

— MODEL-BASED CALIBRATION

CIE Pro Technical Brief

Design of Experiments, physics-informed neural surrogates, and constrained Bayesian optimization for powertrain and EV calibration.

Space-Filling DoE

Physics-Informed Neural Surrogates

Pareto Optimization

A2L · CDF · HEX Export

Dense test sweeps consume excessive dynamometer hours.

Calibrating multi-variable powertrain and EV inverter actuators requires mapping complex response surfaces across broad operating envelopes.

TEST DURATION

Combinatorial Explosion

Full-factorial testing over engine speed, load, valve timing, and injection timing scales exponentially, consuming prohibitive test bench hours.

MODEL DRIFT

Unphysical Extrapolations

Purely statistical regression models often violate conservation laws in sparse data zones, producing calibrations with unphysical boundaries.

TRADE-OFF AMBIGUITY

Conflicting Objectives

Balancing tailpipe emissions, peak torque, and thermal limits manually relies on iterative intuition rather than mathematical Pareto frontiers.

Model-based calibration with physical guarantees.

CIE Pro pairs optimal experimental design with physics-informed surrogate modelling to minimize required test points while preserving accuracy.

SPACE-FILLING EXPERIMENTAL DESIGN

Mechanistic Point Selection

Generates optimal DoE point distributions that cover the operating envelope efficiently. Points are concentrated in regions of non-linear behavior while sparse in predictable zones.

CONSTRAINED BAYESIAN MODELLING

Hard Boundary Enforcement

Fits Gaussian process regressions and Physics-Informed Neural Networks that enforce cylinder pressure limits, turbo speeds, and inverter thermal envelopes.

Mechanistic Advantage: By avoiding redundant sweeps where system behavior is already well-predicted, test point density is optimized based on physical variance rather than arbitrary grids.

Static and dynamic Design of Experiments.

STATIC DOE METHODS

Optimal Steady-State Matrices

- **Sobol Sequences:** Quasi-random space-filling distributions minimizing discrepancy across multi-dimensional input domains.
- **Latin Hypercube Sampling (LHS):** Stratified sampling ensuring uniform representation across every actuator dimension.
- **D-Optimal & Classical:** D-Optimal matrices, Box-Behnken, and Central Composite designs for quadratic response fitting.

DYNAMIC TRANSIENT DOE

Sinusoidal Sweeps & Convex Boundaries

- **Transient Excitation:** Frequency sweeps designed to capture dynamic turbo lag and thermal inertia characteristics.
- **Convex Hull Constraints:** Operating envelopes define strict safety boundaries, preventing dyno trips during automated testing.
- **Active Learning:** Code-ready hooks guide sequential point selection toward regions of highest model uncertainty.

Physics-Informed Neural Networks & Gaussian Processes.

Surrogate models embed thermodynamic relationships to ensure reliable generalization.

PINN ARCHITECTURE

Conservation Law Encoding

Loss functions penalize non-physical states—enforcing mass conservation, energy balances, and electromagnetic flux saturation directly within network backpropagation.

AUTOMATED HYPERPARAMETER SEARCH

Optuna Cross-Validation

Executes Bayesian hyperparameter tuning across surrogate architectures with 5-fold cross-validation, selecting optimal kernel dimensions without manual tuning.

Interactive Pareto frontiers for engineering trade-offs.

Navigate the exact mathematical boundary where competing vehicle attributes conflict.

NSGA-II & BAYESIAN OPTIMIZATION

Multi-Attribute Exploration

Calculates the multi-dimensional Pareto frontier between fuel consumption, NOx/soot emissions, acoustic roughness, and acceleration response.

SURFACE NAVIGATION

Visual Trade-Off Selection

Interactive 3D surfaces allow calibration teams to scrub across operating parameters, inspect constraint safety margins, and lock release values with verified confidence intervals.

Direct export to standard calibration toolchains.

FILE STANDARD	DIRECTION	ENGINEERING CONTENT	TOOLCHAIN TARGET
ASAM A2L (ASAP2)	Import / Export	ECU parameter definitions, memory addresses, and conversion methods	INCA, CAMEO, CANape
ASAM CDF / CDFX	Export	Structured XML calibration values, quality states, and parameter sets	HELIX, Enterprise vCDM
Intel HEX (.hex)	Export	Flash-ready parameter patch images with recalculated checksums	ECU Flashing Tools
DCM / CSV	Import / Export	Tabular parameter matrices, curve definitions, and DoE test logs	Dyno Automation, Excel

What we do not claim.

Clear boundaries ensure realistic evaluation in production test cells.

NOT A LIVE FRONT-END

No Live Online Calibration

CIE Pro does not perform live parameter tuning on running vehicle ECUs. It designs DoE test plans and generates calibrated datasets; active ECU communication is managed by your measurement front-end.

NO ARBITRARY PERCENTAGES

Mechanistic Test Reductions

We publish no headline figure for dyno-time reduction. Dyno time reduction depends strictly on the number of variable factors, system non-linearities, and required model precision.

How to evaluate CIE Pro on your dyno data.

STEP 1

Ingest Historical Runs

Provide existing dyno test datasets (CSV or MDF4). Verify surrogate model fit quality and cross-validation metrics.

STEP 2

Generate DoE Matrix

Define an actuator test envelope with safety bounds. Review the generated Sobol or D-Optimal test matrix against standard grids.

STEP 3

Export Calibration Maps

Generate verified A2L and CDF calibration sets and import them directly into your INCA or CAMEO environment.

TECHNICAL EVALUATION

Request a CIE Pro Test Plan Demo

contact@vehiclelab.in · <https://vehiclelab.in/docs/cie-pro-brief>