# Loyal Wingman Assessment: Social Navigation for Human-Autonomous Collaboration in Simulated Air Combat


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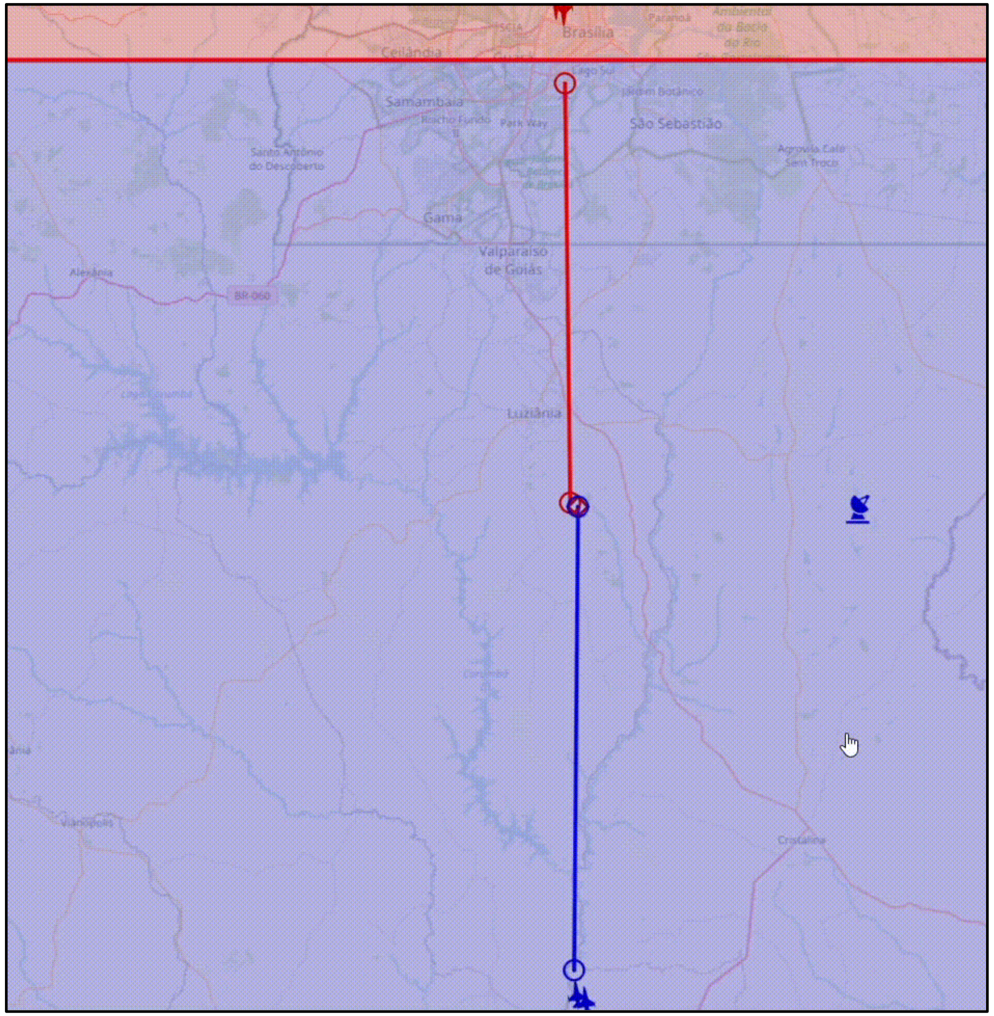
# Introduction

