Autonomous Pop-Up Attack Maneuver Using Imitation Learning

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Motivation

Autonomous systems are widely adopted in military applications.

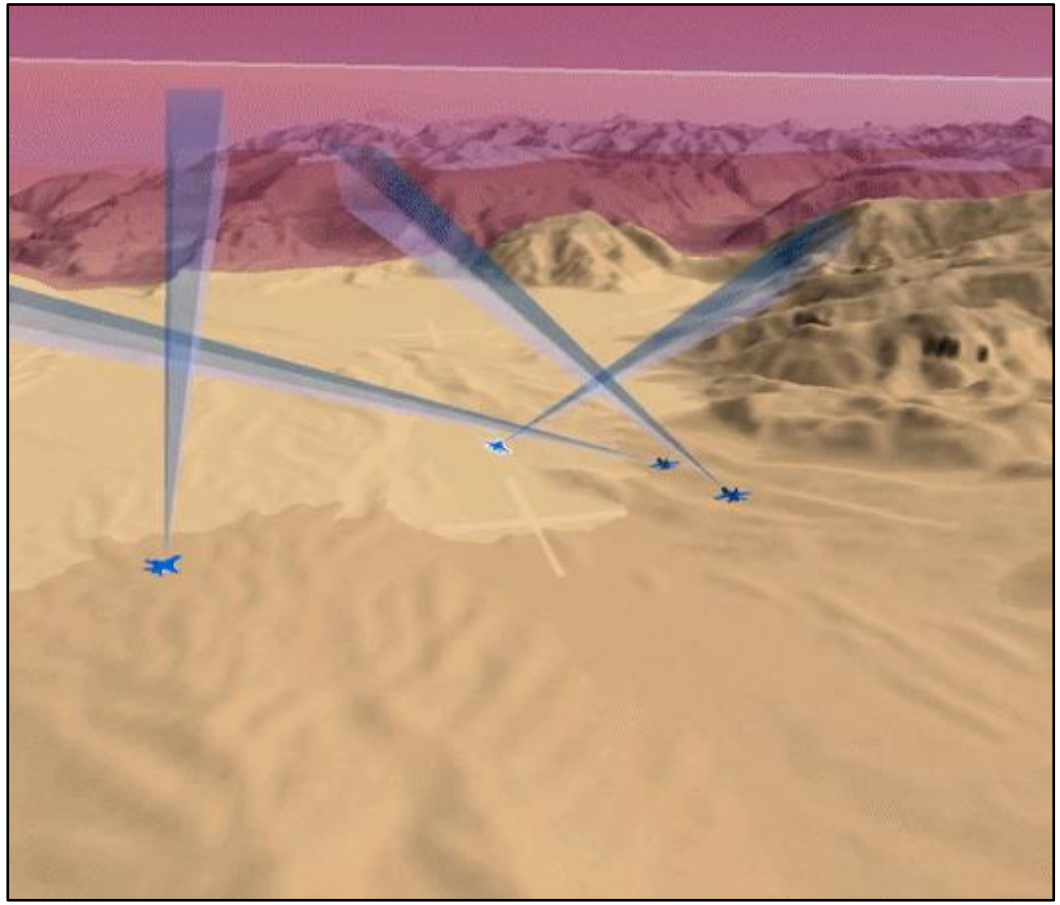
Roles include **surveillance**, **reconnaissance**, and **combat engagement**.

It provides strategic benefits but challenges in replicating human-level proficiency.

Behavior cloning, an imitation learning technique, **aims to replicate human decision-making in complex tasks**.

Main contributions:

- Development of a **BC-based autonomous pop-up attack model**.
- Improve the understanding of **autonomous systems in dynamic air combat operations**.

