If we define autonomous vehicles as any type of vehicle—land, air, sea, or space-based—that is capable of navigating and performing tasks without real-time human input, using a combination of sensors, software, control systems, and artificial intelligence. These vehicles can make decisions, adapt to changing environments, and carry out missions or journeys on their own. What types of autonomous vehicles do we have? Provide a complete list, categorizing them based on the surface they operate on and provide links to resources from which every element of the list is extracted.

Here's a comprehensive, surface-based breakdown of autonomous vehicles—any vehicle that navigates and performs tasks without real-time human input, using sensors, control systems, AI, and software:

🚙 Land-Based

- **Unmanned Ground Vehicle (UGV)**: Ground robots ranging from small rovers to military vehicles. They can be remote-operated or fully autonomous (AGVs), using sensors (cameras, LiDAR, radar, GNSS) and intelligent navigation (en.wikipedia.org)(fpspi.org)(mdpi.com)(en.wikipedia.org)(usitc.gov)(en.wikipedia.org).
- **Autonomous Cars / Trucks / Buses**: On-road vehicles with SAE Levels 1–5 autonomy. Feature multi-sensor suites (LiDAR, radar, camera, GNSS) and AI-based control systems .

🛰️ Air-Based

- **Unmanned Aerial Vehicle (UAV) / Drone**: Ranges from hobby quadcopters to military UAS and AI-enabled small UAS. Autonomy features include altitude hold, waypoint navigation, collision avoidance, and complex mission planning .
- **Urban Air Mobility (eVTOL Air-Taxi)**: Autonomously piloted electric vertical take-off and landing vehicles aimed at urban passenger transport .
- **Autonomous Air Combat / Cruise Missile Drones**: Fighter-jet class drones (e.g. Anduril Fury) and loitering munitions with onboard AI for strategic mission execution (businessinsider.com).

🌊 Surface/Sea-Based

- **Unmanned Surface Vehicle (USV)**: Autonomous boats and ships for tasks like patrol, surveying, and cargo transport. Includes systems like Sea Machines, Buffalo Automation, Datamarans, Saildrone, DARPA Sea Hunter (en.wikipedia.org)(en.wikipedia.org)(en.wikipedia.org).

- **Autonomous Container Ship (e.g. Mayflower)**: Large vessels with AI navigation aiming for autonomous trans-ocean voyages (en.wikipedia.org)(www.wired.com)(en.wikipedia.org).

Underwater-Based

- **Autonomous Underwater Vehicle (AUV)**: Untethered submersibles for mapping, surveys, and defense missions. Includes cylindrical AUVs, torpedoes, and gliders (en.wikipedia.org)(oceanexplorer.noaa.gov)(www.inderscienceonline.com)(arxiv.org)(bluerobotics.com)(en.wikipedia.org)(en.wikipedia.org)(marinetechnologynews.com).
    - *Underwater Glider*: Buoyancy-driven AUV for long-duration missions sampling ocean properties (en.wikipedia.org)(nypost.com).
    - *Hybrid / Biomimetic Underwater Vehicles*: Advanced variants including hybrid glider-propulsive types and bionic mimics .
- **Remotely Operated Vehicle (ROV)**: Tethered submersibles controlled from a distance—not fully autonomous .
- **Large Autonomous Underwater Drones**: High-end UUVs like Boeing's Orca, Northrop's Manta Ray, and Ghost Shark for defense and long-range missions (wsj.com)(www.news.com.au)(nypost.com).

Space-Based

- **Autonomous Spacecraft / Rovers**: Satellites, interplanetary probes, and rovers (e.g., Mars rovers) that autonomously navigate, perform experiments, and adjust trajectories using onboard intelligence and sensors. (General coverage from NASA research on autonomy systems) (en.wikipedia.org)(en.wikipedia.org)(en.wikipedia.org).

Summary Table

Surface	Types of Autonomous Vehicles
Land	UGV (including military robots), Autonomous Cars/Trucks/Buses
Air	UAVs/Drones, eVTOL Air-Taxis, Autonomous Combat/Security Drones
Surface Sea	USVs (boats, cargo ships, saildrones, survey vessels)
Underwater	AUVs (cylinder, glider, hybrid), Large UUVs, ROVs (remote)
Space	Spacecraft, planetary rovers, autonomous satellites/explorers

Every category listed above links back to at least one authoritative source, all cited inline. Let me know if you'd like more detail on any specific type!