Autonomous aircraft in shared airspace must navigate safely and efficiently

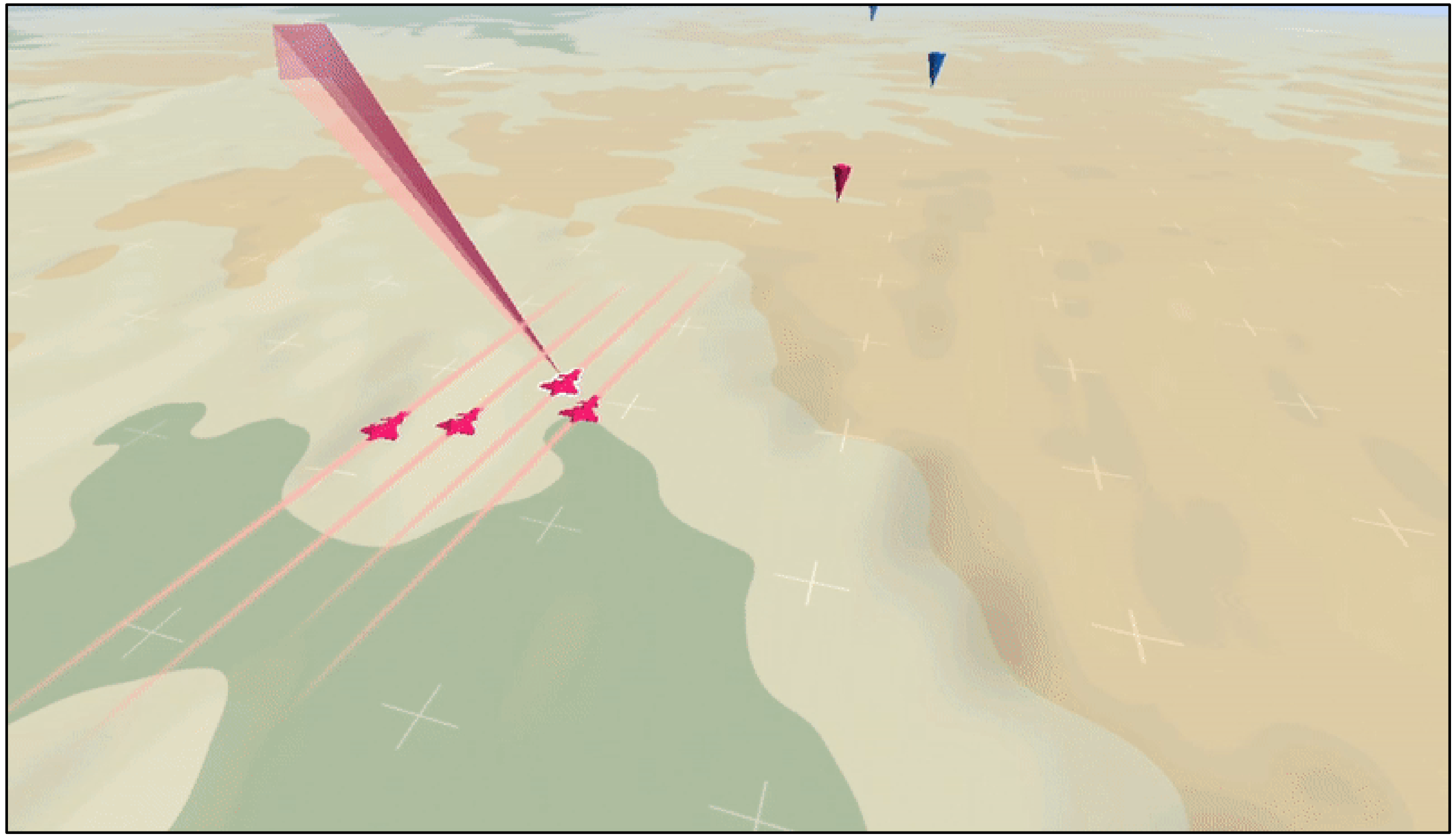
They should adhere to social norms expected in human-centric environments

These norms include:

- Respecting a personal space
- Maintaining comfortable velocities and accelerations
- Keeping a safe distance from other aircraft