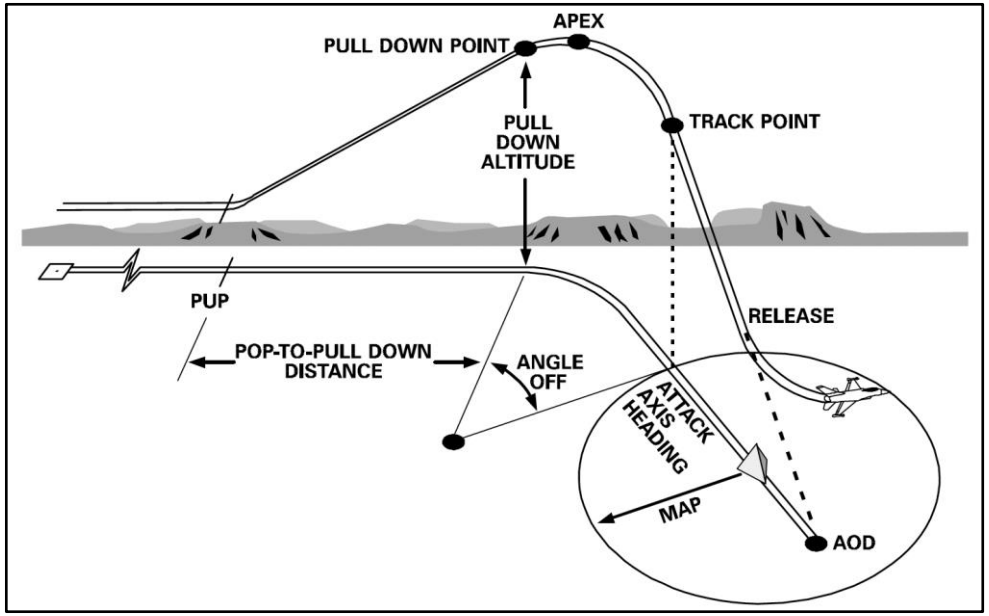


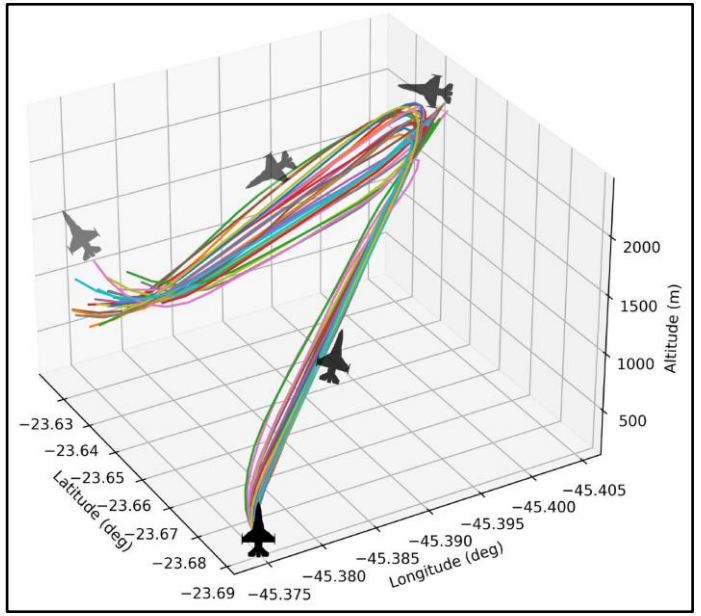
Pop-up Attack Maneuver

Critical air-to-ground air combat technique.

Involves rapid ascent, target engagement, and quick descent.

Requires precision and adaptability under extreme conditions.





