

EXPERT SYSTEM BRIEF: THE 20,000-WATT DETAILED ARCHITECTURE BASELINE

Powerplant Designation: Twin-Opposed Free-Piston Hydrostatic Engine Set

Aircraft Configuration: Group 3 Tactical Cargo UAS (JTAARS)

Document Status: Final Optimization Freeze

Date of Record: September 21, 2026

Design Authority: Dr. Patrick Gray

I. IMMUTABLE POWERPLANT GEOMETRY & FLUID METRICS

The mechanical transmission completely eliminates traditional crankshaft limitations, flywheels, and wearing gaskets, converting chemical expansion directly into high-pressure fluid work through fixed, unalterable cylinder profiles:

- **Combustion Cylinders (PCfire):** 5.35-inch bore diameter machined from heavy 2205 Duplex Stainless Steel. Piston area equals **21.81 square inches**.
 - **Main Hydraulic Pumps (PChyd):** 3.25-inch bore diameter engineered to handle continuous high-pressure surges. Pump area equals **8.04 square inches**.
 - **Active Mechanical Throw:** 8.00-inch maximum linear travel length per single core stroke.
 - **Reciprocating Inertial Flywheel:** A **19.8-lb pure tungsten linear slug** embedded directly behind the steel crown of the combustion piston. This reciprocating mass acts as an internal kinetic battery, storing up to 52.3 ft-lbs of momentum to drive the assembly through the adiabatic expansion phase without stalling.
 - **Peak Casing Ceiling:** 2,721 PSI maximum allowable line pressure.
 - **Maximum Operating Pacing:** 80 Beats Per Minute (BPM) continuous duty ceiling to prevent electronic valve latency and hydraulic flow choking.
-

II. THE SOLID-STATE DIGITAL VALVING TRANSMISSION

To match the "bicycle principle" of continuous, ultra-fast stability trimming without inducing motor fatigue or lag, the fluid distribution uses a loopless, unidirectional digital cam framework:

- **The Unidirectional Sinusoidal Cam:** A continuous, multi-wave sine profile machined as **two bolted-together halves**. This split layout eliminates complex multi-axis CNC undercut machining traps and allows rapid field replacement or timeline advancements.
- **Non-Reversing Stepper Drive:** The stepper motor rotates continuously in a single direction. Rotational torque is translated into bidirectional linear port shunting as permanently lubricated roller bearings travel through the sinusoidal peaks and

valleys, effortlessly matching the drone's **2 to 20-millisecond flight stability response window**.

- **The 8-Bearing Square Cage Anchor:** The valve's T-stem is securely encased inside a square cage gliding between 8 rigid roller bearings. This constraint completely isolates vertical port adjustments while neutralizing severe tangential twisting loads caused by chaotic fluid surges.
 - **Passive Fluid Isolation:** A heavy-duty, spring-loaded mechanical check valve is nested between the pump face and the primary accumulator. This isolates high-pressure fluid, prevents electronic valve lag, and completely stops hot accumulator oil from back-flowing into the cylinder during the exhaust cycle.
-

III. REDUNDANT THERMAL COMBUSTION CONDITIONING

To bypass traditional diesel ignition delay and ensure reliable combustion across volatile atmospheric environments, the delivery network utilizes a dual-stage thermal array:

- **Zero-Oxygen Pre-Heating:** High-pressure metal delivery tubing completely isolates liquid diesel from atmospheric oxygen while pre-heating the fuel mass slightly above its spontaneous auto-ignition threshold.
 - **Instantaneous Nebulization:** Upon leaving the injector, the pre-conditioned fuel flash-boils into a micro-droplet mist with zero thermal inertia, catching fire the exact microsecond it makes contact with an oxygen molecule.
 - **Heated Ceramic Nozzle Insulators:** The fuel is sprayed through a Silicon Nitride (Si_3N_4) or Zirconia (ZrO_2) ceramic nozzle block capable of withstanding 1,800°F.
 - **Nichrome Insurance Array:** Embedded inside the ceramic core are dual parallel Nickel-Chromium (Nichrome) high-resistance cartridge heater elements capable of operating at 2,100°F. Monitored by an internal thermocouple, this array serves as a permanent glow-plug hotspot, ensuring instant cold starts on austere tarmacs and reliable auto-ignition during emergency recovery profiles.
-

IV. MULTI-ALTITUDE PNEUMATIC SELF-REGULATION

The engine achieves universal takeoff capabilities from sea level up to a mountainous 10,000-foot land elevation through passive, pressure-driven variable volumetric efficiency:

- **The Oxygen-Mass Constant:** The independent supercharger cylinder is intentionally oversized to pre-pack an identical mass of **0.474 grams of oxygen** per combustion stroke regardless of altitude density. Piston diameter of the Air Charge creation chamber is 6.2 inches, stroke is 8 inches.

