Evidence-backed preliminary sizing of a parallel-plate channel

Aero automated study pipeline
Numerical verification report; not a peer-reviewed publication

Abstract

Three channel gaps are compared against a prescribed pressure-drop budget using nine steady OpenFOAM calculations and a closed-form reference. The workflow retains numerical inputs, mesh and solver diagnostics, computed fields and reproducibility hashes. 2.5 mm is the smallest tested gap meeting the 40 Pa budget within the stated parallel-plate model. The comparison tests the stated idealized flow model; it does not establish the performance of a manufactured device.

1 Problem definition and scope

Parameter	Value
Length	200 mm
Nominal full gap	2 mm
Reference width	100 mm
Volume flow	25 mL/s
Pressure-drop budget	40 Pa
Density	998.2 kg/m^3
Dynamic viscosity	0.001003 Pa s

Water properties represent nominal 20 °C. The calculation is two-dimensional, incompressible, steady and laminar. No-slip plates, a fully developed parabolic inlet, zero outlet gauge pressure and spanwise empty boundaries define the problem. The 100 mm width converts flow per unit width to total flow; a 1 mm computational slice does not resolve sidewall drag.

2 Governing reference and numerical method

For plane Poiseuille flow [1], with full gap h:

$$\bar{U} = \frac{Q}{Wh}, \qquad Re_{2h} = \frac{2\rho\bar{U}h}{\mu}, \tag{1}$$

$$\Delta p = \frac{12\mu L Q}{Wh^3}, \qquad u(y) = 6\bar{U}\frac{y}{h}\left(1 - \frac{y}{h}\right). \tag{2}$$

At fixed flow and properties, doubling the gap reduces pressure loss by a factor of eight. Each candidate uses 512, 1,152 and 2,048 cells. OpenFOAM Foundation 10, `simpleFoam`, computes the steady solution. Pressure is fitted over $x/L = 0.25$–0.75, multiplied by channel length, and converted from kinematic pressure to Pa using density. This avoids interpreting cell-center endpoints as the entire physical length.

3 Design comparison and decision

2.5 mm is the smallest tested gap meeting the 40 Pa budget within the stated parallel-plate model.

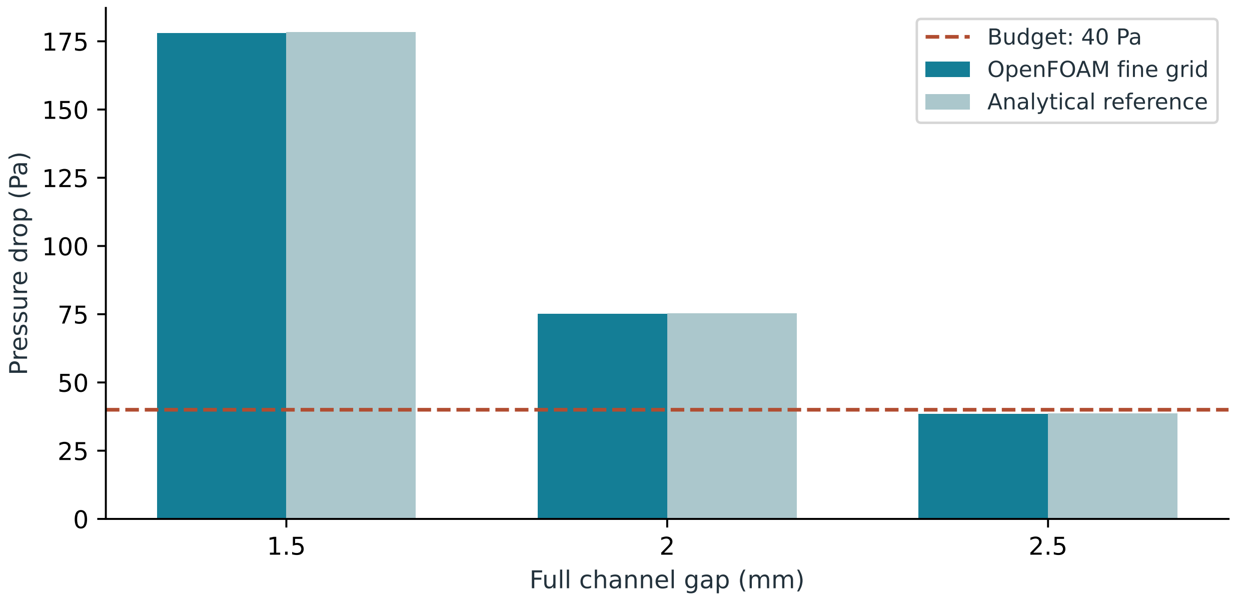


Figure 1. Actual fine-grid OpenFOAM pressure drop versus the analytical reference and the user-specified budget.

