

Supplementary Information

Which spaceflight biology hardware can be modelled?

Supplementary Note S1. Catalogue defects and source conflicts

SPLASH records #121–#147 carry descriptive fields displaced from neighbouring rows (offsets mostly –2). All fields of these records except the name, alternate names, background, category and status are excluded from every analysis. Table S1 lists the fields reviewed individually. Further defects found during curation: SPLASH #36 (MVP) lists “MOBIAS”, a different bioreactor, as an alternate name; the OSDR registry links a ground cabinet of the Lunar Receiving Laboratory (registry 2052) to 36 unrelated studies through a catch-all payload, and links MOBIAS to the STS-115 Group Activation Pack experiment, which used hand-cranked packs; 310 of 641 OSDR datasets have no experiment-platform entry. Source conflicts recorded during literature curation are listed, per hardware item, in `hardware/CURATION_NOTES.md` and in the `note` field of each affected parameter.

Table S1: SPLASH fields judged misattributed, uncertain or duplicated (likely source row given).

#	Field	Verdict	Source row	Reason
127	specimen_types_supported	misattributed	125	Succinonitrile is the transparent model alloy studied by PFMI (#125), not a protein-crystallization specimen
128	specimen_types_supported	misattributed	126	PCAM crystallization trays are the PCG-STES (#126) specimen format; BioMole is a molecular-biology (DNA/RNA) instrument
128	specimen_size	misattributed	126	'up to 6 cylinders per STES' explicitly names STES (#126)
129	note_specs	misattributed	127	'One Ryutai Rack holds ~6 cartridges' describes PCRf (#127), which is installed in the Ryutai Rack
131	specimen_size	uncertain	129	Syringe-pinned drop of ~25.4 mm matches Ring Sheared Drop (#129) rather than SUBSA ampoules
132	specimen_types_supported	misattributed	130	Solid combustible materials (PMMA, cotton) are SoFIE (#130) specimens, not solution crystals
133	specimen_types_supported	misattributed	131	Semiconductor/crystal melts are SUBSA (#131) specimens; SALI is a biological incubator
133	specimen_size	misattributed	131	Ampoules with a hot zone describe the SUBSA furnace (#131)
134	specimen_types_supported	uncertain	132	Generic solution samples; consistent with the -2 row offset seen in neighbouring records
136	specimen_types_supported	misattributed	134	'Small live animals' cannot be a thermal-cycler (SmartCycler) specimen
137	specimen_types_supported	misattributed	135	Blood/saliva/urine/swab list belongs to the Wet Lab Kit (#135); identity of #137 is an aquatic habitat
137	specimen_size	misattributed	135	Vials, syringes, needles, gloves are Wet Lab Kit (#135) contents
137	background	duplicate_of	69	Background describes the JAXA Aquatic Habitat (AQH), which is also record #69
138	specimen_types_supported	misattributed	136	RNA from microbial cultures describes the Wet Lab RNA SmartCycler (#136)
138	specimen_size	misattributed	136	16 reaction tubes per run is a SmartCycler (#136) specification
138	background	duplicate_of	34	Record is named Plant Growth Unit but its background describes the Advanced Plant Habitat (#34)

Table S1, continued

#	Field	Verdict	Source row	Reason
139	specimen_types_supported	misattributed	137	Medaka/zebrafish are Aquatic Habitat (#137/#69) specimens; AAU is a rodent transfer unit
139	specimen_size	misattributed	137	Two aquaria of ~0.7 L each describe the Aquatic Habitat
140	specimen_types_supported	misattributed	138	Arabidopsis, dwarf wheat, lettuce, peppers are the APH crop list (#138 background = APH); BRIC-Opti is a small passive canister
140	specimen_size	misattributed	138	Shoot area ~1708 cm ² and 43 cm shoot height match APH; impossible in a BRIC canister
141	specimen_types_supported	misattributed	142	Live adult mice belong to the Rodent Habitat (#142); ESA Biopack hosted cells and small organisms
141	specimen_size	misattributed	139	Mice in Transporter/Habitat and AAU transfers describe the rodent system (#139/#142)
142	specimen_types_supported	misattributed	140	Microbes and plant tissue cultures in OptiCell plates describe a culture canister (BRIC-Opti #140), not the Rodent Habitat
142	specimen_size	misattributed	140	Up to 4 OptiCell plates is a BRIC-Opti (#140) capacity
142	note_specs	misattributed	140	Text names BRIC-Opti explicitly
144	specimen_types_supported	misattributed	142	Mice belong to the rodent habitat; the Cell Culture Model hosts cells and microbes
144	specimen_size	misattributed	142	Up to 10 adult mice belongs to the rodent habitat
145	specimen_types_supported	misattributed	143	Bacteria, fungi, cell cultures, small plants match BioRack (#143); AAU housed aquatic animals
146	specimen_types_supported	misattributed	144	Mammalian cell lines and microbial cultures match the Cell Culture Model (#144); FEU housed frogs
146	specimen_size	misattributed	144	CEU/CEU2/MEU chamber specifications name the Cell Culture Model (#144) units
146	temperature_range	misattributed	144	CEU/CEU2/MEU set points name the Cell Culture Model (#144) units
147	specimen_types_supported	misattributed	145	Medaka, newt, toadfish were AAU (#145) specimens; CEBAS flew swordtail fish, snails and hornwort
123	note_specs	misattributed	121	Text names MOBIAS (#121) explicitly
120	note_specs	uncertain	123	5000x magnification at 10 kV describes an electron microscope, not a rack
39	specimen_size	uncertain	42	'Type IV and Passive EUE' is EMCS (#42) experiment-container terminology
39	lighting	uncertain	42	'EUE specific' is EMCS (#42) terminology
89	volume	uncertain	91	ELF is a JEM facility; 'EXPRESS rack drawer' unlikely, but non-biological

Supplementary Note S2. The MI-CFD-HW checklist

Table S2: The MI-CFD-HW checklist and its coverage across specimen-housing hardware (public sources).

Item	Description	Group	Critical	Quant. (%)	Qual. (%)	Absent (%)
G1	Enclosure dimensions	geometry	yes	18	38	44
G2	Specimen-chamber volume or dimensions	geometry	yes	17	52	31
G3	Specimen layout / number of units	geometry		28	9	63
F1	Ventilation mode (forced / passive / sealed)	flow	yes	41	18	41
F2	Airflow rate or velocity	flow	yes	4	0	96
E1	Temperature at specimen	environment	yes	30	23	47
E2	Relative humidity	environment		13	14	74
E3	Gas composition / CO ₂ -O ₂ control	environment		8	33	59
E4	Pressure	environment		11	4	86
E5	Lighting (type, flux or darkness)	environment		12	37	51
B1	Specimen types	biology	yes	98	0	2
B2	Nutrient / water delivery	biology		34	28	38
B3	Specimen gas-exchange / metabolic load	biology		0	10	90
T1	Heat load / power	thermal		2	5	94
W1	Wall / membrane gas permeability	boundary		18	20	62

Supplementary Note S3. Literature curation

Table S3: Critical MI-CFD-HW items after literature curation (✓ sourced with a verbatim quotation; F2 n/a: sealed or passive hardware). G1 enclosure dimensions; G2 specimen container; F1 ventilation mode; F2 airflow; E1 temperature; B1 specimen.

