



Validation-Led CFD Assessment and Development of the MCR-S2N/S2N+ Airbox Package

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Introduction

Naturally aspirated race-car airboxes must preserve total pressure and avoid favouring one runner path.

The MCR-S2N/S2N+ package was assessed using steady RANS CFD supported by flow-bench pressure measurements.

The aim was to compare the old and updated airboxes, then develop a practical modification while retaining the existing runners and trumpets.

Method

Pipe-bend validation: 16 pressure taps, 5–25 inH₂O, mesh / wall-layer / turbulence sensitivity.

Airbox correlation: updated airbox pressure tapped and tested at 20 inH₂O, 10 mm valve lift, no filter.

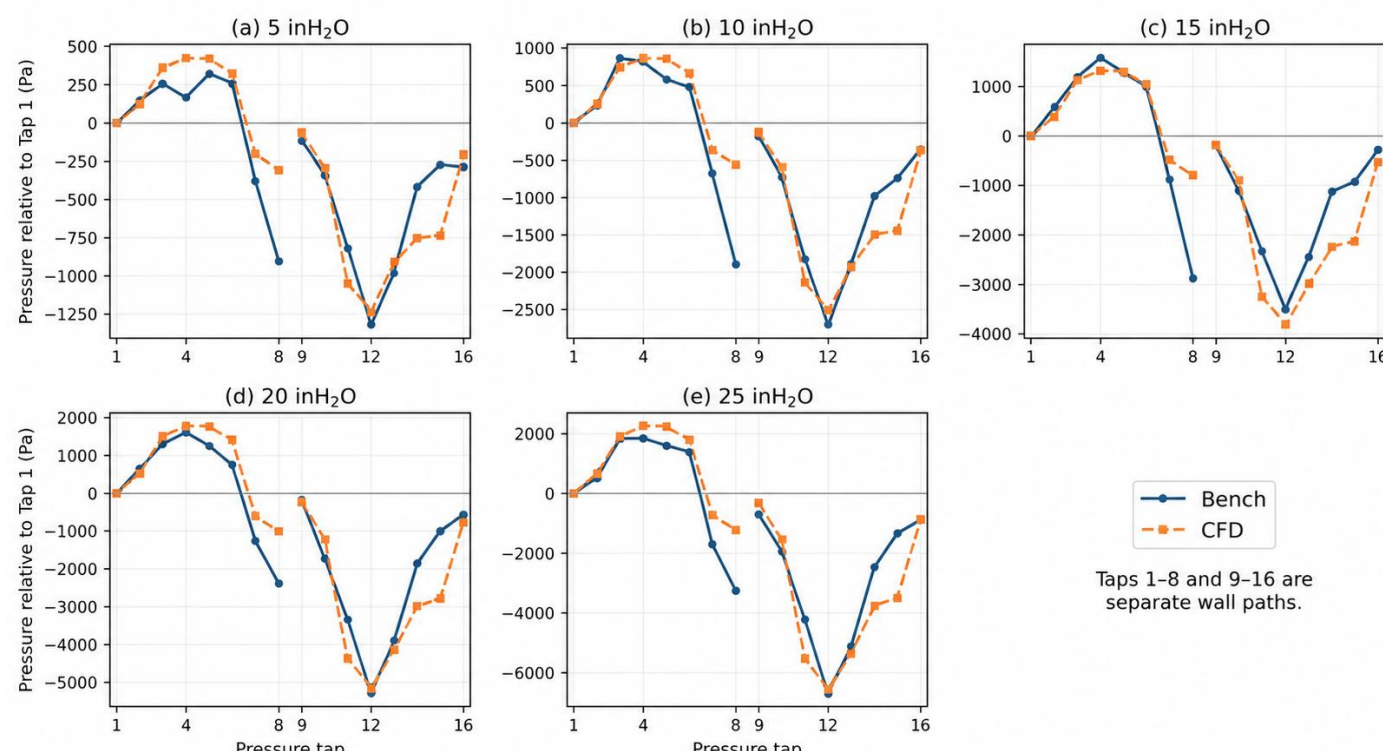
Design CFD: one cylinder path active per case; common 0 Pa inlet and -4982 Pa outlet; D1–D15 screened.