Simulation Data

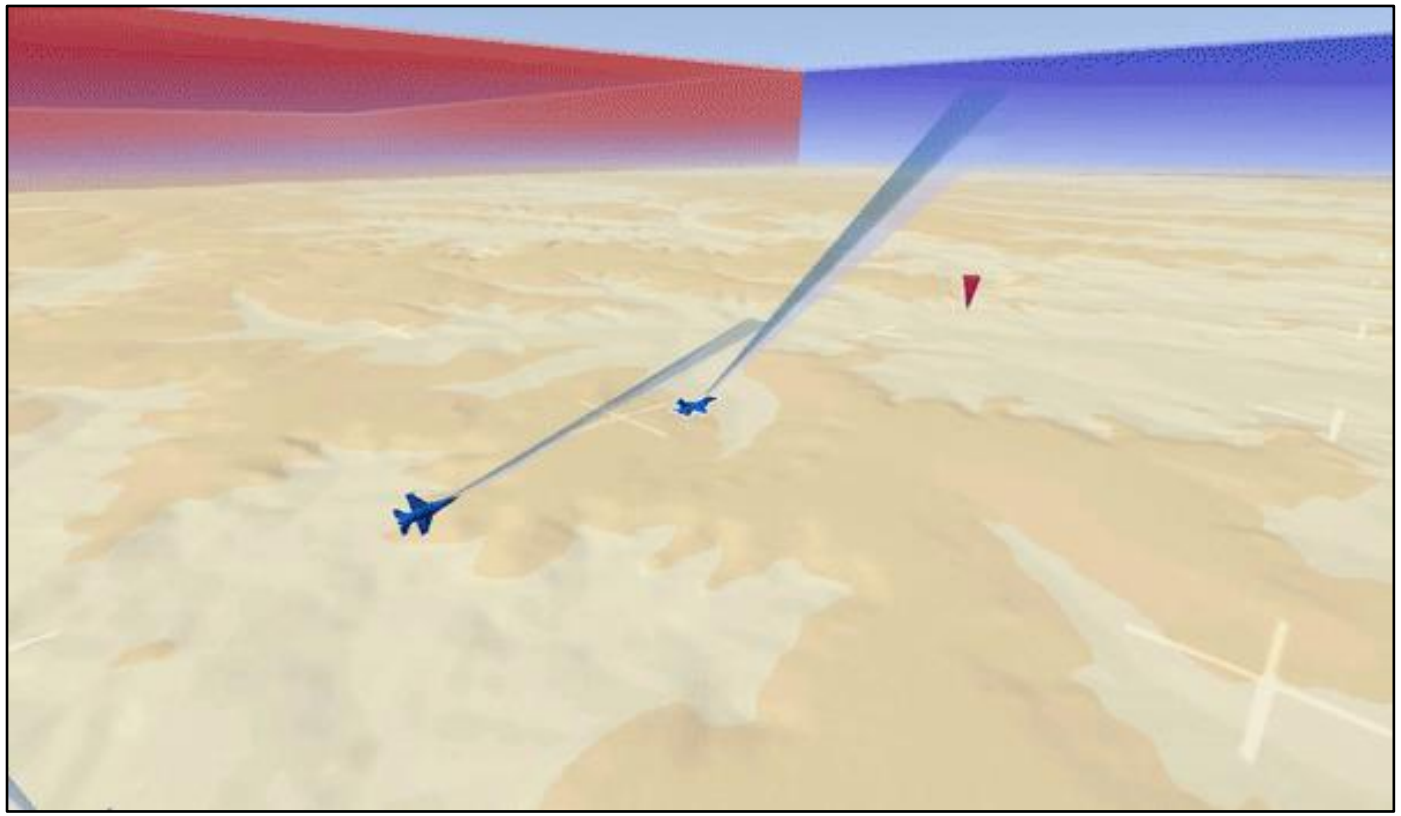
30 flight recordings of pop-up attack maneuvers.

Executed by a Brazilian Air Force fighter pilot.

Data collected using AEROGRAF, a 6DOF flight simulator.

Based on the F-16 Fighting Falcon dynamic model.

All flights start from the same point, **5.9** NM from the target, with a **146**-meters altitude difference.