- **Thin Mountain Profile (11,000 ft Ceiling):** Negligible atmospheric resistance allows the unlinked, floating air-charging piston to travel its absolute maximum physical path length, compressing the thin column up to 23 atmospheres to guarantee diesel auto-ignition.
 - **Dense Sea-Level Profile (The Pneumatic Brake):** Heavy sea-level air molecules create an aggressive pneumatic brake early in the compression stroke. This rapidly absorbs the piston's kinetic momentum, forcing it to short-stroke and turn around early. The shorter stroke naturally traps a smaller volume of dense air, perfectly equalizing oxygen delivery through pure physical feedback.
-

OF NOTE: The Magnetic Based Concept present in this engine design so that the CPU of the Engine can "keep up with" and "monitor" where exactly is the free piston assembly with respect to its distance from Top Dead Center (TDC) or from Bottom Dead Center (BDC) is present in this Engine Design. The system discussed below was originally considered but the form and location of the final Magnetic Sensor system has been changed, so the Magnetic Sensor System discussed below for this engine is no longer the Magnetic Sensor System in this engine design.

V. SELF-CALIBRATING INDUCTIVE TELEMETRY LOGIC

To avoid the wear, oil ingress, and failure points of sliding contact brushes or potentiometer arms, spatial tracking is transitioned to a solid-state, air-gapped linear sensor runway:

- **Thermally Isolated Tracking Line:** The engine block is physically lengthened, pushing the entire telemetry sleeve away from the heat of the combustion chamber to completely eliminate thermal expansion drift.
- **Stepped-Density Coil Winding:** The central connecting rod is machined from non-magnetic, non-permeable **Grade 5 Titanium (Ti-6Al-4V)** to safely bear continuous 17,215 lbs stroke loads. A 12 mm thick permeable pure iron disc is embedded inside the piston assembly, passing through a sleeve of 64 independent sensor rings wound with 30 AWG wire at a stepped turn density (30 turns → 40 turns → 50 turns).
- **The Inductive Lookup Table:** Every ring is paired with a Texas Instruments high-resolution Inductance-to-Digital Converter AFE (LDC1612 architecture). Because inductance scales with the square of the turn count (N^2), a specific inductive signature can only mean the iron disc is at one exact location. The CPU cross-references these spikes against a self-calibrating lookup table, mapping position down to the micron and refreshing the kinematic trajectory every **100 microseconds**.

VI. DUAL-DYNAMIC FAULT MANAGEMENT SCRIPT

Leveraging the real-time velocity calculations provided by the inductive lookup table, the engine actively diagnoses and corrects operational anomalies mid-beat:

1. High-Energy Over-Speed Safety (The Runaway Spike)

- **The Trigger:** A transient hydraulic drop or an oversized fuel charge threatens to send the piston violently crashing into the cylinder heads.

- **The Mitigation:** The 10-microsecond Grand Multiplexer grid evaluates velocity vectors at 0.004-inch increments. If a pre-programmed acceleration threshold is breached, the CPU cuts off fuel injection within 0.20 milliseconds. The leftover coasting momentum bypasses the 8.00-inch line, compressing heavy rectangular-wire **logarithmic die springs** inside a 2-inch over-travel pocket to safely brake the tungsten mass without metal-on-metal impact.

2. Low-Energy Short-Stroke Recovery (The Stall Rescue)

- **The Trigger:** A cold cylinder wall or a fuel delivery dip causes a weak combustion stroke, causing the assembly to freeze mid-cycle against the accumulator pressure.
- **The Mitigation:** The moment the inductive table flags a premature deceleration short of the 8.00-inch threshold, the CPU commands a 3-position directional valve to convert the main pump into a double-acting hydraulic ram. High-pressure fluid is injected into the pump face, physically ramming the rod backward by 2 to 3 inches. This rapidly compresses the trapped lean-burn excess oxygen cushion, where the glowing ceramic nozzle triggers an immediate secondary fuel re-fire wave to kick the powerplant back into its 18 kW loop within a single beat.