Gap mm	CFD Pa	Reference Pa	Allowance Pa	Margin Pa
1.5	177.9635	178.3111	0.3476	-138.3111
2	75.0784	75.2250	0.1466	-35.2250
2.5	38.4401	38.5152	0.0751	1.4848

The numerical allowance is the larger of the medium–fine difference and the fine-grid discrepancy from the analytical solution. Margin is budget minus computed pressure drop minus this allowance. This allowance is not a statistical confidence interval or a bound on omitted physical effects. A candidate is recommended only when all numerical checks pass.

4 Decision limitations

The compared gaps are 75%, 100% and 125% of nominal; this is not a continuous optimum. Side-wall drag, entry losses, roughness, fittings, temperature variation, manufacturing tolerances and unsteady effects require additional models or measurements. Numerical agreement with the analytical solution is distinct from experimental validation. The result supports preliminary sizing within scope.

5 Mesh sensitivity and iterative convergence

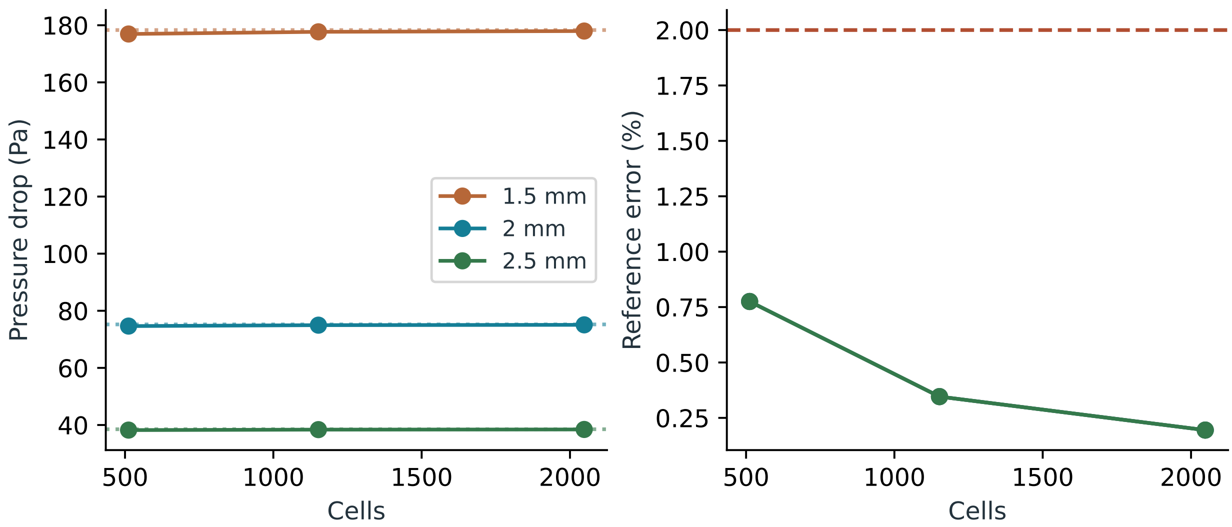


Figure 2. Pressure drop and analytical error across the three mesh resolutions. Dotted lines show analytical pressure; the dashed error threshold is 2 percent.

The largest medium–fine pressure change across the three gaps is 0.1514%. This checks grid sensitivity but is not a formal grid-convergence-index analysis.

