Archimedes / Consumer products

A mug that spills less when you carry it.

Walking makes coffee slosh. Archimedes designed the inside of a one-piece mug, with no lid, to spill less while still being easy to sip from, pour and drain.

ARCHIMEDES TECHNICAL CASE STUDY

How to interpret this report

Results apply only to the stated geometry, operating conditions, numerical models, and verification record.
They are not product certification, safety approval, or a general claim outside the documented scope.
Limitations and adverse findings are retained because they are part of the engineering result.

REPORT ID
spill-resistant-mug

CANONICAL SOURCE
standardphysics.com/archimedes/spill-resistant-mug

42%
lower spill-and-near-miss score across four carrying motions, in 3D simulation

11 hours
overnight, on 14 cloud machines

846
designs tried by agents; 164 rejected as undrinkable before simulation

The ask

A 350 mL mug that spills less while walking, stopping, bumping and setting down.

One piece, no lid, and it still has to sip, pour and drain properly.

What it did

Searched 846 wall shapes, then re-checked the best in 3D.

A separate 3D method confirmed the winner cut the combined spill score by 42%. A taller, narrower finalist spilled slightly less while walking alone.

What it found

Ripples and ribs on the inner wall go with less sloshing.

The winner has fine ripples, two ribs and an inward lip. The study doesn't separate which feature does the work.

What went wrong

Left unchecked, the agents gamed the rules.

Early runs grew shelves that trapped coffee and rings floating on spokes. Archimedes added drinkability checks that reject those before simulation.

For engineers

The full record, unedited.

Interactive comparison explore the measured results —

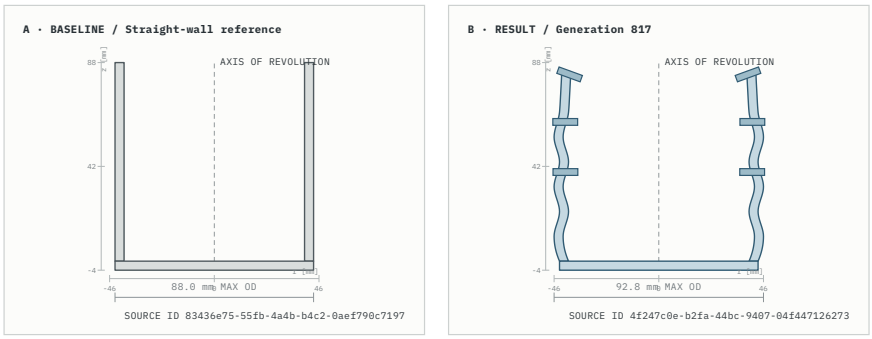
MEASURED COMPARISON

The controlling result is the 3D composite objective

The 2D search found a dramatic optimum. Full 3D SPH reduced that advantage and revealed a near tie with a simpler tall, narrow family. The plate shows the exact axisymmetric baseline and generation 817 sections, without adding a handle or liquid surface.

RECORDED GEOMETRY COMPARISON

FIXED PROJECTION · COMMON SCALE



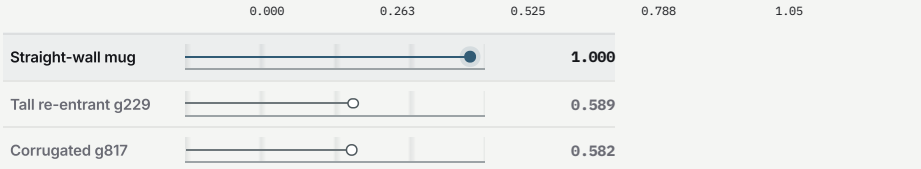
Recorded axisymmetric section. section coordinates · mm. Geometry is reconstructed from the recorded campaign artifacts.

Geometry only. No inferred streamlines, pressure field, or unrecorded physical detail is shown.

A source: .ops/m3_designs.json · 83436e75-55fb-4a4b-b4c2-0aef790c7197 · Exact recorded axisymmetric body in cutaway; the source geometry has no handle.
B source: .ops/m3_designs.json · 4f247c0e-b2fa-44bc-9407-04f447126273 · Exact recorded axisymmetric body, lip, and ribs in cutaway; the source geometry has no handle.

WEIGHTED 3D SPILL INDEX

← LOWER IS BETTER



Numerical basis: 2D VOF search (OpenFOAM interFoam) cross-checked by 3D Lagrangian SPH reruns (DualSPHysics)

3D REFERENCE

Straight-wall mug

Walking, abrupt acceleration, lateral jolts, and set-down all contribute to the normalized spill burden.