Hardware	G1	G2	F1	F2	E1	B1	Tier	sourced/params
Advanced Plant Habitat	✓	✓	✓	✓	✓	✓	A	26/34
Aquatic Habitat	✓	✓	✓	✓	✓	✓	A	16/30
Mice Drawer System	✓	✓	✓	✓	✓	✓	A	23/29
Vented Fly Box	✓	✓	✓	n/a	✓	✓	A	16/28
Advanced Biological Research System	✓	✓	✓	–	✓	✓	B	18/28
Avian Development Facility	✓	–	✓	–	✓	✓	B	19/29
Animal Enclosure Module	✓	–	✓	–	✓	✓	B	21/27
Animal Enclosure Module Transporter	–	–	✓	✓	✓	✓	B	21/27
BioCell Cell Culture and Plate Habitats	–	–	✓	n/a	✓	✓	B	15/28
Bioculture System	–	✓	✓	–	✓	✓	B	17/32
Biomass Production System	✓	–	✓	–	✓	✓	B	18/30
Biological Research in Canisters - Petri Dish	–	✓	✓	n/a	✓	✓	B	19/33
Cell Biology Experiment Facility / Plant Exper	✓	✓	✓	–	✓	✓	B	16/28
Cell Culture Module	–	✓	✓	n/a	✓	✓	B	12/29
Closed Equilibrated Biological Aquatic System	–	–	✓	✓	✓	✓	B	16/30
European Modular Cultivation System	✓	–	✓	–	✓	✓	B	17/28
Fungal Immunity	–	–	✓	n/a	✓	✓	B	16/29
Fruit Fly Lab	–	–	✓	n/a	✓	✓	B	16/30
Group Activation Pack - Fluid Processing Appar	–	✓	✓	n/a	✓	✓	B	13/29
JAXA Mouse Habitat Unit	–	–	✓	✓	✓	✓	B	21/27
Jellyfish Kit	–	–	✓	n/a	✓	✓	B	11/29
Multiple Orbital Bioreactor with Instrumentati	–	–	✓	n/a	✓	✓	B	10/29
Multi-use Variable-g Platform	–	✓	✓	–	✓	✓	B	20/35
Research Animal Holding Facility	✓	–	✓	✓	–	✓	B	22/27
Rodent Habitat	–	–	✓	✓	✓	✓	B	19/27
Space Automated Bioproduct Laboratory	✓	–	✓	n/a	✓	✓	B	18/31
Vegetable Production System	✓	–	✓	–	✓	✓	B	19/29
Vestibular Function Experiment Unit	–	–	✓	✓	✓	✓	B	16/33
ADvanced Space Experiment Processor	–	✓	–	–	✓	✓	C	12/29
BOTEX incubator	–	✓	–	–	✓	✓	C	9/28
Biological Research In Canisters - BRIC-100	–	–	✓	n/a	–	✓	C	11/27
BRIC-100VC	–	–	✓	n/a	–	✓	C	11/28
BRIC-60	–	–	✓	n/a	–	✓	C	13/29
BRIC-LED	–	✓	✓	–	–	✓	C	16/30
Commercial Generic Bioprocessing Apparatus	–	–	–	–	✓	✓	C	11/29
E150 Experiment Unique Equipment	–	–	–	–	–	✓	C	6/27
Kubik incubator	–	✓	–	–	✓	✓	C	12/29

Supplementary Note S4. Modelling assumptions

Table S4: Every modelling assumption in the CFD models (all other numbers reference sourced parameters).

Model	Parameter	Reason
aph	obstacles[0].center	Science Carrier fills the chamber floor ('installed into the base of the growth chamber', registry 2017); footprint equal to the chamber footprint by construction (enclosure footprint was derived from the carrier).
aph	zones[0].size	Canopy zone spans the planted surface minus 10 mm margins; 100 mm height represents a young canopy (PH-04 plants were 14 days old at the first RH change). Sensitivity: canopy height not sourced.
aph	zones[0].center	Canopy zone sits directly on the Science Carrier surface ($z = 51$ mm).
aph	openings[0].size	Vent sizes not published ('Vent sizes not published', aph.yaml). 300 x 60 mm slots assumed on each ECS side.
aph	openings[0].center	ECS returns air 'at plant level from opposing sides' (Monje et al. 2020): inlets centred 50 mm above the carrier.
aph	openings[1].size	As openings[0].
aph	openings[1].center	As openings[0].
aph	openings[2].size	Outlet size not published; equal to inlets.
aph	openings[2].center	ECS fans 'remove air from the top of the growth chamber above the plants' (Monje et al. 2020): outlets centred 40 mm below the ceiling on the same side walls (ECS modules are 'mounted on each side').
aph	openings[3].size	As openings[2].
aph	openings[3].center	As openings[2].
aph	openings.inlet_velocity_interpretation	The PH-04 'wind speed of 0.3 m/s' set-point is applied as the inlet face velocity; where APH measures wind speed is not stated (aph.yaml note).
aph	zones.canopy.co2_load	Canopy net CO ₂ uptake uses the wheat range 7-25 $\mu\text{mol m}^{-2} \text{s}^{-1}$ (Wheeler 1996 as cited by Monje et al. 2020; mid-point 16) over the 0.19 m ² growth area; no pepper rate was found. Transpiration and lamp/canopy heat are not modelled (no sourced value).
aph_fanmax	obstacles[0].center	Science Carrier fills the chamber floor ('installed into the base of the growth chamber', registry 2017); footprint equal to the chamber footprint by construction (enclosure footprint was derived from the carrier).
aph_fanmax	zones[0].size	Canopy zone spans the planted surface minus 10 mm margins; 100 mm height represents a young canopy (PH-04 plants were 14 days old at the first RH change). Sensitivity: canopy height not sourced.
aph_fanmax	zones[0].center	Canopy zone sits directly on the Science Carrier surface ($z = 51$ mm).
aph_fanmax	openings[0].size	Vent sizes not published ('Vent sizes not published', aph.yaml). 300 x 60 mm slots assumed on each ECS side.
aph_fanmax	openings[0].center	ECS returns air 'at plant level from opposing sides' (Monje et al. 2020): inlets centred 50 mm above the carrier.
aph_fanmax	openings[1].size	As openings[0].
aph_fanmax	openings[1].center	As openings[0].
aph_fanmax	openings[2].size	Outlet size not published; equal to inlets.
aph_fanmax	openings[2].center	ECS fans 'remove air from the top of the growth chamber above the plants' (Monje et al. 2020): outlets centred 40 mm below the ceiling on the same side walls (ECS modules are 'mounted on each side').
aph_fanmax	openings[3].size	As openings[2].
aph_fanmax	openings[3].center	As openings[2].
aph_fanmax	openings.inlet_velocity_interpretation	The PH-04 'wind speed of 0.3 m/s' set-point is applied as the inlet face velocity; where APH measures wind speed is not stated (aph.yaml note).

