Aerial Vehicles in Gazebo

Aerial Robotics CWG, 27 March 2024

Outline

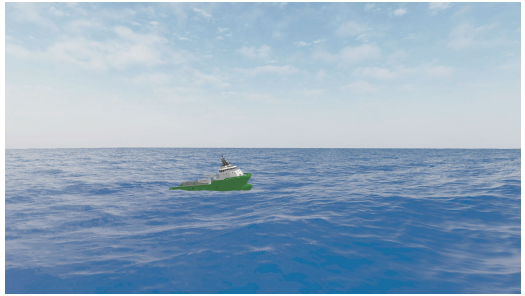
- Gazebo capabilities *
- OSRF projects for aerial vehicles
  - MBZIRC
  - Vehicle Gateway
- Autopilot SITL frameworks integrated with Gazebo
  - Betaflight
  - PX4
  - ArduPilot *

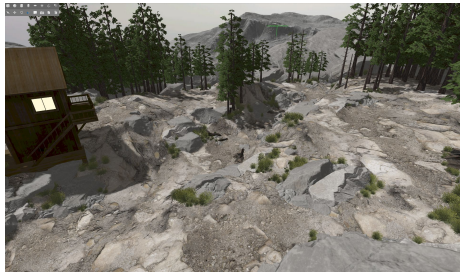
** Some slides reproduced from a presentation given at the 2023 ArduPilot (un)conference.*

What's new in Gazebo

Customisable toolbox of simulation libraries

- Physics
  - Accurate simulation with DART.
  - Plugin system for physics backend.
- Rendering
  - Ogre-Next 2.3 rendering engine (PBR).
  - Plugin system for rendering backend.
- Senors
  - Rich camera system.
  - Extend with sensor plugins.
- Simulation Engine
  - Extend with system plugins.
- GUI
  - Custom GUI widgets as plugins.
- ROS / ROS 2 integration





Much more information at: https://gazebosim.org/home

Gazebo Classic to Gazebo Garden (`gz-sim7`)

Gazebo Classic

- https://classic.gazebosim.org/.
- Monolithic application.
- `gazebo <world>.world`.

Plugin

- `ModelPlugin::OnUpdate`.
- Maintains event connection for time step update.
- Holds pointers to models, joints, sensors.

Models and worlds

- Custom materials using OGRE scripts.
- Systems available automatically.

Gazebo Garden (`gz-sim7`)

- https://gazebosim.org/home.
- Libraries and plugins.
- `gz sim <world>.sdf`.

Plugin

- `ISystemPreUpdate`, `ISystemPostUpdate`,
- Uses Entity Component System (ECS).
- Holds entities (ids) and accesses components.

Models and worlds

- OGRE-Next PBR, script materials will not work.
- Systems must be enabled with plugins.

Gazebo systems and sensors

Physics

- LiftDrag
- AdvancedLiftDrag

Controllers

- JointController
- JointPositionController
- MultiCopterControl
- MultiCopterMotorModel

State

- JointStatePublisher
- OdometryPublisher
- PosePublisher

Sensors

- AirPressure
- AirSpeed
- Altimeter
- Cameras (RGB, Depth, WideAngle, Thermal, ...)
- Imu
- Lidar
- Magnetometer
- NavSat
- ThermalSensor

Global Systems

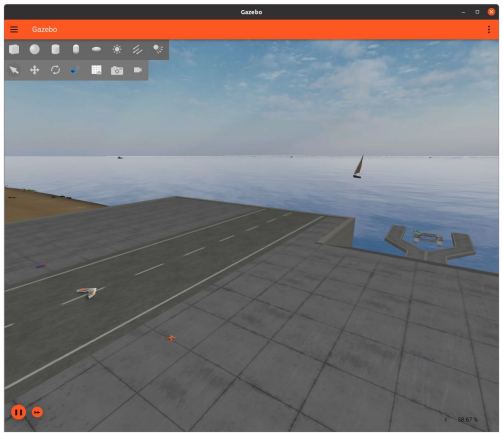
- Physics
- Sensors

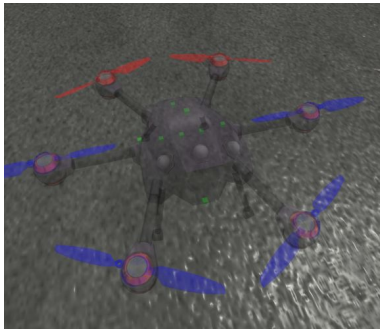
Environment

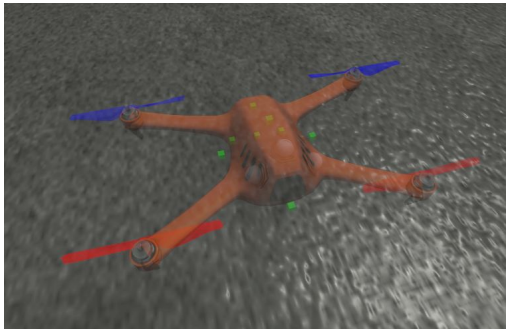
- WindEffects

MBZIRC Maritime Grand Challenge Simulator

- Terrestrial and maritime environments.
- Multiple aerial and surface vehicles.
- UAVs offered
  - fixed_wing
  - quadrotor
  - hexarotor
- SDF models templated using embedded ruby.
- Configurable slots for sensor payloads.
- Multi-rotor UAVs are velocity controlled via `geometry_msgs/msg/Twist`
- Fixed wing UAV has custom controller accepting service calls to `mavros_msgs/CommandTOL` and attitude commands to `mavros_msgs/AttitudeTarget`
- Not actively maintained: last PR Sep 2022







Vehicle Gateway

Plugin libraries to interface to multiple vehicle SDKs

- betaflight
- px4

Manages download and build of autopilot stacks

Python and C++ bindings

Platform

- Ubuntu 22.04
- ROS 2 Humble
- Gazebo Garden
- Zenoh

Challenges

- Arriving at a common interface for vehicle modes and commands (this varies even within an autopilot stack for different vehicle types)
- Does not include ArduPilot (license compatibilty)
- Cross platform support (no macOS)
- Project momentum
  - Last PR from project owners May 2023
  - Some ongoing community maintenance

Suggestions

- A more loosely coupled, message oriented interoperability model may be more sustainable?

