

A Survivability Assessment Method for Surface-to-Air Missile Threat Evasion Based on Probability-of-Kill Analysis Using a Wargaming Tool

Younhyuck Chang*, Head of Virtual Environment Validation Center @ MOASOFT.
Prof. Younggun Lee, Republic of Korea Air Force Academy
Sewon Kim, Republic of Korea Air Force
Seungeun Lee, NP Core

**MOASOFT is a technology that considers the future,
challenge the limits of science and technology.**

Software development and verification processes, software,
integrated logistics support, RF / EMC solutions.
The efforts based on an honest Technology and trust
towards the nation's leading specialist in the Military / Civil Requirement field.

Company Profile



Reliability Expert Company 1998

"MOASOFT Co., Ltd. was established in 1998 for the purpose of 'domestic distribution of global standard reliability analysis technology.'

Physics Based Analysis 2005

Software Testing 2006

UAV Episode-1 2012

Over the past 25 years, **we have been developing and reliability testing Korea's national defense weapon system SW and providing integrated logistics support (IPS) for the weapon system.** We have been leading smart defense innovation in the fields of **PCB design and EMI/EMC/EMP,** and have now grown into a company that **showcases digital engineering technology in various industrial fields."**

Wargaming Overview — Experimenting with War Without Combat



Definition

A structured method in which two opposing sides (Blue/Red) interact under agreed rules, data, and adjudication—without actual combat - to explore how operations and strategies unfold and what outcomes result.

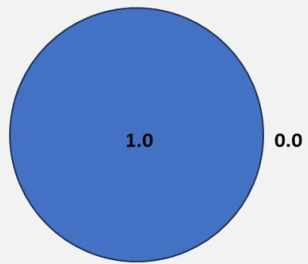
- Enables repeated "**what-if**" exploration at low cost and low risk, combining quantitative **M&S effectiveness analysis** with qualitative insight.
- **Making decisions** that are hard to test **in reality** be experimented with **beforehand**.

*"A wargame is not a tool for predicting war, but a laboratory for **training** and **validating thought and decision**."*

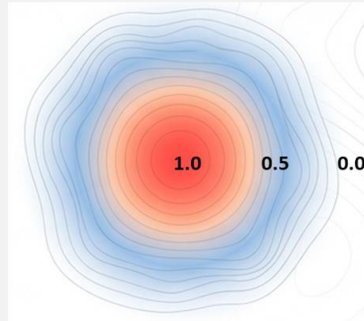
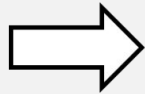
Why binary threat zones are not enough

- Threats are rarely isolated - interlocking SAM and AAA coverage leaves few gaps to fly around
- Standard planners model the engagement envelope as a solid, static obstacle - 1 or 0
- The resulting outer detours burn fuel and prolong time in hostile airspace
- Worse, a blind detour can push the aircraft into a secondary, unobserved threat

From Binary to Gradient



Binary Logic



Continuous Probability

Consequence

- ➔ A binary envelope forces a decision the data does not support.
- ➔ Every point inside is equally lethal
- ➔ Every point outside is equally safe.

Toward risk-aware path planning

The P_k map is not the end product → it is the input data layer for the planner.

1

Grid sweep

Straight-line transit paths
across a bearing and offset
grid around the threat

2

Endgame extraction

Per-engagement kill
probability and hit / miss
outcome from the native
report

3

Polar P_k map

Outcomes binned and
aggregated by aircraft
nose bearing

4

Hit map

Spatial risk layer supplied
to risk-aware hybrid path
planning

Path Planning with Risk-awareness



Hybrid Risk-Aware Path Planning for Survivability Against Integrated Air Defense System(IADS), DAFMSAS, 2026

Why This? Problem Matters: The Operational Context – Saturated Environments



• Overlapping Threat Zones

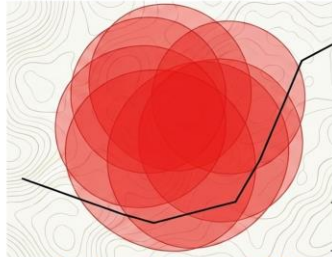
Modern IADS deploy continuous, interlocking anti-aircraft domes (SAMs, AAA).

• The Cost of Detours

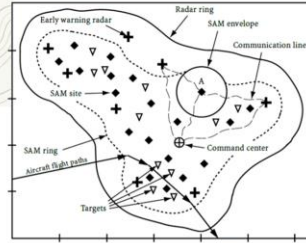
Wide outer detours burn critical fuel and dangerously prolong time-in-hostile-airspace.

• The Tactical Reality

Threats are rarely isolated; Survival requires navigating through the layers, not just around them.



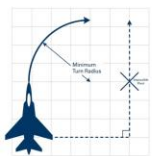
Overlapped Coverage of IADS



General Layout of IADS

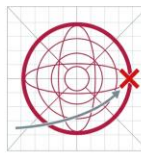
SAM: Surface-to-Air Missile
AAA: Anti-Aircraft Artillery
IADS: Integrated Air Defense System

Technical Challenges / Roadblocks



- Traditional path Finding ignores the aerodynamics.
- Minimum turn radius and maximum pitch limits.
- Paths must be continuously flyable.