# Introduction



Air combat domain: additional layers of complexity to social navigation

We need new metrics to evaluate the human-AI interaction

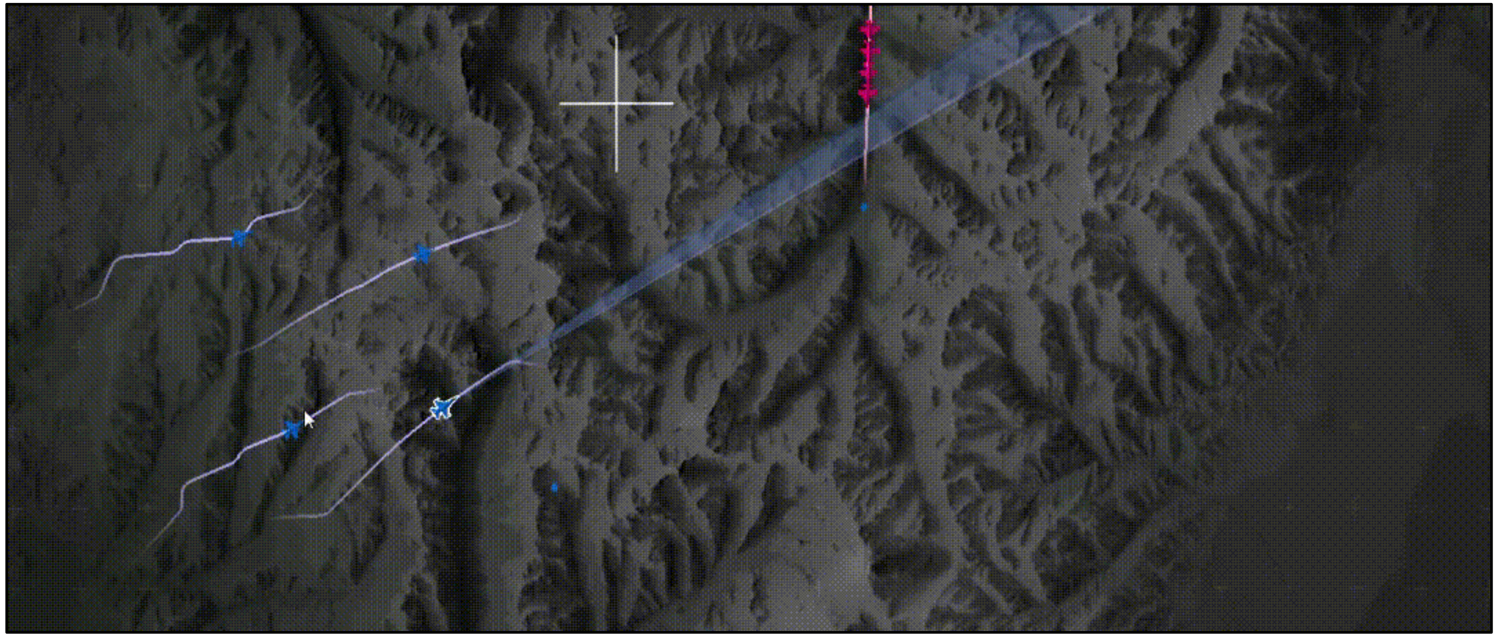
Loyal wingman with human pilot requires not only safety and efficiency but also a deep understanding of tactics and formation dynamics

A mix of social and combat skills

# Contribution

Social Navigation Metrics: Present metrics to enhance the human-AI interaction in the context of air combat

User Study Experiment: Propose a validation process with interactions between real pilots and trained AI agents within a high-fidelity virtual simulation environment



# Aerospace Simulation Environment

Aerospace Simulation Environment – *Ambiente de Simulação Aeroespacial in Portuguese* (Dantas et al. 2022)

