ValerieX (VXXX)

Volume IV — Experimental Protocol

Practical Test Manual: C-Family Validation, Geometry Discriminator, and Medium-Substitution Test

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Supporting deep-dive to the main manuscript

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Abstract

Volume IV is the experimental deep-dive companion to the main ValerieX manuscript. It converts the framework into practical laboratory protocols, defining how the C-family validation measurements should be performed, recorded, and judged. Each test must produce data that supports or challenges the geometry-dependent coupling structure of classical added-mass theory under the ValerieX organisation, with the conventional interpretation of classical fluid mechanics retained.

The C-family validation tests, in order of decisive power:

- Intermediate-density acceleration test (flagship discriminator).
- Sphere–cylinder–capsule geometry test (continuous-parameter discriminator).
- Constrained / supported / unconstrained regime-transition tests.
- Medium-substitution discriminator (density-contrast independence test).
- Exploratory torsion configuration (regime-classification investigation only; **not a C-family discriminator and not a competing prediction**).

Keywords: ValerieX, experimental protocol, C-family validation, intermediate-density discriminator, capsule discriminator, medium-substitution test, transient drag integration, Atwood number, participating medium load.

1 Purpose

This manual answers one question:

> *Can the C-family predictions of the geometry-aware general law $a = g(\rho_o - \rho_m)/(\rho_o + C\rho_m)$ be measured cleanly enough to validate the geometry-dependent coupling structure across C-family branches?*

The experiments must therefore be: simple enough to reproduce on commodity equipment; quantitative enough to compare; controlled enough to avoid mixed-regime confusion; honest enough to register a failure of the C-family validation programme if the data disagree.

2 Core Prediction Being Tested

ValerieX uses the geometry-aware acceleration law

$$a = \frac{g(\rho_\mathrm{o} - \rho_\mathrm{m})}{\rho_\mathrm{o} + C\rho_\mathrm{m}}, \qquad \frac{a}{g} = \frac{r-1}{r+C}, \qquad r = \rho_\mathrm{o}/\rho_\mathrm{m}.$$

All members of the C-family converge at equilibrium ($r = 1$) and in the vacuum limit ($r \to \infty$). Therefore, only intermediate-density unconstrained measurements provide meaningful validation across C-family branches.

Case	C	**Prediction**
Strict object-normalised limit (no medium participation)	0	$a/g = (r-1)/r$
Sphere (inviscid potential flow)	0.5	$a/g = (r-1)/(r+0.5)$
Cylinder $\perp$-axis / ValerieX bounded branch	1	$a/g = (r-1)/(r+1)$

Within the framework being tested, a clean separation is maintained between drive (density-state contrast), coupling (the participation coefficient C), and resistance (viscosity / drag). C is not a universal constant; real systems express the geometry-dependent C-family. The $C = 1$ branch is the symmetry-consistent bounded member on which Valerie's Law is recovered and is the classical cylinder-$\perp$-axis added-mass coefficient (Brennen 1982; Lamb 1932). In the vacuum limit $\rho_\mathrm{m} \to 0$, the participating medium load $C\rho_\mathrm{m}$ vanishes for any value of C, viscous resistance also vanishes, geometry has no effect on realised acceleration, and all positive-density bodies share the same environmental ceiling g.

3 General Laboratory Rules

3.1 Regime Must Be Identified First

Regime	**Condition**	**Measurement type**
Constrained	Blocked by rigid surface	Surface force / scale reading
Supported	Held from above, pathway open below	Tension / torsion / suspension signal
Unconstrained	Pathway open, no support	Acceleration / motion

The same density contrast can produce different measured signatures depending on whether motion is blocked, held, or free. Every experiment must state its regime before interpretation.

3.2 Measure Early-Time Acceleration

For acceleration tests, measure the first clean motion interval before drag closure dominates. Recommended window: 0–100 ms. Use a shorter window if the object accelerates rapidly or if drag becomes visible early.

3.3 Record All Raw Data

Every experiment should record: ρ_o, ρ_m, object volume V, shape, orientation, temperature, video frame rate, initial position, motion-tracking data, calculated acceleration, predicted acceleration, difference / error.