Table S4, continued

Model	Parameter	Reason
aph_fanmax	zones.canopy.co2_load	Canopy net CO2 uptake uses the wheat range 7-25 $\mu\text{mol m}^{-2} \text{s}^{-1}$ (Wheeler 1996 as cited by Monje et al. 2020; mid-point 16) over the 0.19 m^2 growth area; no pepper rate was found. Transpiration and lamp/canopy heat are not modelled (no sourced value).
aqh	openings[0].size	Water inlet/outlet geometry of the aquarium is not published (aqh.yaml: 'aquarium water inlet/outlet geometry'). 20 x 20 mm ports assumed.
aqh	openings[0].center	Inlet low on one end wall, outlet high on the opposite end wall (assumed cross-flow arrangement).
aqh	openings[1].size	As openings[0].
aqh	openings[1].center	As openings[0].
aqh	domain.water_only	The aquarium is modelled full of water; the air pocket of the air-water interface ('air stabilizer') and the fish are not represented (no dimensions or O2 uptake sourced). Walls held at the set-point temperature; no heat sources, so 0 g and 1 g are expected to coincide.
mds	zones[0].size	Mouse represented as a distributed source volume of 80 x 30 x 30 mm (adult-mouse scale) resting on the cage floor; body geometry not modelled as a solid.
mds	zones[0].center	Mouse at the floor centre.
mds	openings[0].size	Flow direction through the cage is not stated; waste filters are 'located below each Habitat' (Liu 2009, mds.yaml note), so air is taken to enter through the whole top grid and leave through the whole floor grid.
mds	openings[0].center	As openings[0].size.
mds	openings[1].size	As openings[0].size.
mds	openings[1].center	As openings[0].size.
mds	openings.velocity_interpretation	Cancedda 2012: airflow of 0.2-0.3 m/s through the cages; applied as a uniform face velocity (mid-point 0.25 m/s).
mds	environment.co2_reference	In-cage CO2 is controlled but not reported; supply air is set to the ISS U.S. Lab cabin CO2 during RR-1 (median of the EDA flight telemetry, hardware/_iss_cabin.yaml). MDS flew in 2009 in JEM and EDA starts in 2014, so this is a proxy; CO2 excess does not depend on it.
mds	zones.mouse.co2_load	Organism-level C57BL/6 rates (ICES-2014-101) and BALB/c heat and moisture (Riskowski 2006) scaled by the generic 30 g adult mass from Cancedda 2012; MDS flew C57BL/10J males.
vented_fly_box_vent20	obstacles[0].center	15 vials (24 x 75 mm) fit the 94 x 94 x 130 mm box only lying along x in a 3 x 5 stack (upright, at most 12 fit); g-load at launch was directed into the food at the vial bottoms (OSD-347). Vials treated as solid (food + flies inside not resolved).
vented_fly_box_vent20	obstacles[0].repeat.n	3 x 5 stack, see centre.
vented_fly_box_vent20	obstacles[0].repeat.pitch	Vials spaced 32 mm (y) and 25 mm (z) to fill the box cross-section.
vented_fly_box_vent20	zones[0].H	CO2 leaves each vial through its open foam plug (OSD-347; Researcher's Guide); released in a 4 mm layer at the plug end (x = 84.5-88.5 mm).
vented_fly_box_vent20	zones[0].center	Plug end of each vial.
vented_fly_box_vent20	zones[0].repeat.n	As obstacles.
vented_fly_box_vent20	zones[0].repeat.pitch	As obstacles.
vented_fly_box_vent20	zones.plugin.sources.CO2_count	13 flies per vial (OSD-347: '8 virgin females and 5 male adult virgin flies') x 15 vials = 195 adults; progeny that emerge during the mission (20-60 per vial on return) are not included, so the load is a lower bound.
vented_fly_box_vent20	openings[0].size	Vent hole number, size and position are not published (vented_fly_box.yaml). Run at two sizes, 20 x 20 and 60 x 60 mm per end wall, to show the sensitivity.
vented_fly_box_vent20	openings[0].center	Vents centred on the end walls.

Table S4, continued

Model	Parameter	Reason
vented_fly_box__vent20	openings[1].size	As openings[0].
vented_fly_box__vent20	openings[1].center	As openings[0].
vented_fly_box__vent20	openings.exterior	The exterior at each vent is taken as well mixed ISS cabin air (CO2 and RH: medians of the EDA RR-1 flight telemetry, hardware/_iss_cabin.yaml) at the box temperature.
vented_fly_box__vent60	obstacles[0].center	15 vials (24 x 75 mm) fit the 94 x 94 x 130 mm box only lying along x in a 3 x 5 stack (upright, at most 12 fit); g-load at launch was directed into the food at the vial bottoms (OSD-347). Vials treated as solid (food + flies inside not resolved).
vented_fly_box__vent60	obstacles[0].repeat.n	3 x 5 stack, see centre.
vented_fly_box__vent60	obstacles[0].repeat.pitch	Vials spaced 32 mm (y) and 25 mm (z) to fill the box cross-section.
vented_fly_box__vent60	zones[0].H	CO2 leaves each vial through its open foam plug (OSD-347; Researcher's Guide); released in a 4 mm layer at the plug end (x = 84.5-88.5 mm).
vented_fly_box__vent60	zones[0].center	Plug end of each vial.
vented_fly_box__vent60	zones[0].repeat.n	As obstacles.
vented_fly_box__vent60	zones[0].repeat.pitch	As obstacles.
vented_fly_box__vent60	zones.plugin.sources.CO2.count	13 flies per vial (OSD-347: '8 virgin females and 5 male adult virgin flies') x 15 vials = 195 adults; progeny that emerge during the mission (20-60 per vial on return) are not included, so the load is a lower bound.
vented_fly_box__vent60	openings[0].size	Vent hole number, size and position are not published (vented_fly_box.yaml). Run at two sizes, 20 x 20 and 60 x 60 mm per end wall, to show the sensitivity.
vented_fly_box__vent60	openings[0].center	Vents centred on the end walls.
vented_fly_box__vent60	openings[1].size	As openings[0].
vented_fly_box__vent60	openings[1].center	As openings[0].
vented_fly_box__vent60	openings.exterior	The exterior at each vent is taken as well mixed ISS cabin air (CO2 and RH: medians of the EDA RR-1 flight telemetry, hardware/_iss_cabin.yaml) at the box temperature.

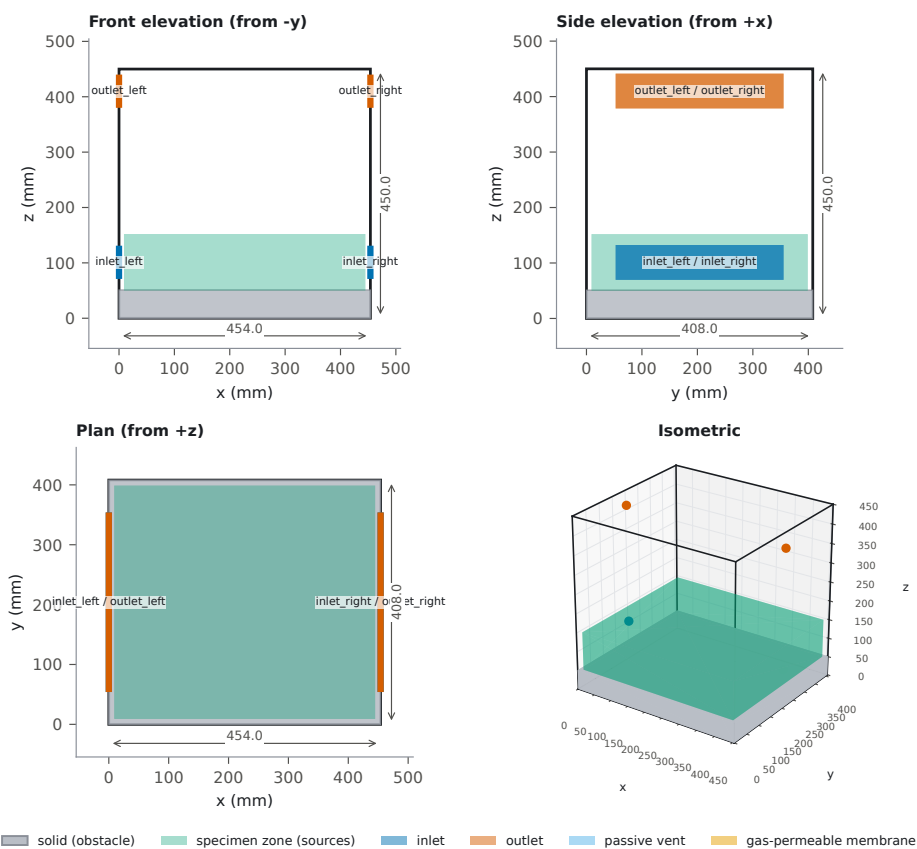
Supplementary Note S5. Discretisation uncertainty

Table S5: Grid convergence [1] of specimen-zone and domain quantities (excess over the supply state; age of air in s; U_{max} in m s^{-1}).