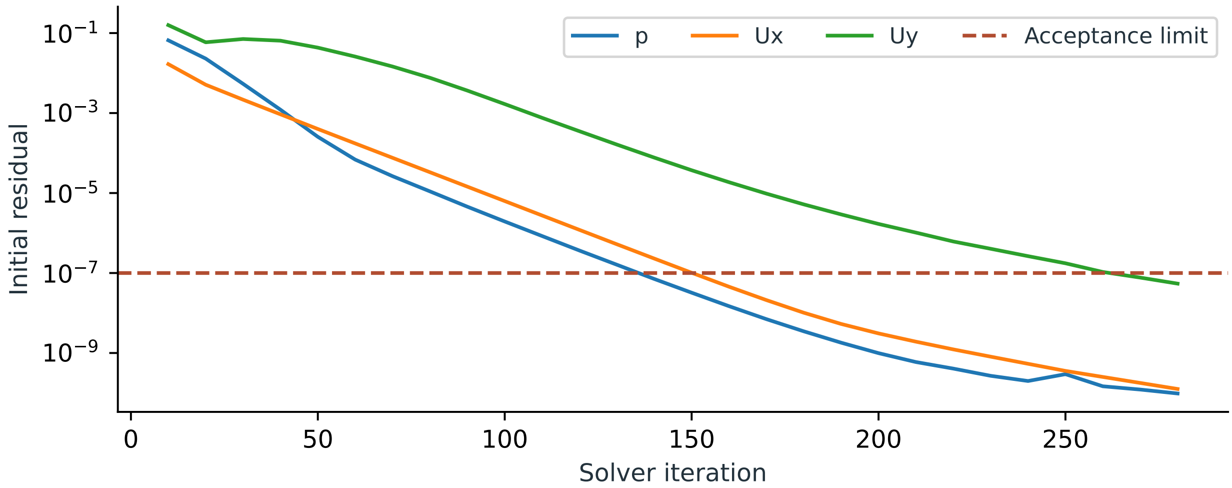


Figure 3. Actual initial-residual history for the nominal-gap fine-grid run, sampled every ten iterations. Final acceptance also uses the last reported residuals, not only these plotted samples.

