

Test campaign report: k3-demo

Campaign k3-demo · 2026-12-04 · Subnavis Sim

Conceptual vehicles and open reference models only. No data of a real platform is used. Every parameter carries its source (OS: open source, EST: estimate, DES: design value, CAL: calibrated); see section 3.

120 scenarios run: **56 passed**, **64 failed**.

Reference autopilot on a conceptual submarine (hold 60 m, go to 80 m, turn to 030°) and on REMUS 100 (dive to 20 m, turn to 090°): 120 scenarios with currents up to 0.8 m/s from any direction, two thermoclines, a jammed rudder, a stern plane jammed to rise or to dive, and a lost propulsor.

Key findings

The failed scenarios are what this campaign looked for: each one is a finding, reproducible from its scenario file (section 5).

- A jammed stern plane removes the conceptual submarine's only vertical-plane stabiliser: open loop the boat is unstable in pitch at speed, so it can dive even with the plane stuck to rise, depending on its pitch at the moment of the jam.
- After a lost propulsor the submarine slows below the speed where the stern planes act (about 2 m/s) and cannot hold depth; REMUS 100 holds it in 13 of 14 cases.
- One boundary case without a fault: a cold thermocline with a 0.75 m/s current takes the submarine 3.6 m off depth (limit 3 m).
- REMUS 100 shows a pitch limit cycle of about 5° in a cold water column with a strong current while it holds depth (no criterion is broken).
- The safety interlock clamps commands; it cannot stop a jammed plane. With a plane stuck to dive, the vehicle passes the interlock's depth limit without a single clamped command.

1. Scope

Every scenario is run by the deterministic Subnavis core with a fixed step. Every command, from the controller or from the schedule, passes the safety interlock and is logged. A row passes when all criteria pass.

Base scenario	Vehicle	Controller
autopilot-remus	remus100	reference autopilot, every 0.1 s: depth, heading, speed
autopilot-suboff	suboff-conceptual	reference autopilot, every 1 s: depth, heading, speed

Acceptance criteria

Name	Metric	Window	Limit	Parameters	src
depth_hold	depth_error_max_m	250 ... end	max 3		DES
pitch	pitch_max_deg	0 ... end	max 20		DES
roll	roll_max_deg	0 ... end	max 20		DES
interlock	interlock_interventions	0 ... end	max 0		DES

2. Test matrix

120 distinct rows drawn with seed 20261211 (SplitMix64); 120 rows. Each row is a scenario file of its own; its id is the digest of its content.

Axis	Parameter	Values	src
base	base scenario	autopilot-suboff, autopilot-remus	DES
current_speed	current_speed_m_s	0 ... 0.8, uniform	DES
current_dir	current_direction_deg	0 ... 360, uniform	DES

water_column	water_column	none, warm, cold	DES
fault	fault	none, rudder_jam, planes_jam_rise, planes_jam_dive, propulsion_lost	DES
fault_time	fault_time_s	60 ... 240, step 10	DES

3. Vehicles and sources

remus100 (base autopilot-remus)

Parameter	Value	Unit	src	Reference / note
added_mass.diameter_m	0.19	m	OS	https://github.com/cybergalactic/PythonVehicleSimulator/blob/a93d1938ba1f78f2580c24c73f003091b2f03cd0/src/python_vehicle_simulator/vehicles/remus100.py
added_mass.length_m	1.6	m	OS	https://github.com/cybergalactic/PythonVehicleSimulator/blob/a93d1938ba1f78f2580c24c73f003091b2f03cd0/src/python_vehicle_simulator/vehicles/remus100.py
added_mass.roll_ratio	0.3	-	OS	https://github.com/cybergalactic/PythonVehicleSimulator/blob/a93d1938ba1f78f2580c24c73f003091b2f03cd0/src/python_vehicle_simulator/vehicles/remus100.py
center_of_buoyancy_m	[0.0, 0.0, 0.0]	m	OS	https://github.com/cybergalactic/PythonVehicleSimulator/blob/a93d1938ba1f78f2580c24c73f003091b2f03cd0/src/python_vehicle_simulator/vehicles/remus100.py
center_of_gravity_m	[0.0, 0.0, 0.02]	m	OS	https://github.com/cybergalactic/PythonVehicleSimulator/blob/a93d1938ba1f78f2580c24c73f003091b2f03cd0/src/python_vehicle_simulator/vehicles/remus100.py
displaced_volume_m3	0.030243065278557742	m ³	OS	https://github.com/cybergalactic/PythonVehicleSimulator/blob/a93d1938ba1f78f2580c24c73f003091b2f03cd0/src/python_vehicle_simulator/vehicles/remus100.py — $W = B$ in the model; $V = 4/3 \pi a b^2$
display_geometry	{"height_m": 0.19, "length_m": 1.6, "shape": "spheroid", "width_m": 0.19}	-	OS	https://github.com/cybergalactic/PythonVehicleSimulator/blob/a93d1938ba1f78f2580c24c73f003091b2f03cd0/src/python_vehicle_simulator/vehicles/remus100.py
effectors[0].actuator	{"max": 0.2617993877991494, "min": -0.2617993877991494, "time_constant_s": 0.1}	-	OS	https://github.com/cybergalactic/PythonVehicleSimulator/blob/a93d1938ba1f78f2580c24c73f003091b2f03cd0/src/python_vehicle_simulator/vehicles/remus100.py — $T_\delta = 0.1$ s, $\pm 15^\circ$
effectors[0].fin	{"area_m2": 0.0133, "axis": "rudder", "lift_slope_per_rad": 0.5, "position_m": [-0.8, 0.0, 0.0]}	-	OS	https://github.com/cybergalactic/PythonVehicleSimulator/blob/a93d1938ba1f78f2580c24c73f003091b2f03cd0/src/python_vehicle_simulator/vehicles/remus100.py — $area = 2 \times S_{fin} = 2 \times 0.00665$ m ² , at $x = -L/2$
effectors[0].stall_angle_rad	0.3490658503988659	-	EST	20°, above the $\pm 15^\circ$ end stop: the reference model has no stall and never reaches it
effectors[1].actuator	{"max": 0.2617993877991494, "min": -0.2617993877991494, "time_constant_s": 0.1}	-	OS	https://github.com/cybergalactic/PythonVehicleSimulator/blob/a93d1938ba1f78f2580c24c73f003091b2f03cd0/src/python_vehicle_simulator/vehicles/remus100.py — $T_\delta = 0.1$ s, $\pm 15^\circ$
effectors[1].fin	{"area_m2": 0.0133, "axis": "plane", "lift_slope_per_rad": 0.7, "position_m": [-0.8, 0.0, 0.0]}	-	OS	https://github.com/cybergalactic/PythonVehicleSimulator/blob/a93d1938ba1f78f2580c24c73f003091b2f03cd0/src/python_vehicle_simulator/vehicles/remus100.py — $area = 2 \times S_{fin} = 2 \times 0.00665$ m ² , at $x = -L/2$
effectors[1].stall_angle_rad	0.3490658503988659	-	EST	20°, above the $\pm 15^\circ$ end stop: the reference model has no stall and never reaches it
effectors[2].actuator	{"max": 1525.0, "min": -1525.0, "time_constant_s": 1.0}	-	OS	https://github.com/cybergalactic/PythonVehicleSimulator/blob/a93d1938ba1f78f2580c24c73f003091b2f03cd0/src/python_vehicle_simulator/vehicles/remus100.py — $T_n = 1$ s, 1525 rpm maximum
effectors[2].propeller	{"diameter_m": 0.14, "j_max": 0.6632, "kq_0": 0.07, "kq_max": 0.0312, "kt_0": 0.4566, "kt_max": 0.1798, "roll_moment_factor": 0.1, "thrust_deduction": 0.1, "wak ... (179 characters; whole in the vehicle file)}	-	OS	https://github.com/cybergalactic/PythonVehicleSimulator/blob/a93d1938ba1f78f2580c24c73f003091b2f03cd0/src/python_vehicle_simulator/vehicles/remus100.py — Wageningen B-series coefficients quoted in the model; Allen et al. (2000) wake 0.944
hydrodynamics[0].values	{"fade_per_speed": 3.0, "heave_s": 20.0, "pitch_damping_ratio": 0.8, "roll_damping_ratio": 0.3, "surge_s": 20.0, "sway_s": 20.0, "yaw_s": 1.0}	-	OS	https://github.com/cybergalactic/PythonVehicleSimulator/blob/a93d1938ba1f78f2580c24c73f003091b2f03cd0/src/python_vehicle_simulator/vehicles/remus100.py