- Conflict between Safety and Performance
- Flight paths must actively account for the lethal ranges of proximity-fuze engagements.



Kinematics Solved, Threats Failed

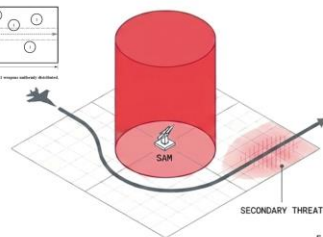
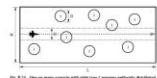
Standard Dubins-RRT* perfectly models flight physics but uses 1-dimensional threat assessment.

The Concrete Wall Fallacy

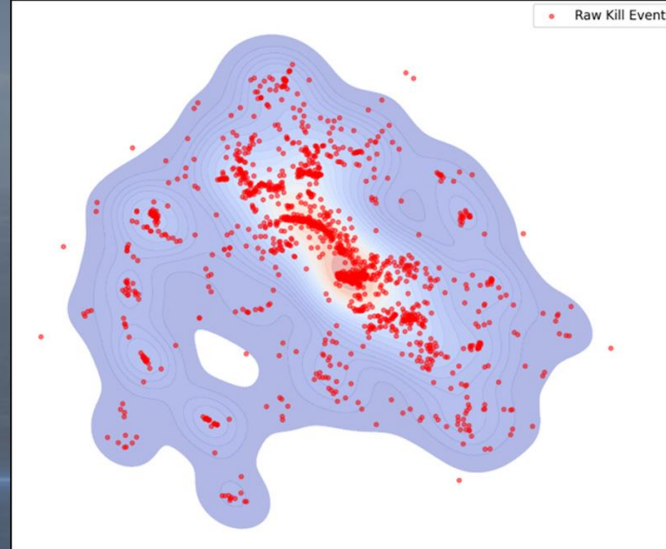
Threats probabilistic missile engagement zones as solid, static obstacles.

The Consequence

Forces the aircraft into massive outer detours, pushing it blindly into secondary, unseen threats.

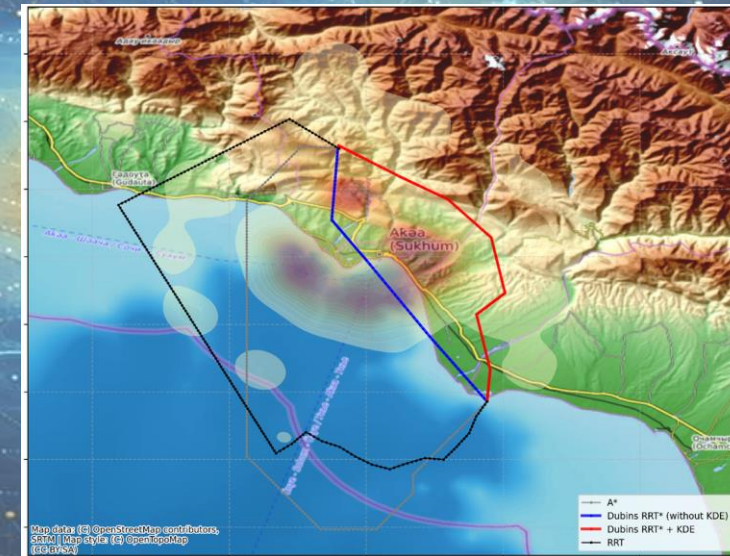


5



Risk Map with Raw Points
Spatial Distribution of Aircraft Kill Events
Scenario Execution Results

Georeferenced Path Planning Algorithm Comparison Over Realistic Terrain



Research question



How does probability of kill vary with aircraft nose bearing, and can that variation be produced with a COTS wargaming tool?

Q1 Feasibility

Can engagement outcomes be instrumented from a COTS tool at a volume sufficient for statistical treatment?

Q2 Phenomenon

Does the kill probability show a systematic, reproducible dependence on the aircraft nose bearing?