Flow-bench validation setup: 90° pipe test and pressure-tapped S2N+ airbox.

Validation evidence

Flow-bench and CFD pressure-distribution comparison across the test range

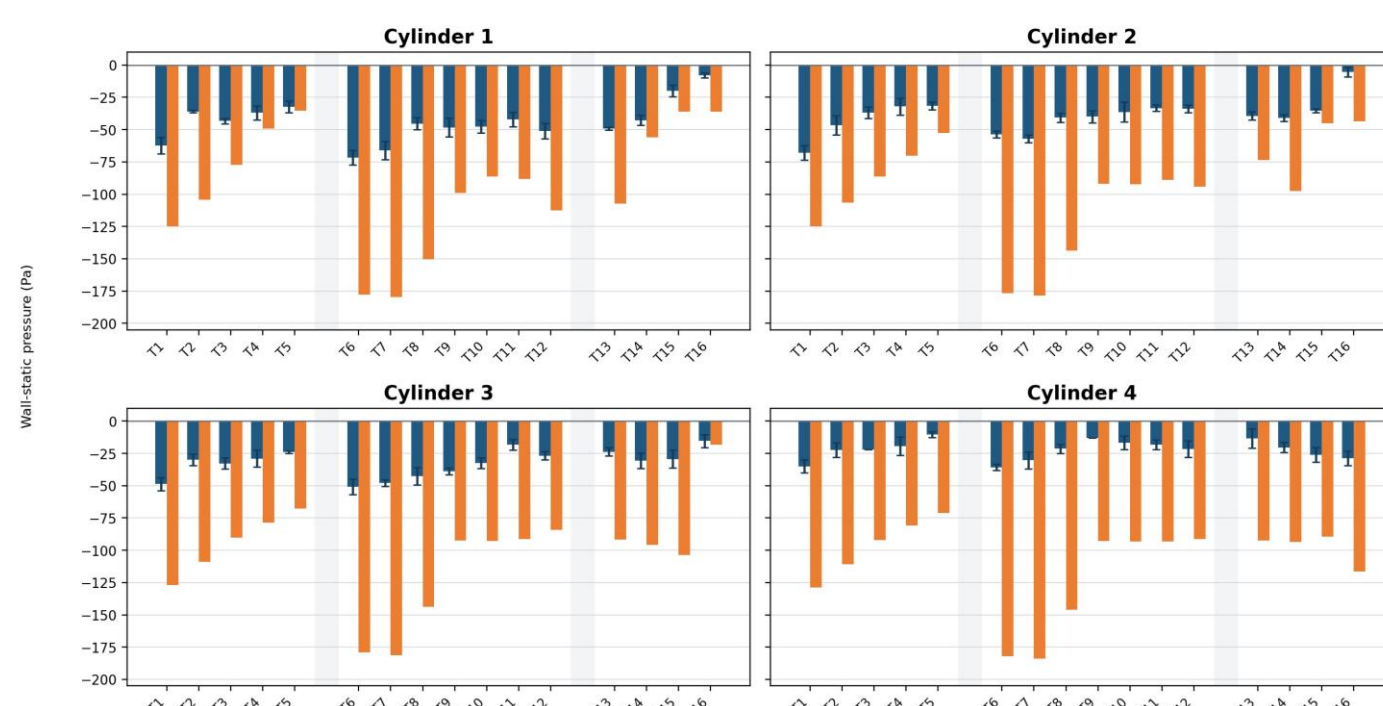


Pipe CFD reproduced the wall-pressure pattern across 5–25 inH₂O: $r = 0.897\text{--}0.943$.

Normalised RMSE was 10.8–14.4% of measured pressure range.

Validation supports comparative geometry ranking, not exact local pressure prediction.