Model	g	Quantity	Fine	Medium	Coarse	p	GCI (%)	Temporal sd	Convergence
MDS	0g	zone mouse CO2	14.76	15.58	17.34	2.29	5.83	0.00	monotonic
MDS	0g	zone mouse T	0.28	0.29	0.33	2.27	6.00	0.00	monotonic
MDS	0g	zone mouse AoA	0.27	0.27	0.27	1.75	0.53	0.00	monotonic
MDS	0g	domain CO2	1.19	1.21	1.24	1.56	2.75	0.00	monotonic
MDS	0g	domain AoA	0.18	0.18	0.18	3.12	0.39	2.79×10^{-17}	monotonic
MDS	0g	U_max_late_m_s	0.31	0.30	0.30	4.44	0.32	–	oscillatory
MDS	1g	zone mouse CO2	14.79	15.61	17.38	2.29	5.86	0.00	monotonic
MDS	1g	zone mouse T	0.28	0.29	0.33	2.26	6.03	0.00	monotonic
MDS	1g	zone mouse AoA	0.27	0.27	0.27	1.81	0.51	5.59×10^{-17}	monotonic
MDS	1g	domain CO2	1.19	1.21	1.24	1.57	2.76	0.00	monotonic
MDS	1g	domain AoA	0.18	0.18	0.18	3.11	0.40	0.00	monotonic
MDS	1g	U_max_late_m_s	0.31	0.30	0.30	4.27	0.34	–	oscillatory
APH	0g	zone canopy CO2	-6.43	-6.50	-6.50	10.35	0.04	0.24	monotonic (within unsteadiness)
APH	0g	zone canopy AoA	1.97	1.98	1.97	3.24	0.10	0.11	oscillatory (within unsteadiness)
APH	0g	domain CO2	-7.19	-7.14	-7.22	1.40	1.42	0.08	oscillatory (within unsteadiness)
APH	0g	domain AoA	4.91	4.89	4.94	4.31	0.08	0.09	oscillatory (within unsteadiness)
APH	0g	U_max_late_m_s	0.45	0.45	0.43	2.95	0.79	–	monotonic
APH	1g	zone canopy CO2	-6.64	-6.82	-6.46	1.96	3.71	0.27	oscillatory (within unsteadiness)
APH	1g	zone canopy AoA	2.10	2.23	2.04	1.24	14.36	0.17	oscillatory (within unsteadiness)
APH	1g	domain CO2	-7.22	-7.31	-7.23	0.50	8.51	0.06	oscillatory (within unsteadiness)
APH	1g	domain AoA	5.00	5.05	4.95	1.94	1.39	0.08	oscillatory (within unsteadiness)
APH	1g	U_max_late_m_s	0.45	0.44	0.44	0.52	11.69	–	monotonic
VFB (20 mm)	0g	zone plug CO2	184.46	187.94	197.02	2.87	2.27	6.56×10^{-3}	monotonic
VFB (20 mm)	0g	zone plug AoA	460.83	469.19	496.32	3.65	1.54	0.02	monotonic
VFB (20 mm)	0g	domain CO2	145.41	148.53	157.31	3.14	2.27	7.00×10^{-3}	monotonic
VFB (20 mm)	0g	domain AoA	490.81	499.40	527.38	3.67	1.47	0.02	monotonic

Supplementary Note S6. Geometry of the modelled hardware

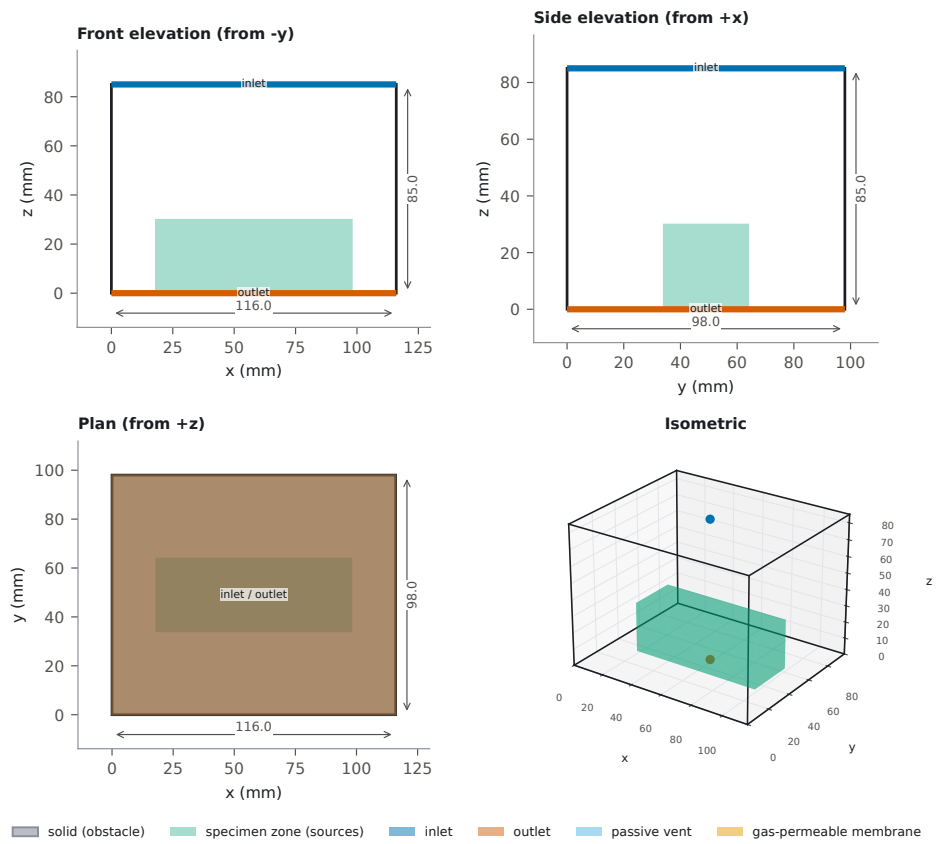
Advanced Plant Habitat (APH) - CFD geometry



Sourced parameters used: 8 (hardware/aph.yaml); modelling assumptions: 13 (models/aph.yaml). Dimensions in mm.

Figure S1: Advanced Plant Habitat growth chamber as modelled (PH-04 set-points).

Mice Drawer System (MDS, ASI / Thales Alenia Space Italia) - CFD geometry



Sourced parameters used: 9 (hardware/mds.yaml); modelling assumptions: 9 (models/mds.yaml). Dimensions in mm.

Figure S2: One Mice Drawer System cage as modelled.

