EDUCATIONAL VERSION FOLLOWS

🏛️ Structural Baseline & Dynamic Spreadsheet Matrix

The engine simulation is constructed around an incremental cycling model that tracks 17 distinct parameters across each discrete step of a single piston stroke (pp. 2-3). This framework continuously maps the shifting chemical mass balances and mechanical forces acting within the system (p. 2):

The 17 Core Simulation Rows

1. **Air Charge Remainder (%):** The percentage of the original compressed air charge mass still remaining in the storage chamber (p. 3).
2. **Transferred Air Mass (g):** The mass of air actively transferred from the air storage chamber into the combustion chamber (p. 3).
3. **Total Chamber Mass (g):** The total mass of the combined gases resting above the combustion piston (`PCfire`) (p. 3).
4. **Gas Temperature (°F):** The instantaneous temperature of the gases within the combustion chamber (p. 3).
5. **Combustion Pressure (PSI):** The pressure exerted by the gases inside the combustion chamber (p. 3).
6. **Total Hydrocarbon Mass (g):** The raw mass of carbon and hydrogen fuel present above the `PCfire` piston (p. 3).
7. **Carbon Mass & Moles:** The mass and corresponding mole count of carbon atoms in the chamber (p. 3).
8. **Hydrogen Mass & Moles:** The mass and corresponding mole count of hydrogen atoms in the chamber (p. 3).
9. **Nitrogen Mass & Moles:** The mass and corresponding mole count of inert nitrogen atoms present (p. 3).
10. **Oxygen Mass & Moles:** The mass and corresponding mole count of reactive oxygen atoms available (p. 3).
11. **Total Molecular Count (\(n\)):** The cumulative number of gas moles resulting from all combined atoms present above `PCfire` (p. 4).
12. **Incremental Fuel Mass Injected (g):** The precise weight of fuel added during the current step (p. 4).
13. **Rod Transmission Force (lbs):** The instantaneous linear force transferred down the solid `fire-hyd-rod` to the hydraulic pump piston (`PChyd`) (p. 4).
14. **Piston Displacement (in):** The linear distance traveled by the `PCfire` piston away from true Top Dead Center (TDC) (p. 4).
15. **Incremental Pump Volume (cu in):** The volume of hydraulic fluid successfully forced past the check valve into the high-pressure accumulator (p. 4).
16. **Storage Chamber Pressure (atm):** The internal pressure of the compressed air remaining within the storage chamber (p. 4).

17. **Combustion Pressure (atm):** The internal pressure of the gas above the `PCfire` piston expressed in atmospheres (p. 4).

⚙️ Geometric Baseline & Core Mechanical Design

The mechanical linkage throws out the traditional crankshaft, heavy flywheels, and connecting rods entirely (p. 7). Instead, it utilizes a direct, free-piston architecture where the combustion piston is rigidly coupled to a hydraulic pump piston by a single straight shaft (`fire-hyd-rod`) (p. 7). This translates fluid and gas expansions directly into linear high-pressure hydraulic output (p. 7).

- **PCfire (Combustion Cylinder) Diameter:** 3.5 inches (pp. 18, 27)
- **PCfire Piston Face Area:** $\pi \times r^2 = \pi \times 1.75^2 = \mathbf{9.62\text{ square inches}}$ (pp. 18, 27)
- **PChyd (Hydraulic Pump Cylinder) Diameter:** 2.6 inches (p. 19)
- **PChyd Piston Face Area:** $\pi \times r^2 = \pi \times 1.3^2 = \mathbf{5.31\text{ square inches}}$ (p. 19)
- **Total Cycle Stroke:** 2.6 inches total displacement (pp. 19, 27)
- **Accumulator Operating Threshold:** Minimum constant pressure of **20 atmospheres** ($20 \times 14.696 = \mathbf{293.92\text{ PSI}}$) (pp. 19-20)

Lever Calculation & Initial Combustion Pressure Minimum

To move fluid past the check valve into the accumulator, the mechanical forces transmitted across the solid rod must overcome the hydraulic resistance (p. 19):

$\text{Resistance\ Force}=\text{Accumulator\ Pressure}\times \text{PChyd\ Area}$

$\text{Resistance\ Force}=293.92\text{\ PSI}\times 5.31\text{\ sq\ in}=\mathbf{1,560.7}\text{\ lbs\ of\ linear\ resistance}$

To balance this force across the straight connection, the gas pressure acting upon the larger `PCfire` piston face must generate a minimum of 1,560.7 lbs of thrust (pp. 19-20):

$\text{Minimum\ Gas\ Pressure}=\frac{\text{Required\ Force}}{\text{PCfire\ Area}}$

$\text{Minimum\ Gas\ Pressure}=\frac{1,560.7\text{\ lbs}}{9.62\text{\ sq\ in}}=\mathbf{162.2}\text{\ PSI\ (or\ }\mathbf{11.04}\text{\ atm)}$

Applied Design Buffer

To provide a built-in safety margin to overcome static seal friction and initiate instantaneous positive kinetic acceleration down the rod, the baseline design peak pressure at Top Dead Center (TDC) is set to **12.0 atmospheres (176.40 PSI)** (pp. 22-23).