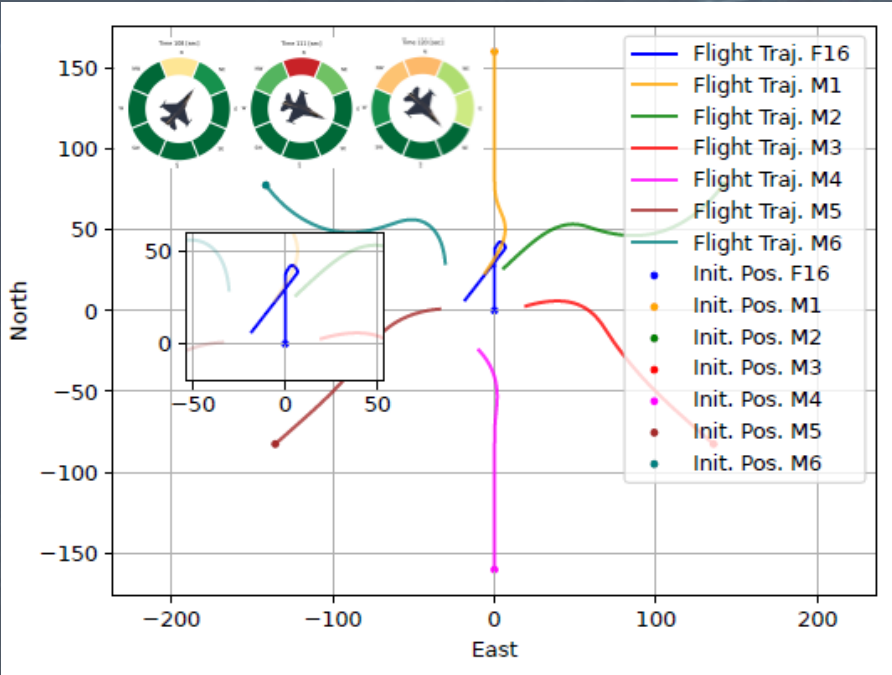
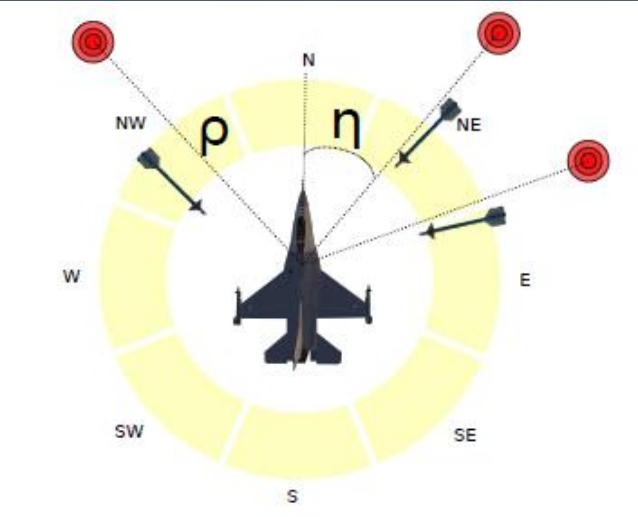
Q3 Utility

Can the result be expressed as a spatial layer that a risk-aware path planner is able to consume directly?

Q1 is answered by the instrumentation pipeline, Q2 by the grid sweep results, Q3 by the hit map handed to the planner.

Literature survey

Deep Learning Based Situation Awareness for Multiple Missiles Evasion



2024 International Conference on Unmanned Aircraft Systems (ICUAS)
June 4-7, 2024, Chania, Crete, Greece

Deep Learning Based Situation Awareness for Multiple Missiles Evasion

Edwards Scutkins^{1,3}, Markus Klein², Lars Kroon¹, and Petter Ögren³

¹Aeronautical Solutions division, SAAB Aeronautics
²Tactical Control and Data Fusion division, SAAB Aeronautics
³Robotics, Perception and Learning Lab, Royal Institute of Technology (KTH)

Abstract—As the effective range of air-to-air missiles increases, it becomes harder for pilots and Unmanned aerial vehicle (UAV) operators to maintain the Situational Awareness (SA) needed to keep their aircraft safe. In this work, we propose a decision support tool to help pilots in Beyond Visual Range (BVR) air combat scenarios assess the risks of different options and make decisions based on those. Building upon earlier research that primarily addressed the threat of a single missile, we extend these ideas to encompass the complex scenario of multiple missile threats. The proposed method uses Deep Neural Networks (DNN) to learn from high-fidelity simulations and provide the pilots with an outcome estimate for a set of different strategies. Our results demonstrate that the proposed system can manage multiple incoming missiles, evaluate a family of options, and recommend the least risky course of action while accounting for all incoming air-to-air threats.

Index Terms—Machine Learning, Beyond Visual Range Air Combat, Situation Awareness

I. INTRODUCTION

Since the First World War, air combat has evolved drastically. Advances in sensors, weapons, and communication allow pilots to engage enemy aircraft at longer and longer distances. Such advances have driven the transition from Within Visual Range (WVR) air combat to Beyond Visual Range (BVR) air combat [1]. In BVR, incoming missiles can fly for up to several minutes, which makes it very difficult for pilots or potential Unmanned aerial vehicle (UAV) operators to evaluate all incoming data and choose the best course of action. In fact, there is a tendency for the operator to lose track of some of the incoming threats [1]. A support tool that can handle several threats simultaneously and provide an overall analysis is thus needed. Such a tool should support the pilots in balancing the risk against the mission goals, as the lowest risk option is often, unfortunately, to ignore the mission entirely, while on the other hand, ignoring the risks ultimately might lead to hefty losses.