hydrodynamics[1].values	{"area_m2": 0.2128, "oswald_efficiency": 0.7, "span_m": 0.19, "zero_lift_drag": 0.05595961914206819}	-	OS	https://github.com/cybergalactic/PythonVehicleSimulator/blob/a93d1938ba1f78f2580c24c73f003091b2f03cd0/src/python_vehicle_simulator/lib/gnc.py
hydrodynamics[2].drag_coefficient	1.1977288343558283	-	EST	Hoerner (1965) 2-D cross-flow curve at B/2T = 0.5, read from the digitized table used by the reference model (docs/10 R5: 1.1–1.2 for a circle)
hydrodynamics[2].geometry	{"height_m": 0.19, "length_m": 1.6, "strips": 20, "vertical_plane": false, "width_m": 0.19}	-	OS	https://github.com/cybergalactic/PythonVehicleSimulator/blob/a93d1938ba1f78f2580c24c73f003091b2f03cd0/src/python_vehicle_simulator/lib/gnc.py
inertia	{"about": "center_of_gravity", "matrix_kg_m2": [[0.11201607976263889, 0.0, 0.0], [0.0, 4.027769316783751, 0.0], [0.0, 0.0, 4.027769316783751]]}	-	OS	https://github.com/cybergalactic/PythonVehicleSimulator/blob/a93d1938ba1f78f2580c24c73f003091b2f03cd0/src/python_vehicle_simulator/vehicles/remus100.py — solid spheroid formulas about the CG
mass_kg	31.029384975800244	kg	OS	https://github.com/cybergalactic/PythonVehicleSimulator/blob/a93d1938ba1f78f2580c24c73f003091b2f03cd0/src/python_vehicle_simulator/vehicles/remus100.py — $m = 4/3 \pi \rho a b^2$ (spheroid of water, $\rho = 1026$); the file's docstring says 31.9 kg

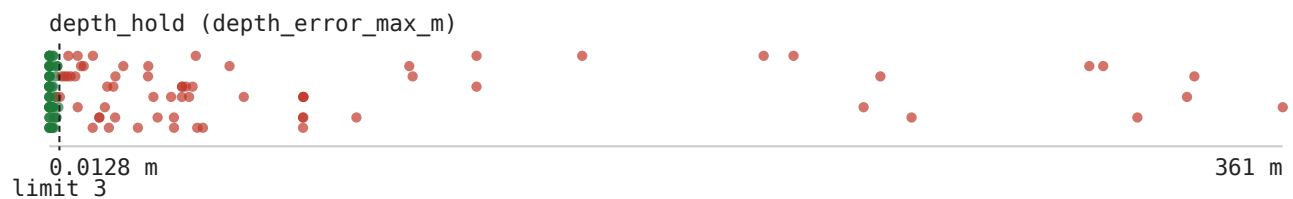
suboff-conceptual (base autopilot-suboff)

Parameter	Value	Unit	src	Reference / note
added_mass.values	{"k_pdot": 0.0, "m_qdot": -0.00086, "m_wdot": -0.000561, "n_rdot": -0.000897, "n_vdot": 0.000396, "x_udot": 0.0, "y_rdot": 0.000398, "y_vdot": -0.016186, "z_qdo ... (195 characters; whole in the vehicle file)}	-	OS	https://archive.org/download/DTIC_ADA227715/DTIC_ADA227715.pdf — R90 Table 4 (p. 19): vertical plane Config 1, horizontal plane Config 2 (fully appended). $\dot{X}_u$ and $\dot{K}_p$ are not in R90: extra_added_mass. Measured $\dot{Z}_q \neq \dot{M}_w$ (−0.000633 vs −0.000561): kept as measured
ballast	{"air_bank": {"exponent": 1.4, "position_m": [0.0, 0.0, 3.0], "pressure_pa": 25000000.0, "reducer_pressure_pa": 4000000.0, "temperature_k": 288.15, "volume_m3": ... (875 characters; whole in the vehicle file)}	-	EST	conceptual: two 300 m ³ main ballast tanks (6 % of ∇ , 10 m tall, keel to $z = -4.1$ m), port 0.8 m ² floods a tank in about a minute at the surface; 8 m ³ bank at 250 bar ($\approx$ 2420 kg of air), adiabatic (Font et al. 2010), reducer 40 bar; each tank 5 m long (x) $\times$ 6 m wide (y), so its water surface stays level in the world (step 55)
center_of_buoyancy_m	[-0.07095744000000356, 0.0, -0.0487850688]	m	OS	https://archive.org/download/DTIC_ADA227715/DTIC_ADA227715.pdf — R90 Table 1 (p. 14): LCB 6.6139 ft vs origin 6.6042 ft (0.0097 ft aft), VCB −0.006669 ft (sail side), $\times$ 0.3048 $\times$ 24
center_of_gravity_m	[-0.07623961875041273, 0.0, 0.29644542657870937]	m	EST	dry CG chosen so that the whole boat at the design state has $x_G = x_G' L = -0.071244$ m (R90 Table 1: $x_G' m' = -0.127467e-4$) and $z_G = z_B + BG$, $BG = 0.40$ m (EST; not in R90)
displaced_volume_m3	9782.348516113594	m ³	OS	https://archive.org/download/DTIC_ADA227715/DTIC_ADA227715.pdf — R90 Table 1 (p. 14), fully appended $VOL = 24.9899$ ft ³ , scaled by $\lambda^3 = 24^3$
effectors[0].actuator	{"max": 0.4363323129985824, "max_rate": 0.08726646259971647, "min": -0.4363323129985824, "time_constant_s": 0.5}	-	EST	$\pm 25^\circ$, 5 °/s, T = 0.5 s: typical of large control surfaces (DES choice)
effectors[0].terms	[{"axis": "Y", "coefficient": 0.005929, "factors": ["u", "u", "control"], "name": "Y_dr"}, {"axis": "N", "coefficient": -0.002217, "factors": ["u", "u", "contro ... (269 characters; whole in the vehicle file)}	-	OS	https://archive.org/download/DTIC_ADA227715/DTIC_ADA227715.pdf — R90 Table 4 (p. 19), Config 2, per radian
effectors[1].actuator	{"max": 0.4363323129985824, "max_rate": 0.08726646259971647, "min": -0.4363323129985824, "time_constant_s": 0.5}	-	EST	$\pm 25^\circ$, 5 °/s, T = 0.5 s: typical of large control surfaces (DES choice)
effectors[1].terms	[{"axis": "Z", "coefficient": -0.005603, "factors": ["u", "u", "control"], "name": "Z_ds"}, {"axis": "M", "coefficient": -0.002409, "factors": ["u", "u", "contr ... (182 characters; whole in the vehicle file)}	-	OS	https://archive.org/download/DTIC_ADA227715/DTIC_ADA227715.pdf — R90 Table 4 (p. 19), Config 1, per radian
effectors[2].actuator	{"max": 1.0, "min": 0.0, "time_constant_s": 5.0}	-	EST	shaft spin-up 5 s; throttle τ in [0, 1]