6 Mesh and computed-field snapshots

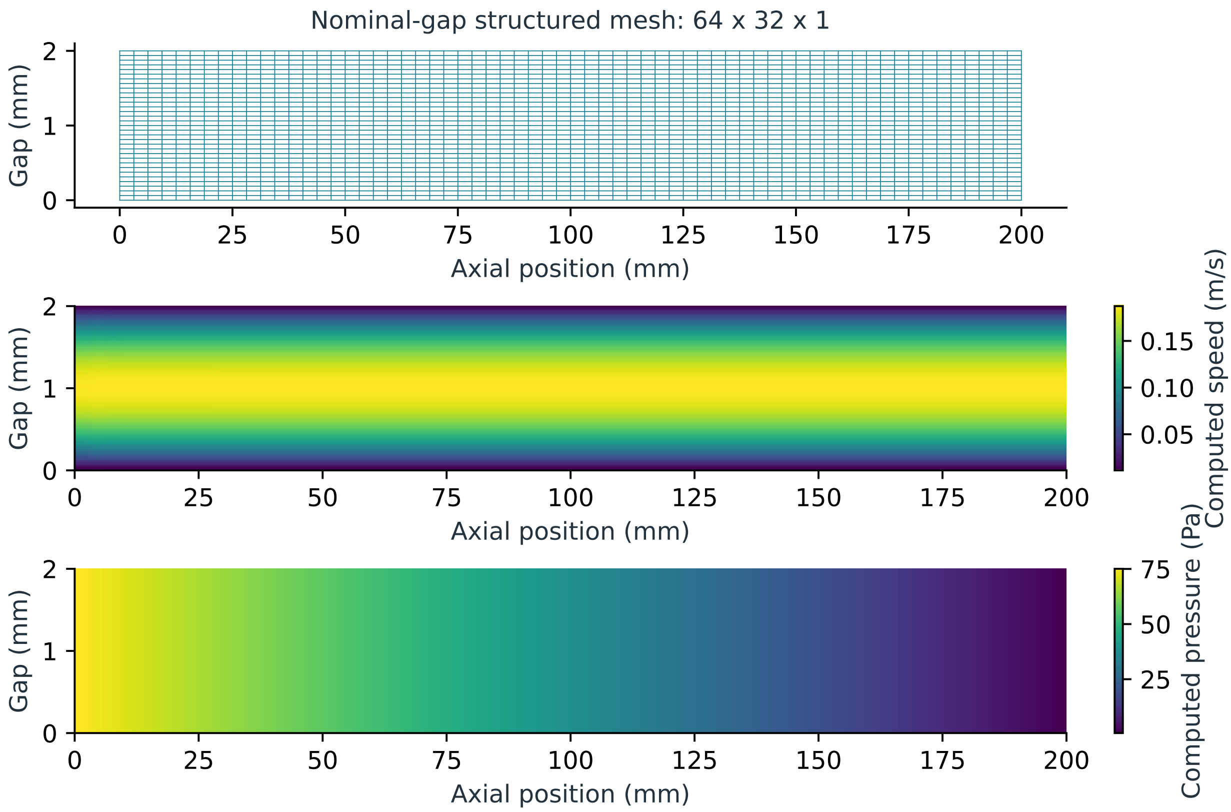


Figure 4. Nominal-gap mesh and actual solved cell fields. The vertical axis is visually expanded; labeled coordinates retain physical units. These are generated field snapshots, not photographs or invented contours.

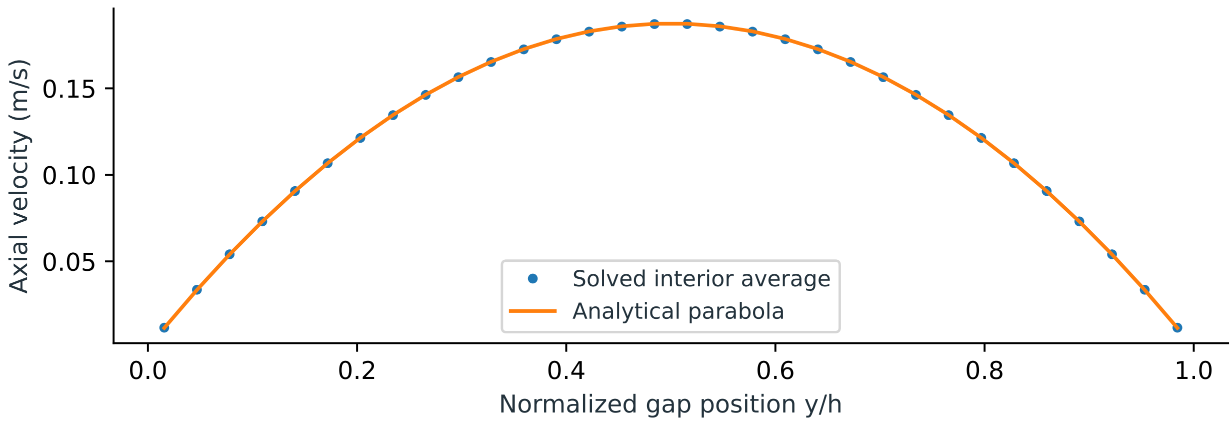


Figure 5. Solved axial velocity averaged over the middle half of the channel against the fully developed analytical parabola.

7 Verification gates and reproducibility

Gap	Grid	Cells	p error %	Flux error %	u error %	Checks
1.5	coarse	512	0.775	4.4e-11	0.361	PASS
1.5	medium	1152	0.346	1.04e-10	0.161	PASS
1.5	fine	2048	0.195	7.68e-11	0.091	PASS
2	coarse	512	0.775	1.3e-09	0.361	PASS
2	medium	1152	0.346	3.24e-10	0.161	PASS
2	fine	2048	0.195	7.28e-11	0.091	PASS
2.5	coarse	512	0.775	8e-11	0.361	PASS
2.5	medium	1152	0.346	1.48e-10	0.161	PASS
2.5	fine	2048	0.195	2.4e-11	0.091	PASS

Each grid must pass `checkMesh`, reported solver convergence, final initial residuals $\leq 10^{-7}$, flux imbalance $< 0.1\%$, pressure-reference error $< 2\%$ and velocity-profile relative L_2 error $< 2\%$. Each gap also requires medium–fine pressure change $< 1\%$. All-checks disposition: **PASS**. Nine-solve compute time: 16.12 seconds, excluding paper generation.

