Comparative Analysis of Development Environments for UAV Software Development

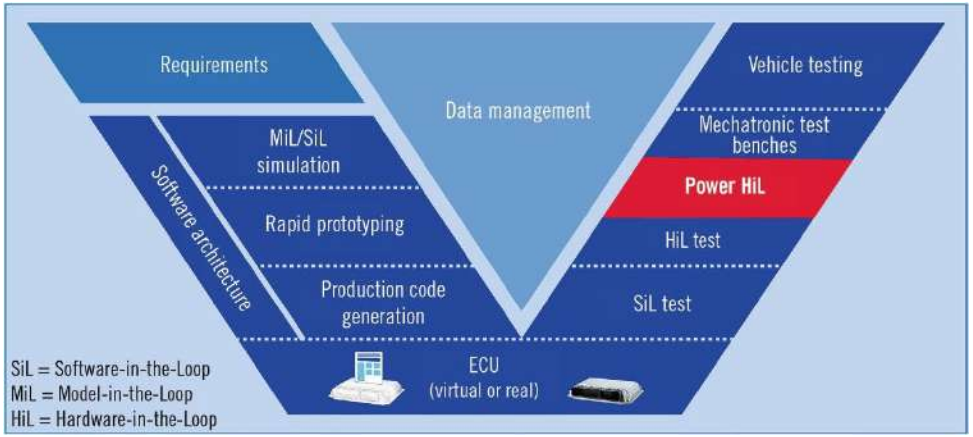
Done by Student:
Sofiia Budilova
Thesis Supervisor:
Andrew Kurochkin

Kyiv, 2025

Contents

Why are simulators needed?

- Improve safety during UAV software development
- Reduce costs for development



Validation procedure in the development cycle

Selection Criteria for UAV Simulators

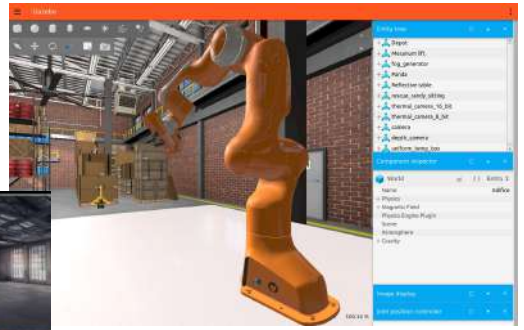
Criteria	Decision Factors
Physics Fidelity	Required fidelity of physics and dynamics model for the intended use case
Visual Fidelity	Level of realism in images (e.g., for computer vision or Machine Learning (ML) applications)
Autopilots	Compatibility with common autopilots like PX4 and Ardupilot, useful for Software-In-The-Loop (SITL) and Hardware-In-The-Loop (HITL) testing
Multiple Vehicles	Capability to concurrently simulate vehicles
Heterogeneity	Integration posibilities with other platforms
Sensors	Integration support for common sensors (e.g., cameras, IMUs, GPS, LIDAR, optical flow)
UAV Models	Support of common UAV models and ease of integrating new models
Simulation Speed	Real-time speed and ability to run in super real-time, crucial for learning applications
APIs	Compatibility with programming languages, middleware like ROS, and package such as OpenAI Gym (now Gymnasium)
Integration	Ease of getting started and development, license type, and maintenance status of the software

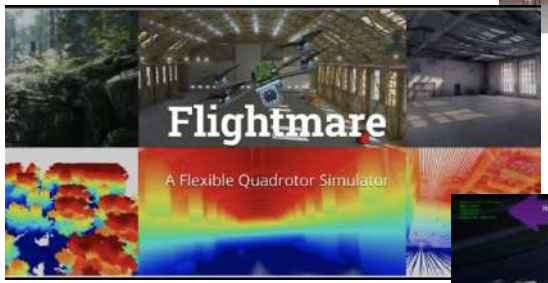
Source: Survey of Simulators for Aerial Robots https://ieeexplore.ieee.org/document/1066597