3.4 Practical Specifications

Drag-timescale estimation (Reynolds-based). For a body of characteristic length L moving at velocity v in a medium of density ρ_m and dynamic viscosity η, the Reynolds number is $\mathrm{Re} = \rho_\mathrm{m} v L/\eta$. The velocity at which drag equals 10% of the net driving force is

$$v_{10} \approx \sqrt{\frac{0.2\,|\rho_\mathrm{o} - \rho_\mathrm{m}|gL}{C_d \rho_\mathrm{m}}},$$

with $C_d \approx 0.4$–1 in the bluff-body regime; $C_d = 24/\mathrm{Re}$ in the Stokes regime. For a 4-cm sphere in water at $\rho_\mathrm{o} = 2\rho_\mathrm{m}$, $v_{10} \approx 0.2$–0.3 m s^{-1} and $\mathrm{Re} \approx 8\,000$–$12\,000$. The early-time fitting window must end before v reaches v_{10}. Trim the fitting window to $t \le t_{10}/2$ to keep the drag correction below $\sim 5\%$.

Early-time measurement window. For centimetre-scale bodies in water at $\rho_\mathrm{o} = 2\rho_\mathrm{m}$ the resulting window is approximately 20–40 ms. Within this window, fit position to $y(t) = y_0 + v_0 t + \frac{1}{2}at^2$ and extract a from the quadratic coefficient. Frame rate ≥ 240 fps gives 5–10 frames within a 20–40 ms window; 1 000 fps gives 20–40 frames and materially improves the uncertainty on a. Refit a using two or three sub-windows within the chosen range; confirm the fitted a varies by less than the stated experimental uncertainty across them.

Release mechanism. Release fully submerged (eliminates surface-tension transients and air-cavity entrainment); use a matched-density holder that opens cleanly without imparting angular momentum (electromagnetic gate or split sleeve held by pin pulled vertically clear; squeezing or rotating mechanisms are not acceptable); ensure the body is at rest (settle ≥ 60 s after disturbance); place the body ≥ 5 body diameters from any wall. Discard the first 5–20 ms after release from the fit. Verify with high-frame-rate playback that the body is moving cleanly without rotation before the fit window begins.

Density-measurement tolerances. Target $\pm 1\%$ on each of ρ_o and ρ_m, propagated as combined $\pm 2\%$ on r and $\pm 1\%$ on the predicted a. Measure ρ_m by hydrometer or mass-balance of a calibrated displacement vessel ($\pm 0.5\%$); measure ρ_o per body by mass and water-displacement volume ($\pm 1\%$). Record temperature with each density measurement (water density varies $\sim 0.05\%$ per °C). Reject any body whose individually measured density deviates from the target by more than 1.5%.

Imaging resolution at $r = 2$. The two discrimination targets at $r = 2$ differ by an order of magnitude in their imaging-precision requirements. The $C = 0$ vs $C = 1$ separation is approximately $0.167\,g$ ($\sim 1.63\,\mathrm{m\,s^{-2}}$): at the upper edge of a 30 ms fitting window this corresponds to a position difference of ~ 0.7 mm between the two predictions. This is comfortably resolvable on commodity 240 fps imaging.

The $C = 0.5$ vs $C = 1$ separation is approximately $0.067\,g$ ($\sim 0.65\,\mathrm{m\,s^{-2}}$). At $t = 30$ ms the position difference between sphere ($C = 0.5$) and cylinder $\perp$-axis ($C = 1$) predictions at $r = 2$

is only ~ 0.3 mm. Resolving this cleanly requires frame rate ≥ 1000 fps; calibration ≤ 0.2 mm per pixel; rigid camera mounting; sub-pixel centroid tracking; and confirmed sub-millimetre repeatability of the release mechanism before the trial set begins.

4 Experiment 1 — Intermediate-Density Flagship Test

4.1 Purpose

Provides a direct and high-sensitivity validation measurement across the C-family. It distinguishes between the $C = 0$ strict object-normalised limit, the $C = 0.5$ sphere branch, and the $C = 1$ cylinder $\perp$-axis branch, validating the geometry-dependent coupling structure.