Betaflight SITL and Gazebo

- https://betaflight.com/docs/development/SITL
- Built in support appears to target support Gazebo Classic
  - `gazebo --verbose ./iris_arducopter_demo.world`
  - Uses a binary protocol similar to `ardupilot_gazebo` plugin for Gazebo Classic to connect to flight controller.
- Vehicle Gateway offers support for Gazebo Garden / ROS 2 Humble
- Most recent PR Feb 18 2023: #12346 Added SITL Gazebo

PX4 SITL and Gazebo

Guide

- https://docs.px4.io/main/en/sim_gazebo_gz/

Platforms

- Ubuntu 20.04, 22.04
- macOS

SITL integration

- Use gz transport layer directly
- No need for custom plugin in model

Models

- https://github.com/PX4/PX4-gazebo-models
- https://app.gazebosim.org/PX4

Vehicles

- Omnicopter
- Holybro PX4 Vision
- RC Cessna
- Standard VTOL
- x500

Systems and sensors

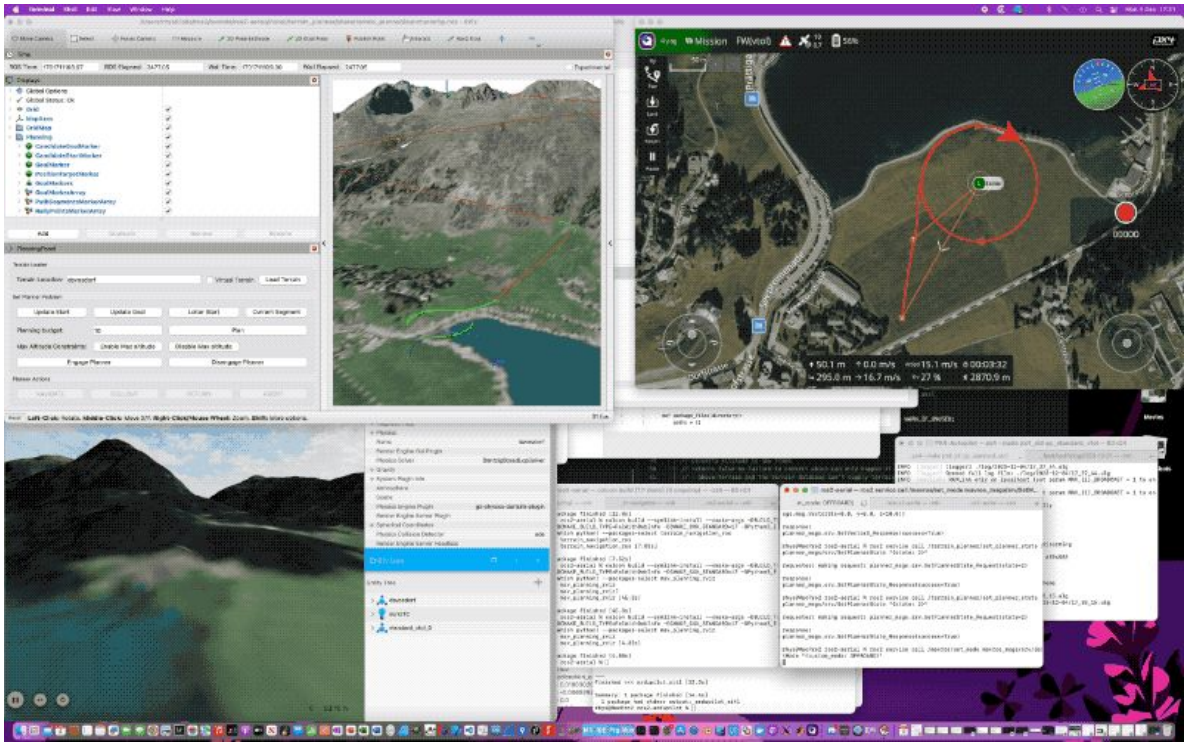
Models use packaged Gazebo systems and sensors

- LiftDrag
- JointPositionController
- MultiCopterMotorModel
- AirPressure
- Camera
- Imu
- OdometryPublisher

PX4 SITL - terrain planning

Terrain navigation with PX4 SITL flight control and Gazebo.

- Standard VTOL frame
- Davos terrain model
- QGC ground station
- Setpoints via MAVROS
- Visualization in rviz2



ArduPilot SITL and Gazebo

Vehicles

- Bicopter
- MiniHawk VTOL
- Skycat TVBS
- Swan K1 H-wing
- Weight-shift-controlled aircraft
- PIK-20B sailplane

Terrain

- Creating terrain models

Other features

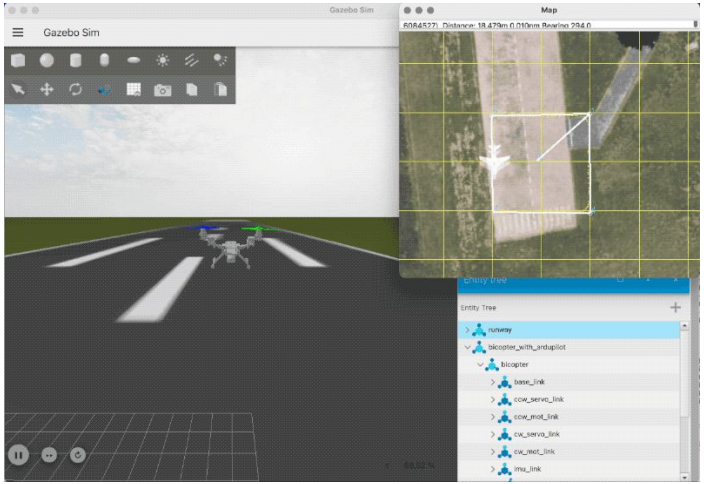
- Lock-step simulation
- Parachute
- Gimbal
- 32 servo support

Applications

- Moving platform takeoff and landing
- Off-board GPS-denied navigation
- Tethered payloads

Bicopter

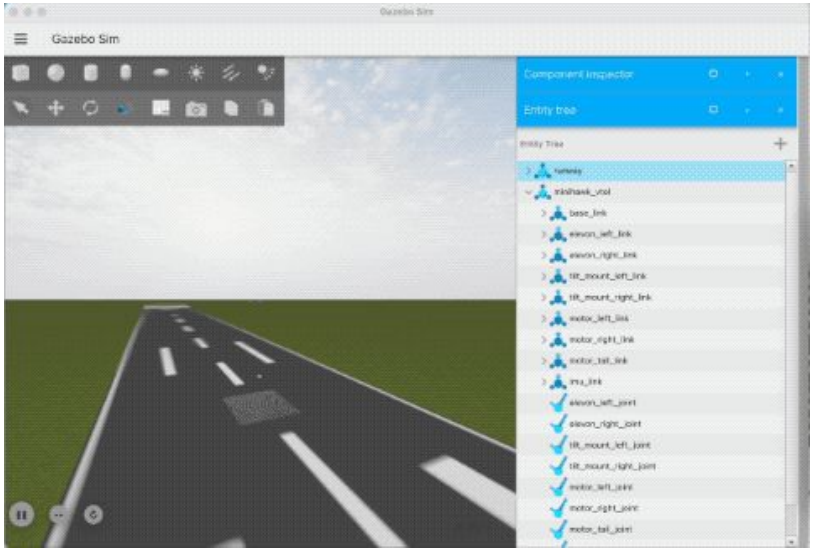
- 2 servos, 2 motors.
- Sensitive to CoM positioning.
- Prone to oscillations - careful rate tune required.
- ArduPilot Discourse user developed frame.



Above: Bicopter joints and inertials.
Left: Bicopter in AUTO mode.