As the flight time of a radar-guided missile can be very long, BVR air combat includes an element that might be compared to real-time strategy games like Starcraft [2]. Significant challenges include highly nonlinear dynamics, information uncertainty, and opponents' unknown strategies and goals. Onboard sensors can output estimates of opponent locations that depend on the type of hostile aircraft, the electronic warfare countermeasure equipment, and the weather. However, although precise information is not always available when facing an enemy, operators are typically

Fig. 1: Symbolic representation of a situation where a high-performance aircraft faces three incoming missiles. The exact current locations of the missiles are unknown, but estimates of the time and location of the launches are available. In Figures 3-6, the colored fields around the aircraft icon are used to show the predicted miss distance (MD) of an evasive maneuver in that direction. Based on this, the aircraft operator can make a trade-off between mission goals and risks when determining what course to choose.

aware of the capabilities of the enemy's aircraft and weapons systems, and the proposed approach will make use of this information.

In our previous work [3], we have studied the case of an aircraft facing one incoming BVR missile. Using Reinforcement Learning (RL), we computed the optimal evasive maneuver and the resulting miss distance (MD) when performing the maneuver. However, that approach cannot be applied when faced with several adversarial aircraft engaging at the same time. When considering multiple incoming missiles from different angles, the optimal evasive maneuver relative to one missile differs from the other, and you clearly cannot execute two different maneuvers simultaneously. Furthermore, the most effective evasive action for one pair of incoming missile threats might be determined by solving a specific problem offline and storing the outcome, but this approach becomes impractical due to the vast number of possible threat combinations.

979-8-3503-5788-2/24/\$31.00 ©2024 IEEE 1446

Authorized licensed use limited to: Hanyang University. Downloaded on August 06, 2026 at 08:54:45 UTC from IEEE Xplore. Restrictions apply.

Positioning This Work



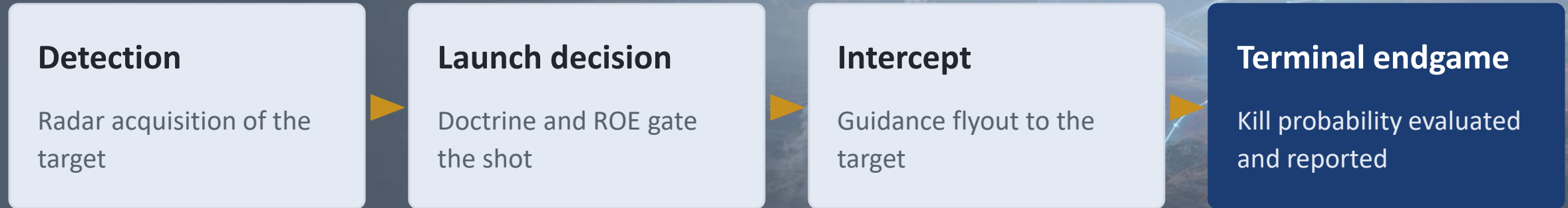
	Scukins et al. (2024)	Risk-aware hybrid planner (2026)	This work
Threat	Air-to-air missile, BVR	IADS — SAM and AAA layers	Surface-to-air threat system
Fidelity source	JSBSim FDM + trained DNN	Assumed threat model	CPE native weapon endgame
Risk metric	Miss distance (MD)	Continuous probability field	Kill probability by nose bearing
Output	Per-heading MD estimate	Flyable, risk-weighted path	Hit map as planner input

The gap.

- The planner needs a probability field over geometry.
- Existing survivability work produces miss distance from an external flight dynamics model plus a learned surrogate.
- Neither line of work delivers a bearing-resolved kill probability obtained from one commercially available tool.

The engagement chain and where P_k is evaluated

Only the terminal node is resolved by the tool's endgame model — the earlier nodes are conditions, not outputs.



Two quantities that must not be conflated

Predicted kill probability

reported as Final PH in the endgame report

A model output.

Available for every engagement without repetition, because the tool exposes the computed value directly rather than requiring it to be inferred from outcome counts.

Realised hit rate

hit / miss outcome after the stochastic draw

A sample statistic.

The probability is re-rolled per engagement, so the realised rate converges on the predicted value only with sufficient samples in each bearing bin.

From scenario to bearing-binned records



1

Scenario build

Threat site and transit lanes placed on a fixed grid

2

Batch execution

Repeated case-runs with the evasion policy removed

3

State export

Truth positions and engagement events written per run

4

Geometry reduction

Nose bearing, intercept angle and LOS rate derived per engagement

5

Binning

Records aggregated into bearing sectors for polar presentation

Collected in this run

7

cases

700

case-runs

3,151

engagements

238

hits

7.6% of engagements

2,913

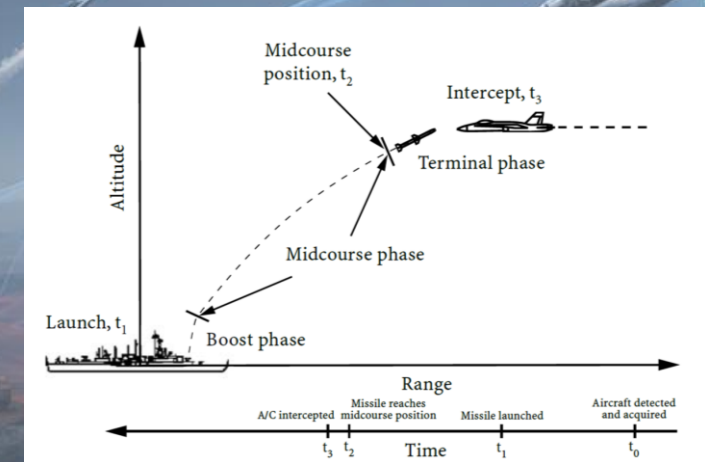
misses

Transit lanes run from -5 nm to +5 nm at 1 nm spacing, giving repeated passes at each offset.