Custom-made in C++ for advanced programming flexibility

High-fidelity representation for accurate scenario reproduction

Supported by the Brazilian Air Force

Dedicated to modeling and simulation of military operational scenarios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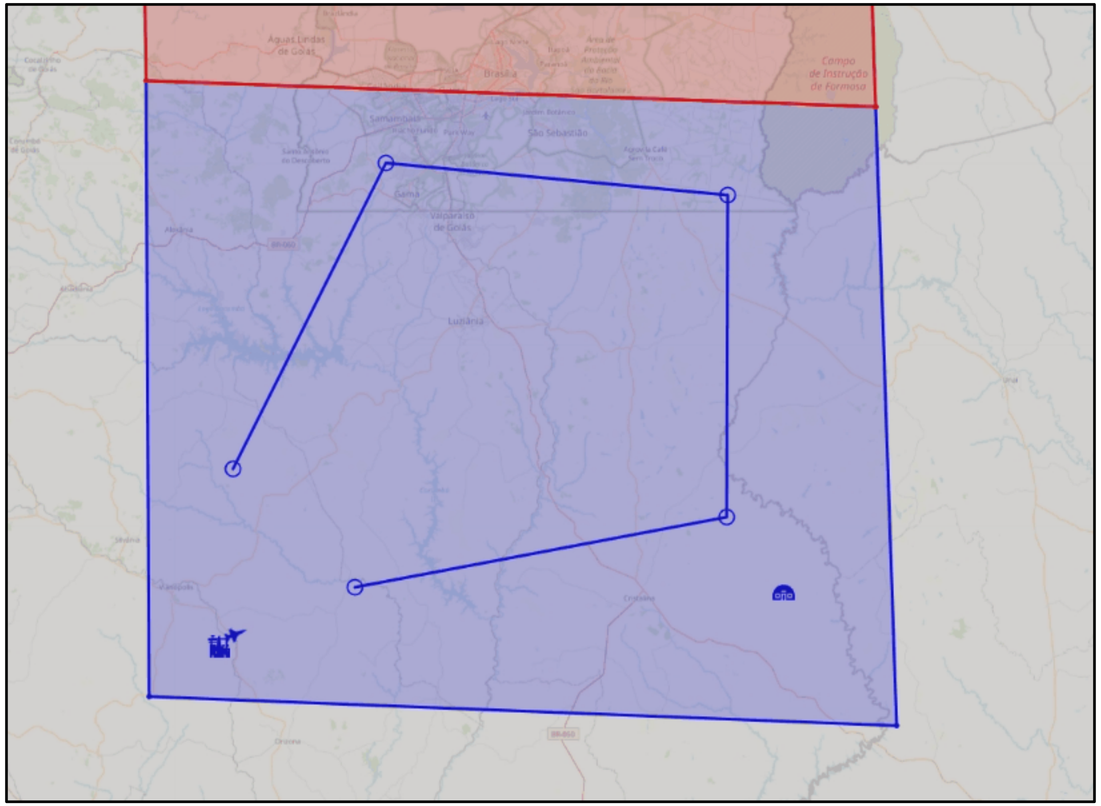
# Social Navigation Metrics

| No. | Aspect | Metric | Description |
|---|---|---|---|
| $M_1$ | Naturalness | Velocity | Computes the mean of the squared velocities over the time period, highlighting significant speed variations from typical human norms |
| $M_2$ | Naturalness | Acceleration | Calculates the average of squared accelerations to assess how naturally the acceleration changes compare to human-like movements |
| $M_3$ | Naturalness | Jerk | Evaluates the mean squared jerk to identify abrupt changes in acceleration, aiming for smoother, more human-like trajectories |
| $M_4$ | Comfort | Minimum Distance | Calculates the smallest distance between two agents by iteratively comparing their positions over a given time period and updating the minimum found |
| $M_5$ | Comfort | Collision Risk | Assesses the collision risk by determining how often two agents come within a critical distance or have a closing velocity that predicts a potential collision |

# Naturalness



This aspect evaluates the similarity of the wingman's motion to human movements and the smoothness of its path

Humans typically exhibit trajectories with:

- Compatible velocities
- Compatible accelerations
- Minimal jerk

# Naturalness Metrics

To measure the wingman's trajectory smoothness:

- Calculate its average velocity, acceleration, and jerk
- Determine if these averages meet predefined thresholds approximating human pilot levels

Squared derivatives:

- Ensure non-negativity
- Highlight significant variations
- Smooth noise for easier mathematical handling

$$M_n = \frac{1}{T} \sum_{t=0}^{T} \left( \frac{d^n p(t)}{dt^n} \right)^2, \quad \text{where } n = \begin{cases} 1 & \text{for velocity,} \\ 2 & \text{for acceleration,} \\ 3 & \text{for jerk.} \end{cases}$$