MiniHawk-VTOL (Stephen Carlson)

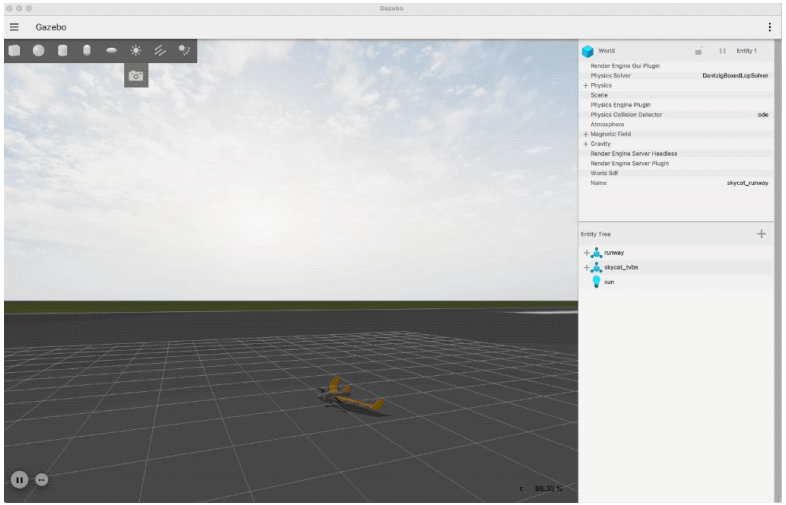
- Tricopter tilt-rotor plane.
- Yaw control by motor vectoring.
- Used to understand effect of parameters when setting up real aircraft (Q_TILT_YAW_ANGLE and yaw rate controllers).

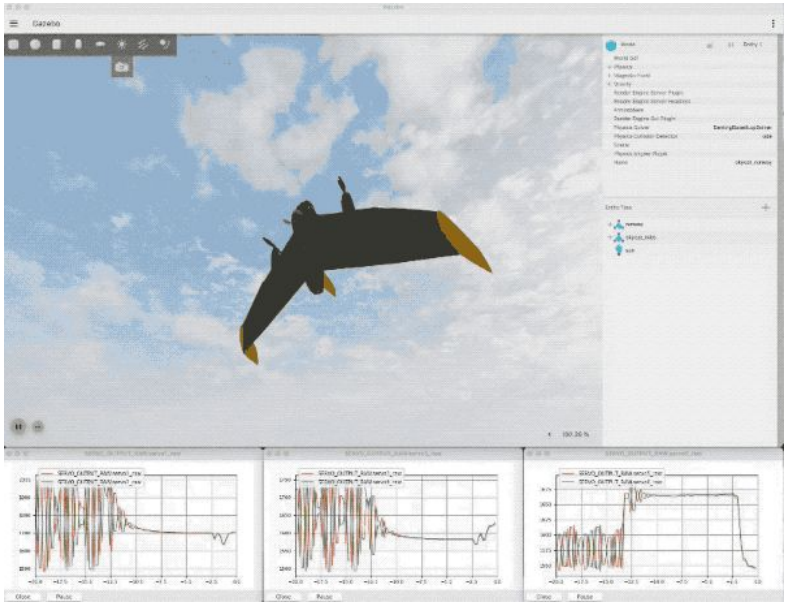


Above: Minihawk takeoff and transition to FBWA.
Left: transition from FBWA to QLOITER.

Skycat TVBS (thrust-vectored belly-sitter)

- Twin motor tilt-rotor + elevons.
- Learn how to configure tilt-rotors.
- Qualitatively reproduce control stability issues such as oscillations.

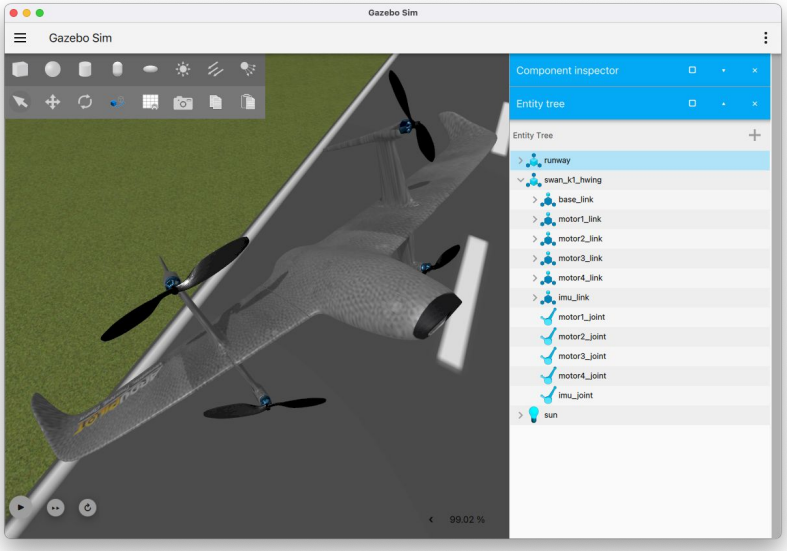


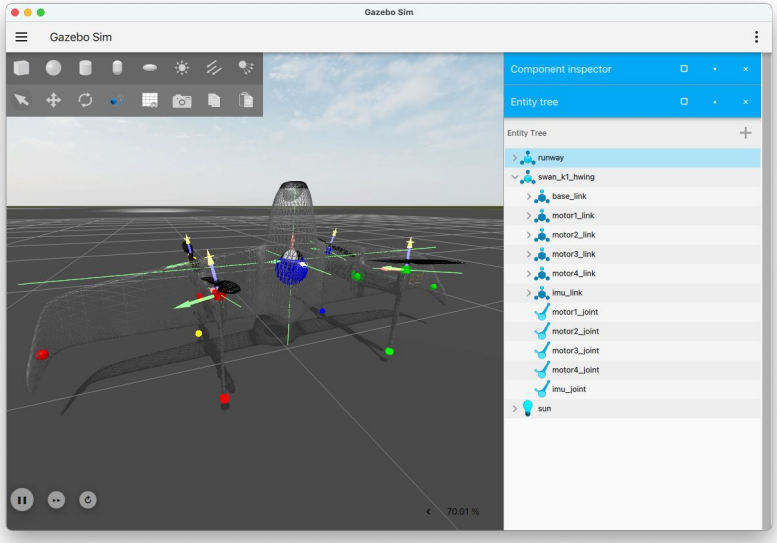


Above: QLOITER oscillations in un-tuned vehicle.
Left: Skycat TVBS - takeoff.

Swan K1 H-wing

- 4 motors, no control surfaces.
- Sensitive to motor orientation.
- Difficult to tune in forward flight.