At $\rho_o = 2\rho_m$ (so $r = 2$), the predictions are:

Model	C	**Prediction**
Classical (no medium participation)	0	$a = g/2 \approx 4.903\,\mathrm{m\,s^{-2}}$
Sphere (potential flow)	0.5	$a = 2g/5 \approx 3.923\,\mathrm{m\,s^{-2}}$
ValerieX (cylinder $\perp$ axis)	1	$a = g/3 \approx 3.269\,\mathrm{m\,s^{-2}}$

4.2 Equipment

Transparent vertical test tank; fluid of known density; test object with $\rho_o \approx 2\rho_m$; high-speed camera (slow-motion phone camera acceptable for the $C = 0$ vs $C = 1$ discriminator); ruler or calibration grid behind tank; thermometer; digital scales; vernier calipers; tracking software or frame-by-frame video analysis.

4.3 Procedure

1. Measure fluid density.
2. Measure object mass and volume; calculate object density.
3. Place calibration scale behind the tank.
4. Release the object without push or spin.
5. Record motion at high frame rate.
6. Track vertical position frame by frame.
7. Fit early-time position to $y(t) = y_0 + v_0 t + \frac{1}{2}at^2$.
8. Extract acceleration a.
9. Compare with $a = g/2$ (classical $C = 0$), $a = 2g/5$ (sphere $C = 0.5$), and $a = g/3$ (ValerieX $C = 1$).

4.4 Pass/Fail Interpretation

Result	Interpretation
$a \approx g/3$	C-family validation: matches $C = 1$ (cylinder $\perp$ axis) branch
$a \approx 2g/5$	C-family validation: matches $C = 0.5$ (sphere) branch
$a \approx g/2$	C-family validation: matches $C = 0$ (no medium participation) branch — challenges added-mass coupling
intermediate values	Indicates intermediate participation coefficient
inconsistent / noisy	Repeat with improved release, tracking, and controls

Vacuum-limit control note. Free-fall comparisons performed under near-vacuum conditions (drop tubes; parabolic-flight microgravity; Apollo 15 reference) are *not* discriminators between C-family branches. As $\rho_{\rm m} \to 0$ all branches collapse to $a = g$. Vacuum tests serve as positive controls for the apparatus and the saturation limit, but cannot discriminate between competing predictions.

5 Experiment 2 — Shape-Controlled C-Family Test

5.1 Purpose

Tests the geometry-dependent C-family structure: whether C varies systematically with object shape, taking the classical values $C \approx 0.5$ for spheres and $C \approx 1$ for cylinders $\perp$-axis (Brennen 1982; Lamb 1932), and intermediate values for capsules.

5.2 Test Shapes

Use three objects with matched density and volume as closely as possible:

Object	Expected C
Sphere	0.5
Hemisphere-ended capsule	0.6 – 0.9 (varies with L/D)
Cylinder moving perpendicular to axis	1.0

5.3 Capsule as Continuous Discriminator

Unlike the sphere ($C \approx 0.5$) and cylinder ($C \approx 1.0$), the capsule provides a continuous transition between these limits. By varying capsule length relative to diameter, the effective participation coefficient C is expected to vary smoothly: short capsule $\to C \approx 0.6$; medium capsule $\to C \approx 0.75$; long capsule $\to C \to 1.0$. This allows the experiment to test whether acceleration varies continuously with geometry, as predicted by the C-family formulation. The Volume III §6 $C(L/D)$ table and figure give the quantitative target.

5.4 Procedure

1. Prepare all three objects with equal or near-equal density.

2. Measure mass, volume, and dimensions.
3. Confirm the same medium density.
4. Release each object from the same position and orientation.
5. Record at least 10 repeats per shape.
6. Track early-time motion.
7. Calculate acceleration for each object.
8. Fit best C value using $C = [g(r-1)/a] - r$ where a is the measured acceleration.

5.5 Falsification Conditions

The C-family validation programme returns a failure signal — challenging both ValerieX and the classical added-mass theory it is consistent with — if:

- sphere, capsule, and cylinder give no measurable separation;
- cylinder does not approach the $C = 1$ branch;
- sphere does not separate toward the $C = 0.5$ branch;
- the measured order is repeatedly opposite to prediction.

6 Experiment 3 — Co-Free-Fall Zero-Reading Test

6.1 Purpose

Demonstrates regime transition. A scale–object system dropped together should lose constrained-regime scale reading because the system moves into the unconstrained regime.

6.2 Procedure

1. Place test mass on the scale; record normal reading at rest.
2. Place scale and mass inside a protective drop box.
3. Start video recording.
4. Drop the box safely over a short distance.
5. Record scale reading during fall.
6. Compare before, during, and after drop.