Vented Fly Box (VFB) - CFD geometry

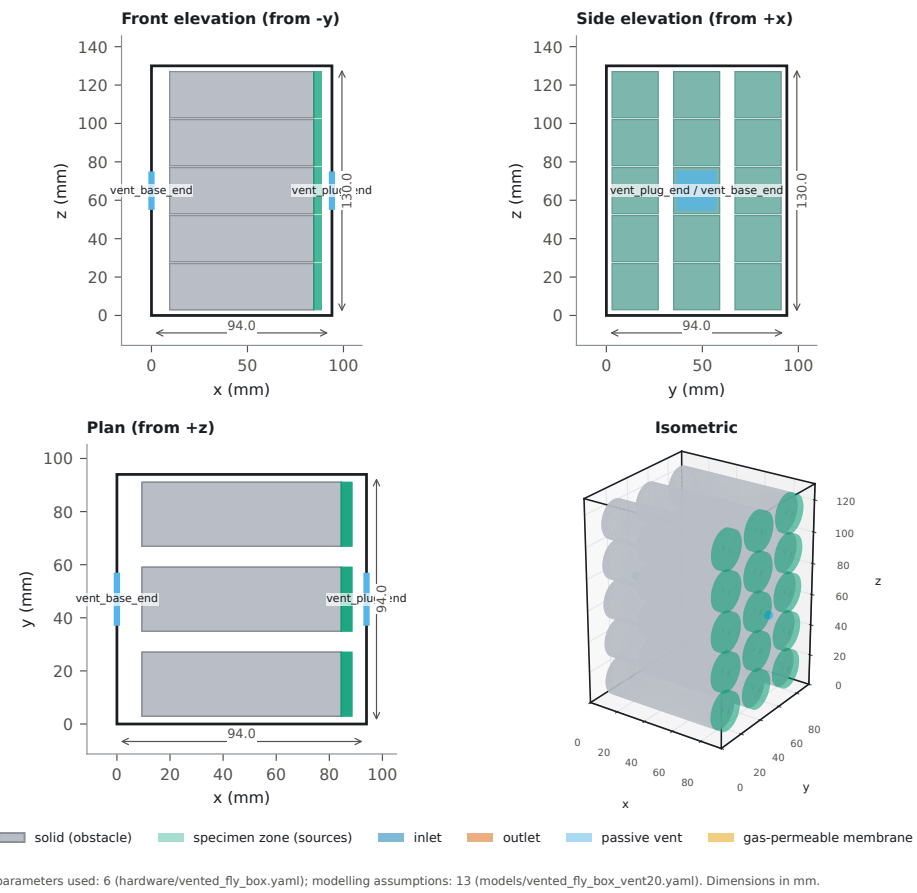
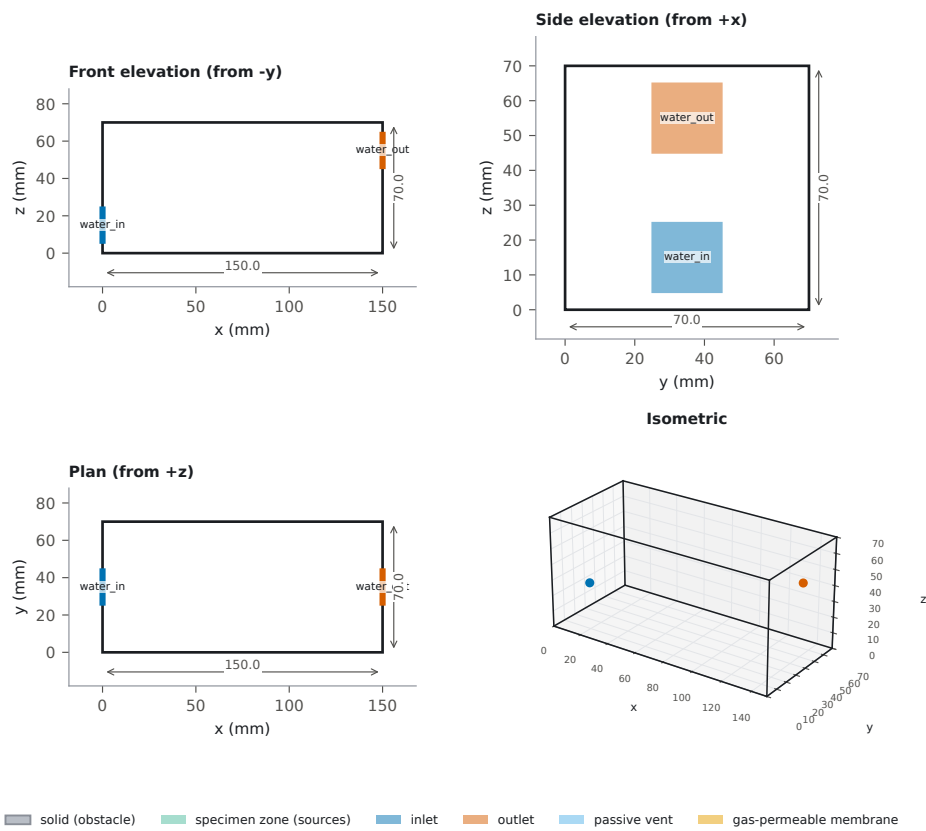


Figure S3: Vented Fly Box as modelled (20 mm vents; the 60 mm variant differs only in vent size).

Aquatic Habitat (AQH) - CFD geometry



Sourced parameters used: 3 (hardware/aqh.yaml); modelling assumptions: 5 (models/aqh.yaml). Dimensions in mm.

Figure S4: One Aquatic Habitat aquarium as modelled (water).

Supplementary Note S7. Field slices

mds: vertical mid-plane, flight (0 g) vs ground control (1 g)

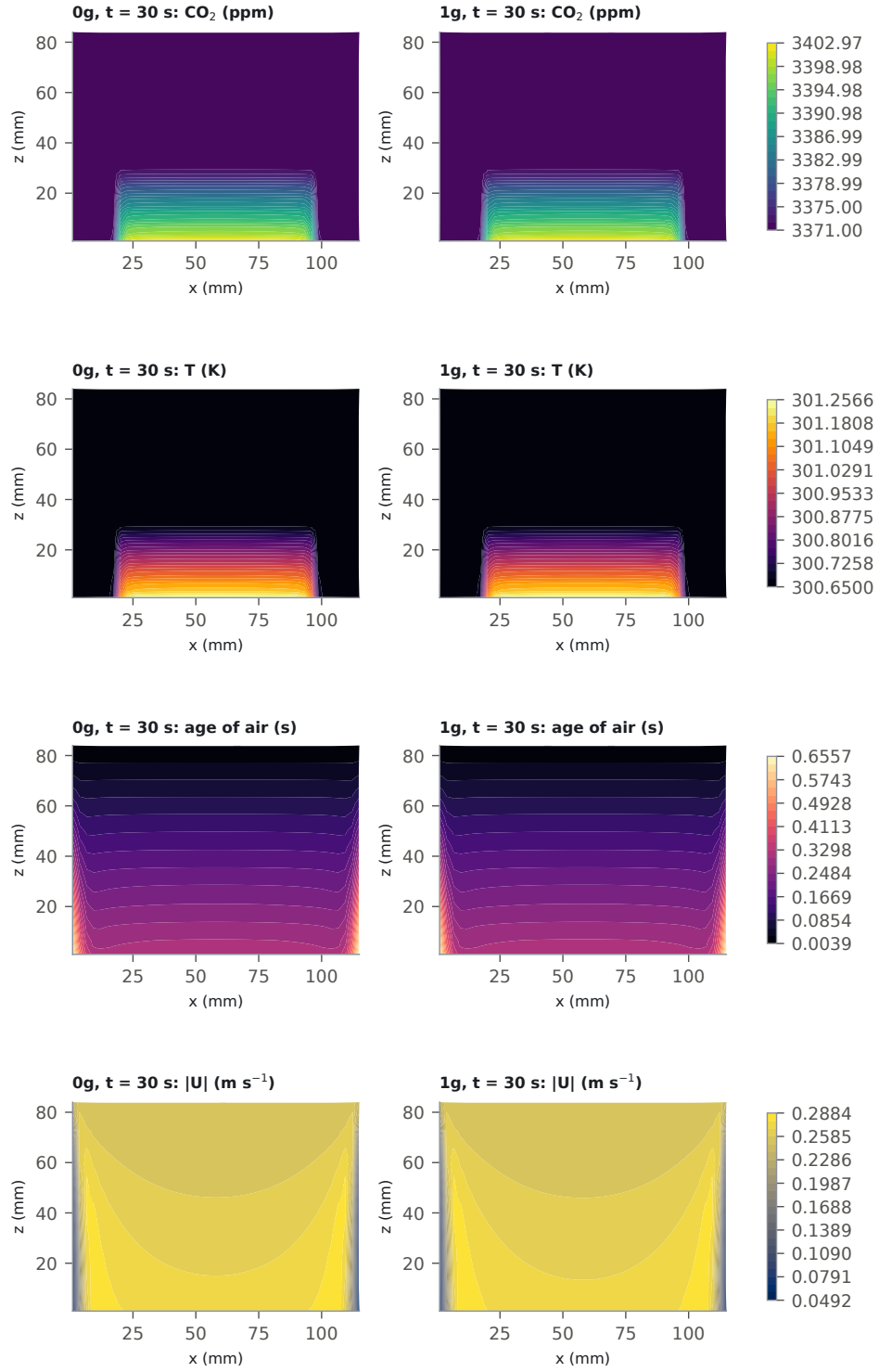


Figure S5: MDS cage, vertical mid-plane at the end of the run, 0 g and 1 g.

aph: vertical mid-plane, flight (0 g) vs ground control (1 g)