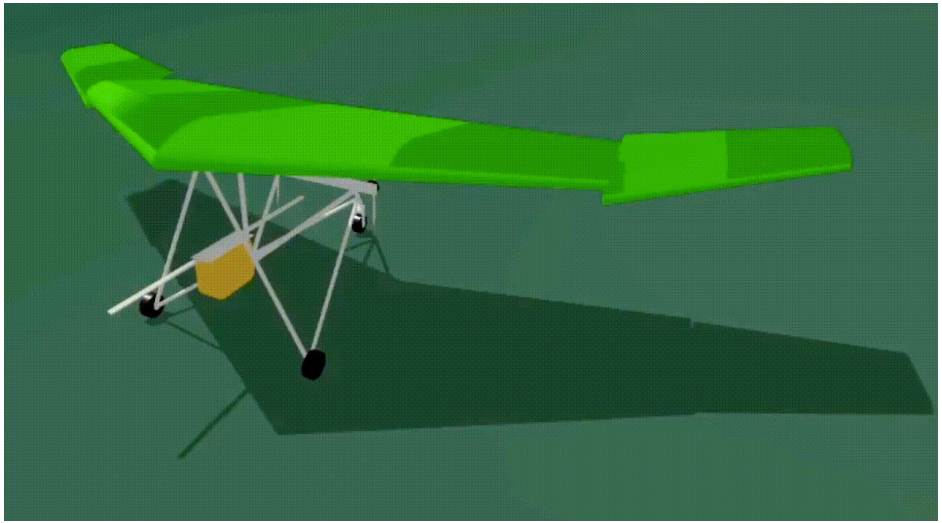


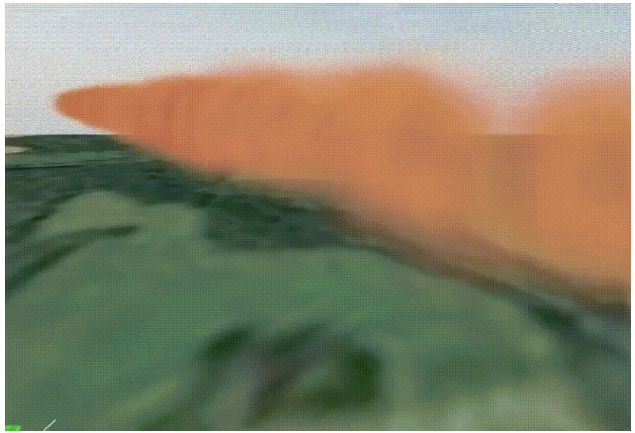


Above: H-wing markers for contacts, pressure and joints.
Left: H-wing flying. Difficult to sim. correct pitch in FBWA.

Romaeris uncrewed weight shift controlled aircraft

- 2 revolute joints to control hang-block
- Mailhot, N., de Jesus Krings, T., Tuta Navajas, G., Zhou, B., & Spinello, D. (2023). *uWSC Aircraft Simulator: A Gazebo-based model for uncrewed weight-shift control aircraft flight simulation*. 2023 IEEE Symposium on Robotics and Sensors Environments (ROSE), Tokyo, Japan.





Above: Hang-block movement.
Left: Weight-shift-controlled aircraft in flight.

PIK-20B sailplane - fitting aerodynamics coefficients

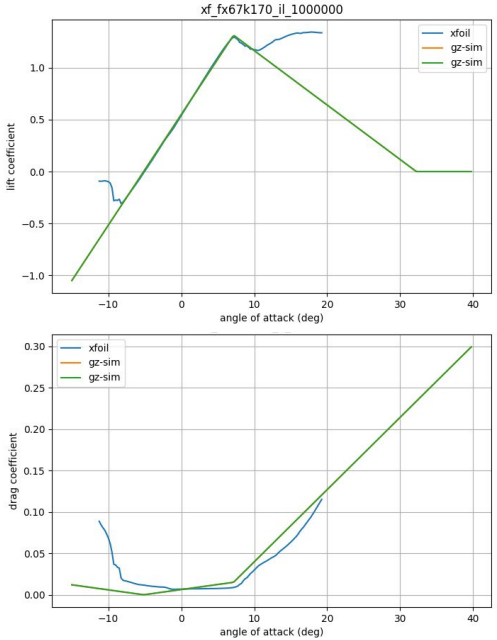
Configure Lift-Drag plugin.

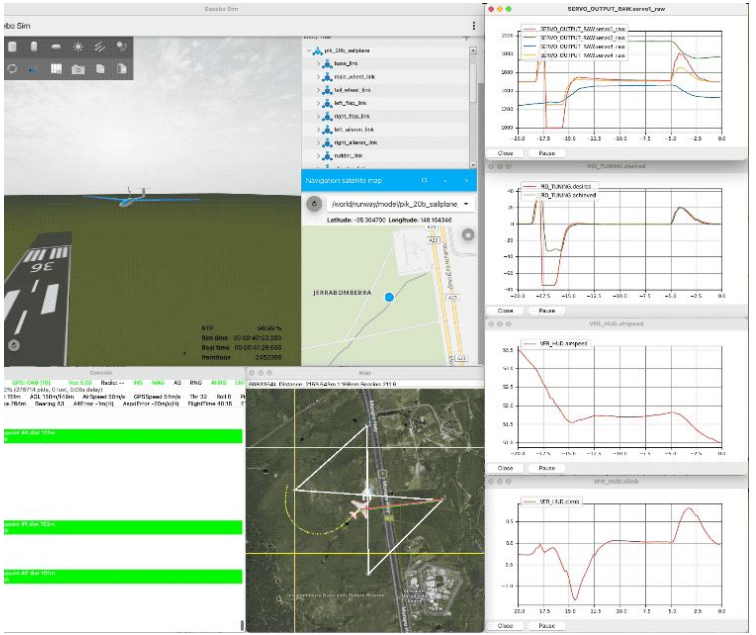
Fit plugin coefficients to lift and drag curves.

Foil profiles from flight manual.

Coeffs from http://airfoiltools.com

Piecewise linear approximation.





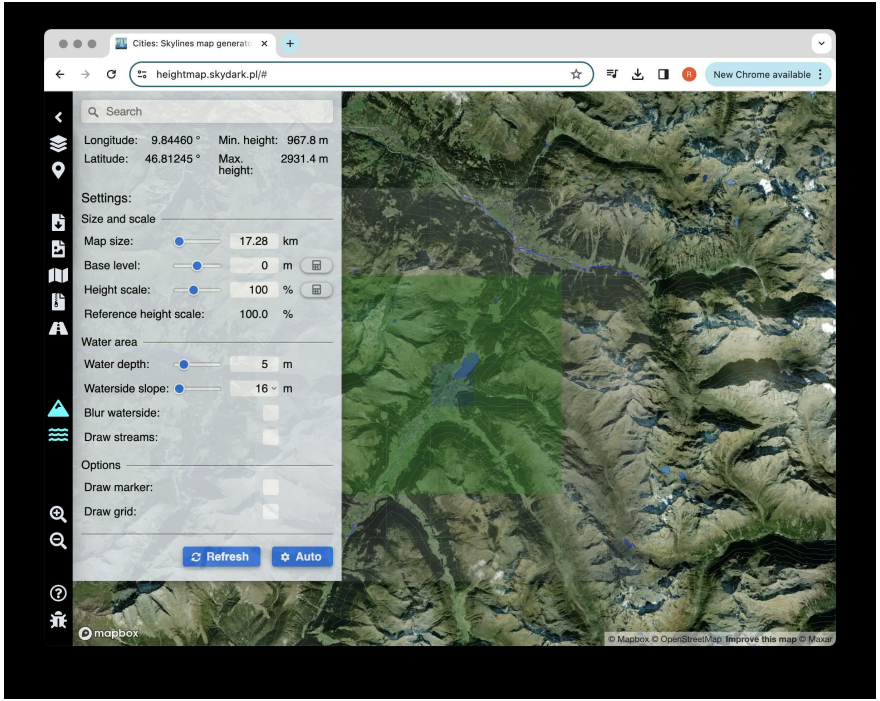
Terrain

Gazebo DEM tutorials (classic and current)