Run identity. `c285c4d248f1f2f8dc00ae43e01fae051e29f2c0f136250a`

Worker source SHA-256.

`964ea1a73bb0d6154c1af169e6b13ac81b3c9e6172e5e1740d6593c47d16cf51`

Case-generator source SHA-256.

`1d8649688ab223edfeda2aa880b3613f3108d9b6bc4b30bd18830ef0f6c38774`

Result JSON SHA-256.

`7990bd5fca3ee73e78ec861a11848c70097ba2a5e230acf47891a7fff7f28195`

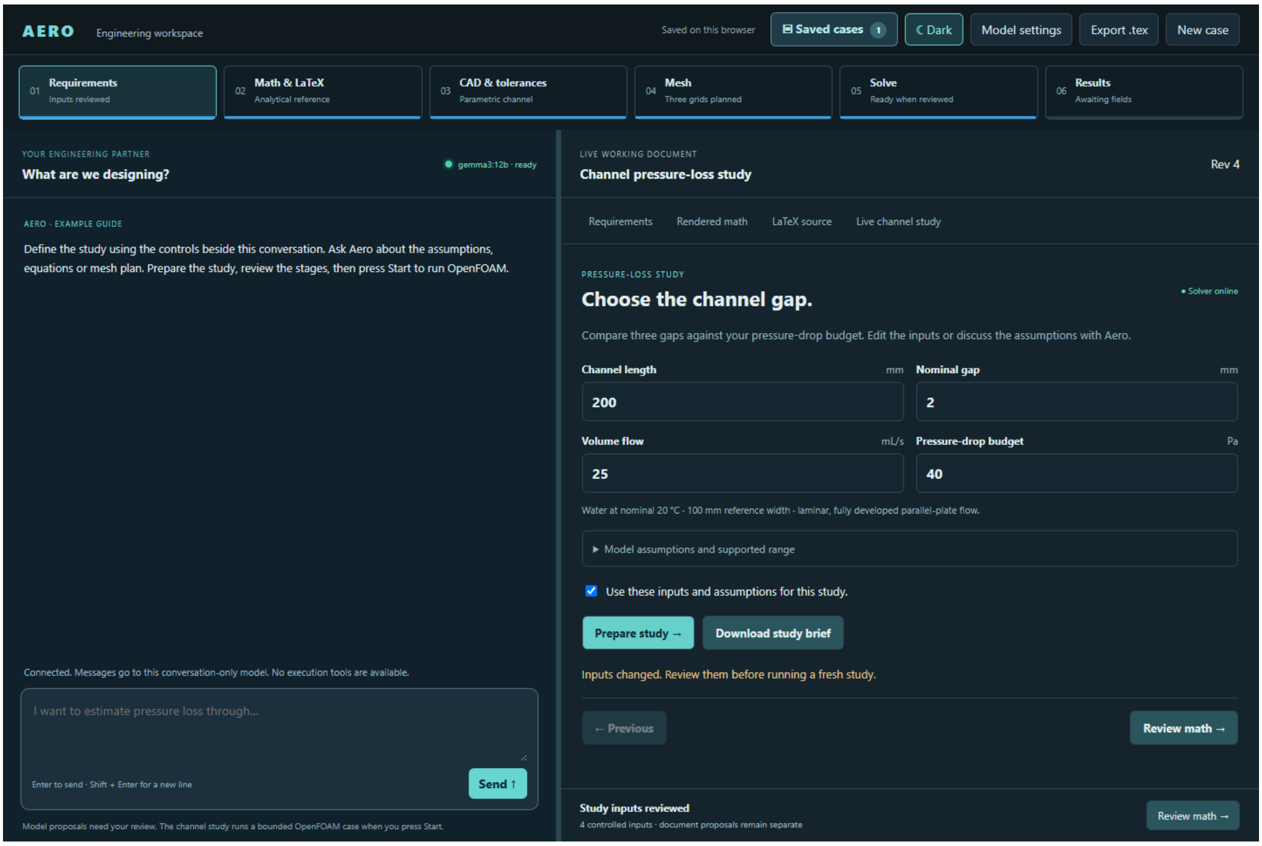
The evidence ZIP contains the exact OpenFOAM dictionaries, generated meshes, final p, U and ϕ fields, logs, result JSON, this PDF and its LaTeX/figure sources. Its SHA-256 manifest checks artifact identity, not scientific validity. Raw source values, not language-model prose, generate this document. Download the live report and evidence within 48 hours to retain a copy.