effectors[2].terms	[{"axis": "X", "coefficient": 619831.4136968006, "factors": ["control", "control"], "name": "X_T"}]	-	EST	no propulsor in the SUBOFF tests; thrust = $T_{\max} \tau^2$, $T_{\max} = -X_u u U_{\max}^2$ with $U_{\max} = 10$ m/s, so the boat settles near $U_{\max} \tau$
extra_added_mass.values	[272757.57423582155, 0.0, 0.0, 18257998.505319826, 0.0, 0.0]	-	EST	$-X_{\ddot{u}} = k_1 m$, $\text{Lamb } k_1 = 0.02720$ for a prolate spheroid of $L/D = 8.575$ (docs/10 R1); $-K_{\ddot{p}} = 0.1 I_x$ (appendages; a body of revolution has none)
hull_compressibility_per_pa	8.809921853184e-10	1/Pa	EST	thin cylindrical shell, $E = 2e11$ Pa, $\nu = 0.3$, $R = 5.8$ m, $t = 0.05$ m, 80 % of the volume
hull_sections	{"stations_m": [[-56.235359, 0.0], [-55.869812, 0.388539], [-55.504265, 0.52506], [-55.138718, 0.6117], [-54.773171, 0.668152], [-54.407624, 0.70174], [-54.0420 ... (6212 characters; whole in the vehicle file)]	-	OS	https://archive.org/download/DTIC_ADA210642/DTIC_ADA210642.pdf – G89 hull equations (p. 4-6; card suboff.md section 1), bare hull, stations every 0.05 ft (model) from nose to tail cap, $x = (6.6042 \text{ ft} - x_{\text{nose}}) \times 0.3048 \times 24$, $r \times 0.3048 \times 24$; generated by tools/geometry/suboff_sections.py (bare-hull volume 9665 m ³ ; sail and appendages are carried by the buoyancy ratio, step 54)
hydrodynamics[0].terms	[{"axis": "Z", "coefficient": -0.01391, "factors": ["u", "w"], "name": "Z_w"}, {"axis": "M", "coefficient": 0.010324, "factors": ["u", "w"], "name": "M_w"}, {"a ... (708 characters; whole in the vehicle file)]	-	OS	https://archive.org/download/DTIC_ADA227715/DTIC_ADA227715.pdf – R90 Table 4 (p. 19), per radian, origin 6.6042 ft aft of the nose (R90 p. 3)
hydrodynamics[1].terms	[{"axis": "X", "coefficient": -0.0011565453524191678, "factors": ["u", "abs_u"], "name": "X_u u "}]	-	EST	from LH98 Table 14 (p. 23): fully appended model, 389.2 N at 11.85 kn; $X' = -R / (\frac{1}{2}\rho L^2 U^2)$ with the tank $\rho = 997.55$ (R90 buoyancy/volume); model Reynolds number, no full-scale correction (conservative)
hydrodynamics[2].terms	[{"axis": "Y", "coefficient": -0.1311472544923887, "factors": ["v", "abs_v"], "name": "Y_v v "}, {"axis": "Z", "coefficient": -0.1311472544923887, "factors": [" ... (567 characters; whole in the vehicle file)]	-	EST	cross-flow drag of a cylinder, $C_d = 1.1$ (docs/10 R5): $Y_v v ' = -C_d D/L$, $N_r r ' = -C_d (D/L)/80$; roll: K_p' gives 10 % damping at 8 m/s with BG = 0.4 m, $K_p p '$ keeps some at rest. None of these are in R90 (linear derivatives only)
inertia	{"about": "origin", "matrix_kg_m2": [[181299612.70177898, 0.0, 0.0], [0.0, 5300960364.459192, 0.0], [0.0, 0.0, 5302240736.810612]]}	-	EST	dry inertia = whole-boat inertia minus the tank contents (point masses). Whole boat: $I_y = I_z = I' \frac{1}{2}\rho L^5$ with $I' = 0.001084$ (R90 Table 1) = 6.2125e9 kg·m ² ; $I_x = m (0.35 D)^2$ (EST: not in R90)
mass_kg	9361637.953399027	kg	EST	dry mass = $\rho V(1 - \kappa_h p)$ – tank contents at the design state (origin at 100 m, main ballast tanks full, trim tanks half, bank full), so the boat is neutral there: 10 026 907.23 × 0.999114875 – 656 394.21 kg. ρV equals Roddy's $m' = 0.018296$ (R90 Table 1) to 2e-5
nondimensional_reference	{"density_kg_m3": 1025.0, "length_m": 102.26064384}	-	OS	https://archive.org/download/DTIC_ADA227715/DTIC_ADA227715.pdf – R90 nondimensionalizes with $L = L_{CP}$ (Table 1, p. 14: $m' = 2V/L^3$ holds); 13.9792 ft × 0.3048 × 24; ρ of the sea the boat runs in
trim_tanks	[{"capacity_m3": 20.0, "initial_m3": 10.0, "name": "forward_trim", "position_m": [35.0, 0.0, 4.0]}, {"capacity_m3": 20.0, "initial_m3": 10.0, "name": "aft_trim" ... (293 characters; whole in the vehicle file)]	-	EST	conceptual trim tanks ±35 m, half full; a compensating tank at the centre

4. Results

One dot per scenario at its metric value (green passed, red failed); the dashed line is the limit.





Pass rate by axis value

base	Rows	Passed	Failed
autopilot-remus	69	42	27
autopilot-suboff	51	14	37

water_column	Rows	Passed	Failed
cold	35	20	15
none	45	22	23
warm	40	14	26

fault	Rows	Passed	Failed
planes_jam_dive	21	0	21
none	19	18	1
planes_jam_rise	30	2	28
propulsion_lost	27	13	14
rudder_jam	23	23	0

5. Failures

64 scenarios failed. Each one is reproduced by running its scenario file with the core (scenario_run): the run prints the digest in the last column.

Row	Id	Base	Parameters	Reason	Digest
0	ca549d3b507f794f	autopilot-remus	current_speed = 0.67228, current_dir = 146.919, water_column = cold, fault = planes_jam_dive, fault_time = 190	depth_hold = 5.610 > 3.000 (max)	cd420fe00781646c
2	fee15cfd043a9f91	autopilot-suboff	current_speed = 0.491114, current_dir = 154.681, water_column = cold, fault = planes_jam_rise, fault_time = 180	depth_hold = 243.368 > 3.000 (max)	8abee2fbda4fc328
6	9392fdd9fab2d14b	autopilot-suboff	current_speed = 0.160373, current_dir = 270.41, water_column = warm, fault = planes_jam_dive, fault_time = 60	depth_hold = 318.613 > 3.000 (max)	bd2427a86379961e
7	26d8c067d0b44042	autopilot-remus	current_speed = 0.164198, current_dir = 307.454, water_column = cold, fault = planes_jam_rise, fault_time = 140	depth_hold = 17.478 > 3.000 (max)	f2adf4f805ce4c5d

9	737f10ffdd025978	autopilot-suboff	current_speed = 0.695327, current_dir = 279.774, water_column = warm, fault = planes_jam_dive, fault_time = 120	depth_hold = 308.605 > 3.000 (max)	6f6915321b103a6a
10	40ceb0f1366bed50	autopilot-remus	current_speed = 0.0895142, current_dir = 334.216, water_column = none, fault = planes_jam_dive, fault_time = 240	depth_hold = 6.282 > 3.000 (max)	3a9b2885f9c15647
11	dc593edb4a057747	autopilot-suboff	current_speed = 0.384395, current_dir = 94.4109, water_column = none, fault = propulsion_lost, fault_time = 90	depth_hold = 40.012 > 3.000 (max)	b9d2c39263c84756
18	3534d854c07d73c5	autopilot-remus	current_speed = 0.377023, current_dir = 280.734, water_column = warm, fault = planes_jam_rise, fault_time = 90	depth_hold = 28.941 > 3.000 (max)	a5a8d5e1435a0606
20	28204e4afb5bf36f	autopilot-suboff	current_speed = 0.424231, current_dir = 137.872, water_column = warm, fault = planes_jam_dive, fault_time = 160	depth_hold = 333.128 > 3.000 (max)	1da9cad542e77066
24	1ccc03b40994ea9a	autopilot-remus	current_speed = 0.126828, current_dir = 126.229, water_column = warm, fault = planes_jam_dive, fault_time = 200	depth_hold = 8.337 > 3.000 (max)	fe95ceecd2a4cc7e
26	4fe32d9f12b47ae7	autopilot-suboff	current_speed = 0.13668, current_dir = 276.81, water_column = warm, fault = planes_jam_rise, fault_time = 190	depth_hold = 106.425 > 3.000 (max)	eecbf1d86806b459
28	6f200907f3ecd7a6	autopilot-suboff	current_speed = 0.0287029, current_dir = 236.491, water_column = cold, fault = propulsion_lost, fault_time = 200	depth_hold = 74.428 > 3.000 (max)	87de632efaf7ccac
29	818612ccf855469b	autopilot-remus	current_speed = 0.508341, current_dir = 310.603, water_column = none, fault = planes_jam_rise, fault_time = 210	depth_hold = 16.301 > 3.000 (max)	fbeaf3672a6bea56
30	24df0e67435cead7	autopilot-suboff	current_speed = 0.545462, current_dir = 71.9779, water_column = warm, fault = planes_jam_rise, fault_time = 220	depth_hold = 89.951 > 3.000 (max)	fe2426d1142b0ca6
33	4e685bfb802998b3	autopilot-remus	current_speed = 0.0496393, current_dir = 67.5047, water_column = none, fault = planes_jam_rise, fault_time = 70	depth_hold = 21.708 > 3.000 (max)	25ad92915116afad
35	c49f9aceb0c0d939	autopilot-suboff	current_speed = 0.173807, current_dir = 340.683, water_column = none, fault = propulsion_lost, fault_time = 110	depth_hold = 38.894 > 3.000 (max)	3acac95f1bdf0b84
36	82e6a7cdcba87c5a	autopilot-remus	current_speed = 0.505739, current_dir = 271.967, water_column = warm, fault = planes_jam_dive, fault_time = 60	depth_hold = 38.849 > 3.000 (max)	f6fb19a5b355dabf
38	39f0317402369335	autopilot-suboff	current_speed = 0.202586, current_dir = 354.03, water_column = warm, fault = planes_jam_dive, fault_time = 200	depth_hold = 252.481 > 3.000 (max)	0ab2203ecb92996f
39	5343d17083606729	autopilot-remus	current_speed = 0.488004, current_dir = 174.953, water_column = cold, fault = planes_jam_rise, fault_time = 180	depth_hold = 12.731 > 3.000 (max)	b96bfe454e1aa356
40	19e65c358c450e2d	autopilot-remus	current_speed = 0.695102, current_dir = 132.761, water_column = warm, fault = planes_jam_rise, fault_time = 130	depth_hold = 12.806 > 3.000 (max)	1956c6025b4c9d6b
41	ce6e71c9634a652b	autopilot-remus	current_speed = 0.563581, current_dir = 255.314, water_column = none, fault = planes_jam_rise, fault_time = 180	depth_hold = 29.019 > 3.000 (max)	74de30516877892f
42	6442271572c4ab8e	autopilot-remus	current_speed = 0.559946, current_dir = 212.503, water_column = warm, fault = planes_jam_rise, fault_time = 190	depth_hold = 19.404 > 3.000 (max)	1915032d3e31447a
43	8ae5f5221d60c2cc	autopilot-suboff	current_speed = 0.137017, current_dir = 149.451, water_column = none, fault = propulsion_lost, fault_time = 90	depth_hold = 38.923 > 3.000 (max)	6945575157924752
44	cd52da499b5b84d0	autopilot-remus	current_speed = 0.765702, current_dir = 183.248, water_column = none, fault = planes_jam_dive, fault_time = 130	depth_hold = 30.520 > 3.000 (max)	cffcba66517b6303
46	2e1ee3a712f2374b	autopilot-remus	current_speed = 0.0236105, current_dir = 46.3064, water_column = warm, fault = planes_jam_dive, fault_time = 100	depth_hold = 19.313 > 3.000 (max)	47b5000f8c1d2204
47	f6b19efefec2d7f	autopilot-suboff	current_speed = 0.13105, current_dir = 178.531, water_column = warm, fault = propulsion_lost, fault_time = 160	depth_hold = 74.322 > 3.000 (max)	c506a590a8882009