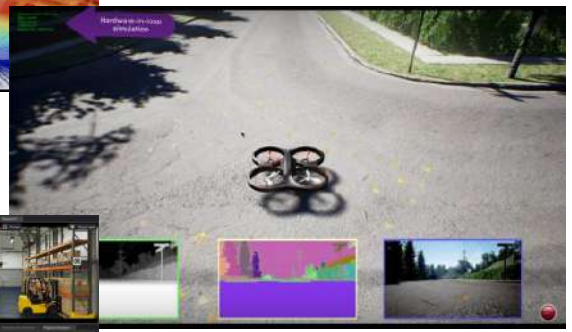
UAV Simulators Overview

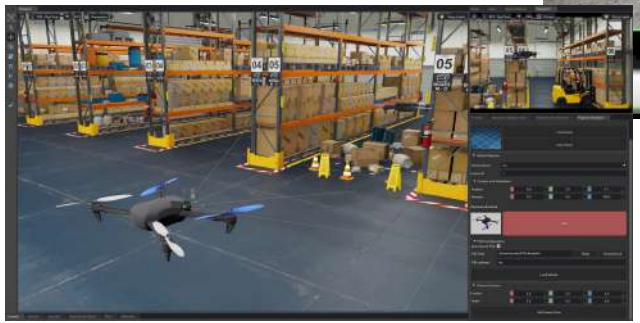
4 simulators were selected:

- Gazebo
- Flightmare
- Microsoft AirSim
- NVIDIA Isaac Sim









UAV Simulators Overview

Name	First release	Latest update	Linux	Mac	Windows	Open-source	SITL	HITL
Gazebo	2002	09.2025	+	+	WSL	yes	PX4, ArduPilot	PX4, ArduPilot
Flightmare	2020	05.2023	+	-	-	yes	SITL absent	HITL absent
AirSim	2017	07.2022	+	+	+	yes	PX4, ArduPilot	PX4, ArduPilot
Isaac Sim	2023	09.2024	+	-	+	no	SITL absent	HITL absent

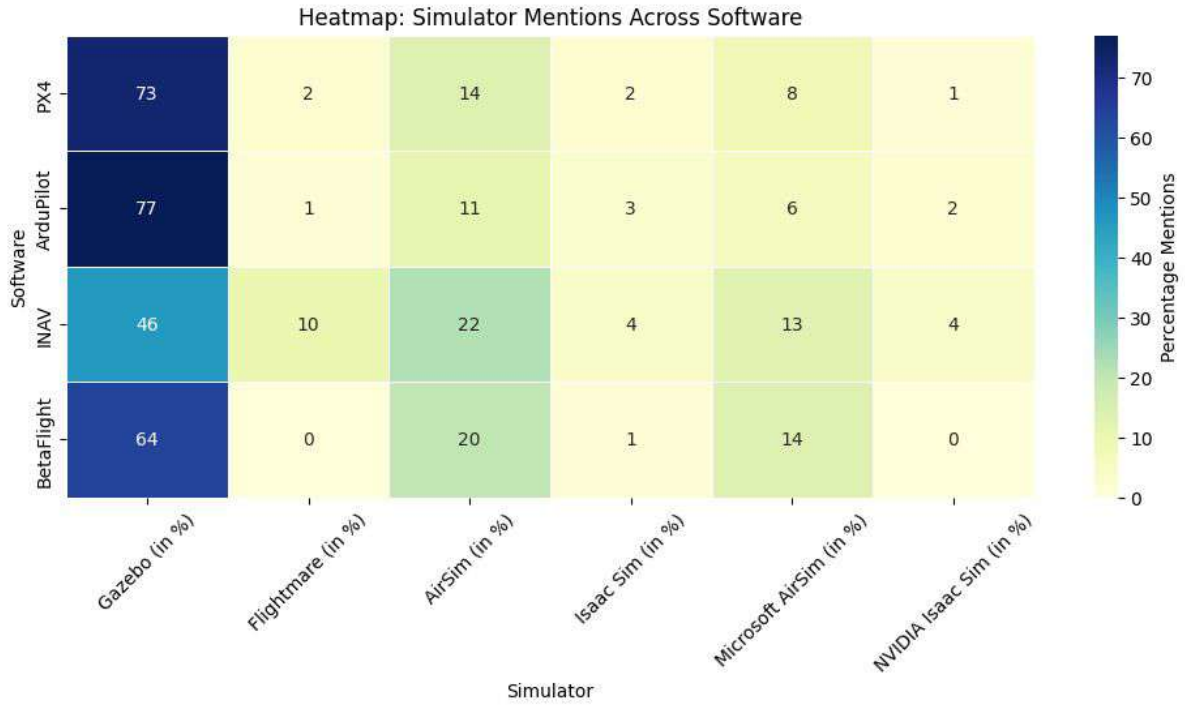
Table 3.1: Aerial robotics simulators comparison: Gazebo, Flightmare, AirSim, Isaac Sim