Experiment Plan Concept for Kill-Zone Characterization



Kill-Zone Characterization



Missile launch and flyout to intercept

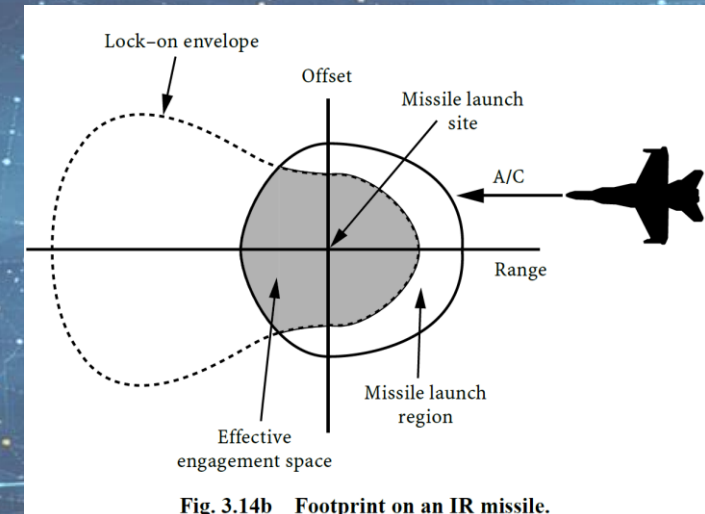


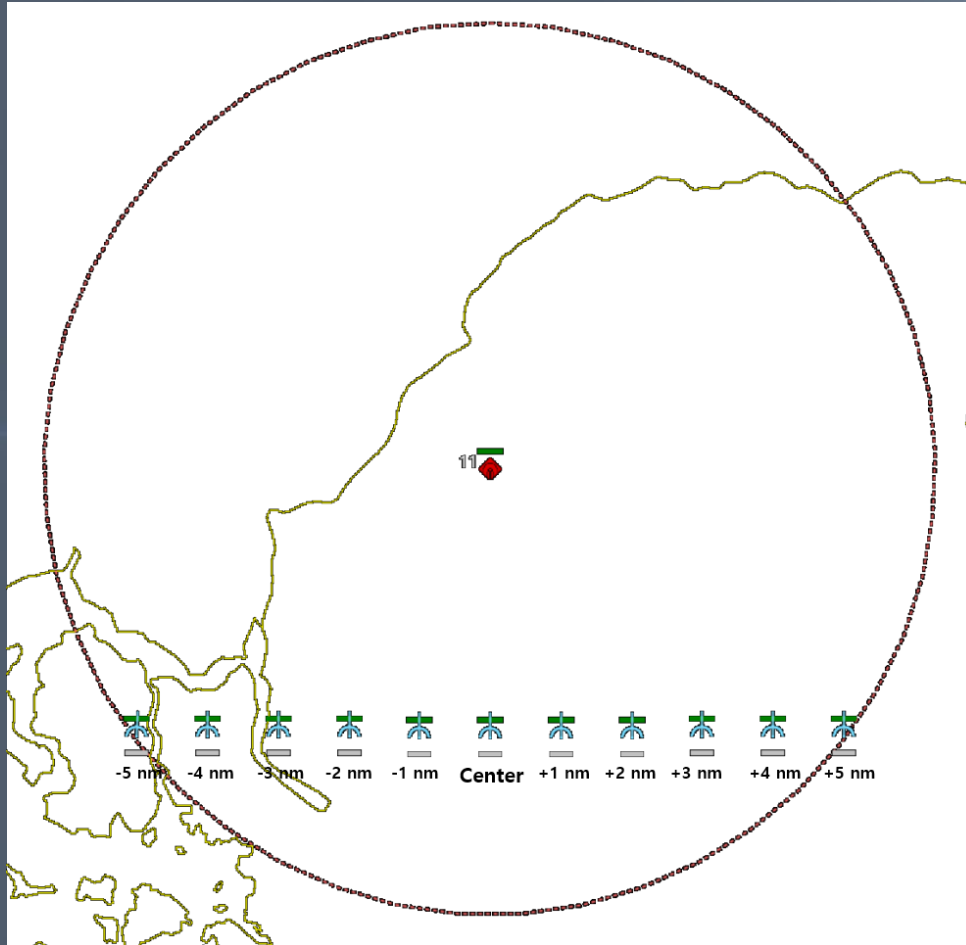
Fig. 3.14b Footprint on an IR missile.