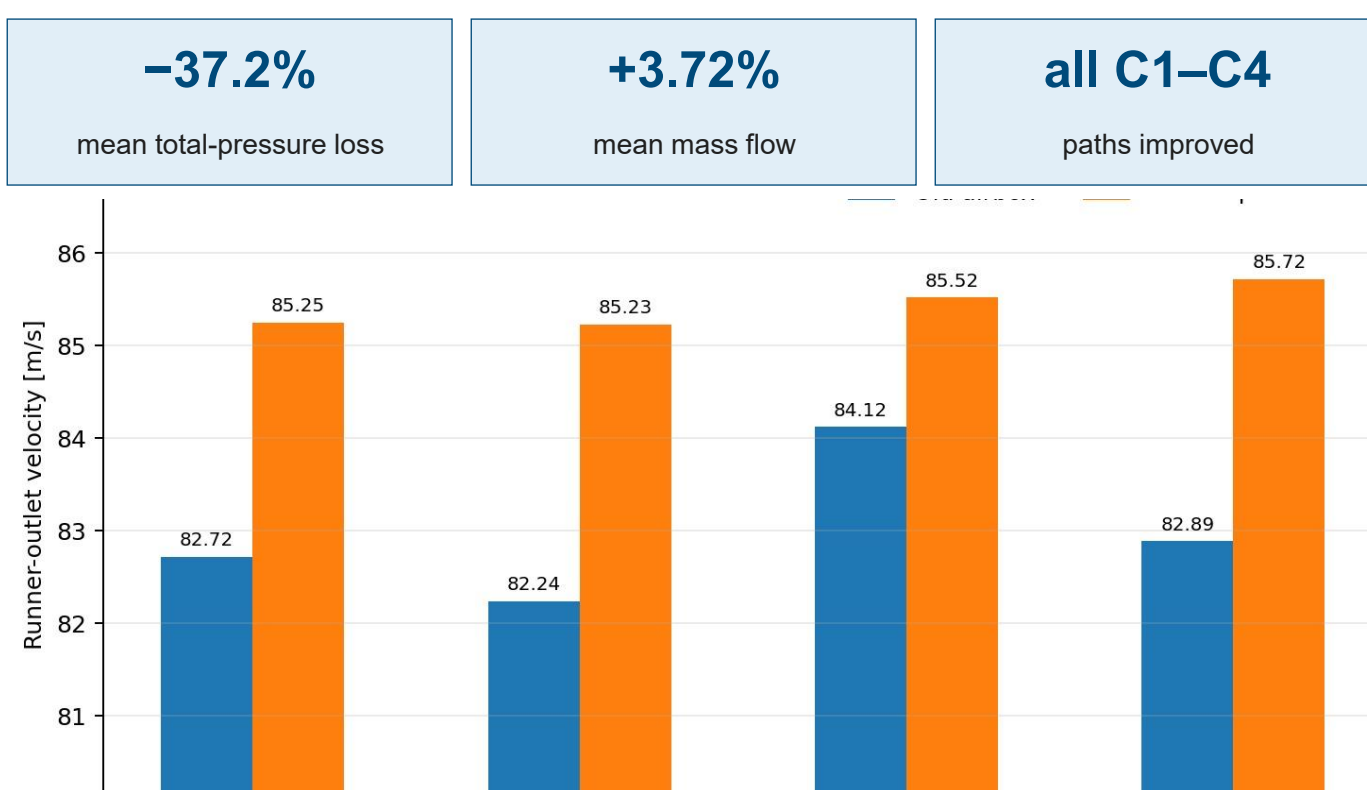
Airbox correlation



Updated-airbox CFD reproduced the regional pressure pattern but overpredicted suction magnitude.

Clean D0 was therefore used as the design-study baseline.

Old vs updated airbox



The S2N+ updated airbox was the largest project-level improvement and became the formal D0 baseline.