Distribution Analysis

- Bibliometric Analysis
- Automation
- Data Visualization

- *Google Scholar and Semantic Scholar*
- *Simulators and Flight Control Software*
- *With UAV and without UAV*
- *In Total and Over Years (2000-2025)*

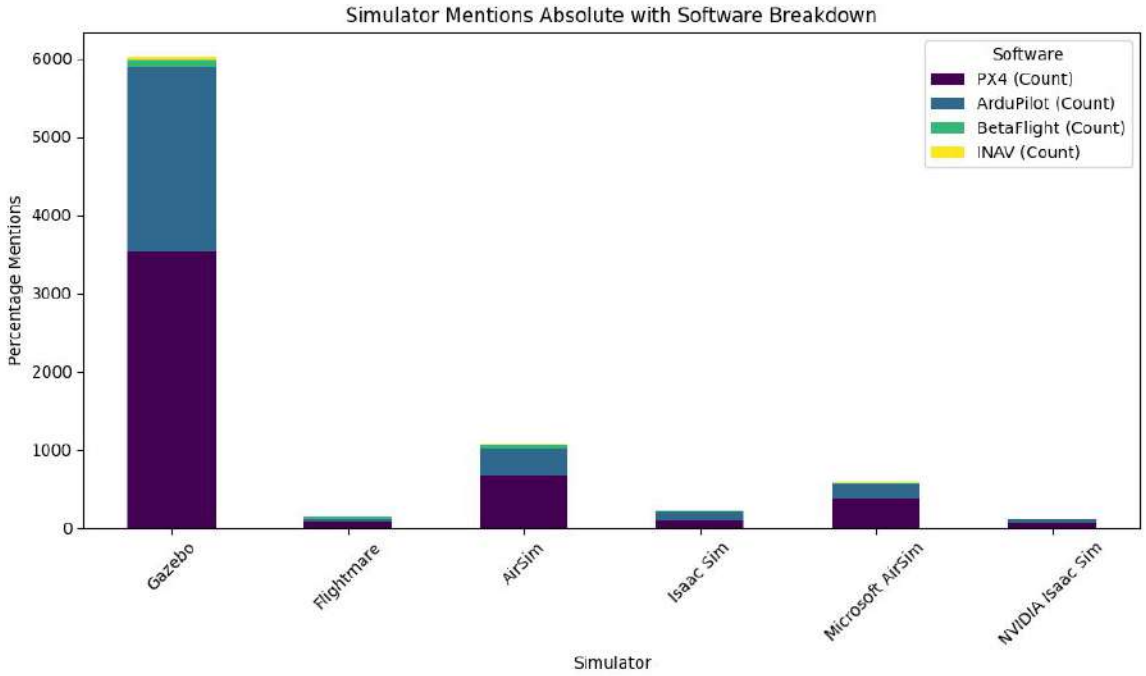
Distribution Analysis



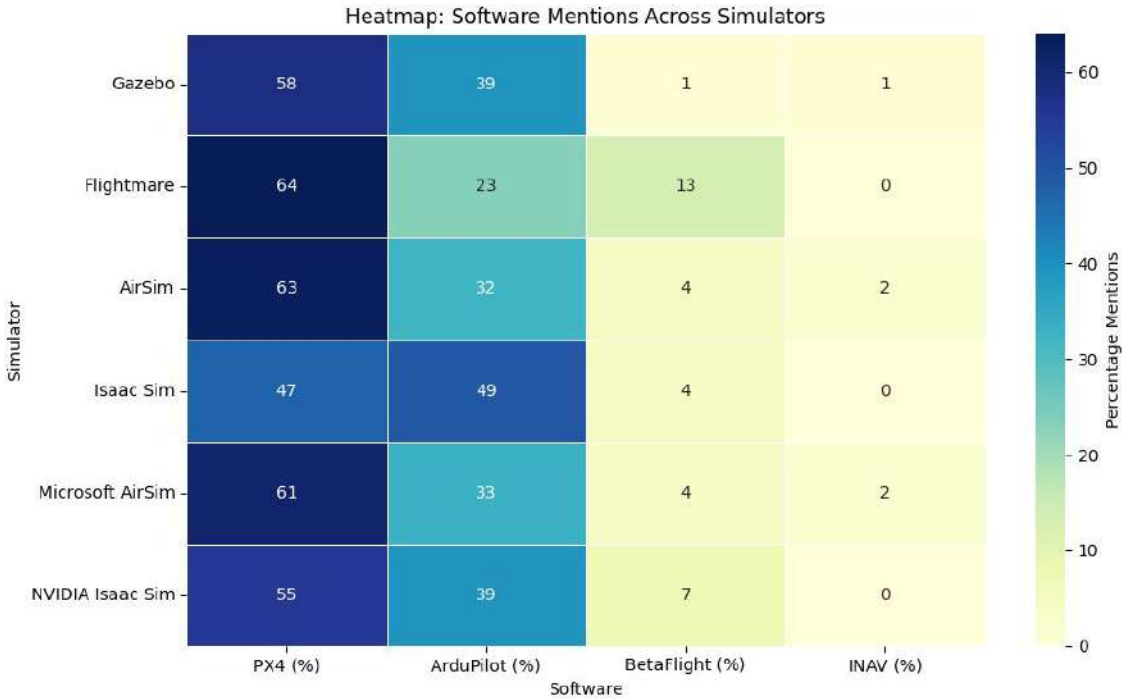
Gazebo is the most popular coupled with all flight control software.

AirSim is also shown to be quite popular but more moderate.