3. The Autonomous Total Mechanical Reset Sequence

- **The Trigger:** An anomaly occurs so severe that mid-stroke shunts or re-fires cannot save the cycle, forcing a hard flight-saving system reboot.
 - **The Mitigation:** If the iron disc remains stationary for more than 5 milliseconds, the engine computer flags a hard stall and signals the drone flight computer ("*We are so sorry, but we need to do an engine re-start...*"). While the opposite twin module alters its pacing to hold altitude, the engine CPU vents all internal combustion and supercharger chambers to atmosphere, converts the pump into a double-acting ram to pull the shaft to true TDC, refills the core with a fresh 0.474-gram air charge, and resumes the primary micro-pacing loop.
-

Please Note: This page is no longer correct for our final decision on how to manage a Low-Energy problem or for managing a High-Energy problem. The newer management plans for these two problems are described in the next page.

The method for the management of a high energy event (the combustion free piston assembly is moving too fast) is based on the magnetic sensing system that tells the cpu-e where exactly is the combustion assembly on its journey of 6.5 inches from TDC (top dead center of the cycle) to BDC (of the cycle). These values of position in the +/- 0.03 mm range and time in the 0.01 msec range are monitored and "watched" by cpu-e. The algorithm plan is that cpu-e will "notice" an unexpected energy event as it is evolving and cpu-e will use its authorities to stop further progression of the unexpected event. For a high energy event, when cpu-e "notifies" it is starting to be present, cpu-e will use its control authorities to ease off fuel flow rate and/or amount of fuel injection with fast effect using piezo electric fuel control valves.

For a low energy event (the combustion free piston assembly is beginning to be moving too slowly), as cpu-e "notifies" this, it will use its authorities to modulate the fuel system (again at high speed via the piezoelectric fuel injection control valves), except for a low energy event, cpu-e will command an increase in the fuel injection values flow rate and/or amount. Of note: this is a reasonable approach because the air injection charge for every cycle is set to inject more air (that includes oxygen) than was expected to be used by the cycle, thus if more fuel is injected than was planned, there is always oxygen around for that fuel to combust with. And another of note: the fuel injections at all times for all cycles and for any emergent fuel flow modulations by cpu-e, the fuel is injected via the heated ceramic fuel injection nozzles. The fuel always arrives in the combustion chamber at a fuel temperature significantly above its spontaneous ignition temperature, so all fuel injected into the combustion chamber whether a normal cycle injection, or a cycle modulation event, this fuel will ignite, any injected fuel never has the option of "declining" to ignite.

And cpu-e has authorities to evaluate and declare that a stall event is occurring, that cpu-e tried to mitigate it, that cpu-e now has the opinion that the stall event cannot be successfully mitigated, and cpu-e can "declare" an emergent restart is needed.

On this decision, cpu-e will "let cpu-d know this, advise cpu-d to rig the drone for single engine flying, will tell cpu-d what wattage output is probably available from the engine that is still currently working properly." cpu-d will acknowledge this declaration from cpu-e, cpu-d will rig the drone for single engine flying, and cpu-e will begin the steps to emergently vent all the chambers, emergently bring the free piston assemblies to TDC, and begin an emergent restart of a new cycle.

VII. AIRFRAME AND CARGO BAY INTEGRATION

Lengthening the engine block and mounting the dual modules side-by-side along the upper ceiling curve of the fuselage shell delivers massive layout advantages:

- **Physical Envelope:** The twin modules take up a minimal spatial ceiling envelope measuring **18.5" Long × 9.6" Wide × 9.6" High**.
- **The Cargo Bay HEADROOM Win:** Placing the engine assembly flush against the upper ceiling curve of the 19.0-inch thick central fuselage pod leaves a continuous, completely unobstructed clearance downstairs. This creates a wide-open, straight-through internal cargo tunnel measuring **26.4 inches wide by 9.4 inches high**, allowing combat cargo, ammo boxes, and medical coolers to slide smoothly into place entirely isolated from the engine's moving components.