- Gazebo : Tutorial : Digital Elevation Models
- Gazebo Rendering: Heightmap

Cities-Skylines Heightmap Generator

- https://heightmap.skydark.pl/
- Select smallest map size (17.28 km)
- Set base level 0 m
- Height scale 100%
- Download zip with PNG and lat/lon info
- Download map image and convert to JPEG

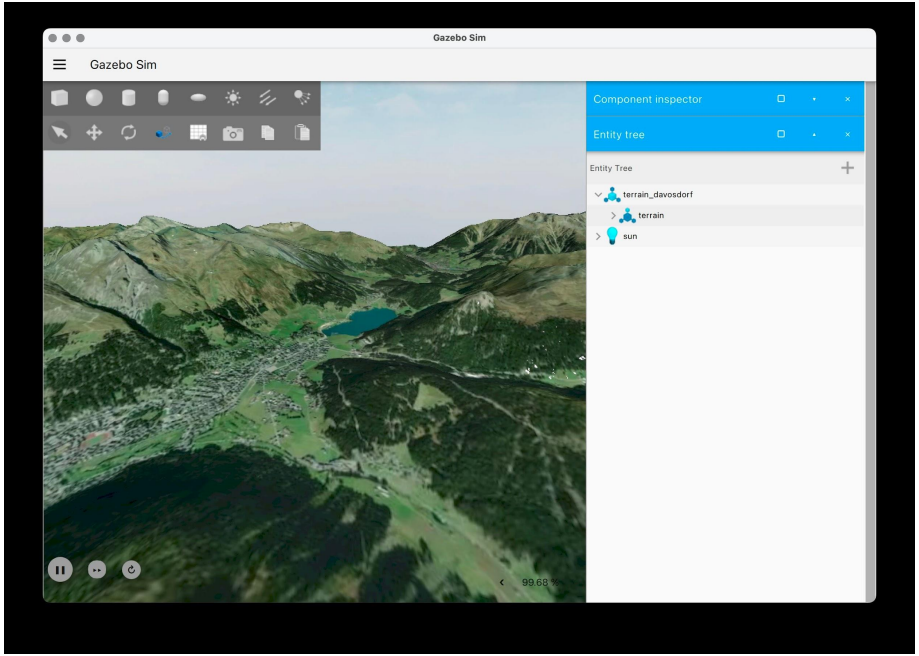


Adjust download settings in https://heightmap.skydark.pl/

Terrain

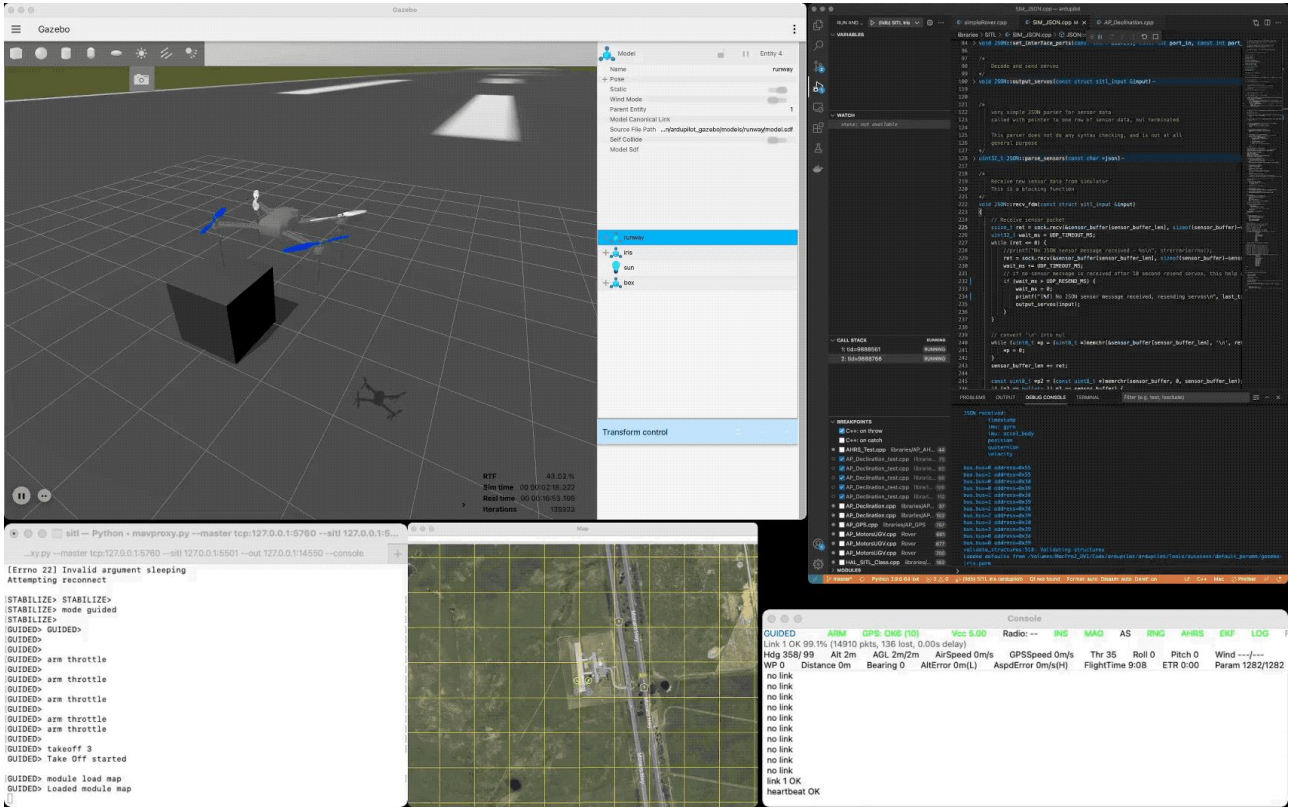
Heightmap geometry with size matching sampled tile.

```
<model name="terrain_davosdorf">
  <static>1</static>
  <link name="terrain">
    <collision name="collision">
      <pose>-280 -100 971.5 0 0 0</pose>
      <geometry>
        <heightmap>
          <size>17280 17280 1963.6</size>
          <uri>media/heightmap.png</uri>
        </heightmap>
      </geometry>
    </collision>
    <visual name="visual">
      <geometry>
        <heightmap>
          <texture>
            <diffuse>media/colormap.jpeg</diffuse>
            <size>17280.0001</size>
          </texture>
          <pos>-280 -100 971.4</pos>
          <size>17280 17280 1963.6</size>
          <uri>media/heightmap.png</uri>
        </heightmap>
      </geometry>
    </visual>
  </link>
</model>
```



Terrain for Davos and surrounds in Gazebo (`gz-sim8`).

Lock-step simulation



- Using SITL_JSON API.
- SITL and Gazebo kept in lock-step.
- Debug plugin or gz-sim.
- Debug flight controller.
- Code either side of the socket waits for response before sending next message.