# Comfort

This aspect assesses human comfort by minimizing disturbance in interactions with autonomous agents

Emphasizes maintaining safe distances to reduce impact on human activities

We propose two metrics to evaluate comfort in shared airspace within air combat scenarios:

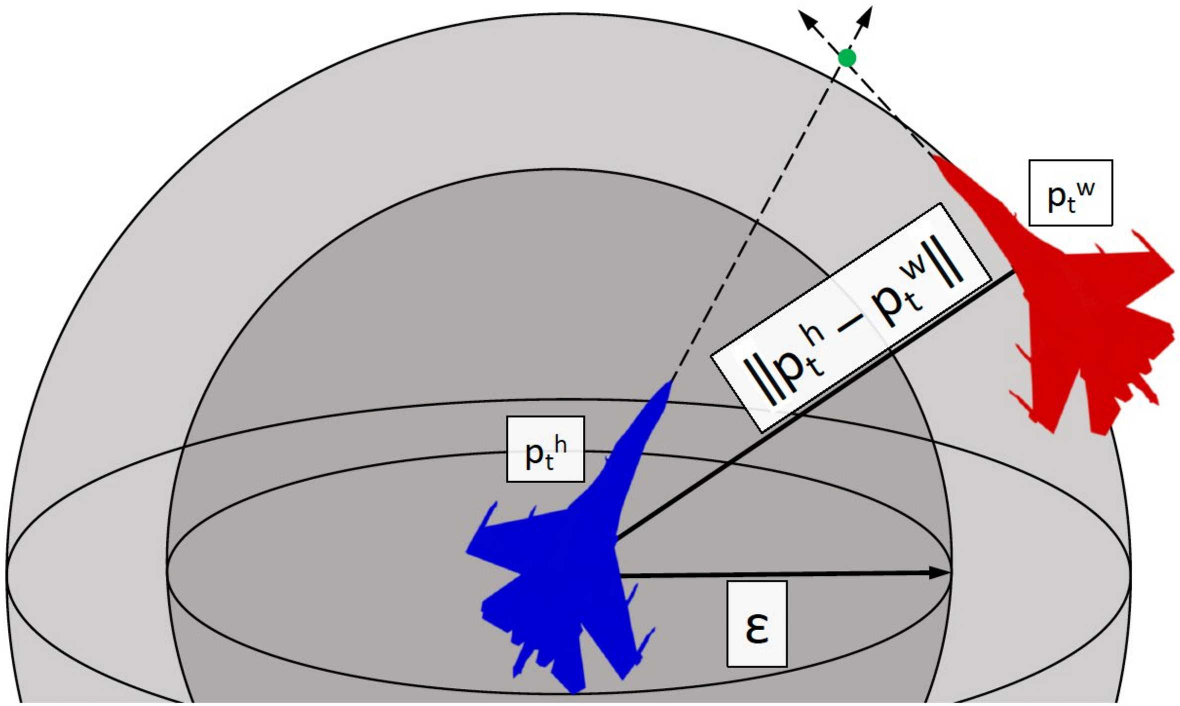
- Minimum Distance Comfort Metric
- Collision Risk Comfort Metric

# Minimum Distance Comfort Metric

The first comfort metric measures the smallest distance maintained between the human and the wingman throughout the air combat simulation

**Algorithm 1** Calculate $M_4$: Minimum Distance Comfort Metric

1: Initialize minimum distance comfort metric: $M_4 \leftarrow +\infty$
2: **for** $t = 0$ to $T$ **do**
3: Calculate distance for frame $t$: $d_t \leftarrow \left\| \mathrm{p}_t^w - \mathrm{p}_t^h \right\|$
4: **if** $d_t < M_4$ **then**
5: Update minimum distance: $M_4 \leftarrow d_t$ ▷ Record new minimum across all frames
6: **end if**
7: **end for**

