Holistic Legacy Integration & Verification Plan (ISO-aligned)

Intent, Method, and Proofs for Kiel + Wall-Static Baseline
with Legacy Piccolo Translation

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This document accompanies the kielproc GUI/package.

1. Intent and Scope

This program establishes a single, defensible measurement and translation process that preserves historical context without corrupting the physics. It operates a co-planar ‘physics channel’ based on Kiel total head and circumferentially averaged wall static, maps that plane to the throat, and overlays legacy piccolo readings via an explicit translation after lag removal. Operators use the physics channel for QA and control; translation is used only for overlaying and comparison.

- Operate on a co-planar Kiel total and averaged wall static (ISO 3966, ISO 2186 intent).
- Map verification-plane dynamic to throat and (optionally) venturi DP for reporting (ISO 5167-4 low-Mach relation).
- Remove piccolo loop lag via cross-correlation before regression; fit translation with errors-in-variables (Deming/ODR).
- Pool replicate fits with random-effects if between-replicate spread exceeds within-replicate variance.
- Treat dynamics in samples; convert to seconds with known logger rate.

2. Standards and Method Anchors

Methods and acceptance align with the following anchors and guidance documents. These references motivate co-planar measurement, proper static-tap practice, pressure transmission integrity, low-Mach venturi relations, and statistically correct translation with uncertainty.

- ISO 3966 — Velocity-area method using Pitot/Kiel tubes; yaw/smear/swirl limits; co-planar static practice.
- ISO 5167-4 — Venturi tubes; low-Mach differential relation to throat dynamic pressure.
- ISO 2186 — Pressure signal transmission; taps, lines, manifolds; avoid dynamic distortion/unequal legs.
- NIST/SEMATECH handbook — Errors-in-variables (Deming/ODR) for method comparison.
- Bendat & Piersol — Cross-correlation, lag identification, and low-pass characterization.

3. Legacy Piccolo Observations and Implications

Legacy piccolo is a dual-manifold array: a distributed total header and a distributed static header measured as a differential. Replicate runs show sample-lag differences (plenum/line/transmitter dynamics) and varying slopes due to header weighting asymmetry. Traverse sheets demonstrate that near-wall ‘static’ is not a robust plane static: floor/roof slices flip sign while the middle is more stable.

- $\Delta p_{picc} = p_{t,manifold} - p_{s,manifold}$ with each manifold being a flow-weighted average of connected ports.
- Replicate-dependent lags of tens of samples; normalized cross-correlation peaks ~0.17–0.35 in 2007 blocks.
- Sign reversals of corr(Static, VP) across bottom vs top slices (e.g., −0.82 vs +0.31 in a 2011 run).
- 2018 file with a flat piccolo tag cannot participate in translation but still informs static behavior/anisotropy.

4. Physics Channel and Mapping — Derivation

We measure at a single axial verification plane using a yaw-robust Kiel total head and a circumferentially averaged wall static. Let r = A_s / A_t (verification plane area over throat area). Under steady, low-Mach, single-phase flow: mass conservation gives v_t = (A_s / A_t) v_s = r v_s. Dynamic pressure is q = 1/2 · ρ v^2. Thus:

Ideal-gas density is used at low Mach: rho = p_s/(R·T). If temperature or pressure at either plane is missing, ρ_t/ρ_s defaults to 1.

$$q_s = p_{t,\,\mathrm{Kiel}} - p_{s,\,\mathrm{avg}}$$

$$q_t = \tfrac{1}{2}\rho_t v_t^2 = \tfrac{1}{2}\rho_t (r v_s)^2 = r^2 \tfrac{\rho_t}{\rho_s}\left(\tfrac{1}{2}\rho_s v_s^2\right) = r^2 \tfrac{\rho_t}{\rho_s} q_s$$

$$\Delta p_{\mathrm{vent}} \approx (1-\beta^4)\, q_t$$

5. Lag Removal and Errors-in-Variables Translation

Before comparing legacy piccolo to the mapped reference, identify and remove the piccolo loop lag. Let x_k be the mapped reference and y_k the piccolo; compute discrete cross-correlation R_xy[τ] and select the τ maximizing |R_xy[τ]|; shift y by τ samples. Then fit y = α x + β via Deming/ODR, accounting for errors in both variables with variance ratio λ = σ_y^2/σ_x^2.