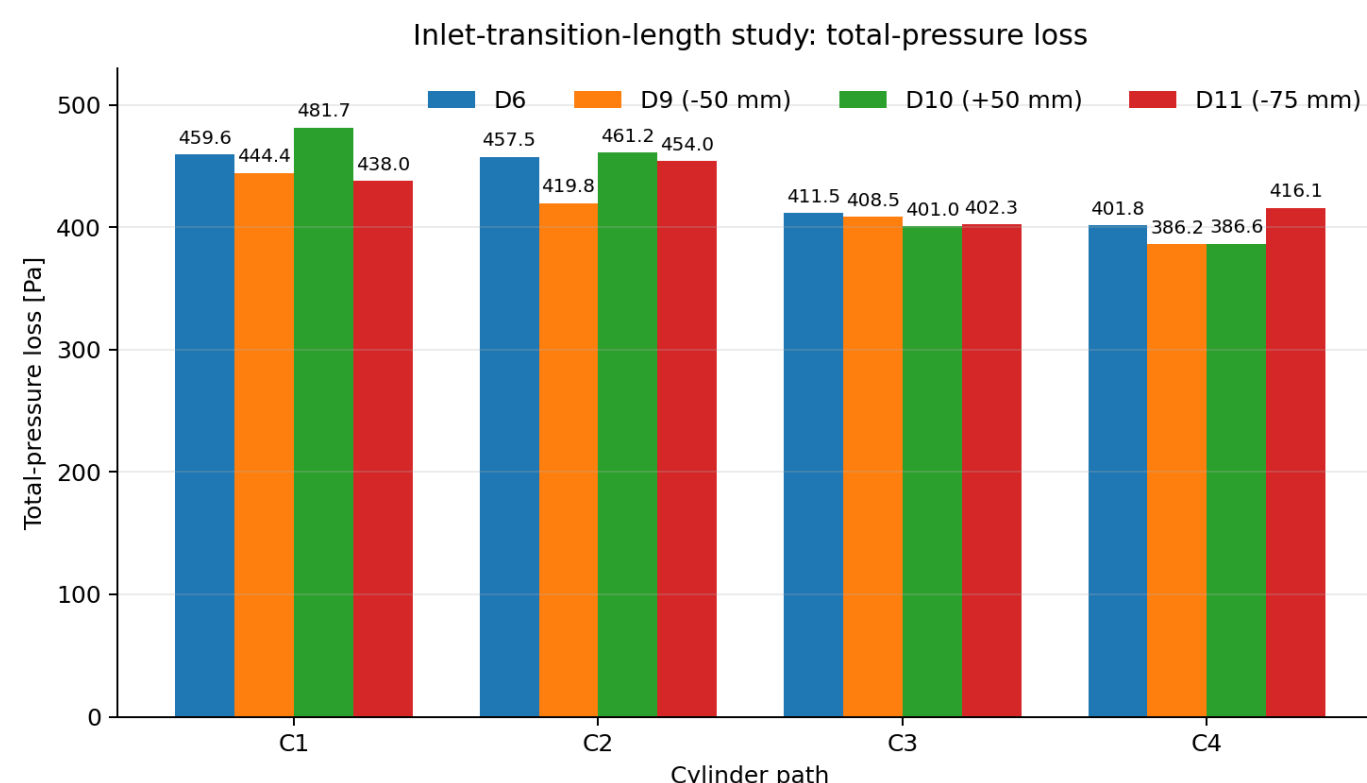
The result is stronger than the later D9 optimisation because every path improved under matched boundaries.

Design development

D1–D15 tested wall profile, inlet size/shape, transition length, divider and tray extension.

D6 = lipless D0 baseline for later size and transition-length studies.

