**VIRTUAL ENGINE TEST BENCH v1.0 – PROGRESS REPORT**

**Executive Summary**

Version 1.0 introduces a physics-based combustion core (Wiebe heat release) and a modular solver that closes the thermodynamic loop from IVC to IVO. The tool now produces physically consistent p–V loops, IMEP/BMEP, and CA10/50/90 markers, and adopts a spec-driven engine database with VE sourced exclusively from tables. Test modes were refactored to run on the new solver.

**Changes from v0.5**

**Combustion & Thermodynamics**

* Wiebe model (SOC→EOC): tunable shape (a, m) and duration; CA10/50/90 computed analytically and shown on plots.
* First law update: dU=dQchem−p dV\mathrm{d}U = \mathrm{d}Q\_\text{chem} - p\,\mathrm{d}V applied per crank-angle step to advance TT and pp.
* Temperature-dependent cv(T)c\_v(T): blended unburned/burned maps to moderate peak temperature and pressure evolution.
* Expansion: polytropic with nexp≈1.25–1.32n\_\text{exp}\approx 1.25\text{–}1.32.
* Exhaust blow-down: adiabatic control-volume with mass bleed to an exhaust target (~1.05 bar / ~1150 K at IVO), integrating T˙\dot{T} with outflow work.

**Solver Architecture & Data Model**

* Engine database: EngineSpec holds geometry (cylinders, bore, stroke, rod, CR) plus a VE table.
* VE tables only: constant-VE path removed. VE interpolated from MAP–RPM grids (rows = MAP kPa, columns = RPM). CSV auto-load and numeric sanitation added; path or DataFrame accepted.
* RunPoint() API: single operating point returning torque, power, IMEP/BMEP/FMEP/PMEP, BSFC, m˙\dot m air/fuel, emissions, CA10/50/90, p\_\max, T\_\max.
* Custom engines: interactive geometry + VE CSV path; name sanitized; table auto-loaded on construction.

**Reporting & Analysis**

* p–V diagram for each analysed point (optional analysis).
* CA10/50/90 markers on pressure, temperature, and MFB plots.
* BSFC and emission intensities (g/kWh) computed from mass flows and brake power.
* CSV and visualization outputs retained and aligned to the new data schema.

**Single-Point Result**

Configuration: VQ35DE-like geometry, VE from 350Z map, 3000 rpm, WOT.

* Torque: ~355 Nm
* Power: ~112 kW
* IMEP: ~13.4 bar; BMEP: ~12.8 bar (simple FMEP/PMEP)
* p\_\max: ~64 bar; T\_\max: ~3170 K
* BSFC: ~189 g/kWh

Absolute values depend on VE fidelity, combustion phasing (CA50), and loss model calibration.

**Validation Snapshot**

* WOT torque/power trends match expected shapes for the 350Z reference; absolute levels track VE and losses.
* Expansion and blow-down reduce pp and TT appropriately post-EOC; CA50 aligns with typical SI timing for the current Wiebe parameters.
* Peak TT remains an upper bound (no heat transfer or dissociation modeled).

**Known Limitations (v1.0 Scope)**

* No spark timing map (MBT/knock phasing not implemented).
* Heat transfer and detailed species thermodynamics omitted; cv(T)c\_v(T) is approximate.
* FMEP/PMEP remain lightweight empirical fits; valve-flow-based pumping loop not closed.
* VE table required; result quality follows table quality.

**User-Facing Changes**

* Displacement + constant-VE input removed. Flow now starts with engine selection (preloaded or custom geometry + VE CSV).
* Menus updated for SingleRun, WOT, FullRangeSweep; optional combustion analysis at selected RPMs.
* Output schema adds: IMEP\_bar, BMEP\_bar, FMEP\_bar, PMEP\_bar, mdot\_air\_kg\_s, mdot\_fuel\_kg\_s, BSFC\_g\_per\_kWh, CO2/CO/NOx/HC (g/s & g/kWh), CA10/50/90, Pmax\_bar, Tmax\_K.

**Conclusion**v1.0 establishes a thermodynamically closed, spec-driven foundation. The solver now supports credible p–V/IMEP outputs and VE-table workflows, enabling phasing/knock development in the next iteration.

**Next Steps**

* **v1.0:** Semi-empirical combustion using Wiebe function, enabling more realistic demonstration of combustion.
  + Spark timing sweep with CA50 targeting and MBT/knock limits.
  + Simple knock surrogate and phasing-aware efficiency to shape torque and p\_\max.
  + Optional heat-transfer and γ(T)\gamma(T) refinements for tighter T\_\max and IMEP.
  + Engine-specific loss model tuning and VE map curation.
* **v1.1:** Spark timing control, allowing users to advance/retard ignition and experience real-world calibration trade-offs.
* **v1.5:** Transient Testing, introducing idle-speed control (PID), inertial & filling dynamics, and validation of transient response.
* **v2.0:** Multi-fuel & Emissions, adding fuel database, EGR & aftertreatment cycle simulation, and full emissions-cycle (WLTP).
* **v2.1:** Automated Reporting, integrating real-time dashboards (Dash/UI) and automated report generation.
* **v2.5:** Reverse Engine Simulation, enabling ingestion of OBD data for real-world analysis and back-calibration.

**Demo video for WOT Test**