6.3 Expected Result

Phase	Regime	Expected reading
Rest on table	Constrained	Normal scale reading
During free fall	Unconstrained	Zero or near-zero
After landing	Constrained	Reading returns / spikes

ValerieX interpretation: the object has not lost density contrast. The regime has changed. The same available motion is no longer expressed as constrained weight because the pathway is open.

7 Experiment 4 — Surface vs Suspension Test

7.1 Purpose

Separates constrained and supported regimes. Tests whether the same object should be interpreted differently when resting on a surface versus hanging from above.

7.2 Procedure

1. Place the object on a digital scale; record surface-supported reading.
2. Hang the same object from a spring scale; ensure clear air gap beneath.
3. Record tension reading.
4. Compare numerical similarity and regime difference.

7.3 Expected Result

The numerical readings may be similar, but the regime classification differs:

Setup	Regime	ValerieX reading
Object on scale	Constrained	Realised weight
Object hanging	Supported	Transmitted force of density / tension

This experiment is mainly conceptual and classificatory, not a decisive numerical discriminator by itself.

8 Experiment 5 — Accelerating-Frame Transition Test

8.1 Purpose

Tracks continuous movement from constrained to partially unconstrained behaviour. The expected observation is that scale reading decreases as the system approaches free fall.

8.2 Procedure

1. Record scale reading at rest.
2. Move the support downward smoothly (lift, descending platform, controlled drop rig).
3. Record scale reading during downward acceleration.
4. Compare reading against platform acceleration.
5. Repeat with different downward acceleration profiles.

As downward acceleration increases, scale reading decreases. In classical terms, this is effective weight reduction. In ValerieX terms, this is reduced constrained expression because pathway availability increases.

9 Experiment 6 — Exploratory Torsion Configuration

Status: Regime-Classification Investigation Only

This is not a C-family discriminator and not a falsifiable competing prediction. Under the regime classification of Volume II, suspended torsion-balance configurations occupy the supported regime — a structural classification that follows from the operational criterion. **No quantitative density-state competing prediction for the magnitude or scaling of the observed Cavendish torque is asserted in this volume or anywhere in the ValerieX programme.**

In the conventional interpretation, the torsion signal is attributed to mass-to-mass gravitational attraction and is expected to remain invariant under changes to vertical support conditions, provided geometry is preserved. The cross-method consistency of the Newtonian gravitational constant G across torsion-balance, free-fall, atom-interferometry, lunar laser ranging, satellite-orbit, and Earth-tide determinations (Gillies 1997, and subsequent precision-G literature) is acknowledged as genuine empirical confirmation of this conventional interpretation, and is not contested.

The configuration variations described below are recorded as variations of interest that would accompany any future quantitative density-state development of the supported-regime torque, not as parts of a falsifiable test programme.

9.1 Design Caveats

- The constrained-regime configuration variant is structurally difficult to realise without losing the torsion measurement itself: if the test masses are supported from below by a rigid platform that takes their weight, the torsion fibre no longer carries net vertical load and the angular degree of freedom is not equivalent to the standard configuration. Any constrained-regime variant must therefore preserve the torsion readout structurally, and the result will not be directly comparable to standard Cavendish data.
- Cross-method consistency of measured G across torsion-balance, free-fall, atom-interferometry, lunar laser ranging, satellite-orbit, and Earth-tide determinations makes any large regime-dependent variation unlikely on prior empirical grounds, regardless of the exploratory regime classification recorded here.

10 Experiment 7 — Medium-Substitution Discriminator

10.1 Purpose

Examines whether the early-time acceleration in the unconstrained regime is set by the density-state contrast $(\rho_o - \rho_m)$ alone, or whether non-density properties of the medium (viscosity, compressibility, dielectric constant, molecular structure) contribute an additional, independently observable term.

At fixed $r = 2$ ($\rho_o = 2\rho_m$) and fixed geometry (cylinder $\perp$-axis, $C = 1$), the C-family early-time prediction depends only on the density ratio r and the geometry coefficient C, so it is invariant under any change of medium that holds ρ_m fixed. This experiment is not intended to distinguish between all formulations of fluid motion. It examines whether the early-time prediction remains invariant under controlled medium substitution.