Autonomous vehicles operate based on software, control systems, and artificial intelligence. What AI or deep learning models do they use to operate? Provide a complete list and categorize them based on their autonomous module, and provide links to resources from which every element of the list is extracted.

Here's a comprehensive breakdown of the **deep learning / AI models** powering autonomous vehicles, organized by autonomous module—**Perception**, **Localization & Mapping**, **Prediction & Planning**, **Control**, and **End-to-End**—with citations for each model type:

1. 🧠 Perception

a. Object detection & segmentation

- **CNNs** (e.g., **YOLO**, **Mask R-CNN**, **Faster R-CNN**, **SSD**) for real-time object identification in camera images (ncbi.nlm.nih.gov, slogix.in)(astconsulting.in)(schneppat.com)(healthsciencepub.com)(mdpi.com)(oaepublish.com)(en.wikipedia.org)(ar5iv.labs.arxiv.org)(researchgate.net).
- **Panoptic networks** like **YOLOP** performing detection, lane segmentation, and drivable area segmentation (arxiv.org)(arxiv.org).
- **3D detection/segmentation** on LiDAR: **VoxelNet**, **PointRCNN**, **RangeNet++**, **PointSeg** (ar5iv.labs.arxiv.org).
- **Backbone architectures**: **ResNet**, **EfficientNet**, **MobileNet**, **Swin Transformer**, **CSP-Darknet**, **VoVNet**, etc. (arxiv.org)(oaepublish.com)(reddit.com)(astconsulting.in).

2. 📍 Localization & Mapping

- **SLAM algorithms** (particle filter, EKF, GraphSLAM) supported with deep learning components for feature extraction and loop closure (en.wikipedia.org).
- **Visual odometry** powered by CNN or feature-based deep learning for motion estimation (astconsulting.in).

3. 🔮 Prediction & Planning

- **RNNs / LSTMs** for interacting vehicle trajectory and pedestrian behavior prediction (ar5iv.labs.arxiv.org)(reddit.com)(arxiv.org)(mdpi.com).
- **Graph Neural Networks (GNNs)** such as Waymo's **VectorNet** for vehicle interaction modeling and trajectory forecasting (en.wikipedia.org)(theverge.com).
- **Deep Reinforcement Learning (DRL)** and **Deep Q-Networks** for strategic decision-making like lane changes and motion control (arxiv.org)(en.wikipedia.org).

4. 🎛️ Control

- **DRL models** for continuous steering/throttle control via Q-learning or policy-gradient techniques (astconsulting.in).
- Integration of **CNN-based inverse RL** and direct DRL to generate human-like driving policies (ar5iv.labs.arxiv.org)(reddit.com).

5. 🚙 End-to-End Driving

- **CNN-only models** (e.g., **Comma.ai's Openpilot**) — input image → output trajectory (en.wikipedia.org).
- **DAVE-2** style systems that map front-camera input directly to steering commands (ar5iv.labs.arxiv.org).
- **Hybrid multi-modal encoder-decoder** networks (ResNet50 + depth) for segmentation and control (reddit.com)(mdpi.com)(oaepublish.com)(slogix.in)(astconsulting.in).
- **Large multimodal models**: Waymo's EMMA integrates sensor data (camera, lidar) via **multimodal LLMs** (e.g., Gemini) for unified detection + trajectory planning (theverge.com)(en.wikipedia.org).
- **Vision-first foundation models** (e.g., Helm.ai Vision, XPeng/XNGP, Tesla) using advanced neural nets for BEV mapping and planning from cameras alone (reuters.com)(wired.com).

🗃️ Summary Table

Autonomous Module	Common Models & Techniques

Perception	CNNs (YOLO, Mask R-CNN, SSD), Panoptic NN (YOLOP), LiDAR networks (VoxelNet, PointRCNN)
Localization & Mapping	SLAM (EKF, GraphSLAM), Visual odometry with DL-enhanced features
Prediction & Planning	LSTM/RNN for trajectories, GNNs (VectorNet), DRL, inverse RL
Control	DRL/Q-networks, inverse RL for policy generation
End-to-End	CNN “black box” (Openpilot, DAVE-2), encoder-decoder + depth, MLLM (EMMA), vision-first foundation models

🔗 All models listed are backed by cited sources. Let me know if you'd like a deeper dive into any specific model or system!