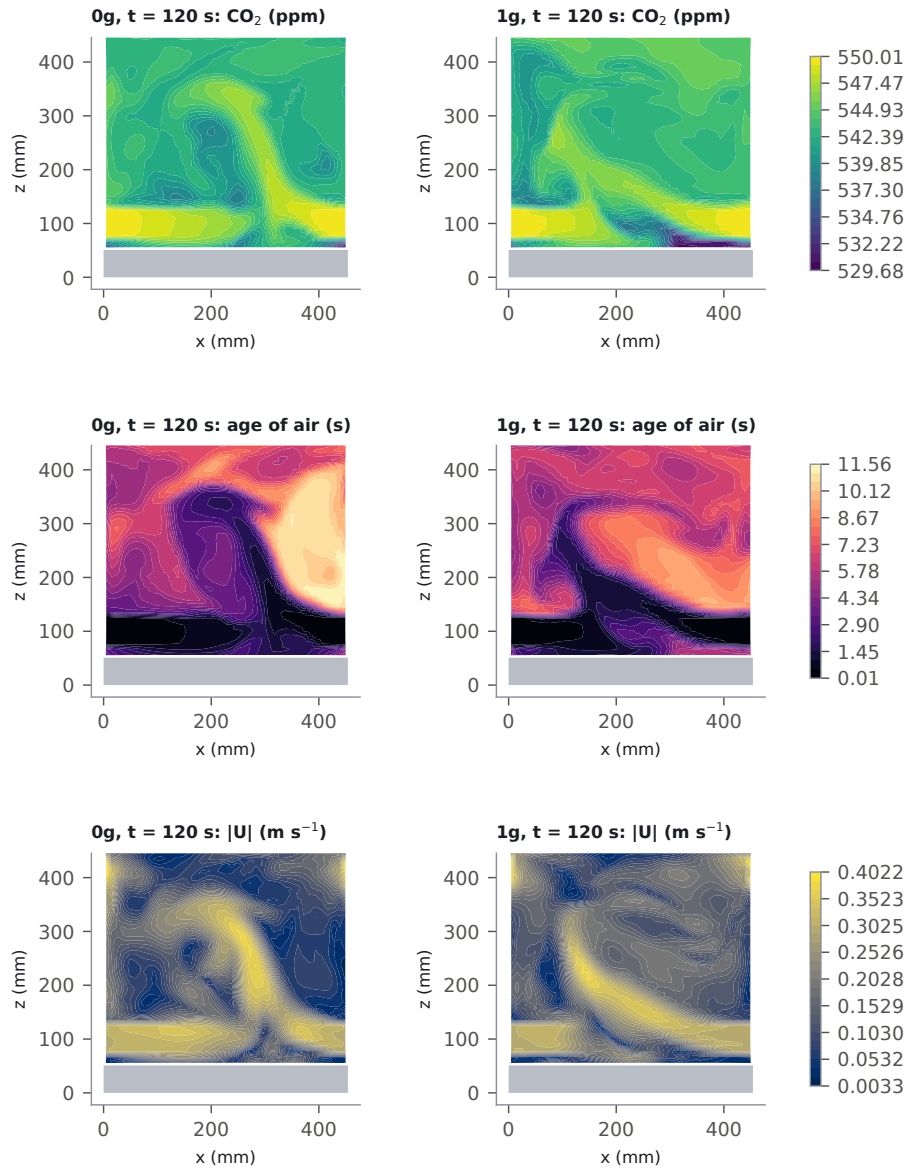


Figure S6: APH growth chamber, vertical mid-plane at the end of the run, 0 g and 1 g.

vented_fly_box_vent20: vertical plane $y = 31$ mm, 0g only (1 g identical by construction)

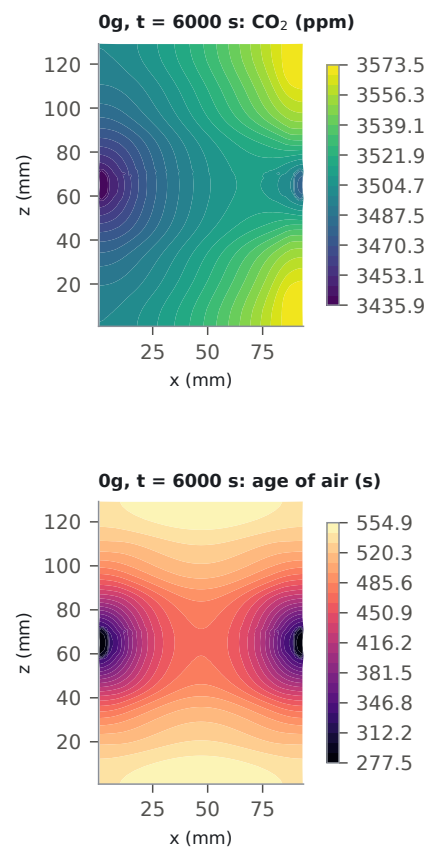


Figure S7: Vented Fly Box (20 mm vents), vertical mid-plane at the end of the run, 0 g and 1 g .

aqh: vertical mid-plane, 0g only (1 g identical by construction)

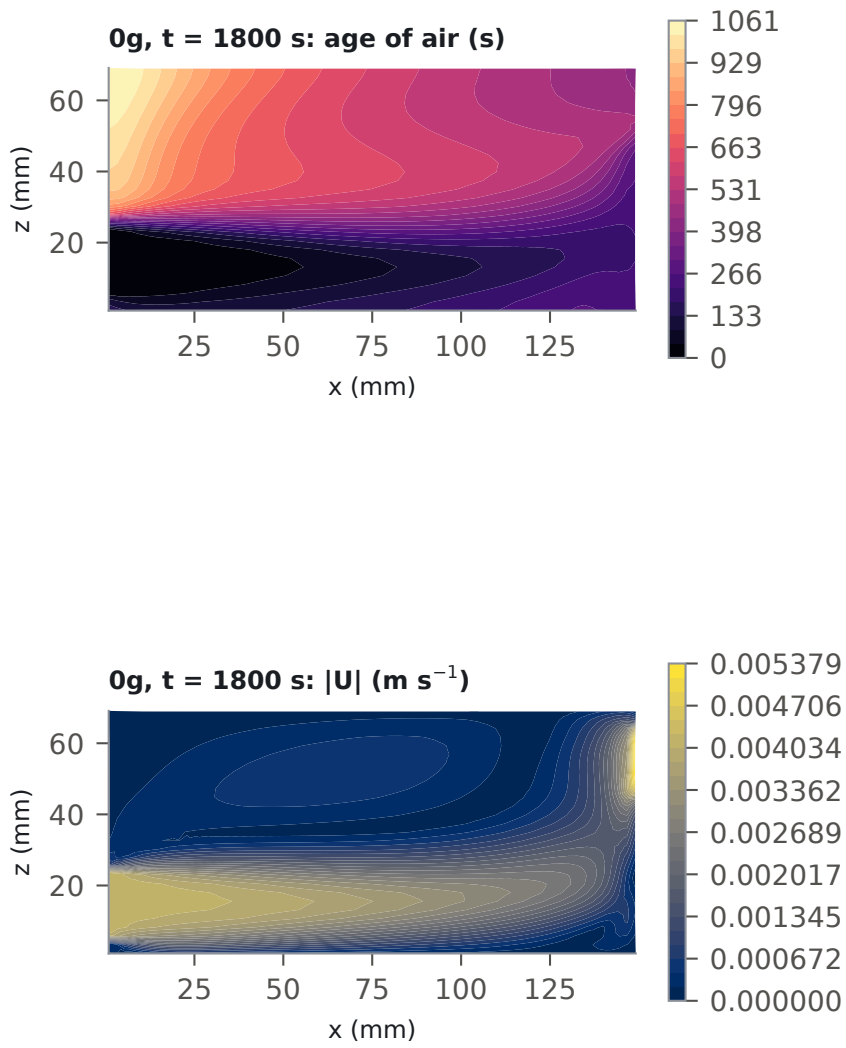


Figure S8: AQH aquarium, vertical mid-plane at the end of the run, 0 *g* and 1 *g*.

Supplementary Note S8. Environment cards

Time series of specimen-zone excess over the supply or initial state, 0 g (blue) and 1 g (red), medium meshes.