State and Actions

Variable	Units	Description	Type
ALT (m)	Meters	Altitude in meters	State
Phi (deg)	Degrees	Pitch angle (positive for nose-up)	State
Theta (deg)	Degrees	Roll angle (positive for left roll)	State
Psi (deg)	Degrees	Yaw angle	State
Vx (m/s)	Meters/second	Velocity in the pitch direction	State
Vy (m/s)	Meters/second	Velocity in the roll direction	State
Vz (m/s)	Meters/second	Velocity in the yaw direction	State
P (deg/s)	Degrees/second	Pitch angular velocity	State
Q (deg/s)	Degrees/second	Roll angular velocity	State
R (deg/s)	Degrees/second	Yaw angular velocity	State
Nx (m/s^2)	$Meters/second^2$	Lateral acceleration	State
Ny (m/s^2)	$Meters/second^2$	Longitudinal acceleration	State
Nz (m/s^2)	$Meters/second^2$	Vertical acceleration	State
Radial (deg)	Degrees	Radial angle	State
Distance (m)	Meters	Distance in meters	State
DeltaAlt:Anv-Tgt (m)	Meters	Altitude difference between aircraft and target	State
JX	–	Positive for nose-up pitch	Action
JY	–	Positive for left roll	Action
Throttle	–	Throttle position	Action

Imitation Learning Model

Used **Long Short-Term Memory (LSTM)** networks for sequential data.

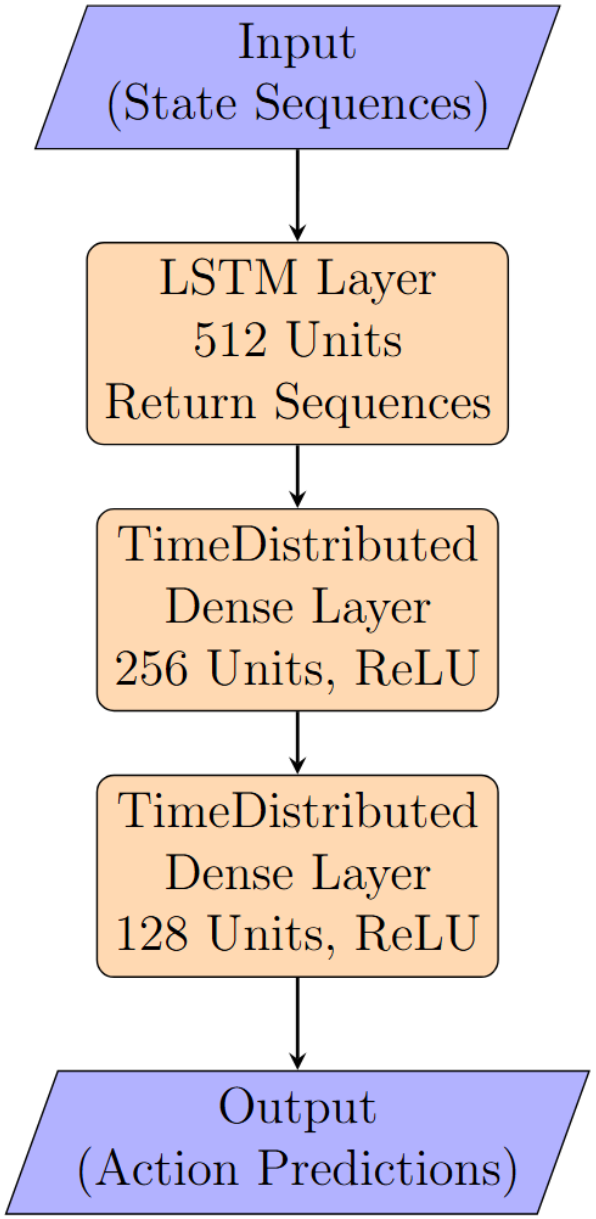
Training employed **5-fold cross-validation** with **early stopping** and optimized with the **Adam** optimizer.

Performance evaluated using **RMSE** and **R^2** metrics.