Footprint on an IR missile

Experimental Design Setup



Grid Layout of Transit Paths Within the Threat Radius



Blue Force Tactical Aircraft Specifications



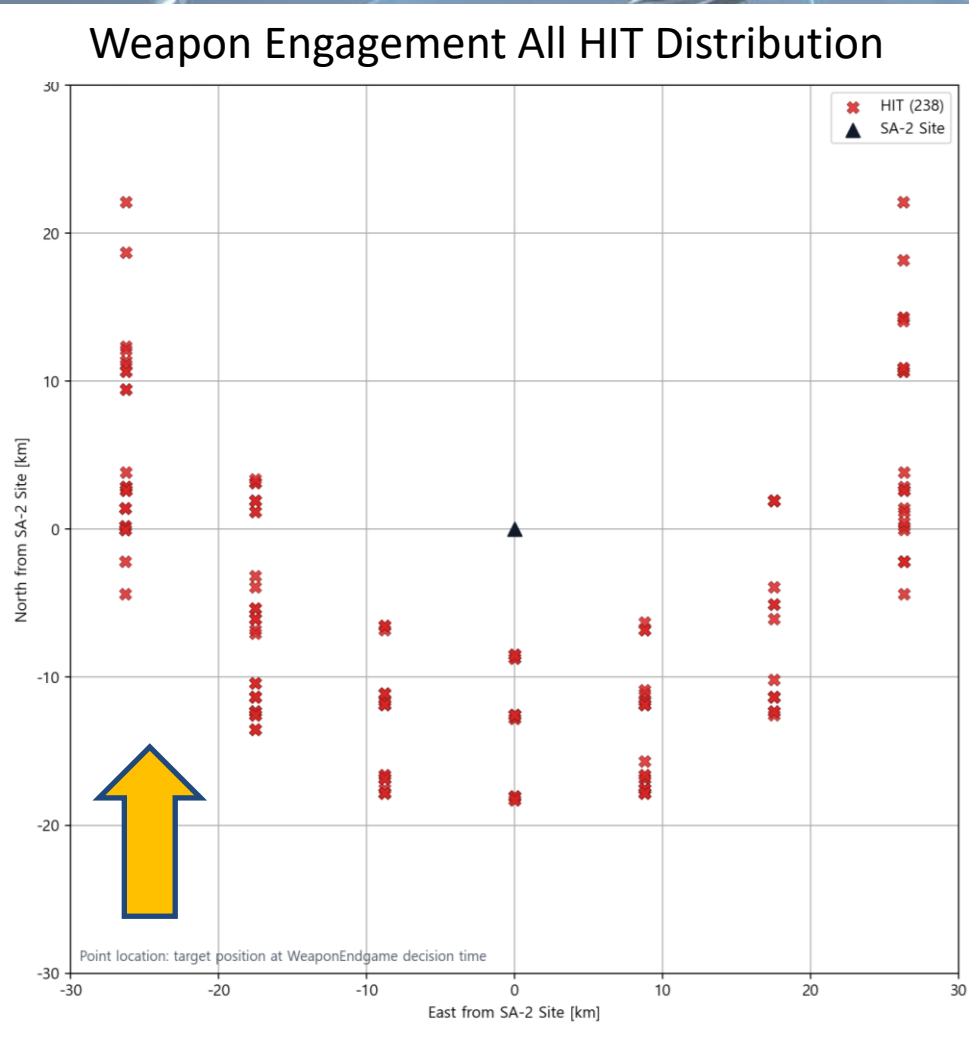
Summarizes the target-role aircraft's key engagement parameters, including detection, targeting, and evasion reaction times (OODA).