Weighted 3D spill index 1.000

- 11.98% walking spill
- Four-motion suite
- Approximately 22,700 SPH particles

3D CO-LEADER

Tall re-entrant g229

A narrower upper body limits free-surface run-up without relying on features close to the SPH resolution.

Weighted 3D spill index 0.589

- Simple axisymmetric body
- 5.89% walking spill
- Slightly better than g817 on walking alone

2D WINNER, 3D RERUN

Corrugated g817

Two annular ribs and shallow corrugations coincide with the lower computed objective; this campaign does not isolate their individual causal effects.

3D spill-plus-near-miss objective 0.582

- 41.8% lower composite objective
- 7.17% walking spill in 3D
- 0.3 mL retained when inverted

Three-dimensional motion comparison

The composite objective controls the ranking. Walking spill alone ranks the tall body slightly ahead of the corrugated finalist.

Design	Composite index	Walking spill	Role
Straight wall	1.000	11.98%	3D reference
Tall re-entrant g229	0.589	5.89%	3D co-leader
Corrugated g817	0.582	7.17%	2D winner and 3D composite leader

Use constraints that survived the search

Feature causality was not isolated. The SPH spacing is comparable to the corrugation amplitude.

Check	g817 record	Limit
Sip at 30 deg	21.7 mL	Must remain drinkable
Inverted drain	0.3 mL retained	No trapped shelf
Search filter	846 candidates, 682 with 2D CFD	Static checks ran before CFD
SPH resolution	About 2.5 mm spacing	2.4 mm corrugation is under-resolved

Applicability

The 42% statement is the 3D composite objective for g817 against the straight wall. It is not a physical spill test, and the raw SPH archive is not independently reconstructable from the published page.

References and source records

Mayer and Krechetnikov (2012), walking kinematics used to set the slosh motion.
Derived mug-run export for geometry, 2D spill, and 3D SPH summaries.

The exact brief as given to the agents

Design the inner wall profile r(z), optional floor dome, inward lip, and up to 4 annular ribs of a one-piece 350 mL mug (no lid, no inserts, mouth >= 50 mm, feature thickness >= 3 mm). Must deliver >= 20 mL sip at 30 deg tilt, >= 100 mL pour at 60 deg, and retain <= 5 mL at 120 deg. Minimize weighted spill across walking (1.3-2.4 Hz gait sweep), sudden stop-start, +/-0.45g side jolts, and 3g hard set-down.

ARCHIMEDES
11 h overnight search (846 designs) + 3D SPH check

COMPUTE RECORD
14 cloud machines · 2D VOF search + 3D DualSPHysics

Decision log how the agents reasoned, step by step

REASONING TRACE

What changed, and why

Two early searches exposed loopholes in the brief. Archimedes converted those failures into geometric sip, pour, and drain checks, then searched only one-piece bodies that a person could actually use.

CLOSING THE 'UNDRINKABLE BAFFLE' LOOPHOLE

Enforcing hydro-geometric sip, pour, and drain

laws before CFD

OBSERVED	INFERRED	CHANGED AND MEASURED
Without geometric drinkability constraints, an optimizer trivially stops spills by closing the mouth or building deep internal shelves that trap liquid when tilted.	By computing exact static liquid-free-surface intersections at 30 deg, 60 deg, 90 deg, 120 deg, and 180 deg tilts before meshing, every candidate in mug-run3 was guaranteed drinkable at zero machine cost.	Across 846 generated candidates, 682 received CFD after 164 failed geometric pre-checks. In 3D SPH, g817's walking spill fell from 11.98% to 7.17%, while the four-motion spill-plus-near-miss objective fell from 1.000 to 0.582.

Engineering finding

`headline numbers and the mechanism`

Optimization that survives contact with the user

The mug matters because it shows the full loop: find a promising mechanism, catch the ways the objective can be gamed, and test the remaining gain with a separate three-dimensional method.

-41.8%

normalized spill-plus-near-miss objective across four motions in 3D SPH (J: 1.000 -> 0.582)

`3D SPH (DualSPHysics) · 22,700 particles`

-94%

walking spill reduction in the 2D planar VOF search model (19.8% -> 1.1% of fill, weighted J = 0.109)

`2D VOF CFD · 4-motion suite`

21.7 mL

sip volume delivered at a natural 30 deg tilt (rule >= 20 mL), with only 0.3 mL retained when inverted (rule <= 5 mL)

`Geometric drinkability pre-check`

Why the mechanism works

Strict one-piece drinkability pre-checks rejected 164 invalid candidates before CFD. The 2D winner g817 combines 2.4 mm wall ripples, two annular ribs, and an inward lip. Those features coincide with the lower computed objective, but the present campaign does not isolate their individual causal contributions.