48	1efc324f5c7b856f	autopilot-suboff	current_speed = 0.688319, current_dir = 159.183, water_column = warm, fault = planes_jam_rise, fault_time = 90	depth_hold = 125.127 > 3.000 (max)	7ddf7471983c14b9
50	8d601fc534baaf76	autopilot-remus	current_speed = 0.484731, current_dir = 153.242, water_column = none, fault = planes_jam_dive, fault_time = 220	depth_hold = 5.313 > 3.000 (max)	979712529ddb5760
51	9c2ba677cdc52cf7	autopilot-remus	current_speed = 0.521451, current_dir = 328.978, water_column = warm, fault = planes_jam_dive, fault_time = 130	depth_hold = 18.792 > 3.000 (max)	d0471fe7d73e346b
52	a361067f276ad313	autopilot-suboff	current_speed = 0.0532512, current_dir = 168.451, water_column = none, fault = planes_jam_dive, fault_time = 70	depth_hold = 40.957 > 3.000 (max)	061e817299f2542f
54	9c9505a20d7ffc7	autopilot-remus	current_speed = 0.479049, current_dir = 277.333, water_column = cold, fault = planes_jam_rise, fault_time = 110	depth_hold = 31.744 > 3.000 (max)	02fa3457d257eae2
55	cb81faedeb285fd2	autopilot-suboff	current_speed = 0.672653, current_dir = 272.996, water_column = none, fault = propulsion_lost, fault_time = 200	depth_hold = 25.975 > 3.000 (max)	b984b56100f32411
56	1dbac7cbeacdfc80	autopilot-suboff	current_speed = 0.0267709, current_dir = 340.326, water_column = cold, fault = planes_jam_rise, fault_time = 100	depth_hold = 209.191 > 3.000 (max)	f4855918179bfbb8
60	223b4c54c929a478	autopilot-suboff	current_speed = 0.700305, current_dir = 248.508, water_column = cold, fault = propulsion_lost, fault_time = 100	depth_hold = 74.459 > 3.000 (max)	b283d13121e2d437
61	fcc35f276a70325d	autopilot-remus	current_speed = 0.220836, current_dir = 324.976, water_column = cold, fault = planes_jam_rise, fault_time = 230	depth_hold = 8.347 > 3.000 (max)	8adcd74a2fc683be
65	0bb78375c22127d1	autopilot-remus	current_speed = 0.197265, current_dir = 162.17, water_column = none, fault = planes_jam_rise, fault_time = 190	depth_hold = 10.121 > 3.000 (max)	0857fc51ef558856
66	72f8cec89eab4199	autopilot-suboff	current_speed = 0.746682, current_dir = 37.2354, water_column = cold, fault = none, fault_time = 210	depth_hold = 3.596 > 3.000 (max)	9a611c69d3f16e7
67	22d27b6b83b77acb	autopilot-remus	current_speed = 0.537473, current_dir = 232.402, water_column = warm, fault = planes_jam_rise, fault_time = 90	depth_hold = 41.989 > 3.000 (max)	6c812aa8d3569117
71	27c4b201270d1207	autopilot-suboff	current_speed = 0.669637, current_dir = 126.957, water_column = none, fault = planes_jam_dive, fault_time = 240	depth_hold = 45.015 > 3.000 (max)	dc2710798afa38fa
72	9bb48f27e28a910f	autopilot-suboff	current_speed = 0.154741, current_dir = 9.2866, water_column = none, fault = propulsion_lost, fault_time = 80	depth_hold = 42.922 > 3.000 (max)	e2fd45daca4ecfba
73	3bbe92c1085fbaec	autopilot-suboff	current_speed = 0.104518, current_dir = 229.765, water_column = warm, fault = planes_jam_dive, fault_time = 170	depth_hold = 304.538 > 3.000 (max)	5a59fb82fbb8ea4f
74	a9ad08e5d9b11e48	autopilot-remus	current_speed = 0.307717, current_dir = 14.2888, water_column = warm, fault = planes_jam_rise, fault_time = 240	depth_hold = 4.468 > 3.000 (max)	128c8e006b26777f
78	2aa3c6cee990e3fc	autopilot-remus	current_speed = 0.392962, current_dir = 124.662, water_column = none, fault = planes_jam_rise, fault_time = 120	depth_hold = 14.717 > 3.000 (max)	c7eac7e39fb43864
79	51a924c922c817cf	autopilot-suboff	current_speed = 0.455475, current_dir = 102.163, water_column = none, fault = propulsion_lost, fault_time = 60	depth_hold = 43.345 > 3.000 (max)	dae87b1e8bf70ab7
80	322348b547eac664	autopilot-suboff	current_speed = 0.267159, current_dir = 132.939, water_column = cold, fault = planes_jam_rise, fault_time = 200	depth_hold = 217.929 > 3.000 (max)	bfbeda5b3d16c20a
81	09f52503d708b6da	autopilot-remus	current_speed = 0.308054, current_dir = 118.877, water_column = none, fault = planes_jam_dive, fault_time = 160	depth_hold = 9.326 > 3.000 (max)	7197b3e523b9c420
82	0cd424f3e2c71151	autopilot-suboff	current_speed = 0.594413, current_dir = 263.617, water_column = warm, fault = planes_jam_dive, fault_time = 120	depth_hold = 335.294 > 3.000 (max)	a26c55256d266ed8
83	bb1185cdb8deb001	autopilot-suboff	current_speed = 0.409164, current_dir = 175.599, water_column = warm, fault = planes_jam_rise, fault_time = 60	depth_hold = 125.117 > 3.000 (max)	b0a224e9929ec14a