MDS mouse cage - specimen zone 'mouse', medium mesh

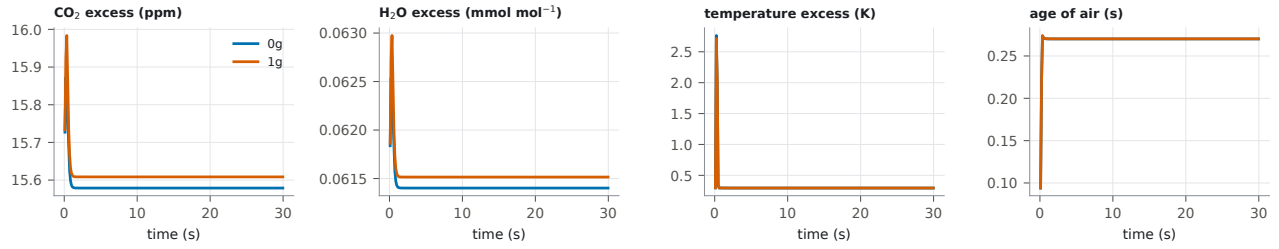


Figure S9: MDS cage.

APH (PH-04 set-points) - specimen zone 'canopy', medium mesh

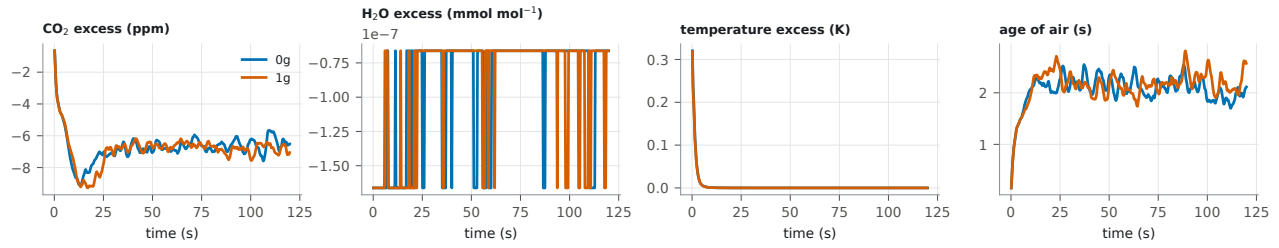


Figure S10: APH, PH-04 set-points.

APH (fan 1.5 m/s) - specimen zone 'canopy', medium mesh

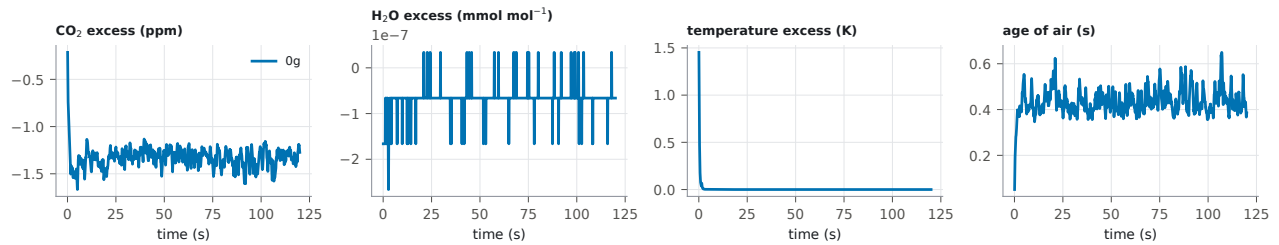


Figure S11: APH, fan at 1.5 m/s.

Vented Fly Box (20 mm vents) - specimen zone 'plug', medium mesh

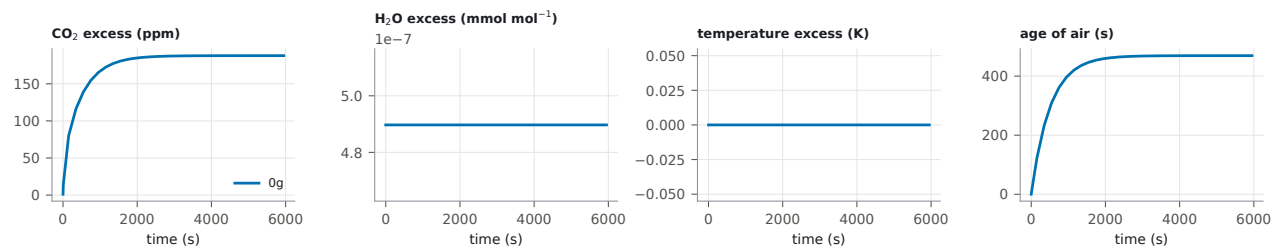


Figure S12: Vented Fly Box, 20 mm vents.

Vented Fly Box (60 mm vents) - specimen zone 'plug', medium mesh

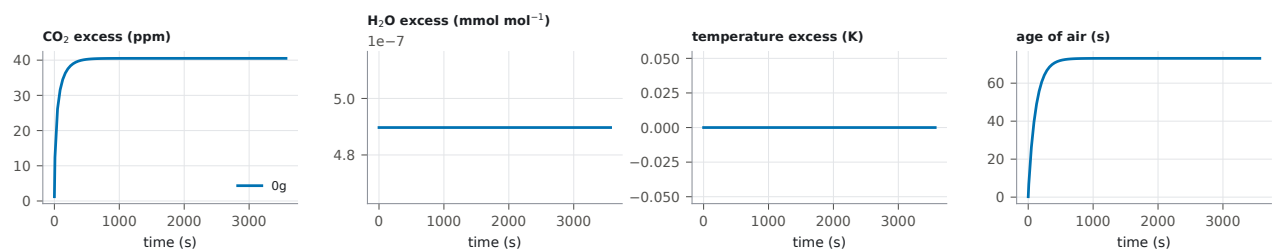


Figure S13: Vented Fly Box, 60 mm vents.

AQH aquarium (water) - domain average, medium mesh

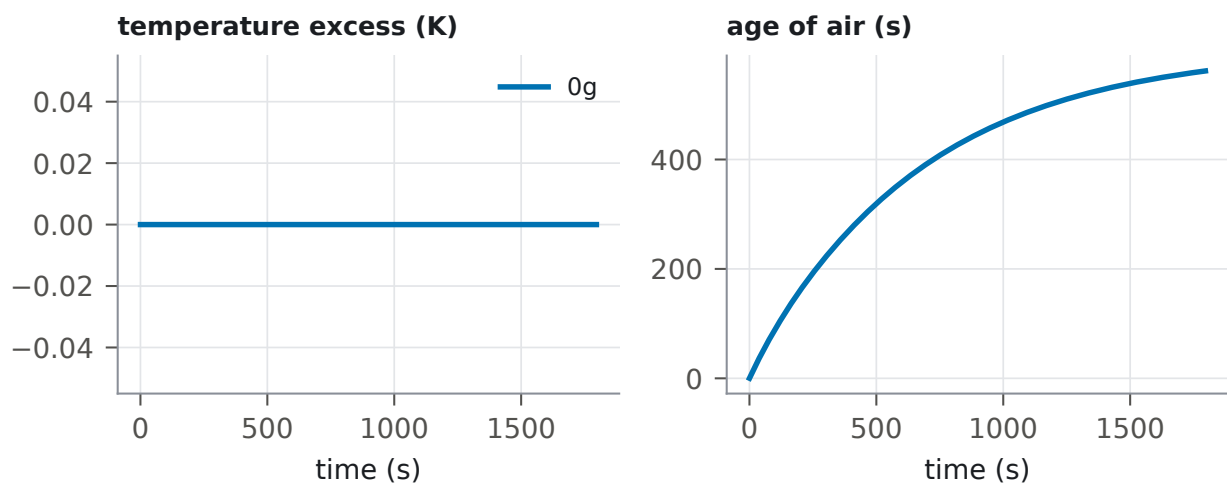


Figure S14: AQH aquarium (water).