Enable 32 servos

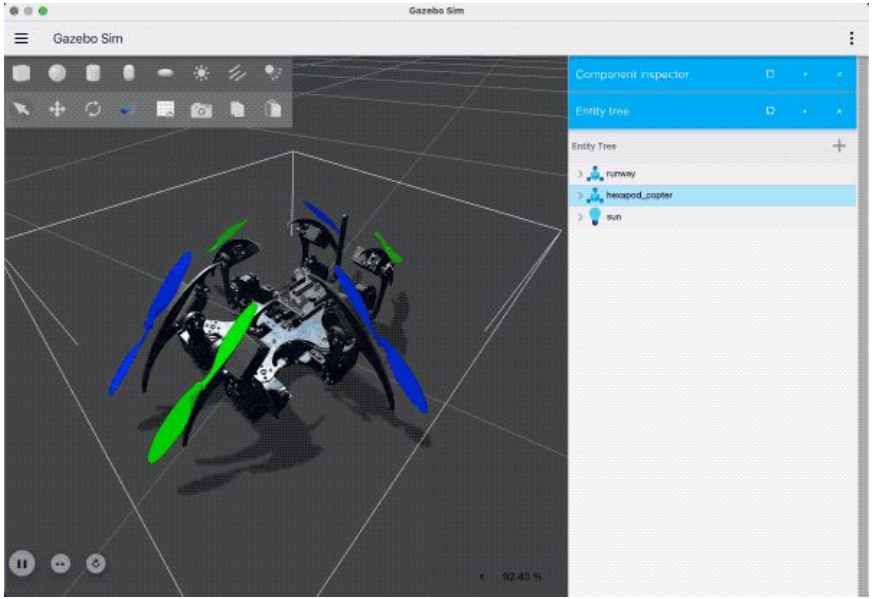
SIM_JSON sends a 16 or 32 channel servo packet depending on SERVO_32_ENABLE.

```
struct servo_packet_16 {
    uint16_t magic = 18458; // constant magic value
    uint16_t frame_rate;
    uint32_t frame_count;
    uint16_t pwm[16];
};
struct servo_packet_32 {
    uint16_t magic = 29569; // constant magic value
    uint16_t frame_rate;
    uint32_t frame_count;
    uint16_t pwm[32];
};
```

ArduPilot plugin checks magic number based on plugin parameter.

```
<plugin name="ArduPilotPlugin" filename="ArduPilotPlugin">
  <have_32_channels>1</have_32_channels>
  ...
</plugin>
```

- https://github.com/ArduPilot/ardupilot/pull/23239
- https://github.com/ArduPilot/ardupilot_gazebo/pull/49



PoC for experimental frame suggested by @Buzz, David Buzz.
- 6 rotors + 16 (4 x 3 + 2 x 2) leg actuators.
- Lua (6 ch. Dynamics Scripting Matrix) + 16 scripting ch.
- https://github.com/ArduPilot/SITL_Models/pull/96.

Parachute

Attach a parachute model when command received.

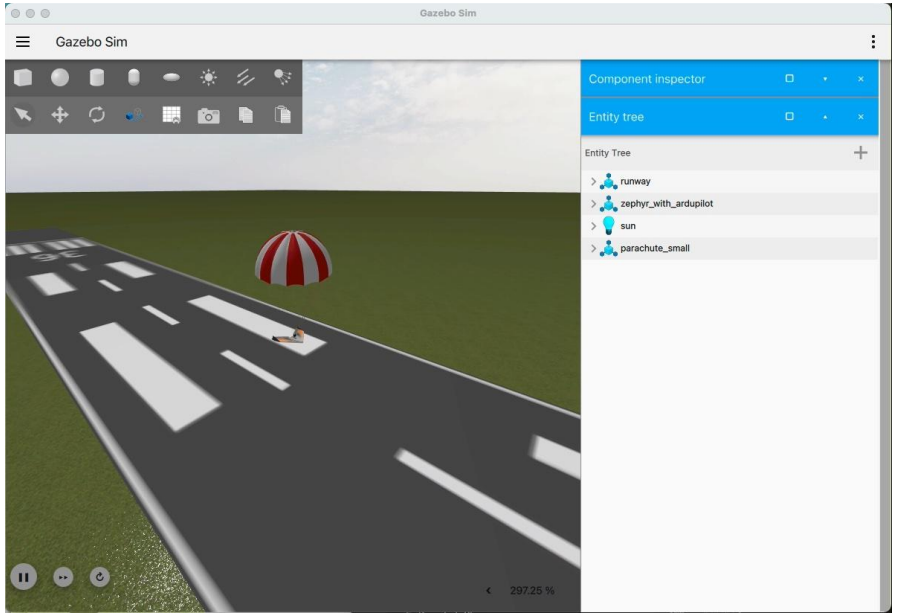
```
<plugin filename="ParachutePlugin" name="ParachutePlugin">
  <parent_link>attachment_link</parent_link>
  <child_model>parachute_small</child_model>
  <child_link>chute</child_link>
  <child_pose>0 0 0 0 0 0</child_pose>
  <cmd_topic>/parachute/cmd_release</cmd_topic>
</plugin>
```

ArduPilot plugin relays the servo command from SITL.

```
<plugin name="ArduPilotPlugin" filename="ArduPilotPlugin">
  <control channel="4">
    <jointName>parachute_attachment_joint</jointName>
    <servo_min>1100</servo_min>
    <servo_max>1900</servo_max>
    <type>COMMAND</type>
    <cmd_topic>/parachute/cmd_release</cmd_topic>
  </control>
</plugin>
```

Configure params and trigger release.

```
SERVO5_FUNCTION    27 # parachute
RC9_OPTION         22 # parachute release
rc 9 1900             # manual release
```



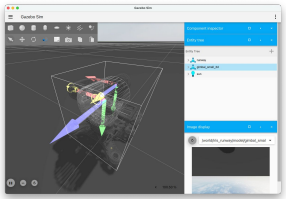
Parachute deployed on Zephyr in Gazebo (`gz-sim7`).

Thanks to @41Mo, Alex Molchanov.
- https://github.com/ArduPilot/ardupilot_gazebo/pull/36.