84	3c390aada3f70a29	autopilot-remus	current_speed = 0.506194, current_dir = 286.504, water_column = warm, fault = propulsion_lost, fault_time = 160	depth_hold = 3.125 > 3.000 (max)	7a64ef602834848f
85	02a8ac5720f10966	autopilot-suboff	current_speed = 0.293835, current_dir = 134.028, water_column = cold, fault = planes_jam_rise, fault_time = 60	depth_hold = 238.444 > 3.000 (max)	070b9536ddef6e83
86	451231d7b18fdf1b	autopilot-suboff	current_speed = 0.285644, current_dir = 310.187, water_column = none, fault = planes_jam_dive, fault_time = 190	depth_hold = 36.519 > 3.000 (max)	7b785744028481b4
89	57245fc6a33b9608	autopilot-suboff	current_speed = 0.0146517, current_dir = 275.047, water_column = warm, fault = planes_jam_rise, fault_time = 180	depth_hold = 105.430 > 3.000 (max)	b52346f14bdc4011
90	6e5705b90ad5594c	autopilot-remus	current_speed = 0.355992, current_dir = 118.037, water_column = warm, fault = planes_jam_rise, fault_time = 160	depth_hold = 7.640 > 3.000 (max)	b9b459e21f626bcb
92	960aed137eac4c76	autopilot-suboff	current_speed = 0.22309, current_dir = 0.822899, water_column = none, fault = planes_jam_dive, fault_time = 120	depth_hold = 35.698 > 3.000 (max)	19d075faa3bbc32a
94	637c703ed6629ba4	autopilot-suboff	current_speed = 0.671652, current_dir = 178.687, water_column = warm, fault = propulsion_lost, fault_time = 160	depth_hold = 74.334 > 3.000 (max)	6c7dc8c62dee72ae
96	4b6a0f3706ff99d9	autopilot-suboff	current_speed = 0.419765, current_dir = 359.929, water_column = cold, fault = planes_jam_rise, fault_time = 80	depth_hold = 156.061 > 3.000 (max)	8e5f93826ee1a659
101	74fd811183479143	autopilot-suboff	current_speed = 0.448564, current_dir = 68.8499, water_column = cold, fault = planes_jam_dive, fault_time = 60	depth_hold = 361.174 > 3.000 (max)	5fa8dfdc4302eb29
107	93d26e566eed1b66	autopilot-remus	current_speed = 0.451975, current_dir = 327.597, water_column = none, fault = planes_jam_dive, fault_time = 170	depth_hold = 16.988 > 3.000 (max)	bbdfeedd857b56e4
108	cc1154fb46d7e6de	autopilot-suboff	current_speed = 0.071638, current_dir = 192.349, water_column = none, fault = planes_jam_rise, fault_time = 210	depth_hold = 56.978 > 3.000 (max)	5871532a14cb2116
110	c0599df8060f5f86	autopilot-remus	current_speed = 0.142569, current_dir = 285.673, water_column = cold, fault = planes_jam_rise, fault_time = 180	depth_hold = 14.619 > 3.000 (max)	af297965b802b329
111	a7bb8d736cda88ce	autopilot-suboff	current_speed = 0.076383, current_dir = 352.27, water_column = none, fault = propulsion_lost, fault_time = 120	depth_hold = 36.557 > 3.000 (max)	970a726c54b00965
113	5dbd88d14252a1e9	autopilot-suboff	current_speed = 0.606566, current_dir = 61.8839, water_column = none, fault = planes_jam_rise, fault_time = 240	depth_hold = 52.800 > 3.000 (max)	0c356c5ec866d7d1
116	28d7c12ada6580e4	autopilot-suboff	current_speed = 0.591249, current_dir = 232.424, water_column = warm, fault = propulsion_lost, fault_time = 80	depth_hold = 74.332 > 3.000 (max)	a7e67de490101286
118	b30457bc6af0f6bf	autopilot-suboff	current_speed = 0.47096, current_dir = 194.03, water_column = warm, fault = propulsion_lost, fault_time = 230	depth_hold = 74.338 > 3.000 (max)	a762990718ca07eb

Reproduce a row: scenario_run <campaign folder>/rows/<id>.yaml.

row 0 (ca549d3b507f794f)

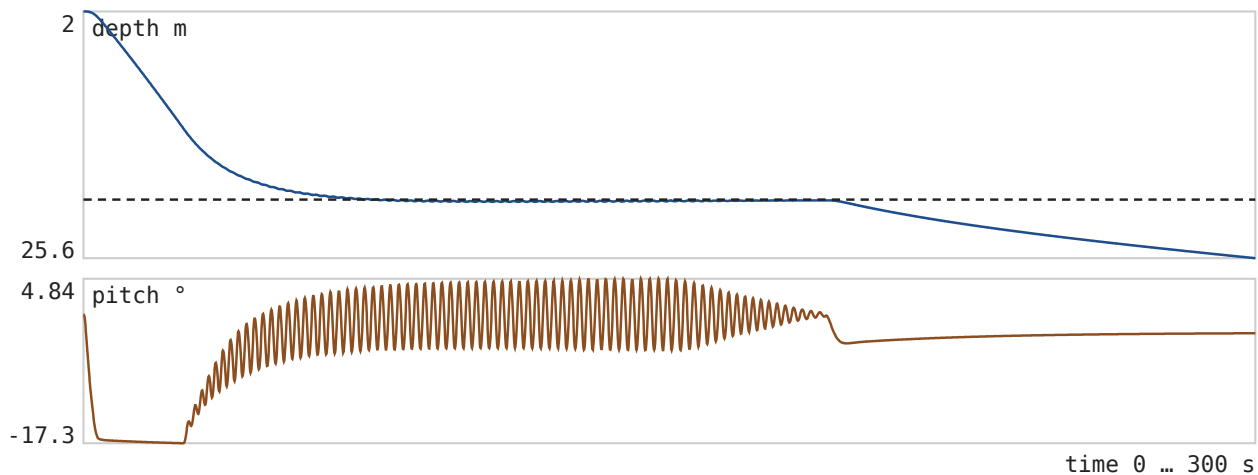


Figure 1: Row 0: depth (setpoint dashed) and pitch.

row 2 (fee15cfd043a9f91)

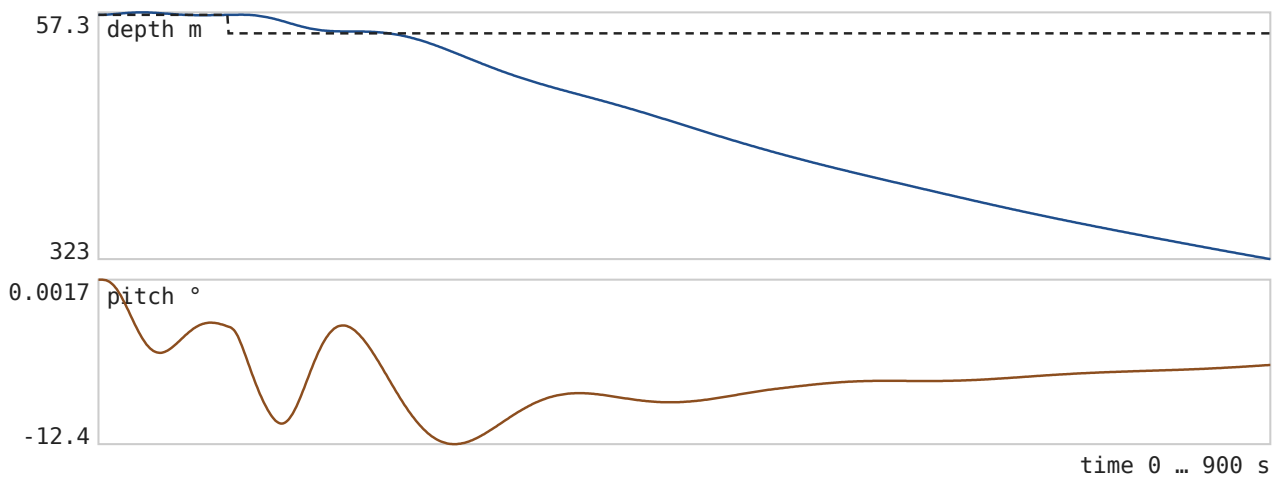


Figure 2: Row 2: depth (setpoint dashed) and pitch.

row 6 (9392fdd9fab2d14b)