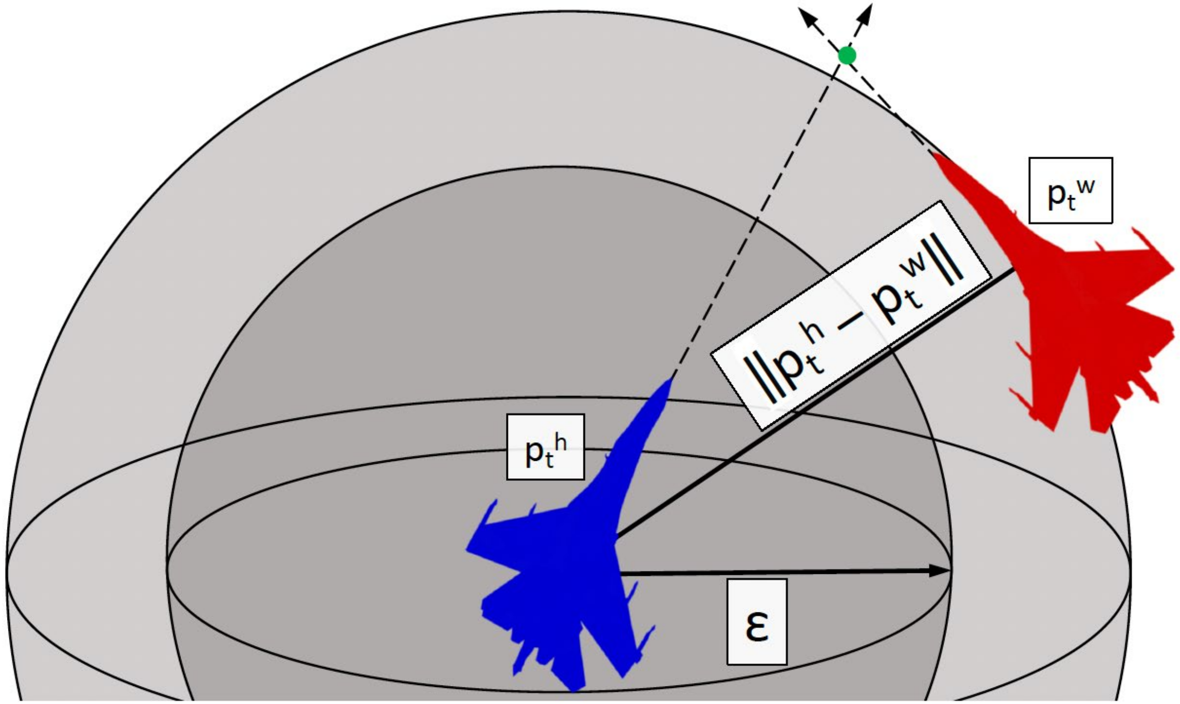


# Collision Risk Comfort Metric

The second comfort metric assesses the safety of autonomous aircraft operations by calculating the risk of collisions based on the principles of the Time to Closest Point of Approach – TCPA (Glozman et al. 2021)

**Algorithm 2** Calculate $M_5$: Collision Risk Comfort Metric

Initialize collision risk comfort metric: $M_5 \leftarrow 0$
**for** $t = 1$ to $T$ **do**
  Calculate relative position vector: $\mathbf{r}_t \leftarrow \mathbf{p}_t^h - \mathbf{p}_t^w$
  Compute distance: $d_t \leftarrow \|\mathbf{r}_t\|$
  Compute relative velocity vector: $\mathbf{v}_t \leftarrow \frac{d\mathbf{p}_t^h}{dt} - \frac{d\mathbf{p}_t^w}{dt}$
  Calculate closing velocity: $v_{\text{close},t} \leftarrow \frac{\mathbf{r}_t \cdot \mathbf{v}_t}{d_t}$
  **if** $d_t < \varepsilon$ **then** ▷ If within critical distance
    Increment collision risk comfort metric: $M_5 \leftarrow M_5 + 1$ ▷ Log alert
  **else**
    **if** $v_{\text{close},t} > 0$ **then** ▷ If distance decreasing
      Calculate Time to Reach (TTR): $TTR \leftarrow \frac{d_t}{v_{\text{close},t}}$
      **if** $TTR < t_{\text{critical}}$ **then** ▷ If below critical time
        Increment collision risk comfort metric: $M_5 \leftarrow M_5 + 1$ ▷ Log alert
      **end if**
    **end if**
  **end if**
**end for**