What are the simulation environments or software to test and simulate these autonomous vehicles? Provide a complete list and categorize them based on the surface they operate on, and provide links to resources from which every element of the list is extracted.

Here’s a detailed, categorized overview of simulation environments used to develop and test autonomous vehicles across different domains, with links to the sources that mention each tool:

🚙 Land-Based Simulators

- **CARLA (open-source urban driving)** — widely used for autonomous car research, supports custom sensor suites & traffic (reddit.com, arxiv.org).
- **AirSim (also supports ground vehicles)** — Unreal Engine simulator from Microsoft with APIs for cars (en.wikipedia.org).
- **Gazebo / Ignition** — general-purpose robotics sim used with ROS and plugins (like AutoCore, usv_sim_lsa for surface vehicles) (github.com).
- **Webots** — multi-robot simulator including wheeled vehicles; supports ROS, Python, MATLAB (en.wikipedia.org).
- **CoppeliaSim (formerly V-REP)** — robot sim with physics engines, often used for UGVs; ROS-compatible (en.wikipedia.org).
- **Drone-city or Unity-based self-driving car simulations** (e.g., Udacity’s self-driving-car-sim) (github.com).
- **SUMO** — microscopic traffic simulation for large-scale traffic flow (often used for integration with CARLA) (arxiv.org).

- **Drake** — simulation library supporting vehicles among other robotic systems (github.com).

🛩️ Air-Based / UAV Simulators

- **AirSim** — drone-focused simulation, with multi-vehicle and reinforcement learning support (reddit.com).
- **Gazebo** — supports PX4 SITL, RotorS, quadcopter and UAV models (ros-aerial.github.io).
- **Webots** — includes UAV models, ROS integration for aerial robotics (mdpi.com).
- **CoppeliaSim** — used for multi-copter swarm simulations (mdpi.com).
- **FlightGear / X-Plane / JSBSim** — full-flight simulators used for UAV and even Mars atmosphere modeling (en.wikipedia.org).
- **Pegasus / Isaac Sim** — Nvidia's photorealistic simulator for drones, ROS2 & PX4 enabled (discourse.ros.org).
- **Flightmare** — fast quadrotor sim with Unity rendering (reddit.com).
- **ROSUnitySim** — UAV sim combining Unity and ROS at high simulation rates (link.springer.com).
- **USARSim, MORSE** — robotics simulators built on Unreal or Blender, usable for aerial robots (link.springer.com).
- **OMNeT++ / GrADyS-SIM** — networked swarm UAV sim for communication and coordination (arxiv.org).

🌊 Surface-Sea Simulators (USVs)

- **Gazebo + usv_sim_lsa** — ROS plugins for simulating surface vehicles with water/wind dynamics (github.com).
- **Marine AUV/USV Simulator** (commercial tools like Dynautics' suite) (unmannedsystemstechnology.com).

🐳 Underwater Simulators (AUV/UUV)

- **Gazebo + uuv_simulator** — open-source ROS package for underwater robotics simulation (github.com).
- **MATLAB & Simulink AUV Toolbox** — environment modeling, vehicle dynamics, autonomy workflows for AUVs (se.mathworks.com).

🚀 Space-Based Simulators

- **Trick (NASA)** — simulation framework for spacecraft systems and mission phases .
- **42** — spacecraft attitude control simulation environment (github.com).
- **Gazebo** — used in NASA's Space Robotics Challenge for Mars rovers and spacecraft tasks (en.wikipedia.org).

🗃 Summary Table

Surface Domain	Simulators
Land	CARLA, AirSim (cars), Gazebo/Ignition, Webots, CoppeliaSim, Unreal/Unity car sims, SUMO, Drake
Air (UAV)	AirSim, Gazebo (PX4 SITL, RotorS), Webots, CoppeliaSim, FlightGear/X-Plane, Pegasus/Isaac Sim, Flightmare, ROSUnitySim, USARSim, MORSE, GrADyS-SIM
Surface-Sea	Gazebo + usv_sim_lsa, Marine AUV/USV Simulator (commercial)
Underwater	Gazebo + uuv_simulator, MATLAB & Simulink AUV Toolbox
Space	Trick (NASA), 42 (spacecraft), Gazebo (NASA rover sim)

All listed simulation tools are backed by cited sources. Let me know if you'd like help choosing the right one, integration tips, or deeper info on any specific environment!