Archimedes / Turbines

A turbine blade with 25.5% less loss than a classic benchmark.

The LS89 is a standard test blade that researchers use to compare designs. Archimedes reshaped it to waste less energy without turning the flow any less, and finished ahead of a published optimized design. These are 2D simulations of a slice of the blade, not a full engine.

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
`ls89-turbine-blade`

CANONICAL SOURCE
`standardphysics.com/archimedes/ls89-turbine-blade`

25.5%
less energy lost than the benchmark blade, in 2D simulation

2.2 points
ahead of a published optimized design for the same blade

1,333
designs tried on 18 cloud machines in 30 hours

The ask

Waste less energy as gas flows through a row of turbine blades.

Without turning the flow any less, or changing how much gas gets through.

What it did

Spaced the blades out and reshaped them to keep the shock weak.

It widened the spacing from 57.5 to 78 mm, re-angled the blades, and added a subtle contour on one surface.

What it found

Wider spacing helps, until a shock wave forms.

Spacing the blades further apart cuts friction, but loads each blade harder until a shock wave appears and undoes the gain.

Fine print

It caught a flaw in the published comparison.

The published design it compared against turned the flow slightly less than the rules allow, so Archimedes fixed that before comparing. Its own blade leads at most, but not all, off-design conditions.

For engineers

The full record, unedited.

Interactive comparison

explore the measured results

MEASURED COMPARISON

A constraint-compliant loss comparison

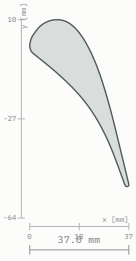
Every point is the reduction in mass-averaged entropy loss against the LS89 baseline under the same solver and turning constraint. The plate compares the exact recorded baseline and generation 502 sections.

RECORDED GEOMETRY COMPARISON

FIXED PROJECTION · COMMON SCALE

A · BASELINE / VKI LS89

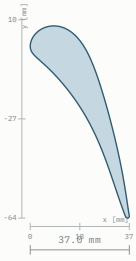
PITCH 57.5 mm



SOURCE ID 1ffd82dfb4aa53d4

B · RESULT / Generation 502

PITCH 78.0 mm



SOURCE ID f38f5076936fe4a8

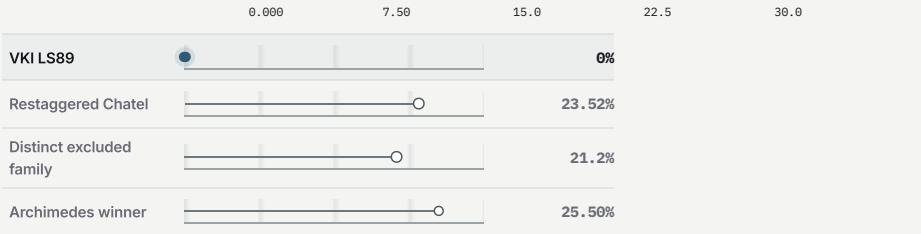
Recorded 2D midspan section. section coordinates · mm. Geometry is reconstructed from the recorded campaign artifacts.

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

A source: evolve/ls89/robustness_designs/baseline.py · 1ffd82dfb4aa53d4 · Exact recorded 2D section with arbitrary display-span extrusion; not a 3D vane.
B source: evolve/ls89/robustness_designs/open16_g502.py · f38f5076936fe4a8 · Exact recorded 2D section and pitch with arbitrary display-span extrusion; not a 3D vane.

ENTROPY LOSS REDUCTION

HIGHER IS BETTER →



Numerical basis: 2D midspan compressible RANS (HiSA HLLC, Spalart-Allmaras, y+ < 1) · 4-level grid study to 0.66M cells

EXPERIMENTAL BENCHMARK GEOMETRY

VKI LS89

The baseline vane provides the calibrated MUR47 flow field and the required exit turning floor.

Reference loss, 57.5 mm pitch

- Exit Mach 0.90
- Spalart-Allmaras, y+ below 1
- Mass flow and turning define the contract

PUBLISHED OPTIMUM MADE COMPLIANT

Restaggered Chatel

The published blade was restaggered after re-solving exposed a small exit-turning violation.

23.52% lower loss on the refined comparison

- Constraint-compliant reference
- Same frozen evaluator
- Used as the literature bar

INDEPENDENT GEOMETRY FAMILY

Distinct excluded family

A second campaign forbade Chatel-like shapes and still found a different low-loss solution.

21.2% lower loss

- Chatel-like geometry excluded
- 1.5x refined mesh
- Nearly twice the Torreguitart reduction

FOUR-GRID STUDIED

Archimedes winner

A 78 mm pitch and a localized suction-side contour control the rear shock while preserving the required turning.