Supplementary Note S9. ISS cabin telemetry

Source and processing. The telemetry and daily absorbed dose of all 24 missions in the OSDR Environmental Data App [2] were archived verbatim with checksums (`data/raw/2026-10-12/eda/`). The app describes them as measurements “recorded in the ISS cabin and ground control”. Quality control (`src/hwreview/eda.py`) merges duplicated timestamps, removes values outside physical bounds (temperature 5–40 °C, relative humidity 1–100%, CO₂ 100–20 000 ppm) and removes CO₂ values held unchanged for two hours or more, which are fills: in RR-1 the flight series holds 2,646 ppm for 153 h from the day of launch. Each mission was restricted to its habitation period on the ISS, chosen from the app’s milestones (`data/curated/eda_mission_windows.csv`). Flight–ground differences use hourly means, after shifting the ground series by the lag (within ± 7 days) that minimises the median absolute difference in CO₂, or in temperature where CO₂ is absent.

Cabin conditions for the models. The exterior of the cabin-ventilated hardware (mouse-cage supply air, fly-box vents) is the median of the quality-controlled RR-1 flight series over the habitation period: 3,371 ppm CO₂, 22.60 °C and 43% relative humidity (`hardware/_iss_cabin.yaml`, `results/tables/T11a_cabin_rr1.csv`). The ranges that Choi et al. [3] report for the U.S. Lab cabin during RR-1 equal, to the last digit, the extremes of the app’s *ground-control* series over the same dates (CO₂ 788–4,690 ppm); the flight series spans 1,862–4,667 ppm. We use the flight series, because its minimum is consistent with cabin CO₂ whereas the ground series reads room-air values before launch; which label is correct awaits confirmation by the data provider. Because CO₂ and water vapour are passive scalars in the models, this choice shifts absolute concentrations but not the specimen-zone excesses.

Data issues. RR-9 telemetry is dated a year after its own dose record and milestones; its flight–ground differences share one clock and are kept. RR-18 has flight series only, with relative humidity up to 125.80% (removed). The plant missions (VEG-01, APEX-03, APEX-04) return no values through the API, and some rodent missions return no rows.

Table S6: ISS cabin minus ground-control environment in the OSDR Environmental Data App: median and interquartile range of hourly flight – ground differences after aligning the ground series by its best lag, and the mean daily absorbed dose over the window. – : not available (RR-9: EDA dates its telemetry a year after its dose record, so the two do not overlap).

Mission	Habitation window	Lag (h)	ΔT (°C)	ΔRH (%)	ΔCO_2 (ppm)	Dose (mGy d ⁻¹)
RR-1	2014-09-25 – 2014-10-25	0	0.00 [-0.02, 0.02]	0.0 [-0.2, 0.2]	9 [0, 17]	0.20
RR-3	2016-04-12 – 2016-05-20	0	-2.00 [-2.02, -1.97]	-0.1 [-0.5, 0.2]	6 [-1, 15]	0.23
RR-5	2017-06-07 – 2017-08-02	0	0.00 [-0.02, 0.03]	0.0 [-0.2, 0.2]	-2 [-11, 3]	–
RR-6	2017-12-19 – 2018-02-06	0	0.00 [-0.02, 0.02]	0.0 [-0.2, 0.2]	-1 [-7, 4]	0.28
RR-7	2018-07-04 – 2018-09-13	0	0.00 [-0.02, 0.02]	0.3 [0.0, 0.7]	-9 [-18, -3]	0.29
RR-9	2018-08-18 – 2018-09-16	0	0.00 [-0.03, 0.02]	0.0 [-0.2, 0.2]	-2 [-8, 3]	–
RR-12	2019-04-21 – 2019-05-22	0	0.00 [-0.01, 0.02]	0.0 [-0.2, 0.1]	-44 [-50, -38]	0.36
RR-19	2019-12-10 – 2020-01-08	0	0.00 [-0.07, 0.04]	0.0 [-0.6, 0.7]	-67 [-163, -34]	0.37
RR-10	2020-12-09 – 2021-01-03	0	0.00 [0.00, 0.01]	0.0 [0.0, 0.0]	-38 [-74, -17]	–
RR-23	2020-12-09 – 2021-01-15	-1	0.00 [-0.08, 0.09]	1.0 [0.1, 1.9]	33 [-1, 118]	0.35
RR-18	2021-12-23 – 2022-01-24	–	–	–	–	–
RR-25	2022-11-29 – 2023-01-25	0	0.08 [0.03, 0.13]	–	–	–
RR-20	2023-11-10 – 2023-12-22	0	-0.10 [-0.23, -0.02]	–	–	–
RR-28	2024-03-24 – 2024-04-30	0	-0.06 [-0.09, -0.03]	–	–	–

ISS cabin (flight) minus ground control, hourly means during habitation

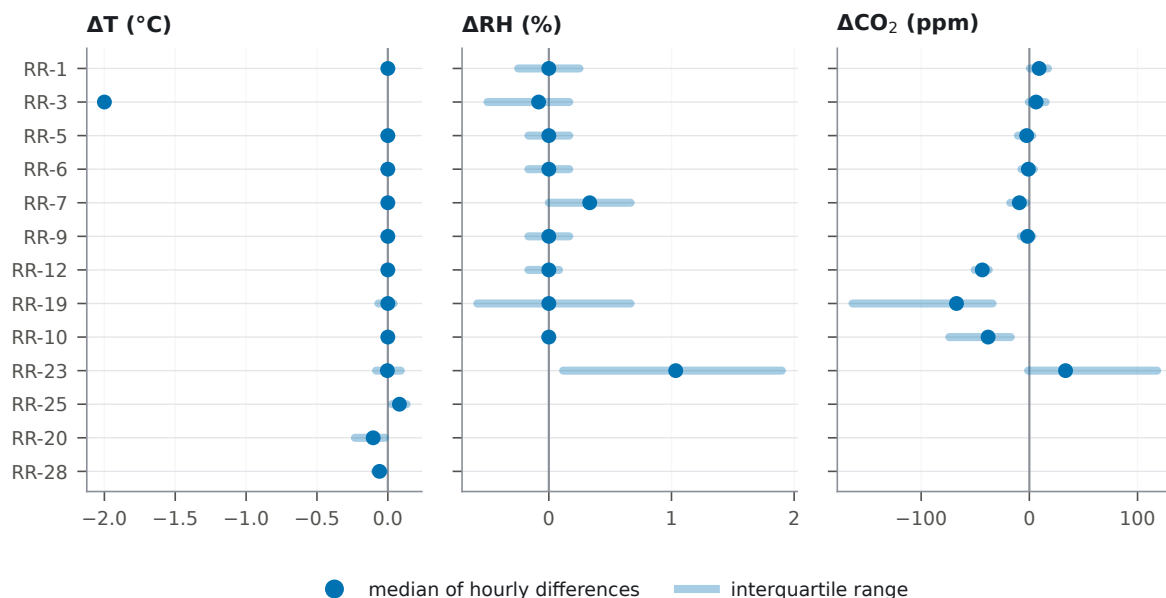


Figure S15: Flight (ISS cabin) minus ground-control environment for each Rodent Research mission with both series, from the OSDR Environmental Data App: median and interquartile range of hourly differences during habitation. Missions without relative humidity or CO_2 series show temperature only.

References

- [1] Ismail B. Celik, Urmila Ghia, Patrick J. Roache, and Christopher J. Freitas. Procedure for estimation and reporting of uncertainty due to discretization in CFD applications. *Journal of Fluids Engineering*, 130:078001, 2008. doi: 10.1115/1.2960953.
- [2] NASA Open Science Data Repository. OSDR environmental data app (EDA). <https://visualization.osdr.nasa.gov/eda/>, 2026. API snapshot 2026-10-12.
- [3] Sungshin Y. Choi, Amanda Saravia-Butler, Yasaman Shirazi-Fard, Dennis Leveson-Gower, Louis S. Stodieck, Samuel M. Cadena, Janet Beegle, Stephanie Solis, April Ronca, and Ruth K. Globus. Validation of a new rodent experimental system to investigate consequences of long duration space habitation. *Scientific Reports*, 10:2336, 2020. doi: 10.1038/s41598-020-58898-4.