**WHITE PAPER**

# The Genesis of Electro-Hydraulic Proportional Control: The 1971 Rugby Patents and the Foundation of Modern Pulse-Width Modulation (PWM) Fluid Dynamics

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## Executive Summary

This paper establishes the definitive historical and technical lineage of modern electro-hydraulic and electro-pneumatic proportional control, tracing its origin to the engineering breakthroughs achieved in Rugby, Warwickshire, in 1971.

While contemporary engineering literature frequently treats Pulse-Width Modulation (PWM) fluid control as a ubiquitous, anonymous industry standard—found in everything from modern dual-clutch automatic transmissions to high-pressure common-rail diesel fuel injectors—the foundational architecture of this technology was born out of a specific industrial directive: the need to achieve precise, electronic control over automatic vehicle transmissions and cruise control systems.

Prior to 1971, solenoid-operated valves were strictly binary devices, limited to fully open or fully closed states, rendering them incapable of the smooth, variable fluid pressure modulation required for sophisticated automotive dynamics. In response to this limitation, the author, alongside John Noddings and his team at Associated Engineering Developments (AE Developments), pioneered a radical departure from conventional fluid mechanics.

By applying a high-frequency, constant-cycling digital on/off electrical signal to a solenoid valve and dynamically varying the duration of the "on" window (the duty cycle), they proved that an analog fluid pressure wave could be infinitely and smoothly manipulated. This breakthrough was formally recorded in January 1972 through UK Patent 1,382,331, effectively defining the application of PWM to fluid dynamics decades before the technology was widely co-opted by global corporate entities.

This white paper presents the primary evidence, original schematics, and chronological timeline of the 1971 "Autotrans" and subsequent Econocruise systems. By documenting these facts, this paper redresses the historical record, ensuring that the critical bridge between electronic computing brains and physical hydraulic control is correctly attributed to its true British engineering origin.

## SECTION 1: Context and Technical Genesis

*The Cross-Disciplinary Leap from Fuel Injection to Transmissions*

The foundation of modern Pulse-Width Modulation (PWM) fluid control did not emerge from an isolated mechanical failure. Rather, it was born from a direct technology transfer between electronic fuel metering and automotive hydraulics.

Following several years of intensive involvement in developing an Electronic Fuel Injection (EFI) system at Associated Engineering Developments (AE Developments) in Rugby, the author was handed a new industrial brief: to create an electronically controlled automatic transmission.

At the time, the wider automotive industry viewed solenoid valves as binary "on/off" mechanisms. However, the author’s background in milli-second fuel pulse timing sparked a critical realisation: an electronic solenoid valve could be fundamentally repurposed. Instead of acting as a simple gate, the valve could be driven by a high-frequency, variable-duration electronic pulse sequence

—a PWM valve. This approach would allow an electronic brain to continuously adjust fluid flow, providing infinitely variable control over transmission shift sequences and shift quality.

*Empirical Development and the 1971 Prototypes*

The journey from concept to operational hardware followed a rigorous path of empirical validation:

1. The Paper Design:The initial mathematical models and circuit/valve architecture were mapped out to define how a constant frequency could modulate fluid pressure via a changing electronic duty cycle.
2. Bench and Vehicle Testing:The paper design was subjected to extensive bench testing to isolate fluid dynamics under pressure, followed by intensive in-vehicle calibration to smooth out physical shift points.
3. The Ford Capri Prototype:This empirical cycle culminated in a fully operational prototype system successfully installed in a 3-litre Ford Capri.

Corporate and International Engagement

The functional capability of the system immediately attracted high-level industry attention. In 1971, the 3-litre Ford Capri prototype was formally demonstrated to:

- The Board of Directors of Associated Engineering (AE), proving the commercial viability of the patent.

- Spencer King, the visionary engineering director of Triumph International, who recognised the system's potential to redefine vehicle refinement.

Following the success of these initial demonstrations, the technology garnered international interest. Both Volkswagen (VW) and BMW expressed keen interest in the system's capabilities, formally providing fleet vehicles to AE Developments for the installation and testing of further advanced prototype systems.

## SECTION 2: Empirical Validation, Corporate Trials, and Parallel Pneumatic Development

*Establishing the 20Hz Operational Benchmark*

Moving from a conceptual paper design to a physically viable electro-hydraulic system required solving a fundamental problem in fluid dynamics: finding an operational frequency fast enough to smooth out hydraulic pressure pulsations, yet matched to the mechanical response limits of a standard solenoid.

Through rigorous bench testing and live vehicle calibration, the author established 20Hz as the ideal nominal frequency. Operating the solenoid valve at a constant 20Hz, while dynamically modifying the duty cycle, successfully transformed erratic binary fluid movement into a smooth, linear hydraulic pressure wave. This specific frequency delivered the highly refined, seamless shift sequences and exceptional shift quality demonstrated in the 3-litre Ford Capri.

*The 1971 BorgWarner Evaluations*

The operational capabilities of the Autotrans Ford Capri prototype attracted intense scrutiny from major tier-one automotive suppliers. In 1971, senior engineers from BorgWarner conducted a formal evaluation of the vehicle.

Beyond standard road track testing, BorgWarner engineers subjected the vehicle to an aggressive, static roadside diagnostic test designed to push the PWM control logic to its absolute limits:

The Procedure:The vehicle’s brakes were fully applied while simultaneously depressing the throttle to 100% load.

