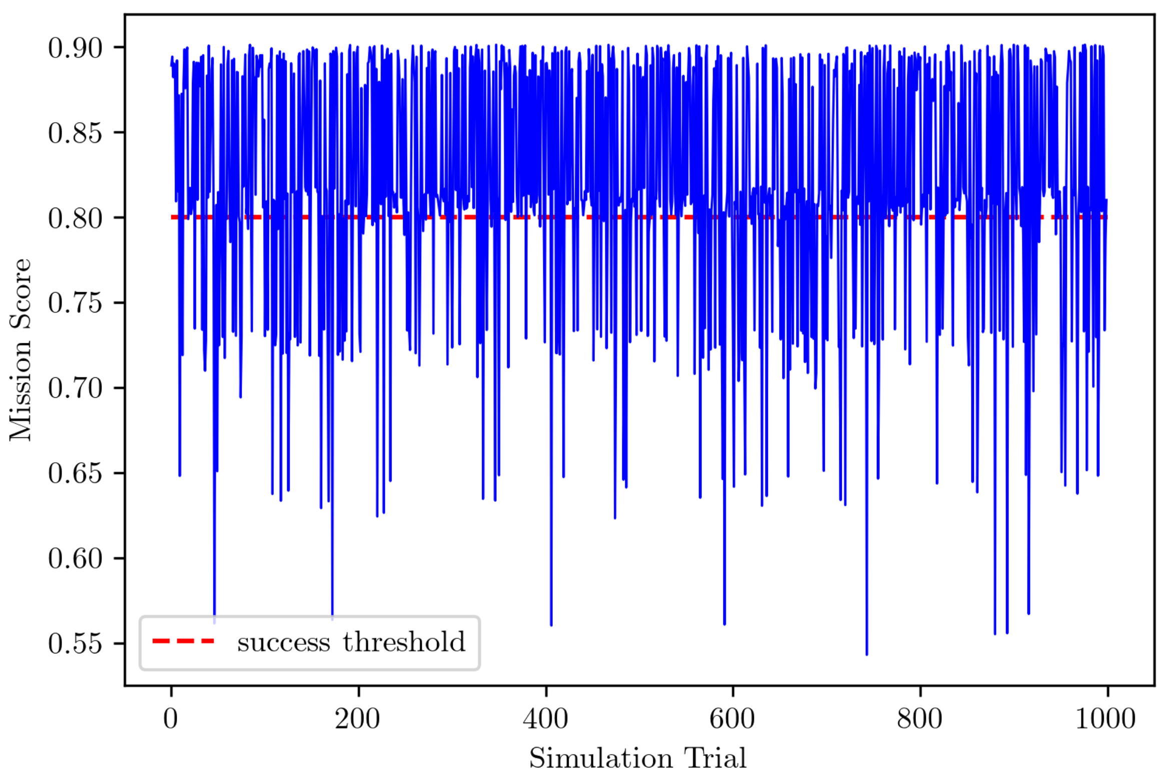

Figure 7: Mission scores of 1000 campaign simulations, with an 80% success threshold

Plotting the mission scores over all 1000 simulated runs, we observe how the stochastic components in each of the parameters contributes to a considerable degree of model volatility. These parameters can be adjusted to measure how the standard deviation in the mission score changes as part of a sensitivity analysis.

Note that one way to measure the campaign feasibility would be to set a mission score threshold, e.g. 80%, and compute the frequency with which the mission scores lie above this threshold. However, this metric is limited in that it may be arbitrarily chosen, and a single number does not singularly reflect the various contingencies that may be in place, such as loss of civilian life or remaining nuclear risk. The weights can, however, be adjusted to isolate these parameters.

For 1000 simulations, we find the following data:

Mission Score Threshold	Number of Passing Trials	Percentage of Successful Missions
80%	738	73.8%
85%	411	41.1%
90%	52	5.2%
95%	0	0%

Figure 8: Number of campaign simulations surviving past increasing mission score thresholds

As expected, a nearly perfectly executed mission is virtually impossible under the given conditions and parameters. The model can be altered and made more robust, or parameter values can be chosen to demonstrate how perhaps mission success rates might increase, or suggest what steps need to be taken to limit uncertainty.

Depending on the goals of the United States and the risks that the Coalition for East Asian Freedom is willing to take, it may be unacceptable to proceed with the mission given the high degree of volatility in mission success rates. The threshold is subjective, but balancing the threats of nuclear retaliation and the loss of life on massive scales does not inspire leniency in interpreting these model results.

§5. Conclusion

§5.1 Contingencies

Thus far, our question and model address the feasibility of an air-based campaign against North Korea's nuclear infrastructure. What this study has not addressed is what follows in the wake of such an attack; namely, what would the repercussions be against the US and CEAF from the DPRK and/or the global community?

The highest priority of the operation was to cripple all missile launch sites and ballistic missiles, much more than to neutralize research facilities. The motivation for this is that the opportunity cost for the former is gravely higher than for the latter; should any major ballistic missile launch sites be left intact, then CEAF is risking an imminent nuclear strike from North Korea that could level various cities across the Asian Pacific. There is a possibility that the DPRK remains unwilling to or is pressured against the use of nuclear weapons in retaliation due to the fact that the armaments employed by coalition forces are non-nuclear kinetic weapons. Nonetheless, there is no guarantee when nor by what manner the DPRK should choose to respond to a bolt-from-the-blue attack unless there is certainty that every military outlet and major weapons facility is crippled.

Another assumption that requires questioning is the existence of the Coalition for East Asian Freedom. The US, South Korea, and Japan all enjoy amicable relationships[24] and benefit from the outward knowledge that each supports the other, but there are limits on the availability of information to suggest that a military campaign led by the US would garner any support from the East Asian democracies. For one, both Japan and South Korea are in immediate proximity of North Korea, placing them in direct danger of short-term retaliation by the DPRK. The launch of even a medium range ballistic missile by North Korea would spell the impending doom of thousands of civilians in either country, whereas the US enjoys a much larger geographic separation. Risking this seems uncharacteristic for both nations, and an unprovoked attack by the US against North Korea is unlikely to receive their backing.

§5.2 Lessons and Reflections

The level of simplifying assumptions made to construct a model aimed at answering our question is itself an indicator of the sensitivity and precariousness of striking North Korea. While this strategy does not remain out of the question, it demands serious thought into what risk factors are acceptable and how much planning is required to conduct such a mission.

[24] "U.S. Relations With the Republic of Korea." n.d. *United States Department of State* (blog). https://www.state.gov/u-s-relations-with-the-republic-of-korea/.

In answering the question posed at the beginning of the study, we can safely say that, given the assumptions, the US and its coalition partners are certainly capable of executing a reasonably successful airstrike against North Korea's network of nuclear technology. However, simulations remind us that these are nonetheless imperfect models representing imperfect campaigns which are seldom perfectly replicable in realistic scenarios. Even if the simulations prove to be faithful representations of a real conflict above the Korean peninsula, weighing the costs and benefits of the operation is essential to deciding whether a military strike is the correct avenue to standing against the North Korean regime. The question we posed is simple to answer, but much harder is to contextualize it.

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