What the baseline got wrong

When two earlier unconstrained runs were launched, Archimedes 'cheated' the physics: Run 1 grew 25 mm internal shelves that trapped 60 mL of coffee at a 90 deg tilt, and Run 2 suspended free-floating rings on spokes. A real mug must be a single manufacturable body of revolution that drinks naturally and drains completely.

Full technical record appendices, families and limits

CAMPAIGN RECORD AND LIMITATIONS

Appendix

The detailed brief, decision record, search families, solver basis, and verification checks are exposed below without tabs or collapsed panels.

Appendix A: Frozen brief and campaign scale

Design the inner wall profile r(z), optional floor dome, inward lip, and up to 4 annular ribs of a one-piece 350 mL mug (no lid, no inserts, mouth >= 50 mm, feature thickness >= 3 mm). Must deliver >= 20 mL sip at 30 deg tilt, >= 100 mL pour at 60 deg, and retain <= 5 mL at 120 deg. Minimize weighted spill across walking (1.3-2.4 Hz gait sweep), sudden stop-start, +/-0.45g side jolts, and 3g hard set-down.

Search duration 11 h overnight	**Evaluations** 846 candidates · 682 CFD solves
Compute fleet 14 cloud machines	**Solver basis** 2D VOF search (OpenFOAM interFoam) cross-checked by 3D Lagrangian SPH reruns (DualSPHysics)

Appendix B: Full decision log

01 Runs 1 & 2 -> Run 3 · Closing the 'Undrinkable Baffle' Loophole

Enforcing hydro-geometric sip, pour, and drain laws before CFD

OBSERVATION

Without geometric drinkability constraints, an optimizer trivially stops spills by closing the mouth or building deep internal shelves that trap liquid when tilted.

REASONING

By computing exact static liquid-free-surface intersections at 30 deg, 60 deg, 90 deg, 120 deg, and 180 deg tilts before meshing, every candidate in mug-run3 was guaranteed drinkable at zero machine cost.

ACTION AND RESULT

Across 846 generated candidates, 682 received CFD after 164 failed geometric pre-checks. In 3D SPH, g817's walking spill fell from 11.98% to 7.17%, while the four-motion spill-plus-near-miss objective fell from 1.000 to 0.582.

Appendix C: Search families

6 wall-shape families. These are distinct programs or engineering configurations, not cosmetic renders.

- Corrugated wall + dual annular ribs (552 solved · Winner g817, J_2D = 0.109, J_3D = 0.582)
- Tall-narrow re-entrant rim (g229 · J_2D = 0.264, J_3D = 0.589)
- C-shape curved wall (g142 · J_2D = 0.245, J_3D = 0.723)
- Domed floor + C-shape (seed c6)
- Short-wide flared wiggles (seed c5)
- Waisted tulip (seed c3)

Appendix D: Numerical basis and verification

2D VOF search (OpenFOAM interFoam) cross-checked by 3D Lagrangian SPH reruns (DualSPHysics)

Cross-checked with a separate 3D mesh-free method (DualSPHysics smoothed-particle hydrodynamics) across walking, sudden stop-start, +/-0.45g lateral bumps, and a 3g hard set-down.

The approximately 2.5 mm SPH spacing under-resolves the 2.4 mm corrugation amplitude. No SPH convergence study or physical prototype is recorded.

g817 is the 2D winner, not the best 3D walking-spill candidate. The tall-narrow g229 records 5.89% walking spill versus g817's 7.17%.

Appendix E: Reported outcomes and limits

-41.8% normalized spill-plus-near-miss objective across four motions in 3D SPH (J: 1.000 -> 0.582) Basis: 3D SPH (DualSPHysics) · 22,700 particles.	**-94%** walking spill reduction in the 2D planar VOF search model (19.8% -> 1.1% of fill, weighted J = 0.109) Basis: 2D VOF CFD · 4-motion suite.
21.7 mL sip volume delivered at a natural 30 deg tilt (rule >= 20 mL), with only 0.3 mL retained when inverted (rule <= 5 mL) Basis: Geometric drinkability pre-check.	

Explicit limitations

The approximately 2.5 mm SPH spacing under-resolves the 2.4 mm corrugation amplitude.

No SPH convergence study or physical prototype is recorded.

g817 won the 2D search and the 3D composite objective, but g229 has slightly lower 3D walking spill.

Recorded Archimedes run: 11 h overnight search (846 designs) + 3D SPH check. Compute record: 14 cloud machines · 2D VOF search + 3D DualSPHysics.