$\text{Peak\ Design\ Force\ at\ TDC}=176.40\text{\ PSI}\times 9.62\text{\ sq\ in}=\mathbf{1,697.00}\text{\ lbs\ of\ thrust}$

This creates a net accelerating force of **136.3 lbs** beyond the hydraulic resistance threshold to drive the piston assembly forward (pp. 23-24).

🔬 The "Chemical Lever" Solution to Thermodynamic Constraints

In a standard closed or static system, an engine cannot execute an expansion that is simultaneously **isobaric (constant 12 atm)** and **isothermal (constant 385°F)** without breaking the ideal gas law ($PV=nRT$), as the volume growth causes pressure and temperature to drop (pp. 23-24).

This limitation is bypassed by running an open, dynamically metered chemical injection loop during the initial expansion phase (pp. 25-26). Because this is a chemical reaction system, the number of independent gas molecules (n) is treated as a dynamic variable (p. 25).

When liquid diesel fuel ($\text{C}_{12}\text{H}_{23}$) is introduced into the superheated chamber, it shatters its heavy chemical bonds and reacts with oxygen (p. 25). A single molecule of liquid fuel breaks apart to create dozens of new gaseous molecules (CO_{2} and H_2O vapor) (p. 25). By timing the fuel injection rate perfectly, the percentage increase in total gas moles ($\frac{n_{2}}{n_{1}}$) precisely tracks and matches the physical volumetric expansion rate ($\frac{V_{2}}{V_{1}}$) (p. 26). Consequently, pressure (P) and temperature (T) stay pinned flat at **12 atm** and **385°F** during the controlled burn phase (p. 26).

The Engine Cycle Breakdown

1. **The Controlled Burn Phase (Phase 1):** The dual-stage ceramic injector meters fuel as the piston travels away from TDC, matching the $\frac{V_2}{V_1} = \frac{n_2}{n_1}$ ratio (p. 26). Pressure stays flat at 12 atm, delivering a sustained 1,697-lb force impulse to build massive kinetic energy (pp. 26, 28).
2. **The Inertial Coast Phase (Phase 2):** The fuel injector cuts off completely (pp. 24, 26). No new moles are added (p. 26). The gas now expands purely adiabatically, with internal pressure and temperature dropping (p. 26). The piston does not stop; the rod assembly carries immense momentum gathered from the initial 1,697-lb punch and easily coasts the remaining distance to the 2.6-inch Bottom Dead Center (BDC) mark, continuing to force hydraulic fluid into the accumulator (p. 24).

📊 Simulation Framework: Start and Increment 1

The cycle relies on an initial baseline condition where a trace gas mass (0.01% of the full air charge) rests in the cylinder head at 1 atm and 70°F (pp. 29, 32). At the start of the stroke, a metered **10% slice of the original total compressed air charge** is released concurrently with a matching fuel bolus (p. 29).

- **Total Full Air Charge Weight:** 6.58 grams (p. 38)
- **Absolute 10% Increment Mass:** 0.658 grams of air per step (consisting of approximately 0.153g Oxygen and 0.505g inert Nitrogen) (p. 38)

The Initial Simulation Ledger:

- **Column A: Start (TDC)**

    - *Distance from true TDC:* 0.00 inches (p. 30)
    - *Cylinder Physical Volume:* 0.0025 cubic inches (Clearance baseline) (p. 30)
    - *Cumulative Air Charge Mass Moved:* 0.01% residual baseline (p. 30)
    - *Total Gas Moles (n):* 1.0×10^{-6} moles (p. 30)
    - *Gas Temperature:* 70°F (p. 30)
    - *Combustion Pressure:* 1.0 atm (14.7 PSI) (p. 30)
    - *Linear Transmission Force:* 0.0 lbs (p. 31)
    - *Injected Fuel Bolus:* 0.00 grams (p. 31)
    - *Unburned Fuel Above PCfire:* 0.00 grams (p. 35)
- **Column B: Increment 1**
    - *Distance from true TDC:* **0.12 inches** (p. 30)
    - *Cylinder Physical Volume (V_{2}):* **1.157 cubic inches** (p. 30)
    - *Cumulative Air Charge Mass Moved:* 10.0% of full air charge (0.658 grams) (pp. 30, 38)
    - *Gas Temperature:* **385°F (844.67 Rankine)** (p. 30)
    - *Combustion Pressure:* **12.0 atm (176.4 PSI)** (p. 30)
    - *Linear Transmission Force:* **1,697.0 lbs** (p. 31)
    - *Injected Fuel Bolus:* **0.00067 grams of diesel fuel** (p. 31)
    - *Unburned Fuel Above PCfire:* **0.00 grams** (p. 35)