Gimbal

Update material and add extra DoF.

```
<include>
    <uri>model://gimbal_small_2d</uri>
    <name>gimbal</name>
    <pose>0 -0.01 0.070 1.57 0 1.57</pose>
</include>
```

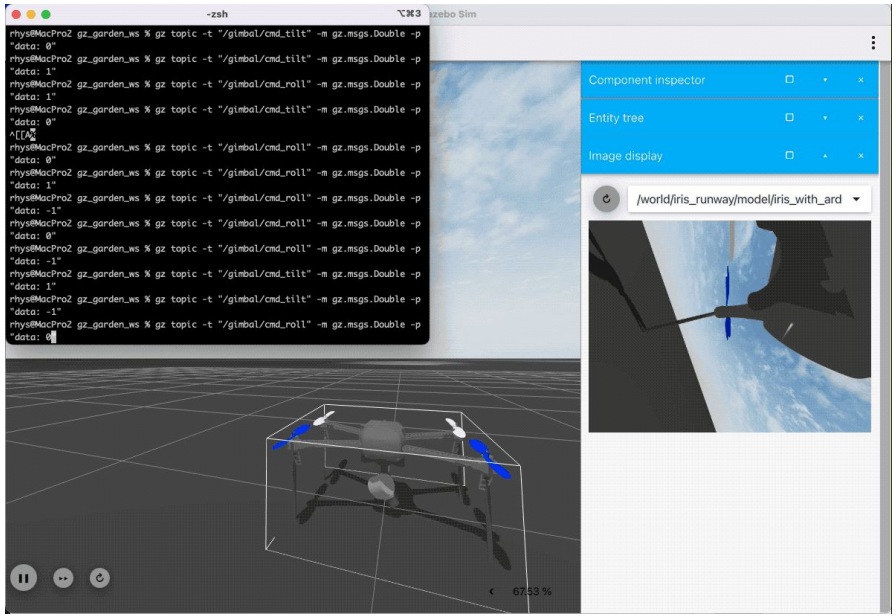


Use Joint Position Controller plugin (ditto for tilt joint).

```
<plugin
    filename="gz-sim-joint-position-controller-system"
    name="gz::sim::systems::JointPositionController">
    <joint_name>gimbal::roll_joint</joint_name>
    <topic>/gimbal/cmd_roll</topic>
    <p_gain>2</p_gain>
</plugin>
```

ArduPilot plugin relays the servo command from SITL.

```
<control channel="4">
  <jointName>gimbal::roll_joint</jointName>
  <multiplier>3.14159265</multiplier>
  <offset>-0.5</offset>
  <servo_min>1100</servo_min>
  <servo_max>1900</servo_max>
  <type>COMMAND</type>
  <cmd_topic>/gimbal/cmd_roll</cmd_topic>
  <p_gain>3</p_gain>
</control>
```



Iris quadcopter configured with servo gimbal (iris_with_gimbal)

- https://ardupilot.org/copter/docs/common-camera-gimbal.html

Camera Zoom

Add camera zoom plugin to camera sensor

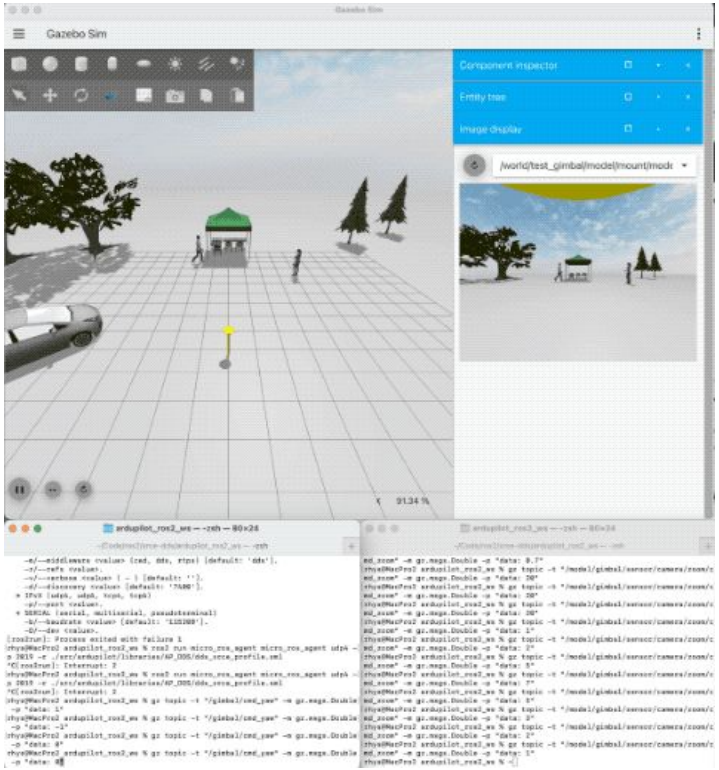
```
<plugin filename="CameraZoomPlugin"
    name="CameraZoomPlugin">
  <max_zoom>125.0</max_zoom>
  <slew_rate>0.42514285714</slew_rate>
</plugin>
```

Gimbal may be controlled directly using `gz topic`

```
gz topic -t "/gimbal/cmd_yaw" -m gz.msgs.Double -p "data: -1"
```

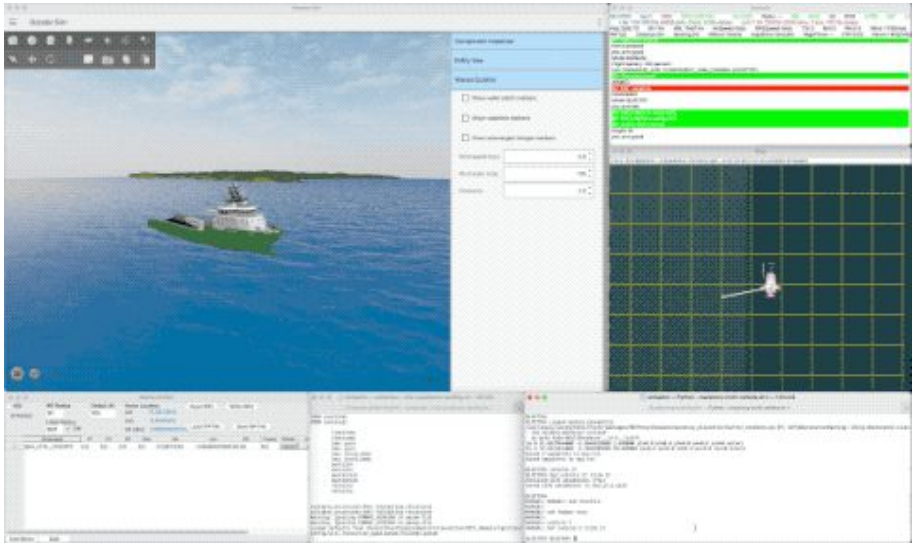
Zoom is similarly controlled from the command line

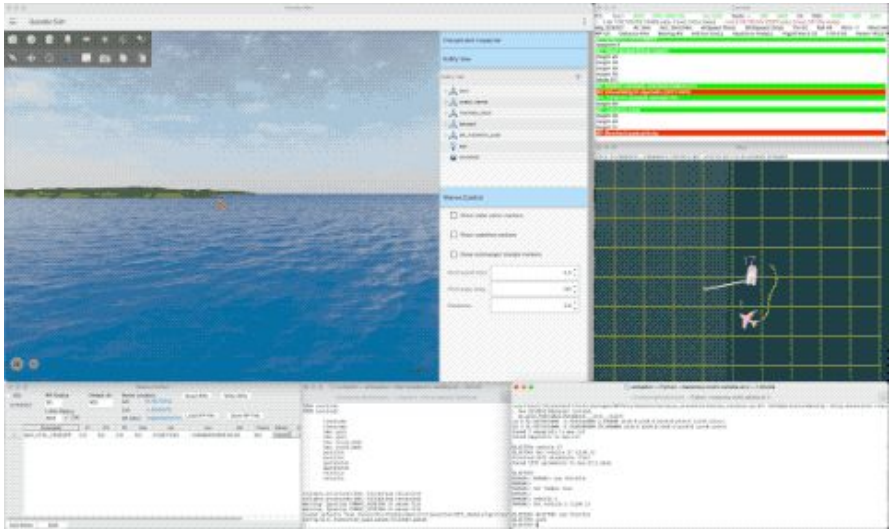
```
gz topic -t "/model/gimbal/sensor/camera/zoom/cmd_zoom" -m
gz.msgs.Double -p "data: 2"
```



Moving platform takeoff and landing

- Alti-transition quadplane.
- Multi-vehicle simulation.
- Ship subject to wave action.
- GPS beacon set on ship deck.
- ArduPilot: Moving platform takeoff & landing.