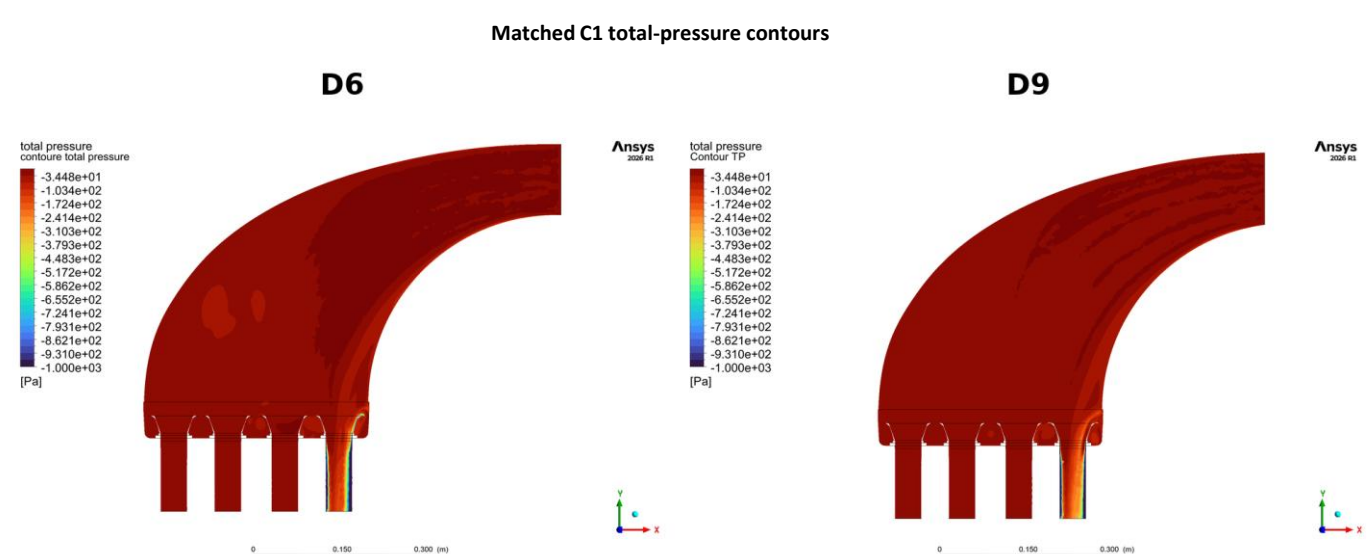
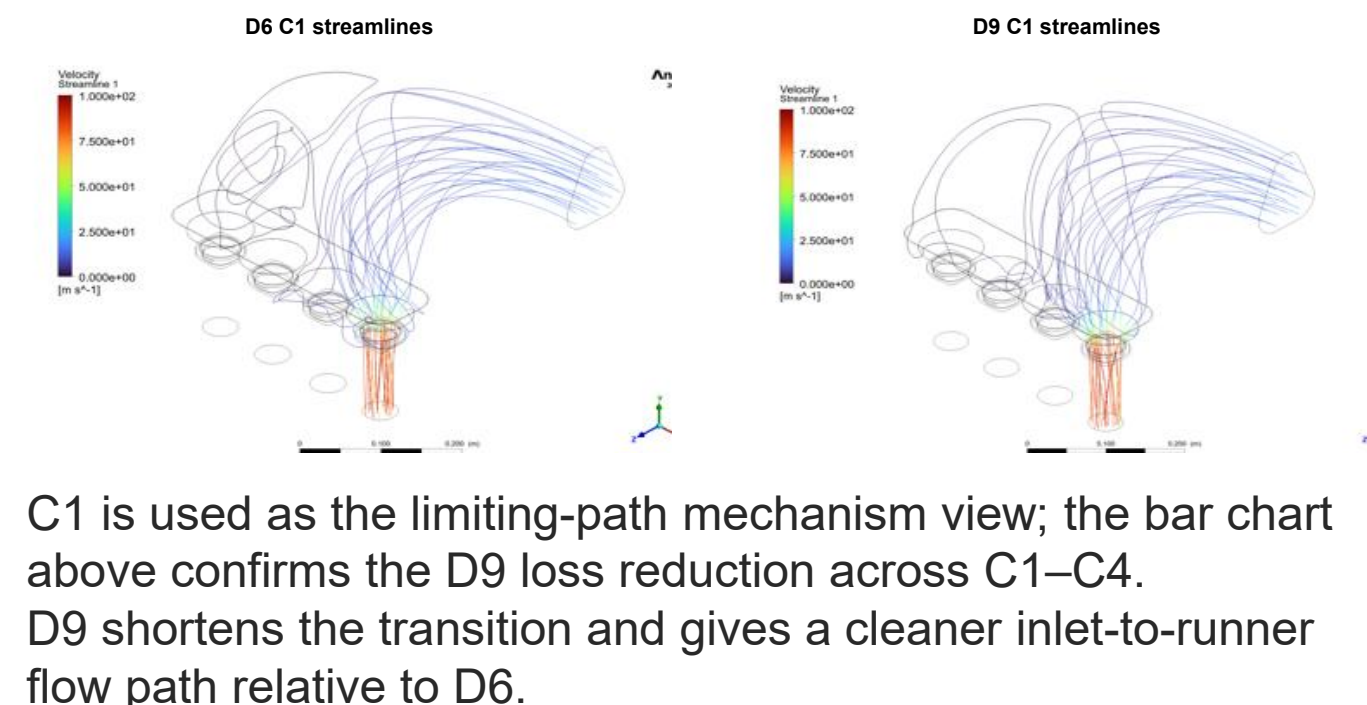
Mean loss, worst path, spread, flow mechanism and feasibility were used for design decisions.