References

[1] R. Fitzpatrick, *Flow Between Parallel Plates*, University of Texas at Austin, Fluid Mechanics lecture notes. `https://farside.ph.utexas.edu/teaching/336L/Fluidhtml/node134.html`.

Appendix: browser evidence 1

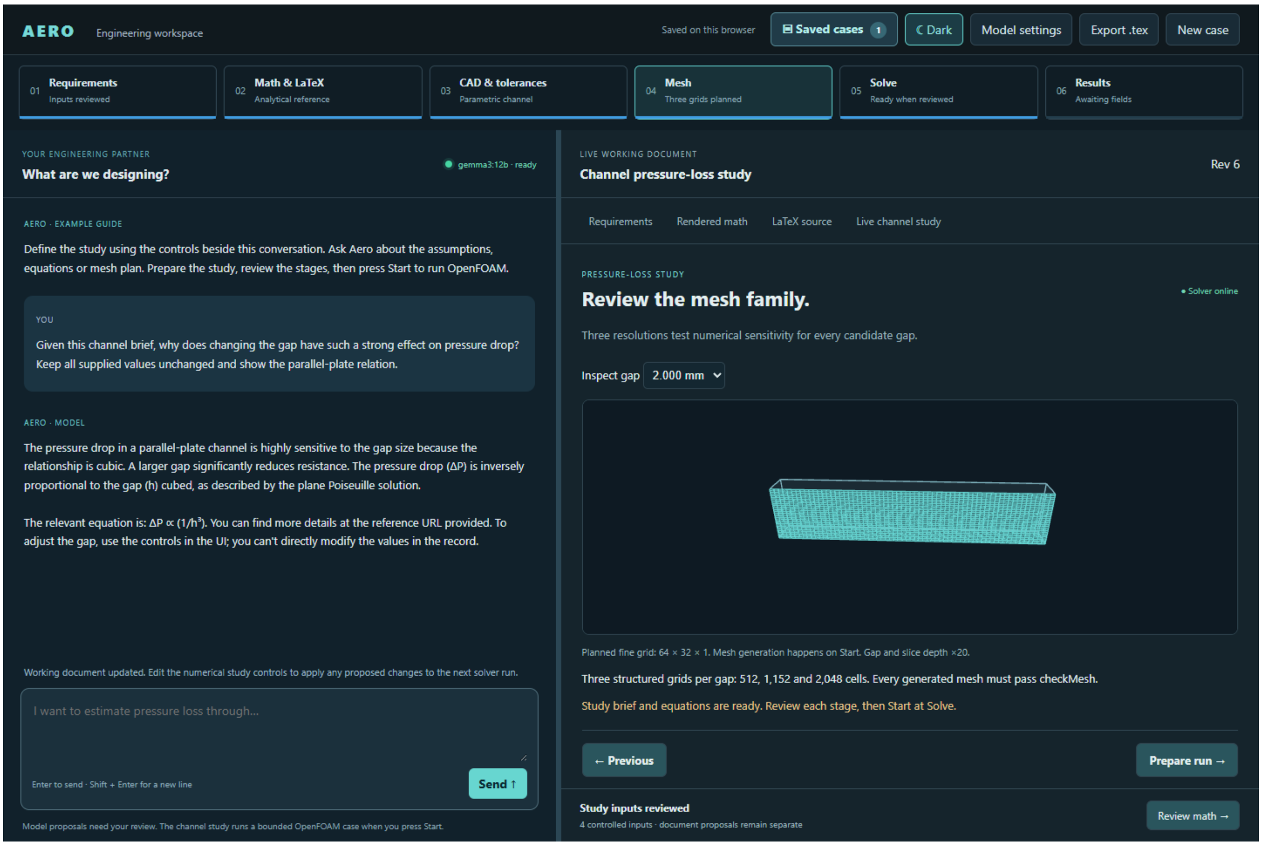
Actual headless-browser capture for the study ID in this paper. This image demonstrates interface state; numerical evidence is in the charts, fields and hashed solver files.