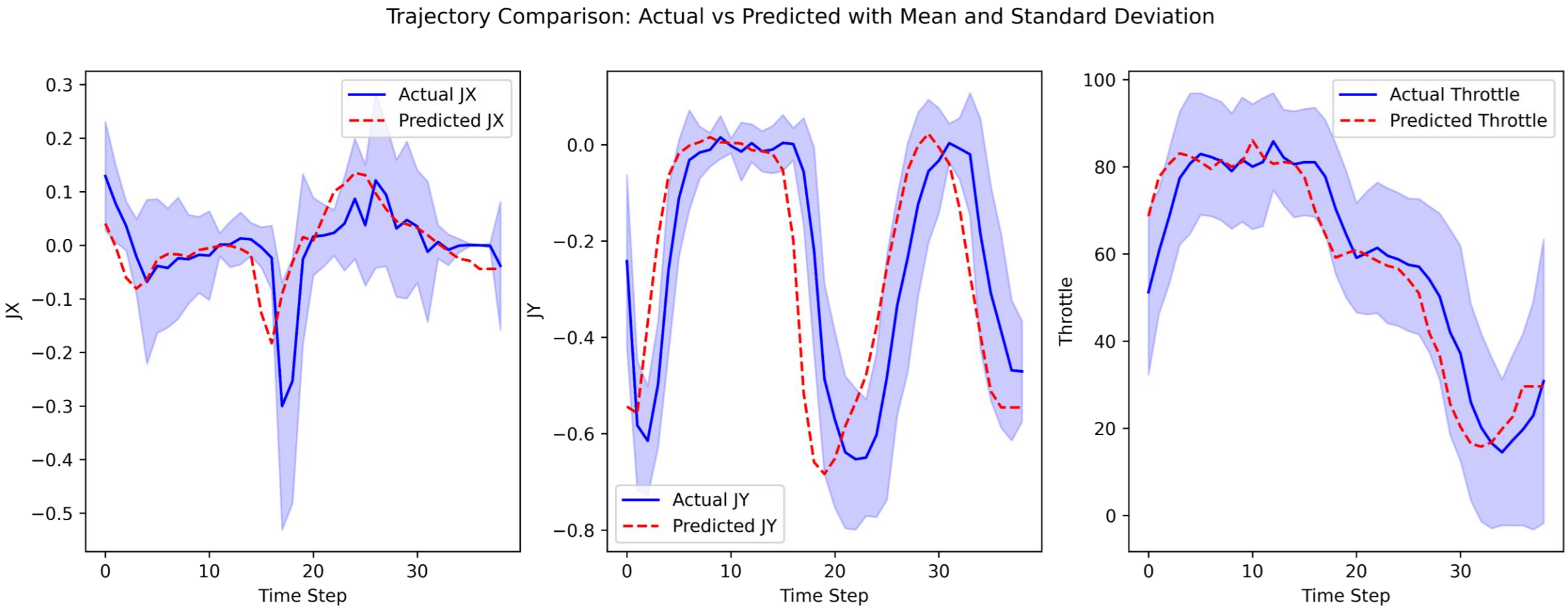
Best model selected for detailed analysis.

Generated flight trajectories using a **sliding window approach**.

Predictions compared to actual maneuvers based on mean and standard deviation of actions.



Results



R^2 of **0.73** and an RMSE of **1.55** on the test group

Conclusion and Future Work

Developed a model to replicate the pop-up attack maneuver in air combat using real fighter pilot data.

The model effectively predicted aircraft control inputs, mimicking an experienced pilot.

Future work includes:

- Expanding the dataset with diverse pilot profiles and strategies and explore additional air combat maneuvers.
- Using generative learning to create synthetic data, aiming to improve accuracy in autonomous combat scenarios.
- Testing new imitation learning models – we have already conducted experiments with the **Gated Recurrent Unit (GRU)** and achieved better results compared to the LSTM.