The physical volumetric equilibrium is calculated directly using the shifted ideal gas law ratio (p. 31):
$\frac{V_{\text{inc1}}}{V_{\text{start}}}=\frac{n_{\text{inc1}}\cdot T_{\text{inc1}}\cdot P_{\text{start}}}{n_{\text{start}}\cdot T_{\text{start}}\cdot P_{\text{inc1}}}$
When transitioning from the initial cold baseline up to the highly packed 12.0 atm at 385°F under active stoichiometric molecular expansion, the gas demands exactly 1.157 cubic inches of physical room to stay in static pressure equilibrium (pp. 31, 33). Dividing this required volume by the 9.62 sq in piston face yields a clean physical travel distance of 0.12 inches per 10% mass block (pp. 32-33).

🎨 Visual & Mechanical Geometry References

Fuel Injection & Ceramic Nozzle Core

The entry interface utilizes advanced structural ceramics such as Silicon Nitride (Si_3N_4) or Zirconia (ZrO_{2}) capable of withstanding operational environments up to 1,800°F while acting as total thermal insulators (p. 12). This isolates intense heat within the core fluid channel, protecting the surrounding 23-lb thorax engine frame from structural heat soak (p. 12).

- **Heating Core Elements:** Dual parallel Nickel-Chromium (Nichrome) high-resistance cartridge heater pins capable of operating up to 2,100°F without oxidation (pp. 9, 12).

- **Sensor Matrix:** Embedded low-diameter Type K or Type N high-temperature micro-thermocouples nested right at the micro-orifices of the nozzle tip to feed real-time millivolt tracking data back to the CPU (p. 12).
- **Regenerative Thermal Feedback Layout:** The ceramic injector body is designed to protrude or "poke" slightly directly into the active combustion chamber fire zone (pp. 13, 15). Once initial cycles are executed, the extreme heat retention of the ceramic allows the burning gas to keep the nozzle superheated, enabling the CPU to drop the active electrical current draw to the internal Nichrome wires down to zero during steady-state operation (pp. 13-14).
- **Zero-Oxygen Condensation Line:** Smooth, high-pressure delivery tubes completely isolate pressurized liquid diesel from atmospheric oxygen right up to the heated nozzle tip block, preventing pre-ignition detonation or varnishing (pp. 8-9). The micro-orifices force the superheated, pressurized fluid to undergo massive mechanical shearing and flash-boiling, fracturing the liquid into a high-surface-area vapor plume that catches fire spontaneously the microsecond it contacts incoming oxygen molecules (pp. 9, 14).

📊 Increment 2 Matrix

- **Column C: Increment 2**
    - *Distance from true TDC:* **0.24 inches** (p. 36)
    - *Cylinder Physical Volume:* **2.314 cubic inches** (p. 36)
    - *Cumulative Air Charge Mass Moved:* 20.0% of full air charge (1.316 grams cumulative) (p. 36)
    - *Gas Temperature:* 385°F (844.67 Rankine) (p. 36)
    - *Combustion Pressure:* 12.0 atm (176.4 PSI) (p. 36)
    - *Linear Transmission Force:* 1,697.0 lbs (p. 36)
    - *Injected Fuel Bolus (This Step):* 0.00067 grams (p. 37)
    - *Unburned Fuel Above PCfire:* **0.00 grams** (p. 37)

Because the air charge introduction and fuel bolus increments are kept perfectly uniform and linear (0.658g air and 0.00067g fuel per step), the total molecular mole count exactly doubles (pp. 36-38). Under ideal gas laws at a flat pressure and temperature, volume scales in direct linear proportion to mole count—meaning the required space doubles exactly to 2.314 cubic inches, moving the piston face cleanly to the 0.24-inch mark away from true TDC (p. 37).

End of Document Section. Ready for the next sequential files or instruction parameters.