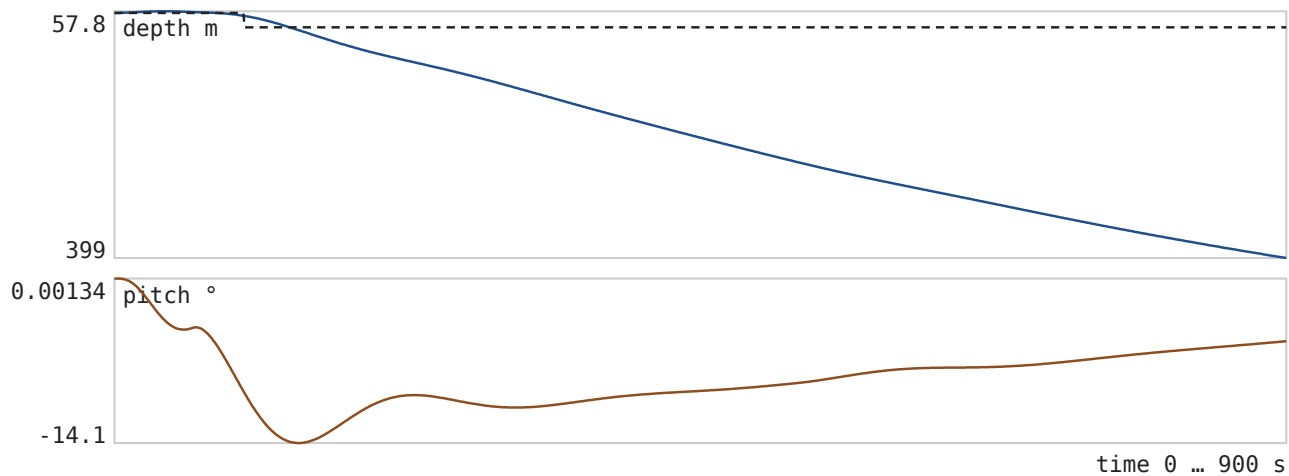


Figure 3: Row 6: depth (setpoint dashed) and pitch.

row 7 (26d8c067d0b44042)

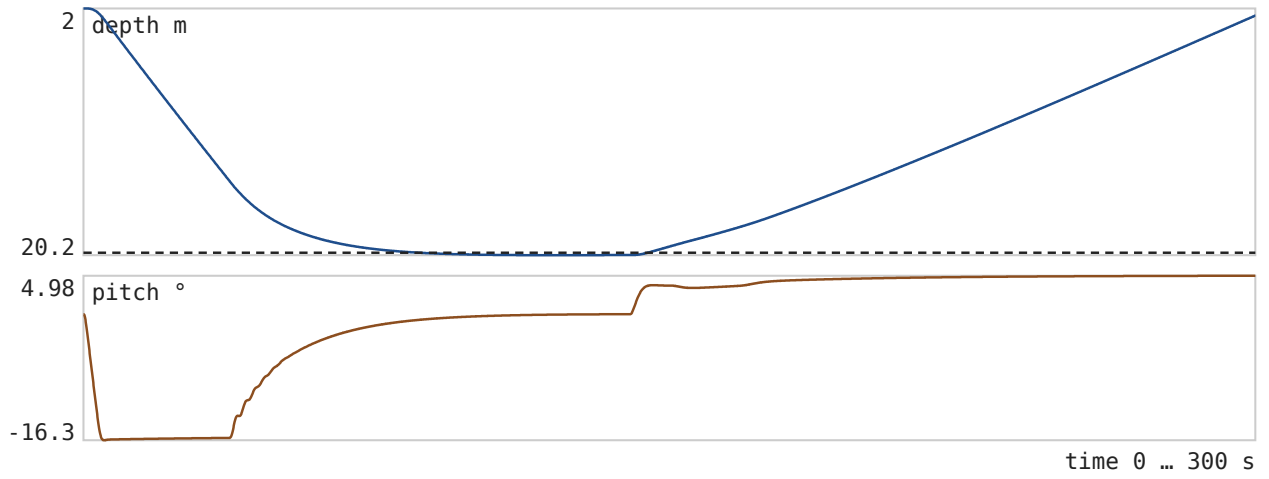


Figure 4: Row 7: depth (setpoint dashed) and pitch.

row 9 (737f10ffdd025978)

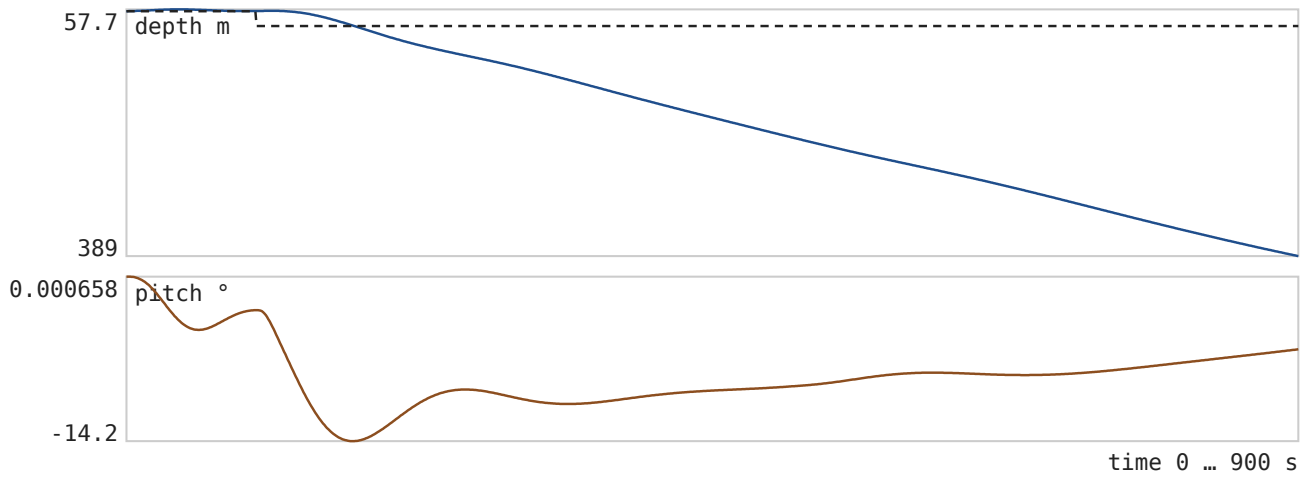


Figure 5: Row 9: depth (setpoint dashed) and pitch.

row 10 (40ceb0f1366bed50)

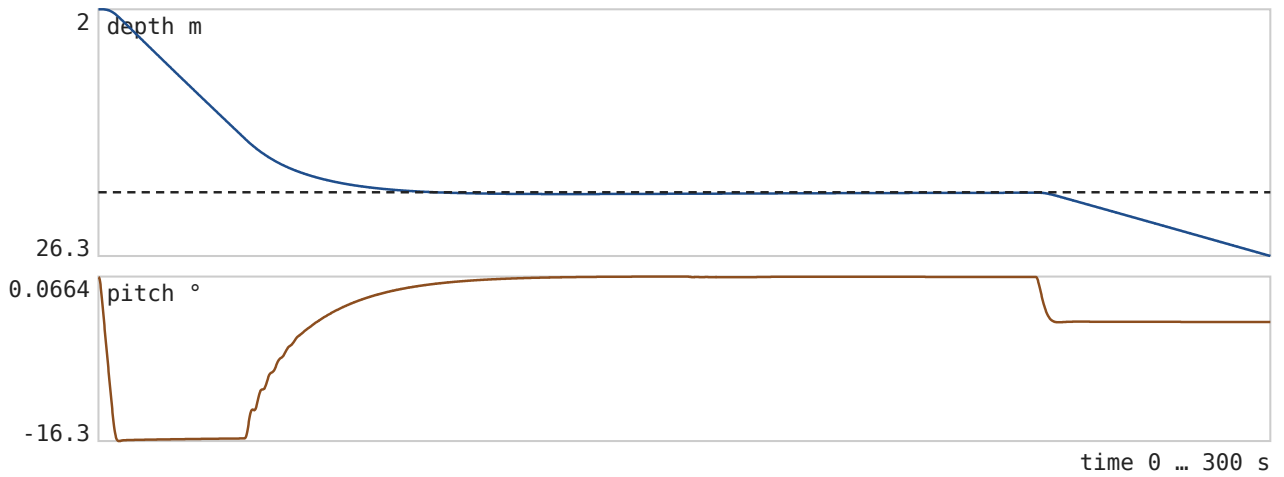


Figure 6: Row 10: depth (setpoint dashed) and pitch.

row 11 (dc593edb4a057747)