Distribution Analysis

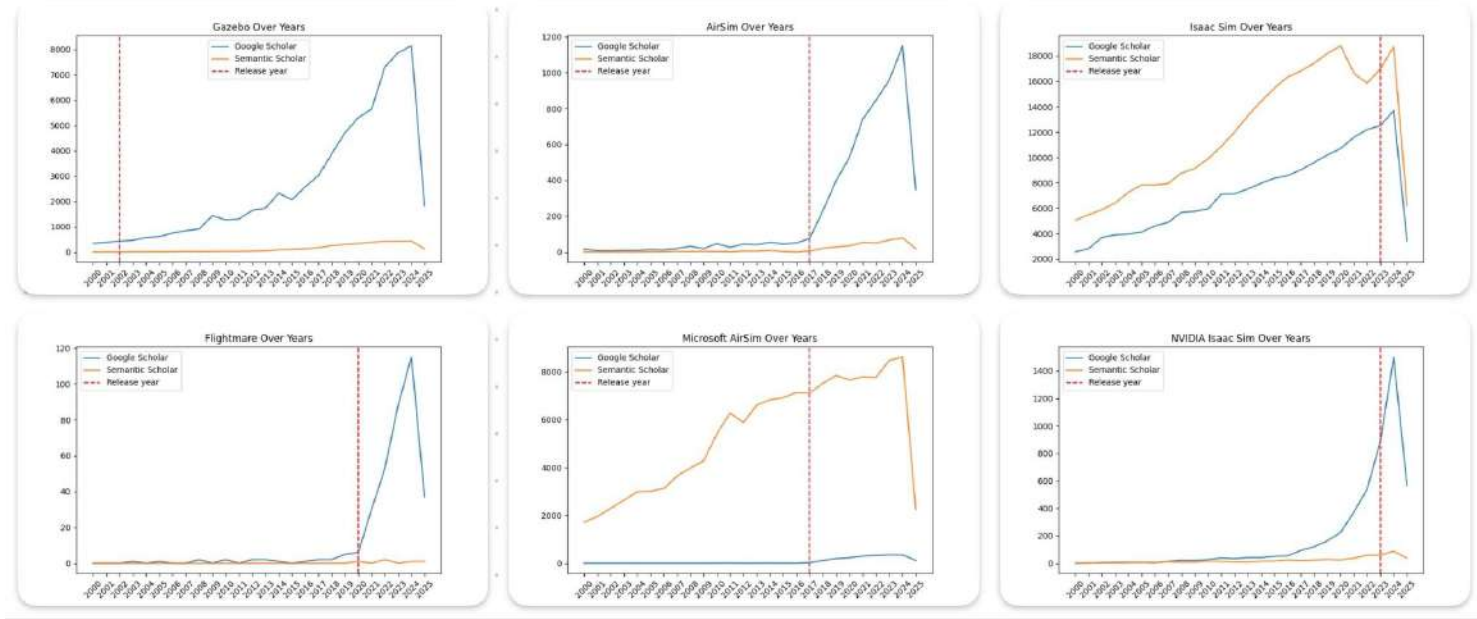


Distribution Analysis