The Result: Under extreme stall-test conditions, the electronic control brain accurately modulated the hydraulic fluid via the 20Hz PWM valves, causing the stationary vehicle to smoothly roar sequentially through its automatic shift pattern at a complete standstill.

This test conclusively proved to external industry giants that electronic duty cycles could master severe hydraulic line pressures under peak engine torque.

*The Parallel Timeline of Econocruise Pneumatics*

While the electro-hydraulic Autotrans system was being validated, a parallel development track was underway at AE Developments: Econocruise pneumatics. This system applied the identical core principle of high-frequency variable duty cycles to pneumatic actuators for electronic cruise control.

The historical discrepancy in patent dates between the two systems—where the primary Autotrans technology was patented in 1972 (UK Patent 1,382,331) while the Econocruise work was patented later in 1974 (UK patent 1,486,821)—was strictly a consequence of physical mechanical development rather than conceptual lag:

The Pneumatic Actuator Delay:During initial testing, an engineering fault was identified within the proprietary design of the pneumatic actuator.

The Impact:Rectifying this hardware fault required intensive redesign and iterative bench testing to ensure the actuator could reliably match the rapid electronics. This mechanical troubleshooting phase temporarily paused the timeline, leading to the two-year gap between the initial electronic disclosure and the finalised 1974 pneumatic patent filings.

**SECTION 3: Industrial Licensing, Manufacturing Overcomes, and the 23-Year Technology Adoption Curve**

*Public Disclosures and the 1973 Saloon Trials*

By 1973, the achievements at AE Developments (AED) had broken into the public eye. Official corporate press releases from 1973 formally announced a licensing arrangement with Volkswagen (VW). Concurrently, BMW advanced their evaluations by installing an AED electronic control unit directly into a high-performance BMW 3.0S saloon, logging real-world data on European roads.

While the internal corporate mechanisms of subsequent licensing and patent-sharing remained shielded from the engineering teams by AE management, the timeline of global automotive architecture makes the outcome clear. Having been handed fully functional prototypes and complete patent disclosures, industry leaders like VW, BMW, and BorgWarner absorbed the foundational concept of high-frequency variable duty-cycle fluid control, eventually refining and adapting it to fit their respective engineering structures.

*The Decades-Long Adoption Gap*

The true impact of the 1971 Rugby breakthroughs is highlighted by how long it took the rest of the global automotive industry to catch up.

Despite having the working AED prototypes in their possession in the early 1970s, it took these international conglomerates well over a decade to successfully integrate electro-hydraulic PWM control into their production powertrains. In some instances, it took as long as 23 years after the publication of UK Patent 1,382,331 for global Tier-1 suppliers to completely phase out purely mechanical or basic binary hydraulic logic and render PWM solenoids robust enough for mass production.

The industry did not invent a new concept; they spent two decades building the manufacturing infrastructure required to mass-produce the architecture Norman Hunt had already proven in a Ford Capri in 1971.

Solving the Econocruise Pneumatic Fault: A Lesson in Materials Science

The two-year delay before the formal filing of the 1974 Econocruise pneumatic patent provides a classic case study in bridging advanced electronics with imperfect physical manufacturing. While the 20Hz electronic pulse logic was flawless, early road testing of the pneumatic actuator revealed an intermittent, critical failure mode:

- **The Metallurgy Problem:** The initial batch of actuator housings suffered from poor-quality zinc-based alloy die castings. Air pockets were trapped inside the zinc matrix, directly adjacent to the precision control orifice.
- **The Failure Mechanism:** When subjected to intense under-bonnet engine temperatures, the air trapped within these pockets expanded. This physical distortion warped the internal dimensions of the zinc control orifice, physically jamming the high-speed PWM valve and preventing it from closing fully.
- **The Engineering Solution:** The author engineered a highly reliable system-level redundancy. A second, standard binary (on/off) solenoid valve was integrated into the pneumatic circuit. This valve acted as a dedicated electronic fail-safe mechanism, ensuring that if a mechanical or electronic fault developed in the system, the secondary valve could immediately isolate the circuit and guarantee vehicle safety.

## SECTION 4: Conclusion & Historical Re-Attribution

*The Indelible Bridge Between Logic and Fluid Dynamics*

The technological evolution of the automotive industry over the last half-century confirms that the modern vehicle is completely dependent on the marriage of electronic computing brains and physical fluid pressures. Every time a modern dual-clutch transmission executes a seamless millisecond shift, or a high-pressure common-rail diesel injector fires a microscopic mist of fuel at 2,000+ bar, it is executing the exact engineering logic pioneered in Rugby, Warwickshire, in 1971. The historical record must reflect that this was not a gradual, anonymous evolution by global conglomerates. It began as a distinct, cross-disciplinary breakthrough by an engineer who took the millisecond pulse principles of early electronic fuel injection and realised that a binary solenoid valve could be fundamentally repurposed.

*Final Statement of Priority*

By establishing the 20Hz operational benchmark, validating it through the brutal stall-testing of BorgWarner engineers in a 3-litre Ford Capri, overcoming the physical limitations of early zinc-alloy die castings with electronic fail-safe redundancies, and securing UK Patent 1,382,331, Norman Hunt and John Noddings drew the original blueprint for electro-hydraulic and pneumatic PWM control.

The fact that it took the world's leading automotive manufacturers anywhere from one to two decades to fully productionise this architecture is not proof of their invention; it is proof of the profound foresight of the 1971 AED design. This White Paper stands as a permanent, verifiable record to ensure that as technology continues to advance, the true genesis of the PWM solenoid valve is rightfully restored to its origin.