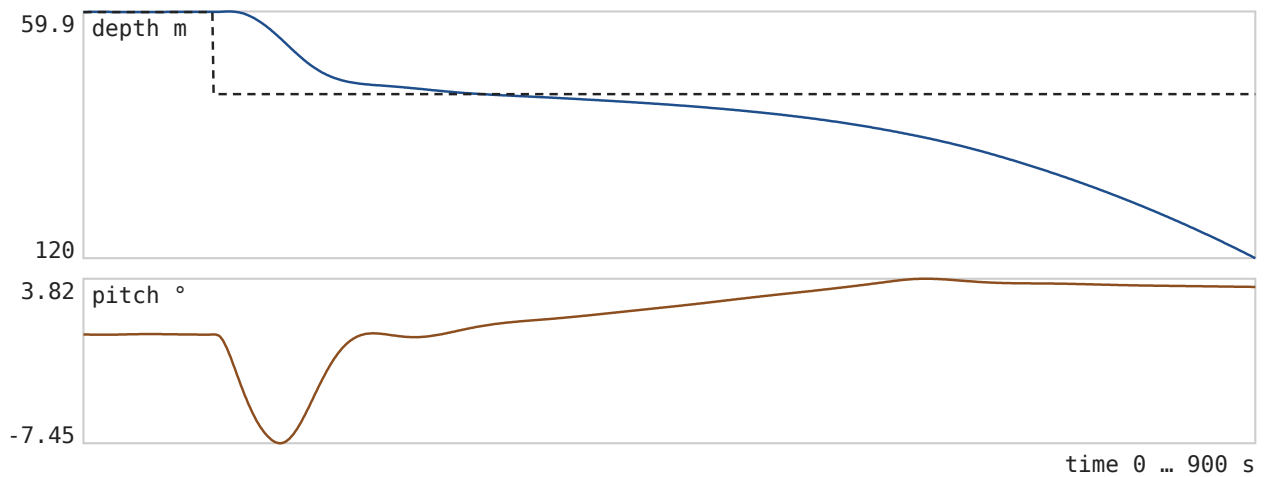


Figure 7: Row 11: depth (setpoint dashed) and pitch.

row 18 (3534d854c07d73c5)

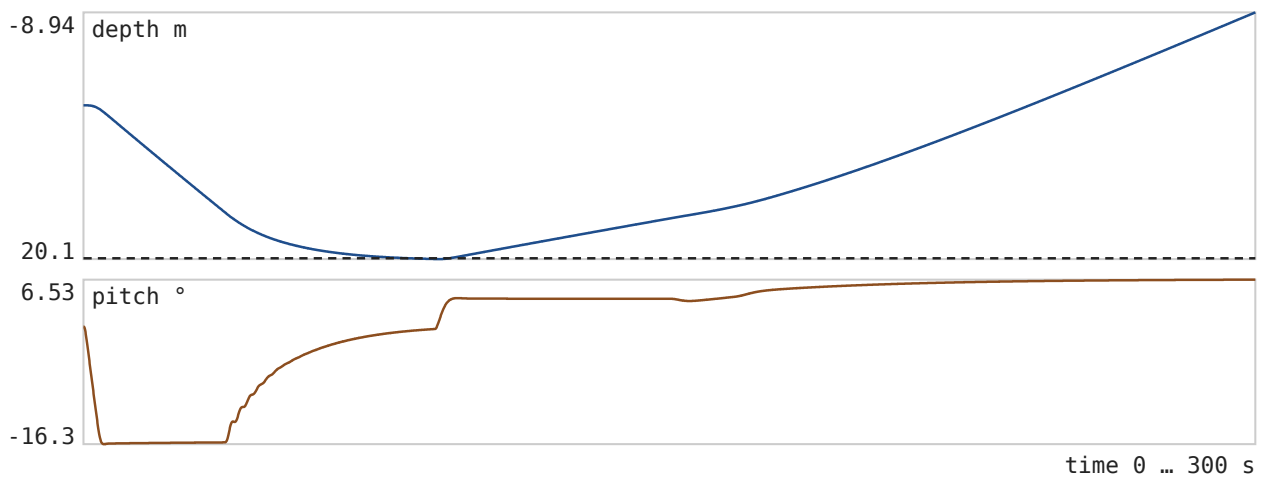


Figure 8: Row 18: depth (setpoint dashed) and pitch.

row 20 (28204e4afb5bf36f)

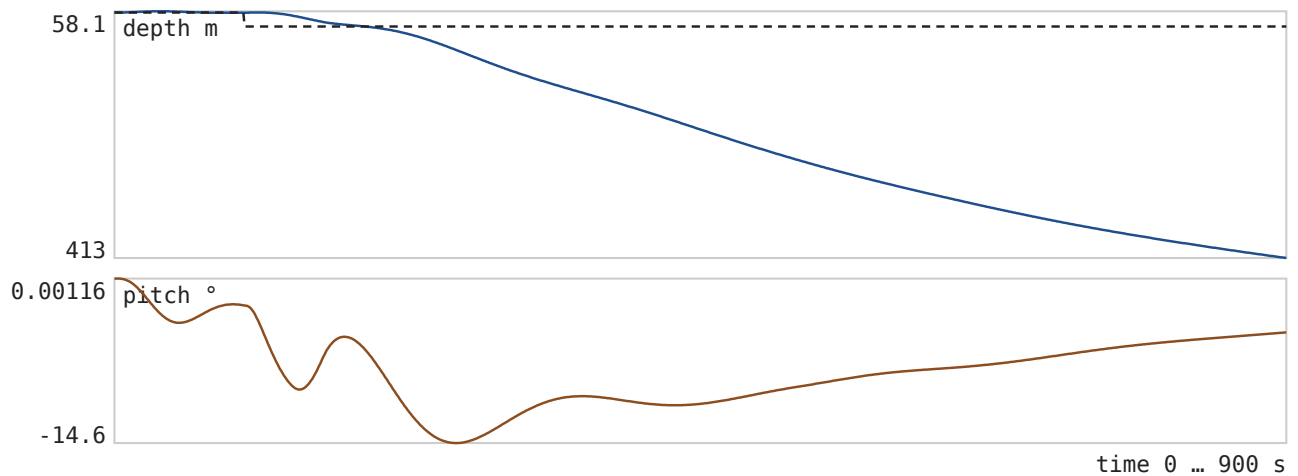


Figure 9: Row 20: depth (setpoint dashed) and pitch.

row 24 (1ccc03b40994ea9a)

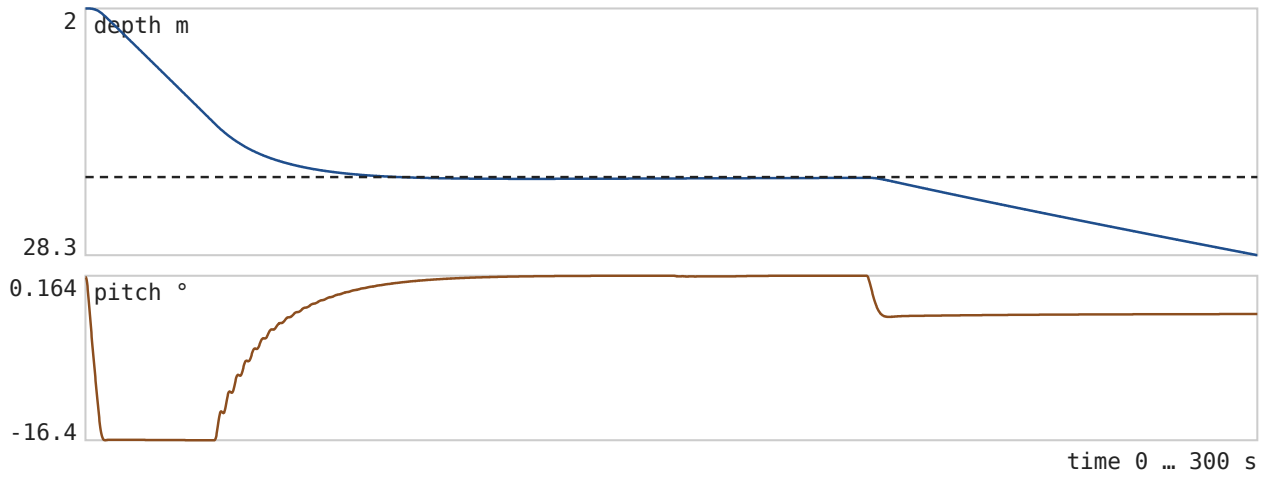


Figure 10: Row 24: depth (setpoint dashed) and pitch.

row 26 (4fe32d9f12b47ae7)