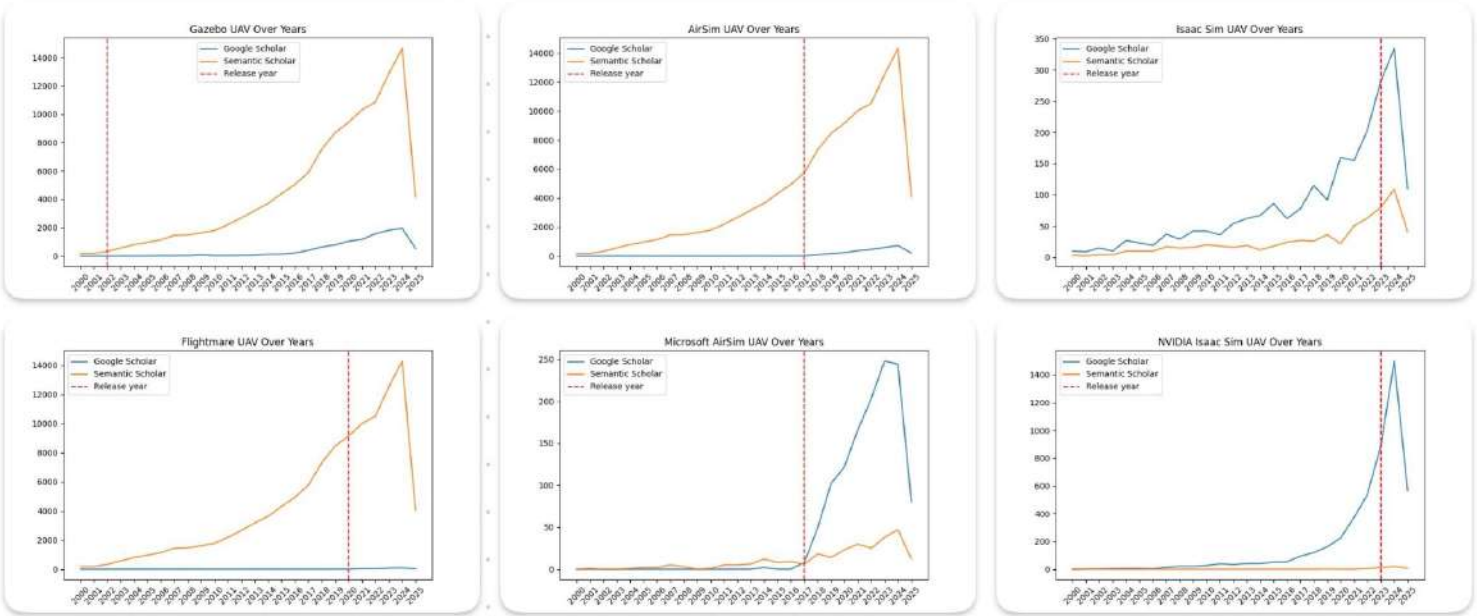
PX4 and ArduPilot are considerably more widespread.