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# User Study Experiment

This user study aims to validate social navigation metrics by comparing them against human pilot perceptions in simulated air combat scenarios

Involves military pilots with varied experience

Selected based on:

- Flight hours
- System proficiency
- Simulation experience

Pilots will operate alongside a loyal wingman, controlled by AI, to accomplish a specific defense mission

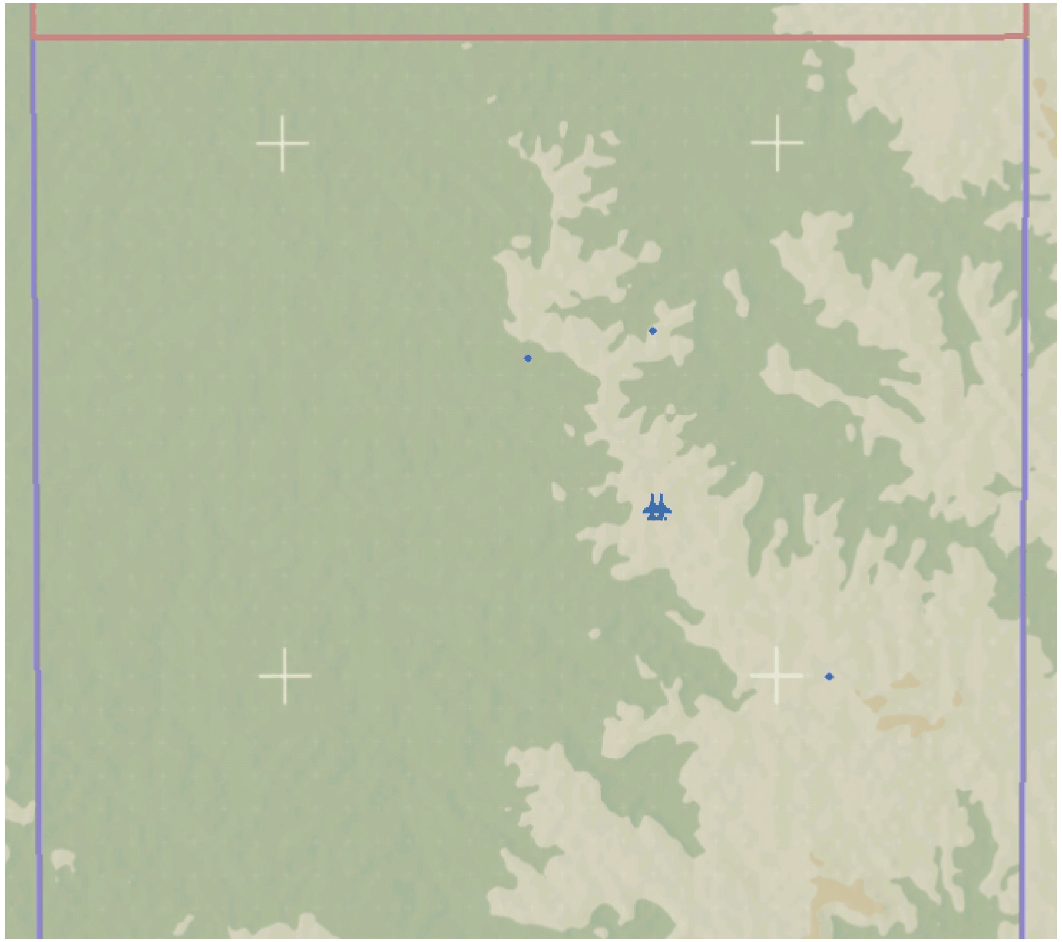
# Scenario Analysis

The simulation scenario evaluates the feasibility and effectiveness of continuous Combat Air Patrol operations:

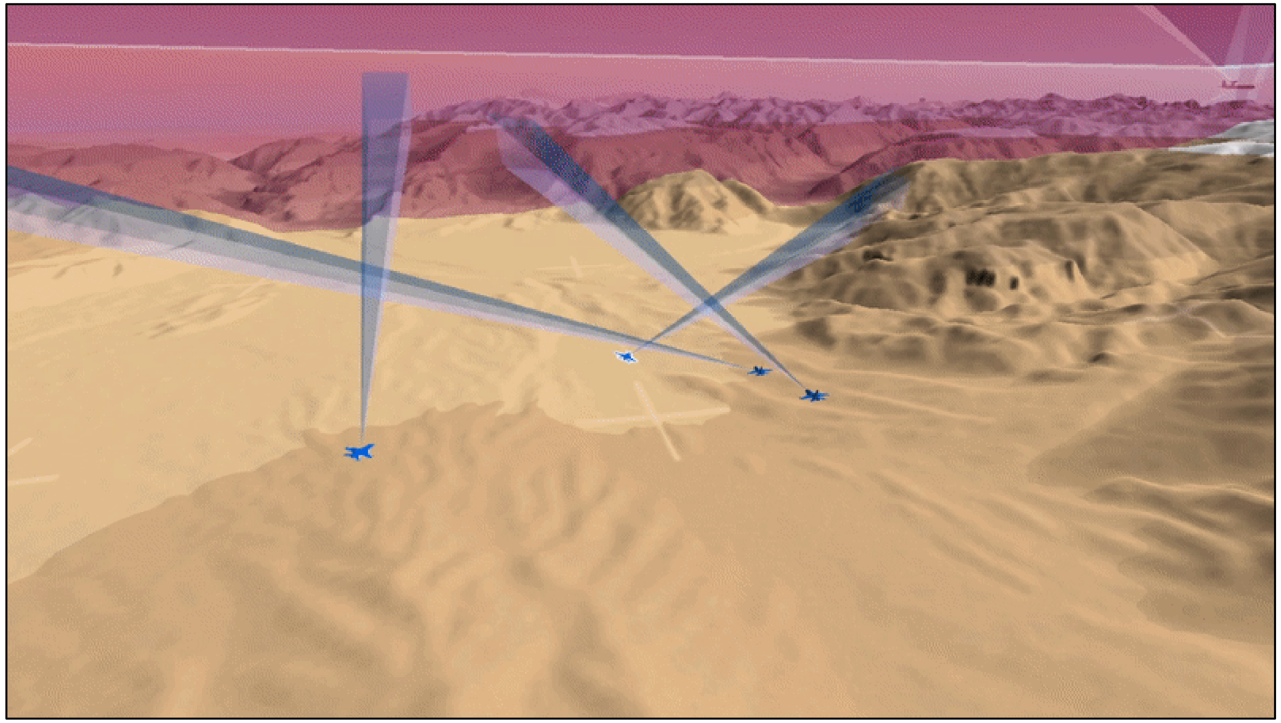
- Aiming to defend a strategic point of interest
- The Defensive Counter Air index (Dantas et al. 2021) will be used to evaluate the performance of the human-autonomous team

Data will be gathered via post-trial questionnaires:

- Assessing naturalness and comfort
- Compare the pilot's evaluation with the social navigation metrics
- The analysis will be conducted using the AsaPy Library (Dantas et al. 2024)



# Ongoing Research



Finish the training and evaluation for the Deep Reinforcement Learning agent (Dantas et al. 2023)

Achieve the full integration of human pilots and AI fighters within a unified training environment

# Conclusion

This study introduces social navigation metrics to enhance human-autonomous collaboration in air combat

The metrics presented can optimize autonomous agents' algorithms, including those based on:

- Behavior trees
- Reinforcement learning techniques

Enhance the quality of air combat training through the development of socially-aware Unmanned Combat Air Vehicles

Advancing AI fighters to support pilots or potentially even replace them

**Future Work**

- Execution of Turing Tests in collaboration with Brazilian fighter pilots
  - Assessing the competencies of the AI fighter
  - Validate the social navigation metrics proposed

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