25.50% lower loss on the 0.6M-cell mesh

- 78.0 mm pitch
- Peak suction Mach 1.14
- +0.021° turning margin

Constraint-compliant loss comparison

Mass-averaged entropy loss against the VKI LS89 baseline at exit isentropic Mach 0.90. Turning must remain at least the baseline value.

Geometry	Loss reduction	Pitch	Turning	Evidence level
VKI LS89	0%	57.5 mm	Reference floor	Calibrated baseline
Restaggered Chatel	23.52%	Published family	Made compliant	Refined comparison
Excluded family	21.2%	Independent family	Constraint retained	1.5x mesh
Generation 502	25.50%	78.0 mm	+0.021 deg margin	0.6M-cell mesh

Grid and off-design record

The formal convergence statement uses the recorded mesh triplet. The off-design map is incomplete where a point did not finish.

Study	Recorded result	Qualification
Mesh series	1x, 1.5x, and 2.25x plus the 0.6M-cell solve	2D midspan RANS only
Fine result	25.50% on 0.6M cells	Not an engine-efficiency number
Off-design	Eight completed winner points	The -2.5 deg incidence point did not complete
Adverse points	Trails the compliant Chatel reference	M2is 1.02 and -5 deg incidence

Applicability

This is a 2D midspan cascade result at one design point plus a partial off-design map. It does not establish 3D endwall, cooling, structural, or whole-engine performance.

References and source records

Arts, Lambert de Rouvroit, and Rutherford (1990), VKI Technical Note 174.
Chatel et al. (2018), digitized and re-solved on this evaluator.
Sanchez Torreguitart, Verstraete, and Mueller (2018).
Celik et al. (2008), procedure used for the grid-convergence statement.

The exact brief as given to the agents

Minimize mass-averaged entropy generation J across the VKI LS89 transonic turbine nozzle guide vane cascade at exit isentropic Mach 0.90 (inlet 159.6 kPa, 420 K, Spalart-Allmaras, y+ < 1). Exit flow angle must be >= baseline (74.81 deg) with mass flow per unit pitch matched within +/- 0.7%. Both airfoil surfaces, pitch, stagger, throat, and LE radius are free; axial chord and TE are fixed.

ARCHIMEDES
30 h across 2 campaigns (1,333 CFD solves)

COMPUTE RECORD
18 cloud machines · 4 grid levels to 0.66M cells

Decision log how the agents reasoned, step by step

REASONING TRACE

What changed, and why

The search did not simply smooth a blade. It widened the cascade, recovered turning through stagger and throat control, then shaped the suction-side pressure recovery so the shock penalty stayed smaller than the boundary-layer gain.

DIGITIZING & RE-SOLVING

PUBLISHED OPTIMA

Catching a 0.06 deg turning violation in the published

benchmark

1,333 COMPRESSIBLE RANS EVALUATIONS

Co-evolving 78 mm pitch with a 57%-chord shock-control contour

OBSERVED	INFERRED	CHANGED AND MEASURED
Opening pitch above 75 mm cuts boundary-layer wetted area by 16%, but pushes peak suction Mach above 1.18 with a strong trailing shock.	Adding a localized class-shape-function inflection near 57% chord controls the supersonic expansion and recovery while holding exit turning within 0.007-0.021 deg of the floor.	Reached -25.14% on the 1.5x mesh and -25.50% on the 2.25x (0.6M-cell) mesh (25.99 +/- 0.61% extrapolated), plus a second completely distinct family at -21.2% when all Chatel-like shapes were banned.

Engineering finding
headline numbers and the mechanism

A stronger benchmark result with its constraints intact

The value is not only the 25.5% loss reduction. It is a reproducible demonstration that program-level geometry search can challenge a published adjoint result while retaining the stage quantities a turbine designer must protect.

-25.5%

entropy loss vs the LS89 blade on the 0.6M-cell mesh (25.99 +/- 0.61% Richardson-extrapolated), turning and mass flow matched

2D midspan RANS CFD · 4-level grid study

+2.20 pts

lead over the compliant Chatel et al. reference (+2.20 +/- 0.35 pts extrapolated)

Same solver · 4-level grid study

-21.2%

loss of a second, geometrically distinct blade family discovered when all Chatel-like shapes were mathematically forbidden

1.5x refined mesh · nearly 2x Torreguitart 2018

Why the mechanism works

Archimedes coordinated three coupled geometric moves: it opened pitch from 57.5 to 78.0 mm, restaggered to 60.35 deg with throat/pitch = 0.269 to hold exit turning at a +0.021 deg margin, and added a localized CST suction-side contour that controls the loaded vane's M = 1.138 peak and approximately 0.105 Mach recovery jump.

What the baseline got wrong

Over 98% of the entropy loss in the LS89 transonic cascade comes from wetted boundary layers and the trailing-edge wake. Widening blade pitch cuts wetted surface area per unit mass flow, but higher per-blade loading drives the rear suction side supersonic - triggering a normal shock wave that destroys the efficiency gain and under-turns the exit flow.