Distribution Analysis Over Years



The growth is observed for all simulators.

Distribution Analysis Over Years UAV



The growth in the context of UAVs is also seen for all simulators.

Identifying the Research Gap

- 13 sources
- 234 worlds, 164 unique worlds
- 1870 models, 1029 unique models

Gazebo world is an XML file with *.world* or *.sdf* extension.

Number	Latest update	Worlds count	Gazebo version	Source
1	03.09.2020	50	Gazebo new (not classic)	[42]
2	–	7	7	[43]
3	06.12.2020	20	5+	[44]
4	15.09.2023	13	Gazebo new (not classic)	[45]
5	18.04.2019	4	–	[46]
6	29.11.2023	8	–	[47]
7	14.05.2021	12	Gazebo 2, 5, 7, 9, 11	[48]
8	11.02.2021	16	Gazebo 9, 11	[49]
9	25.09.2021	12	Gazebo 11	[50]
10	07.03.2025	10	Gazebo new (not classic)	[51]
11	26.07.2021	51	–	[52], [53]
12	13.05.2024	5	Gazebo 7, 9	[54]
13	11.05.2025	5	Gazebo Garden, Harmonic, Ionic	[55]

Table 5.1: List of resources taken into the Gazebo worlds' dataset

Gazebo worlds and models analysis

Element	0	1-5	6+	Max amount
<model>	42%	21%	37%	658
<include>	36%	32%	32%	541
<model> and <include>	0%	41%	59%	1080
<plugin>	74%	18%	8%	49
<joint>	88%	5%	7%	50
<sensor>	93%	7%	0%	3
<link>	10%	33%	57%	1440
<plugin>, <joint>, and <sensor>	87%	2%	11%	50

Table 5.2: Conclusions About **Gazebo Worlds** Analysis

Most worlds and models do not contain any plugins, joints, and sensors.

Element	0	1-5	6+	Max amount
<include>	94%	5%	1%	28
<plugin>	90%	7%	3%	17
<joint>	88%	6%	6%	65
<sensor>	92%	7%	1%	18

Table 5.3: Conclusions About **Gazebo Models** Analysis

Development of a New Gazebo World With a Moving Car

- Gazebo as a simulator
- ArduPilot as a flight control software
- ArduPilot Gazebo official plugin as a connector
- Plugin DiffDrive is used to make the car move
- Plugins TriggeredPublisher and KeyPublisher are used to make car move with a keyboard

Demonstration

https://www.youtube.com/@sofiia_budilova

Conclusion and Future Work

Aerial robotics and UAVs are developing. Simulators prove useful in testing new algorithms.

Many simulators already exist. Each year the amount of papers with simulators grows.

Gazebo is the most robust out of all of them.

Many Gazebo worlds do not contain moving objects. Because of that a new Gazebo world with a moving car was presented.

This simulation can accelerate and enhance the security of UAV software development, such as for object-tracking algorithms.

Thank you for your attention!