Red Force Surface-to-Air Threat System Specifications

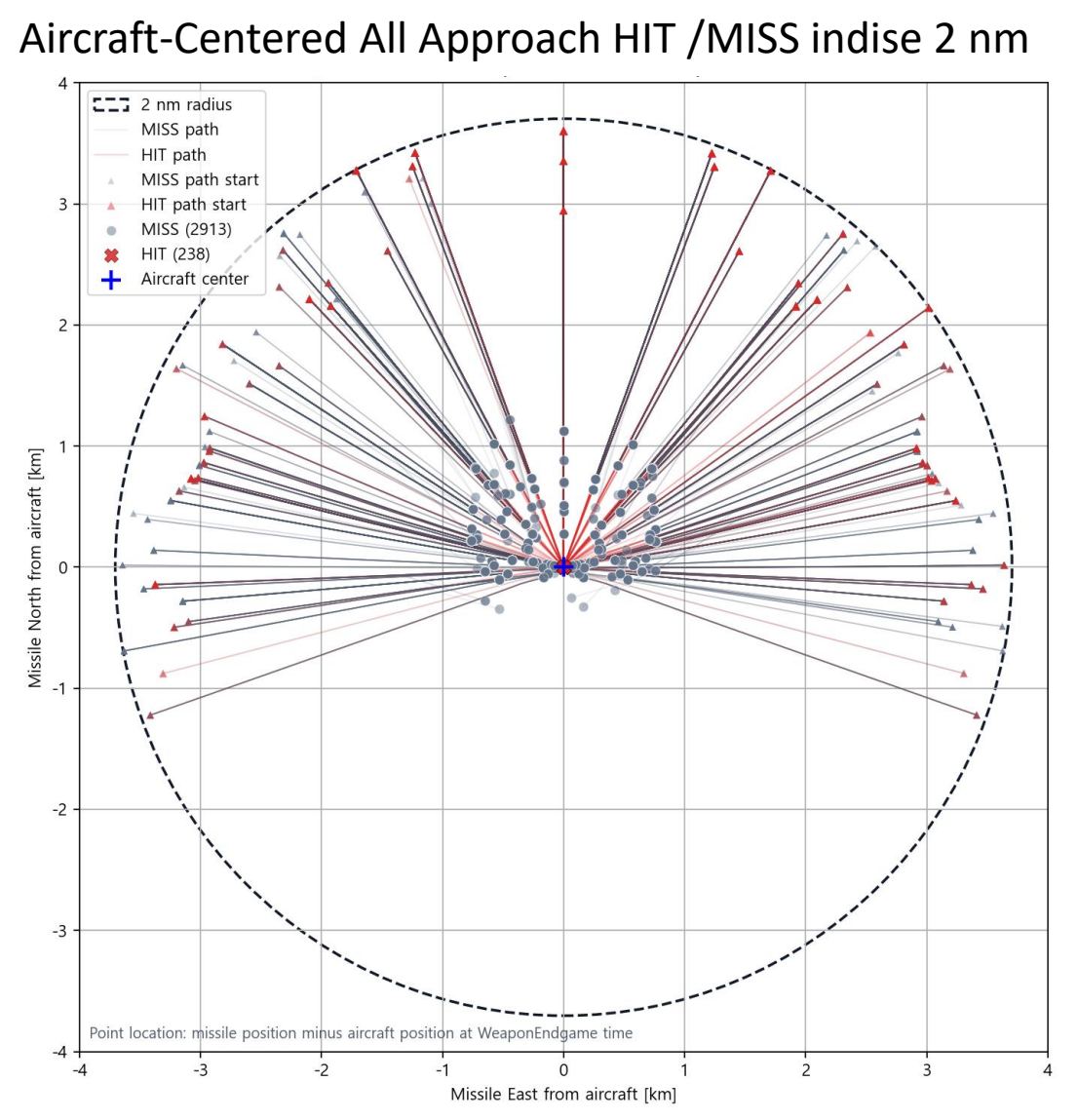
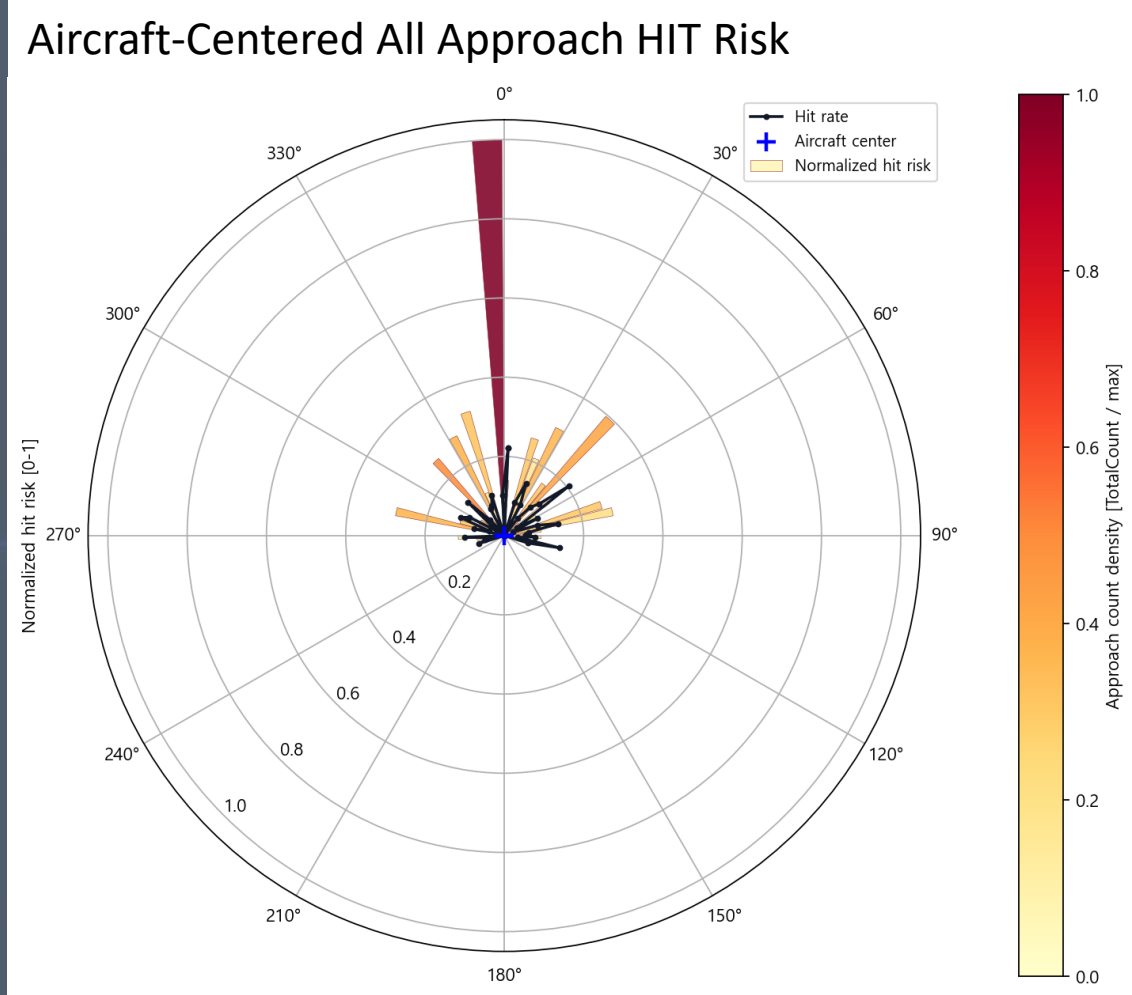