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

Minimize mass-averaged entropy generation J across the VKI LS89 transonic turbine nozzle guide vane cascade at exit isentropic Mach 0.90 (inlet 159.6 kPa, 420 K, Spalart-Allmaras, y+ < 1). Exit flow angle must be >= baseline (74.81 deg) with mass flow per unit pitch matched within +/- 0.7%. Both airfoil surfaces, pitch, stagger, throat, and LE radius are free; axial chord and TE are fixed.

Search duration 30 h (14.3 h + 15.7 h)	**Evaluations** 1,333
Compute fleet 18 cloud machines	**Solver basis** 2D midspan compressible RANS (HiSA HLLC, Spalart-Allmaras, y+ < 1) · 4-level grid study to 0.66M cells

Appendix B: Full decision log

01 Step 1 · Literature Audit · Digitizing & Re-Solving Published Optima

Catching a 0.06 deg turning violation in the published benchmark leader

OBSERVATION

Digitizing the Chatel et al. (2018) and Torreguitart et al. (2018) optima (0.06 mm registration accuracy) and solving them on our VKI MUR47-validated HiSA evaluator showed Chatel's published blade misses the exit turning floor by 0.046-0.06 deg.

REASONING

To establish a constraint-compliant comparison, Archimedes created a restaggered Chatel reference (-23.52% on the 1.5x mesh) and reported both the published and compliant forms.

ACTION AND RESULT

Wrote 40 physically distinct concept blade programs; before evolution even began, Archimedes' aft-loaded high-pitch concept reached -23.45% on the search mesh, already surpassing the restaggered Chatel bar (-22.7%).

02 Step 2 · Open & Excluded Campaigns · 1,333 Compressible RANS Evaluations

Co-evolving 78 mm pitch with a 57%-chord shock-control contour

OBSERVATION

Opening pitch above 75 mm cuts boundary-layer wetted area by 16%, but pushes peak suction Mach above 1.18 with a strong trailing shock.

REASONING

Adding a localized class-shape-function inflection near 57% chord controls the supersonic expansion and recovery while holding exit turning within 0.007-0.021 deg of the floor.

ACTION AND RESULT

Reached -25.14% on the 1.5x mesh and -25.50% on the 2.25x (0.6M-cell) mesh (25.99 +/- 0.61% extrapolated), plus a second completely distinct family at -21.2% when all Chatel-like shapes were banned.

Appendix C: Search families

2 profile families + 40 concepts. These are distinct programs or engineering configurations, not cosmetic renders.

High-pitch shock-contoured B-spline / CST family (Open winner Gen 502, -25.5% at 2.25x mesh)

Excluded-Chatel curvature-integrated drooped-LE family (Explore winner Gen 449, -21.2%)

Aft-loaded high-pitch concept seeds (-23.45% before evolution began)

Restaggered Chatel 2018 (-23.52%) & Torreguitart 2018 (-10.96%) replications

Appendix D: Numerical basis and verification

2D midspan compressible RANS (HiSA HLLC, Spalart-Allmaras, y+ < 1) · 4-level grid study to 0.66M cells

Frozen HiSA evaluator validated against VKI MUR47 experimental blade-surface Mach measurements (mean error 0.020 in isentropic Mach).

Four-level grid study up to 656,656 winner cells: finest-grid reduction 25.5016%, Richardson-extrapolated reduction 25.9873% +/- 0.6072%.

Nine-point off-design map: the winner leads the compliant Chatel reference across Mach 0.84-0.95 and at +2.5/+5 deg incidence, but not at the two trailing conditions (Mach 1.02 and -5 deg incidence).

Appendix E: Reported outcomes and limits

-25.5% entropy loss vs the LS89 blade on the 0.6M-cell mesh (25.99 +/- 0.61% Richardson-extrapolated), turning and mass flow matched Basis: 2D midspan RANS CFD · 4-level grid study.	**+2.20 pts** lead over the compliant Chatel et al. reference (+2.20 +/- 0.35 pts extrapolated) Basis: Same solver · 4-level grid study.
-21.2% loss of a second, geometrically distinct blade family discovered when all Chatel-like shapes were mathematically forbidden Basis: 1.5x refined mesh · nearly 2x Torreguitart 2018.	

Explicit limitations

The evidence is 2D midspan cascade RANS, not a 3D vane, endwall, cooling, structural, or engine-efficiency result.

The winner trails the compliant Chatel reference at M2is 1.02 and at -5° incidence.

Chatel et al. is a hybrid evolutionary and adjoint reference, not an adjoint-only comparator.

Recorded Archimedes run: 30 h across 2 campaigns (1,333 CFD solves). Compute record: 18 cloud machines · 4 grid levels to 0.66M cells.