Above: quadplane takeoff sequence.
Left: quadplane velocity matching and landing.

Off-board GPS-denied navigation

2023 ArduPilot GSoC projects

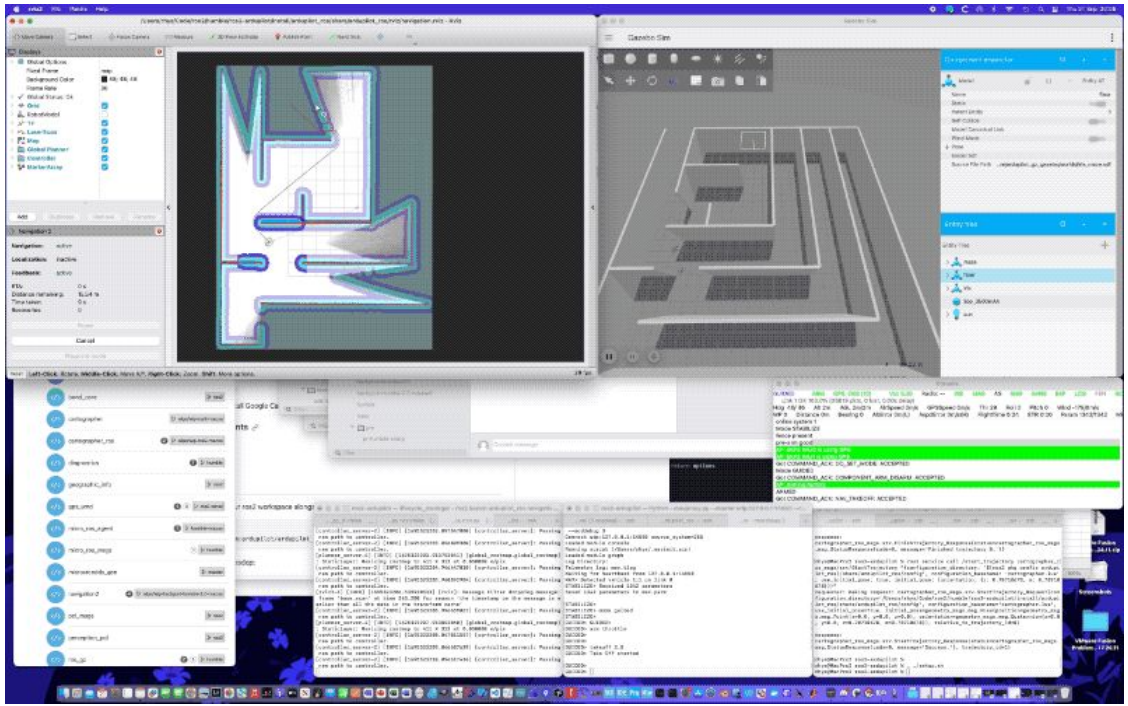
- Arsh Pratap (DDS extensions)
- Pedro Fuoco (GPS denied nav)

Packages used

- ArduPilot SITL
- Micro XRCE DDS
- ROS 2 Humble
- Gazebo Garden (or Harmonic)
- ros_gz bridge
- nav2

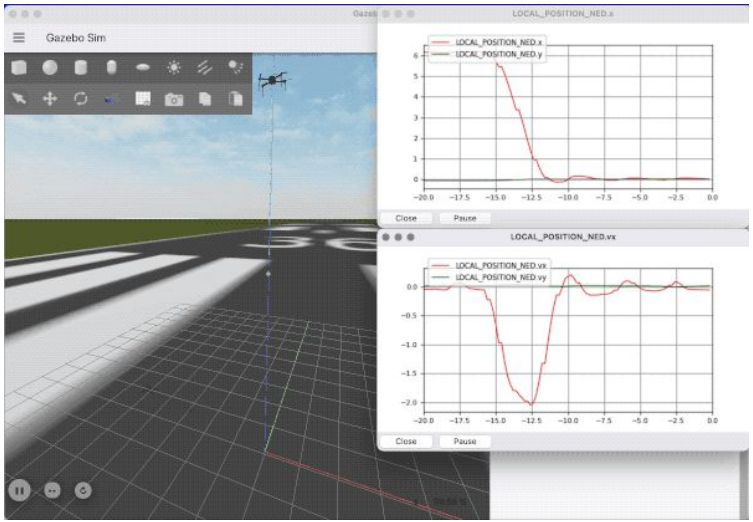
More detail on ArduPilot Discourse

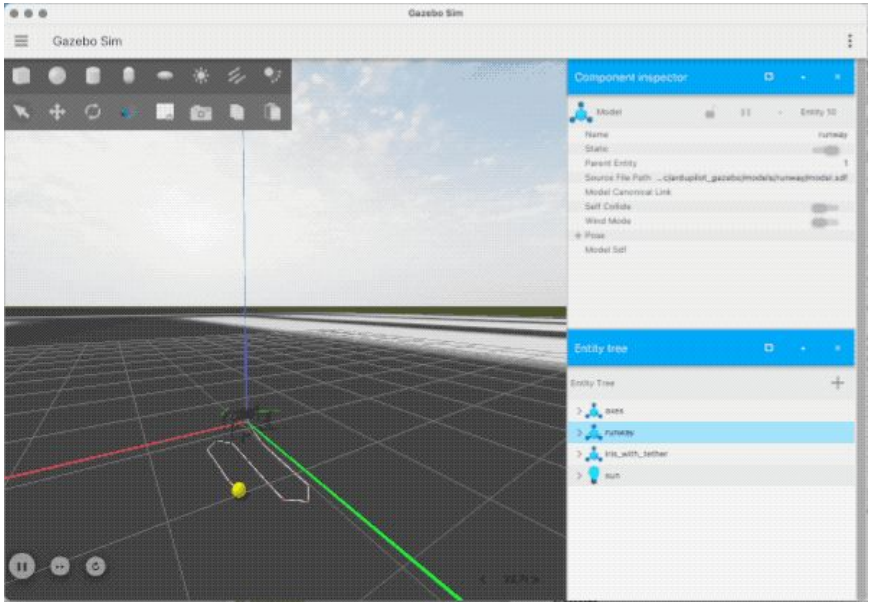
- gsoc-2023 gps denied autonomous
- gsoc-23 improvements for dds



Copter with tethered payload

- Iris quadcopter with tethered payload (approx. 50% mass of copter).
- ArduPilot devs want to investigate position control with tethers.
- Application to bushfire control, magnetic surveys.





Above: copter takeoff with tethered payload.
Left: copter landing plotting horizontal position and velocity.

Questions?