Decision table

Concept	Mean Δp_t	Worst path	Decision
D1	429.7 Pa -1.61% vs D0	C2 459.3 Pa	No: marginal
D8	421.4 Pa -2.59% vs D6	C2 458.6 Pa	Size candidate
D9	414.7 Pa -4.10% vs D6	C1 444.4 Pa	GO: prototype
D12	423.9 Pa -2.01% vs D6	C1 448.3 Pa	Use in D15
D14	451.4 Pa +4.35% vs D6	C1 517.7 Pa	Reject
D15	452.7 Pa +9.16% vs D9	C1 506.0 Pa	Reject

Flow mechanism



Key findings

1. The updated S2N+ airbox is clearly better than the original airbox under matched internal boundaries.
2. D9 is the preferred prototype candidate, but not yet a confirmed final improvement.
3. The +728.92 Pa sensitivity case retained only a small D9 mean-loss advantage and introduced a C2 penalty.

Final interpretation

D9 = preferred prototype, not a proven production upgrade

The isolated D9 gain (-4.10% vs D6, the lipless baseline) is close to the 4.48% model-preparation sensitivity.

Prototype testing and a matched airbox refinement are therefore required.

Recommended next work

Manufacture D9 and compare it directly with D0 on the flow bench.

Run a matched D0/D9 airbox mesh-refinement check.

Repeat the final comparison with the intended filter installed.

If the bench advantage remains, test D9 on the car under representative running conditions.

Research questions answered

- RQ1 – Pipe validation:** CFD captured the 90° bend pressure trend.
- RQ2 – Numerical sensitivity:** Mesh, wall-layer and turbulence-model effects were assessed.
- RQ3 – External sensitivity:** The effect of the +728.92 Pa inlet total pressure was tested.
- RQ4 – Old vs updated airbox:** The updated design produced the main reduction in total-pressure loss.
- RQ5 – Airbox correlation:** CFD reproduced the regional pressure pattern measured by the pressure taps.
- RQ6 – D9 development:** The improvement was not proven conclusively; D9 is therefore taken forward as the preferred prototype for further testing.

Acknowledgements

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References

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- Celik et al. (2008) Procedure for reporting CFD discretisation uncertainty.
- Menter (1994) SST two-equation turbulence model.
- Muckova et al. (2023) Engine intake airbox CFD optimisation and experimental validation.
- Sudo, Sumida and Hibara (1998) Turbulent flow in a circular 90° bend.

Principal metric

$$\Delta p_t = \text{mean}(p_{t,\text{in}}) - \text{mean}(p_{t,\text{out}}); K_t = \Delta p_t / 4982 \text{ Pa}$$

Conclusion

A validation-supported steady CFD workflow was sufficient for comparing airbox geometries.

The old → D0 comparison is the major finding: -37.2% mean total-pressure loss.

D9 is the best follow-on concept and is suitable for prototype testing.