Summarizes the threat system's detection/targeting reaction times and engagement parameters, and supports that its SARH guidance characteristics are the source of the bearing-dependent Pk.

Site-Centered Hazard Field and Distribution



Aircraft-Centered All Approach HIT Risk



Conclusion



Geometry-dependent survivability assessment using a COTS wargaming tool

MD

Prior work — Scukins et al. (2024)

- High-fidelity JSBSim flight dynamics, BVR air-to-air missile evasion
- Deep neural network trained on large-scale simulation data
- Miss distance predicted for each compass-direction evasion policy
- Requires an external flight dynamics model and a learned surrogate

Pk

This work

- Command Professional Edition only — no external FDM, no learned surrogate
- Surface-to-air threat system engaged over a straight-line transit grid
- Kill probability mapped by aircraft nose bearing instead of miss distance
- Values read directly from the native weapon endgame report

Both approaches answer the same question — which heading is survivable — through different risk metrics.

Key contribution



01

The native endgame model is sufficient

Geometry-dependent engagement exposure (Pk) can be assessed with the tool's own weapon endgame model → no deep-learning surrogate and no external flight-dynamics model need to be integrated into the pipeline

02

A bearing-parameterized risk metric

Engagement outcomes are aggregated in polar form by aircraft nose bearing, giving a directly interpretable exposure profile across the sampled headings.

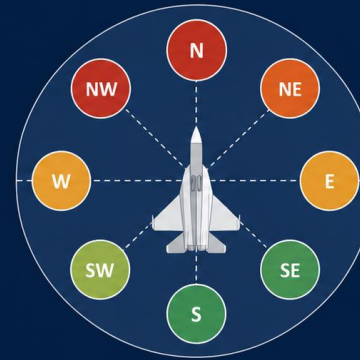
03

Reproducible with existing COTS tooling

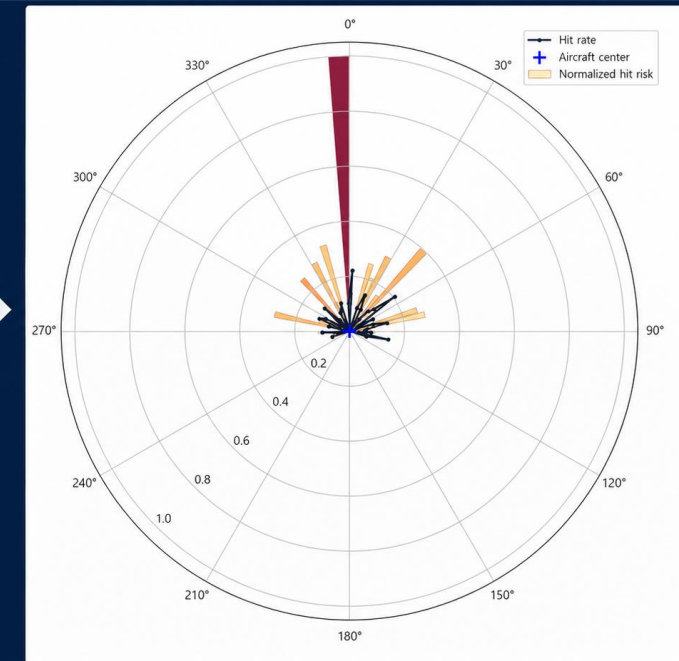
The pipeline runs on a commercially available tool using its native reports plus light scripting → for teams already operating that tool, it removes the need for a data-generation and model-training pipeline, lowering the methodological barrier to replication and reuse.

Pk by Nose Bearing

Concept → Measured Distribution



- Front (N, NE, NW): Highest Pk / Hit Risk
- Beam (E, W): Moderate Pk / Hit Risk
- Rear (S, SE, SW): Lowest Pk / Hit Risk





QUESTIONS?

Acknowledgements



This work was supported by the **National Research Foundation of Korea (NRF)** under Grant RS-2024-00466509.