10.2 Equipment

Transparent vertical test tank (or two identical tanks) of sufficient height and lateral standoff (≥ 5 body diameters); two media of identical density $\rho_\mathrm{m} \approx 1000\,\mathrm{kg\,m^{-3}}$ but different composition (Medium A: pure water; Medium B: aqueous glycerol/NaCl mixture tuned to exact same ρ_m within $\pm 0.1\%$); test object: smooth cylinder $\rho_\mathrm{o} \approx 2000\,\mathrm{kg\,m^{-3}}$ matched to the flagship test; high-speed camera (≥ 240 fps, ideally 1 000 fps); thermometer / temperature-controlled environment ($\pm 0.5°$C); density-measurement tools; matched-density release mechanism.

10.3 Procedure

1. Measure and record temperature and exact density ρ_m for Medium A and Medium B; adjust Medium B until $|\rho_{mA} - \rho_{mB}| \leq 0.1\%$.
2. Confirm object density ρ_o (same body for both media).
3. Fill tank with Medium A; allow full thermal and flow equilibration (≥ 60 s after disturbance).
4. Release the cylinder fully submerged, perpendicular to its axis, using the matched-density release mechanism.
5. Record motion at high frame rate; capture full early-time window.
6. Repeat 10–15 times in Medium A.
7. Thoroughly clean and dry the tank and object.
8. Repeat steps 3–6 in Medium B (same object, same orientation, same release depth and standoff).
9. Track vertical position frame-by-frame in both datasets.
10. Fit early-time position to $y(t) = y_0 + v_0 t + \frac{1}{2}at^2$ over the drag-free window $t \leq t_{10}/2$ (compute t_{10} separately for each medium using its viscosity).

10.4 Core Prediction

For $r = 2$ and cylinder $\perp$-axis ($C = 1$): $a = g/3 \approx 3.269\,\mathrm{m\,s^{-2}}$ (identical in both media). The density-contrast picture predicts no measurable difference in fitted early-time acceleration between Medium A and Medium B, because the drive term depends only on the density ratio r and the coupling term C depends only on geometry.

10.5 Pass/Fail Interpretation

Result	**Interpretation**	**Framework impact**
Measured a identical within $\pm 1\%$ in both media (difference $\leq 0.05\,\mathrm{m\,s^{-2}}$)	Supports the C-family early-time prediction	Confirms density-contrast sufficiency
Systematic difference correlated with non-density medium properties	Evidence for separate gravity/buoyancy contributions beyond density contrast	Challenges density-contrast sufficiency

Result	Interpretation	Framework impact
Noisy / inconsistent	Repeat with tighter density match	Inconclusive; refine protocol

This test is designed as a robustness and isolation check on the early-time prediction under matched-density conditions. Any observed deviation should first be interpreted in terms of experimental uncertainty, medium-property influence, or incomplete early-time isolation before being attributed to theoretical failure.

11 Full Transient Drag Integration

This section extends the early-time C-family acceleration law into a full time-dependent motion model. It does not replace the C-family law. It shows how the initial acceleration predicted by the framework evolves under viscous and inertial drag until terminal behaviour is reached. The early-time window used by Experiments 1, 2, and 7 lies before drag closure and is therefore unaffected by the integration developed here.

11.1 Governing Equations

Effective participating inertia: $m_{\text{eff}} = (\rho_{\text{o}} + C\rho_{\text{m}})V$.
Drive term: $F_{\text{drive}} = (\rho_{\text{o}} - \rho_{\text{m}})Vg$.
Resistance term, combining Stokes (linear) and quadratic (bluff-body) drag:

$$D(v) \;=\; 6\pi\mu R v + \tfrac{1}{2}\rho_{\text{m}} C_d A|v|v.$$

The full transient system:

$$\frac{dz}{dt} = v, \qquad \frac{dv}{dt} = \frac{(\rho_{\text{o}} - \rho_{\text{m}})Vg - 6\pi\mu R v - \frac{1}{2}\rho_{\text{m}} C_d A|v|v}{(\rho_{\text{o}} + C\rho_{\text{m}})V}.$$

11.2 Continuity with the C-Family

At release $v = 0$, both drag terms vanish identically and the right-hand side reduces to $a(0^+) = (\rho_{\text{o}} - \rho_{\text{m}})g/(\rho_{\text{o}} + C\rho_{\text{m}})$, or $a(0^+)/g = (r-1)/(r+C)$. This recovers the early-time C-family acceleration law of Volume I exactly. The transient-drag extension is therefore continuous with the framework: the early-time discriminator remains valid because the C-family acceleration is measured before drag closure dominates, and the later-time integration then predicts the full curve from initial acceleration through drag-limited motion toward terminal velocity. Volume III §9.3 provides the reference Python implementation.