Browser requirements and reviewed numerical controls before execution.

Appendix: browser evidence 2

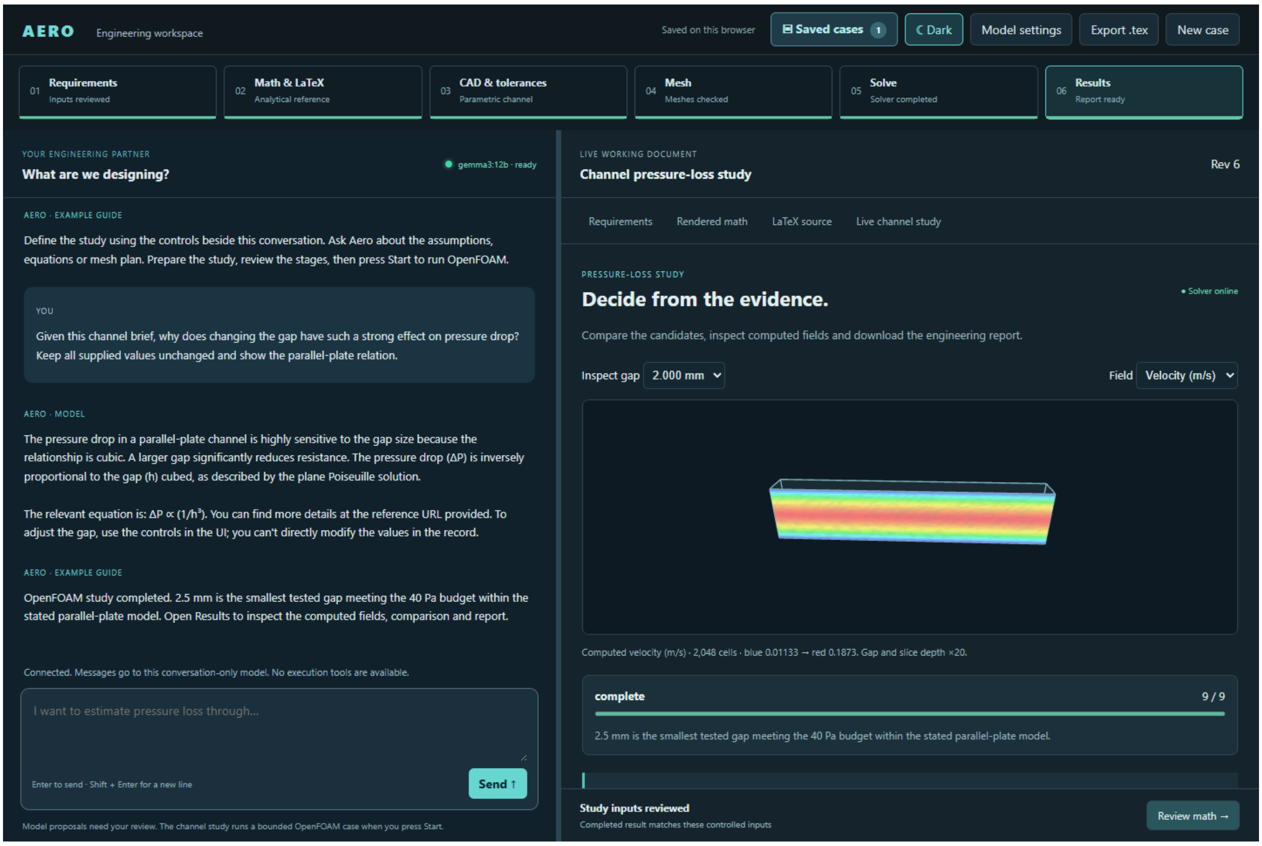
Actual headless-browser capture for the study ID in this paper. This image demonstrates interface state; numerical evidence is in the charts, fields and hashed solver files.



Browser mesh stage: planned mesh family before the explicit Start action.

Appendix: browser evidence 3

Actual headless-browser capture for the study ID in this paper. This image demonstrates interface state; numerical evidence is in the charts, fields and hashed solver files.



Browser result stage: computed velocity field and completed nine-solve run.