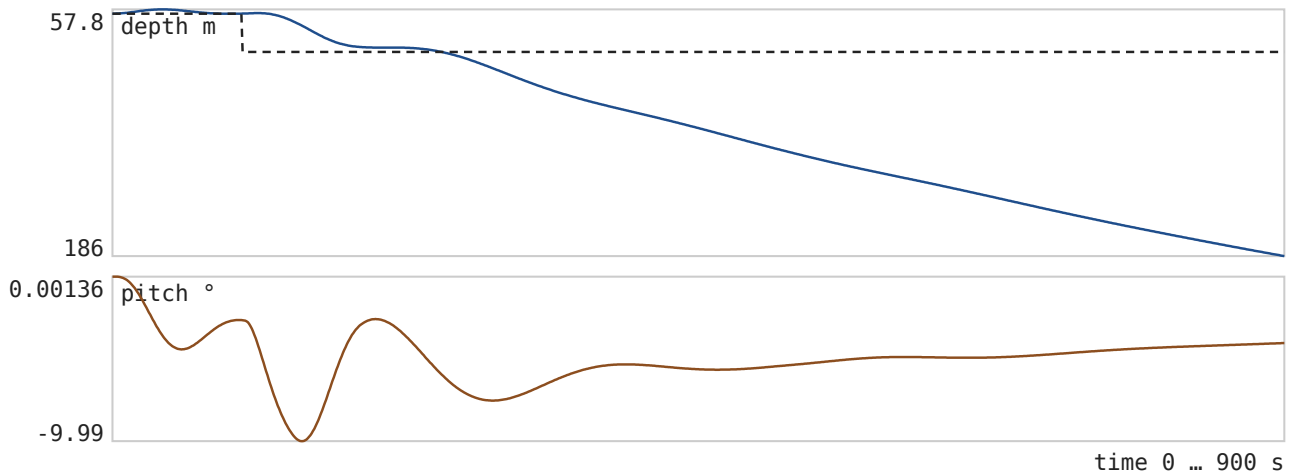


Figure 11: Row 26: depth (setpoint dashed) and pitch.

row 28 (6f200907f3ecd7a6)

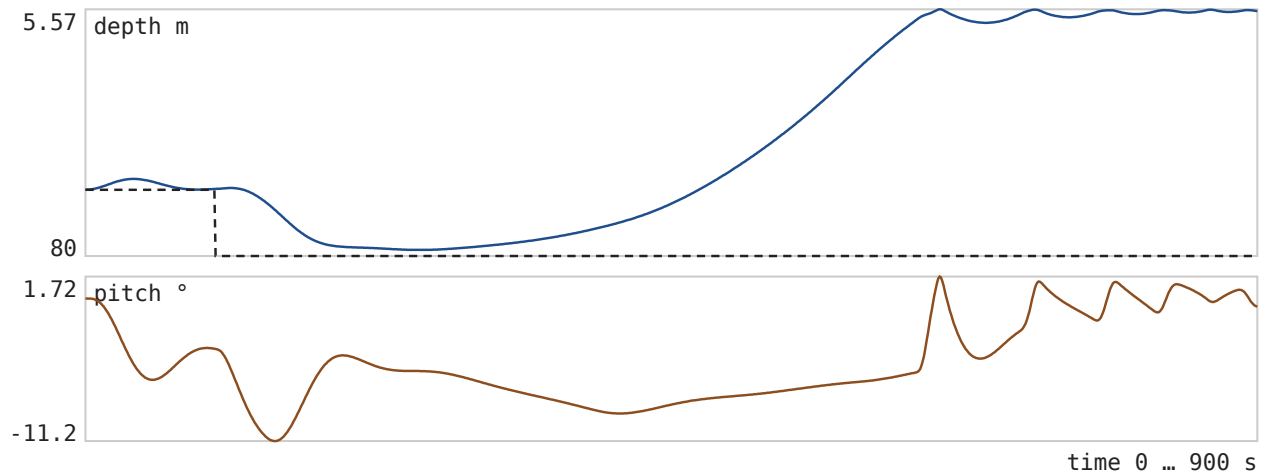


Figure 12: Row 28: depth (setpoint dashed) and pitch.

Appendix A. Campaign file

```
# K3 demonstration (step 85): the reference autopilot on the conceptual submarine and on REMUS 100,
# 120 scenarios drawn from currents, water columns, faults and fault times. src: DES – every number
# below is a campaign design choice; the vehicles are conceptual or published open models.
#
# subnavis campaign run builtin:k3-demo -o k3 -j 8 --report-date 2026-12-04
```

```

campaign_version: 1
name: k3-demo
description: >
  Reference autopilot on a conceptual submarine (hold 60 m, go to 80 m, turn to 030°) and on REMUS
  100 (dive to 20 m, turn to 090°): 120 scenarios with currents up to 0.8 m/s from any direction,
  two thermoclines, a jammed rudder, a stern plane jammed to rise or to dive, and a lost propulsor.
bases:
  - { builtin: autopilot-suboff }
  - { builtin: autopilot-remus }
axes:
  - { name: current_speed, param: current_speed_m_s, range: { value: { min: 0.0, max: 0.8 }, src:
DES } }
  - { name: current_dir, param: current_direction_deg, range: { value: { min: 0.0, max: 360.0 }, src:
DES } }
  - { name: water_column, param: water_column, values: { value: [none, warm, cold], src: DES } }
  - { name: fault, param: fault, values: { value: [none, rudder_jam, planes_jam_rise, planes_jam_dive,
propulsion_lost], src: DES } }
  - { name: fault_time, param: fault_time_s, range: { value: { min: 60.0, max: 240.0, step: 10.0 },
src: DES } }
sampling: { seed: 20261211, rows: 120 }
faults:
  # Effector order on both vehicles: rudder, stern plane(s), propulsor.
  rudder_jam: { value: { actuator_jammed: { effector: 0, position: 0.08726646259971647 } }, src: DES,
note: "rudder stuck at +5°" }
  planes_jam_rise: { value: { actuator_jammed: { effector: 1, position: -0.05235987755982989 } }, src:
DES, note: "stern plane stuck at -3° (rise)" }
  planes_jam_dive: { value: { actuator_jammed: { effector: 1, position: 0.05235987755982989 } }, src:
DES, note: "stern plane stuck at +3° (dive)" }
  propulsion_lost: { value: { actuator_lost: { effector: 2 } }, src: DES, note: "propulsor lost" }
water_columns:
  # Conceptual thermoclines between 12 and 30 m (warmer, fresher water above).
  warm:
    value:
      - { depth_m: 0.0, absolute_salinity_g_kg: 35.0, conservative_temperature_c: 20.0 }
      - { depth_m: 12.0, absolute_salinity_g_kg: 35.0, conservative_temperature_c: 20.0 }
      - { depth_m: 30.0, absolute_salinity_g_kg: 35.2, conservative_temperature_c: 14.0 }
      - { depth_m: 300.0, absolute_salinity_g_kg: 35.2, conservative_temperature_c: 13.0 }
    src: DES
  cold:
    value:
      - { depth_m: 0.0, absolute_salinity_g_kg: 35.0, conservative_temperature_c: 18.0 }
      - { depth_m: 12.0, absolute_salinity_g_kg: 35.0, conservative_temperature_c: 18.0 }
      - { depth_m: 30.0, absolute_salinity_g_kg: 35.3, conservative_temperature_c: 10.0 }
      - { depth_m: 300.0, absolute_salinity_g_kg: 35.3, conservative_temperature_c: 8.0 }
    src: DES
criteria:
  # From 250 s both vehicles have settled on their depth (REMUS changes depth at 0 s, the submarine
  # at 100 s); a turn later (150 s, 500 s) must not cost more than the margin.
  - { name: depth_hold, metric: depth_error_max_m, from_s: 250.0, max: { value: 3.0, src: DES } }
  - { name: pitch, metric: pitch_max_deg, max: { value: 20.0, src: DES } }
  - { name: roll, metric: roll_max_deg, max: { value: 20.0, src: DES } }
  - { name: interlock, metric: interlock_interventions, max: { value: 0.0, src: DES } }
# What the report's cover says besides the numbers (step 86b, review S2): the failed rows are the
# campaign's findings, not a failed product. From the P5 closure (analyses/2026-09-28-p5-kapanis.md).
report:
  key_findings:
    - "A jammed stern plane removes the conceptual submarine's only vertical-plane stabiliser: open
loop the boat is unstable in pitch at speed, so it can dive even with the plane stuck to rise,
depending on its pitch at the moment of the jam."
    - "After a lost propulsor the submarine slows below the speed where the stern planes act (about 2
m/s) and cannot hold depth; REMUS 100 holds it in 13 of 14 cases."
    - "One boundary case without a fault: a cold thermocline with a 0.75 m/s current takes the
submarine 3.6 m off depth (limit 3 m)."
    - "REMUS 100 shows a pitch limit cycle of about 5° in a cold water column with a strong current
while it holds depth (no criterion is broken)."

```

- "The safety interlock clamps commands; it cannot stop a jammed plane. With a plane stuck to dive, the vehicle passes the interlock's depth limit without a single clamped command."

Appendix B. Software and determinism

Package	Version
subnavis	0.1.0
polars	1.44.2
jinja2	3.1.6
typst	0.15.0

The core is deterministic: the same scenario file gives the same bits on every platform (macOS, Linux, WebAssembly, Python). Random draws come only from the seed in the campaign file. This report is generated from the results files; the same results and date give the same HTML bytes.