12 Data Recording Templates

Acceleration Test Sheet

Trial | Shape | ρ_{o} | ρ_{m} | r | C assumed | Predicted a | Measured a | Error %

Geometry Test Sheet

Trial | Shape | Mass | Volume | Density | Orientation | Measured a | Fitted C

Regime Test Sheet

Trial | Object | Regime | Support condition | Reading | Notes

Medium-Substitution Test Sheet

Trial | Medium | ρ_o | ρ_m | r | Temp | Frame rate | Fit window (ms) | Measured a | Predicted a | Error % | Notes

13 Minimum Evidence Standard

For a result to count as meaningful:

1. At least 10 repeats per condition.
2. Density measurements recorded.
3. Temperature recorded.
4. Raw video retained.
5. Early-time fitting method stated.
6. Drag-dominated late-time data must not be used as initial acceleration.
7. Regime declared before interpretation.
8. Error bars shown.
9. Null or failed results included.
10. Mean, standard deviation, and confidence intervals reported; any systematic drift between trials investigated and documented.

14 Recommended Build Order

Stage 1 — Easy demonstrations. Surface vs suspension; co-free-fall scale drop; accelerating-frame transition. Purpose: demonstrate regime logic.

Stage 2 — Core discriminator. Intermediate-density $r = 2$ test. Purpose: test the $C = 1$ bounded branch against the $C = 0$ object-normalised limit.

Stage 3 — Geometry discriminator. Sphere vs capsule vs cylinder. Purpose: test C-family prediction across the continuous geometry spectrum.

Stage 4 — Density-contrast independence. Medium-substitution test (water vs density-matched alternative medium, same $r = 2$ cylinder). Purpose: test whether early-time acceleration depends only on density contrast, or also on non-density medium properties.

Stage 5 — Exploratory torsion (optional). Supported vs constrained torsion comparison. Purpose: exploratory regime-classification investigation only. **No quantitative density-state competing prediction is asserted**; not part of the C-family validation programme.

15 Pass/Fail Summary

Test	C-family validation supports the framework if...	C-family validation challenges the framework if...
$r = 2$ discriminator	Measured acceleration approaches $g/3$ ($C = 1$) for cylinder $\perp$-axis bodies; tracks predicted C-family branch for each geometry	Repeatedly approaches $g/2$ ($C = 0$) for cylinder $\perp$-axis bodies
Sphere / cylinder / capsule	Fitted C separates by shape; capsule traces continuous interpolation $0.5 < C < 1$	No repeatable shape dependence
Co-free-fall	Scale reading collapses during free fall	Scale reading remains unchanged
Surface / suspension	Same χ gives different regime signature	Regime has no measurable relevance
Torsion (exploratory)	**No falsifiable density-state competing prediction is asserted**	Configuration is exploratory; cross-method G consistency acknowledged as confirming the conventional interpretation
Medium-substitution	Same a (within $\pm 1\%$, $\leq 0.05\,\mathrm{m\,s^{-2}}$) measured in two media of identical ρ_m but different composition	Systematic, repeatable difference correlated with non-density medium properties

16 Closing Statement

Volume IV completes the practical testing layer of the ValerieX programme. Across all four supporting volumes the framework is organised by the same drive $\rightarrow$ coupling $\rightarrow$ resistance $\rightarrow$ realisation structure: drive (density-state contrast, expressed through χ); early-time coupling (geometry through participation coefficient C); resistance (viscosity / drag); later motion (drag-limited evolution toward terminal state).

The validation structure is finite-medium: vacuum tests serve as positive controls for the apparatus and the saturation limit, while the C-family branches are distinguished only by intermediate-density and shape-controlled measurements. The geometry-aware general law is a member of the recognised added-mass family of classical fluid mechanics; the experimental programme validates classical added-mass theory under the ValerieX organisation rather than positioning ValerieX as an alternative to it.

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