$$R_{xy}[\tau] = \sum_k (x_k - \bar{x})(y_{k+\tau} - \bar{y}), \quad \hat{\tau} = \arg\max_\tau R_{xy}[\tau]$$

$$\alpha = \frac{S_{yy} - \lambda S_{xx} + \sqrt{(S_{yy} - \lambda S_{xx})^2 + 4\lambda S_{xy}^2}}{2S_{xy}}$$

$$\beta = \bar{y} - \alpha\bar{x}$$

6. Replicate Pooling (Random-Effects)

Where multiple replicates exist, pool α and β estimates using DerSimonian–Laird random-effects to account for between-replicate heterogeneity. Let θ_i be an estimate with variance V_i. Fixed-effects weights are w_i = 1/V_i; Cochran’s Q and the between-replicate variance τ² are:

$$Q = \sum_i w_i(\theta_i - \hat{\theta}_{FE})^2, \quad \hat{\theta}_{FE} = \frac{\sum_i w_i \theta_i}{\sum_i w_i}$$

$$c = \sum_i w_i - \frac{(\sum_i w_i)^2}{\sum_i w_i}, \quad \tau^2 = \max\left(0, \frac{Q-(k-1)}{c}\right)$$

$$w_i^{RE} = \frac{1}{V_i + \tau^2}, \quad \hat{\theta}_{RE} = \frac{\sum_i w_i^{RE} \theta_i}{\sum_i w_i^{RE}}$$

7. How New and Legacy Data Are Leveraged

Outputs: mapped_ref.csv (q_s, q_t, Δp_{vent}, Sample, Time_s), α/β tables (per-block and pooled), alignment plots, and optional flow maps and polar slices for diagnostics.

- Operate and QA on the physics channel: q_s from co-planar Kiel minus mechanically averaged wall static; map to q_t and Δp_{vent}.
- Use legacy piccolo only through an explicit translation layer: $\Delta p_{picc} = \alpha \, \Delta p_{mapped} + \beta$ (after lag removal).
- Exclude legacy blocks with flat piccolo tags; 2018 informs static anisotropy but not translation parameters.
- Down-weight near-wall windows when forming legacy mapped references for translation (neutralizes wall contamination).
- Maintain time in samples; only compute seconds after providing the logger sampling rate.

8. Built-In QA and Acceptance Criteria

Continuous QA indices computed from wall-static taps (when available) guard translation quality; thresholds gate refitting. Acceptance targets keep transmitter zero, pooled α/β stability, residual spread, and lag consistency within narrow bands.

- Opposite-tap difference: $\Delta_{opp} = (|p_{s,N} - p_{s,S}| + |p_{s,E} - p_{s,W}|)/2$.
- Ring non-uniformity: $W = (\max p_{s,i} - \min p_{s,i})/\mathrm{mean}(p_{s,i})$.
- Example thresholds: $W < 0.2\%$ and $\Delta_{opp}/\overline{q} < 1\%$ for high-accuracy fitting (tune on site).
- Acceptance (illustrative): zero within ~0.5% FS; pooled α stable within ~1%; pooled β within ~0.5% FS after equalization; residuals <~1% of DP; lag documented and stable.

9. Known Caveats and Neutralization

- Absolute time in older exports is unreliable — do all dynamics in samples; convert after sampling rate is known.
- 2018 piccolo flat tag — exclude from translation fits but keep for static/anisotropy context.
- Near-wall contamination — use circumferential average and down-weight near-wall windows in translation.
- Header asymmetry — appears as $\alpha \neq 1$; unequal leg head/zero shows as $\beta \neq 0$; address via array cleaning, line balancing, or transmitter snubbing at the secondary.

10. References

- ISO 3966 — Measurement of fluid flow in closed conduits: Velocity-area method using Pitot static tubes.

- ISO 5167-4 — Measurement of fluid flow by means of pressure differential devices: Part 4 — Venturi tubes.

- ISO 2186 — Fluid flow in closed conduits: Connections for pressure signal transmissions between primary and secondary elements.

- NIST/SEMATECH Engineering Statistics Handbook; Errors-in-Variables (Deming/ODR).

- Bendat, J. S., and Piersol, A. G., Random Data: Analysis and Measurement Procedures (Wiley).