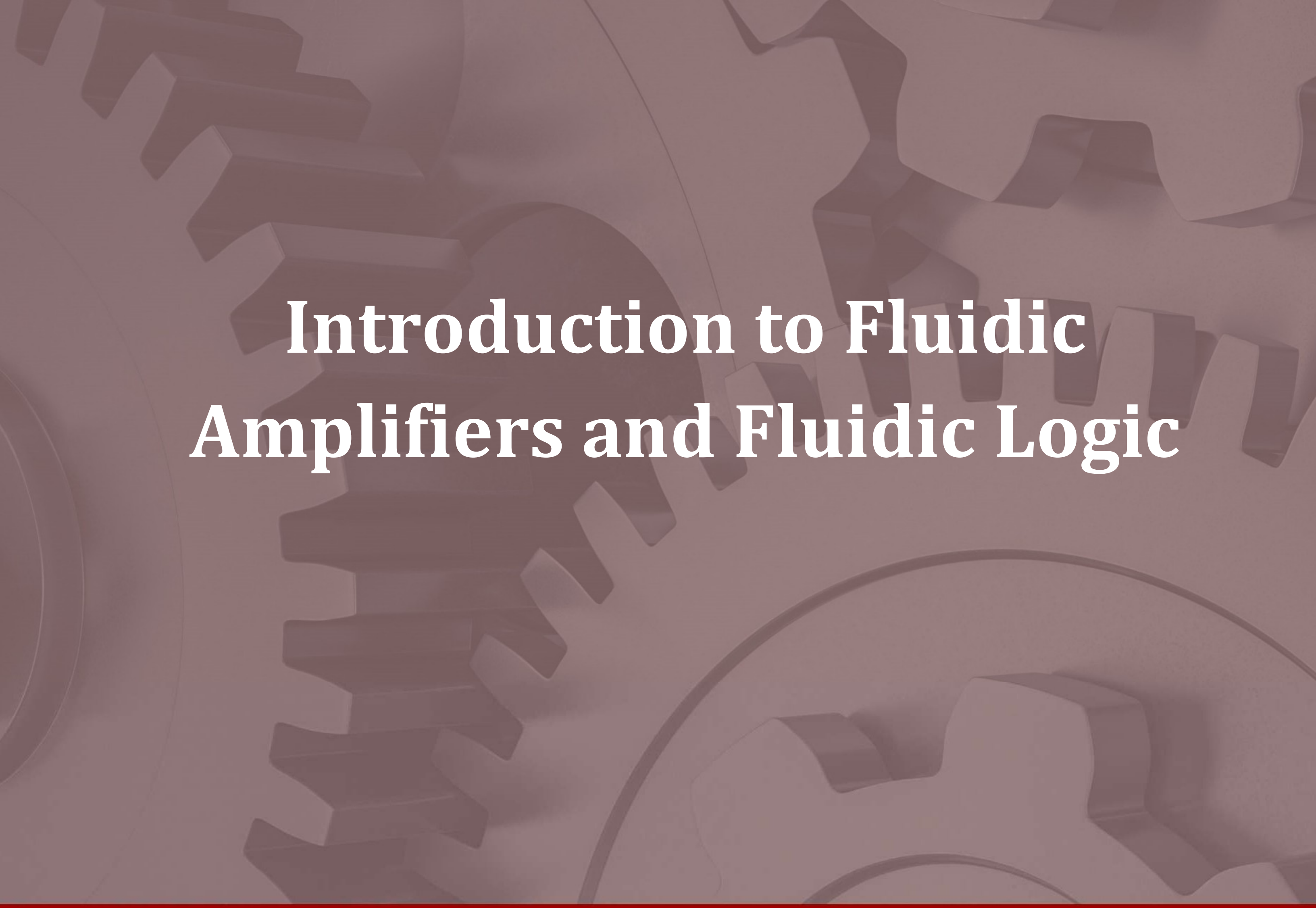
Introduction to Fluidic Amplifiers and Fluidic Logic



An Online Continuing Education Course for Engineers

Course Number: M-1068

Credit: 1 Hours / 1 PDH / 1 CPD

Introduction to Fluidic Amplifiers and Fluidic Logic

Michael Jacob Lunday, P.E.

1. Definition of Fluidics

Fluidics is a branch of engineering and technology that leverages the dynamic behavior of fluids—either gases or liquids—to execute essential functions such as sensing, signal processing (logic), control, and amplification, typically without relying on mechanical moving parts or electrical components. The term "fluidic" is derived from the combination of "fluid" and "logic," reflecting its ability to perform logical operations similar to those found in electronic systems but using fluid flow as the medium instead of electrical current. A fluidic system is characterized by the inclusion of one or more fluidic devices, which are components designed to manipulate fluid streams through fluid dynamic phenomena.

The defining characteristic of fluidic systems is their reliance on fluid dynamic phenomena to achieve control and processing signals, functions, and tasks. These phenomena include jet interaction, where a control jet directly modulates a supply jet; surface interaction, such as the Coandă effect, where a fluid jet attaches to a nearby surface; and vortex flow, where swirling fluid motion is used to regulate flow or pressure. Fluidic systems are particularly advantageous in environments where electrical systems may be impractical or unsafe, such as in high-radiation settings, explosive atmospheres, areas with extreme temperatures, and austere environments. For instance, depending on the circumstances, fluidic devices may operate more reliably in industrial settings where sparks from electrical components could pose a safety hazard. Additionally, the absence of moving parts in many fluidic designs enhances their durability and reduces maintenance needs, making them a robust choice for applications requiring long-term reliability. For example, fluidic valves are very reliable devices that do not suffer the same fatigue failure issues seen in certain spring-loaded valves.

Fluidic technology also offers unique advantages in terms of simplicity and cost-effectiveness. By eliminating the need for integrated electrical power, fluidic systems can be deployed in remote or resource-constrained environments, such as space missions or rural medical facilities. Moreover, the materials used in fluidic devices—often plastics or ceramics—can be fabricated using cost-effective methods like injection molding, further reducing production costs. As we progress through this course, we will explore how these characteristics have made fluidics a versatile technology across various industries, from aerospace to medicine, and demonstrate their applicability within modern engineering efforts.

As a refresher (or introduction) to fluidics, a cross-sectional view of a simple fluidic element, a monostable fluidic element, is shown below, along with snapshots of what the fluid flow looks like at various points in the cycle.

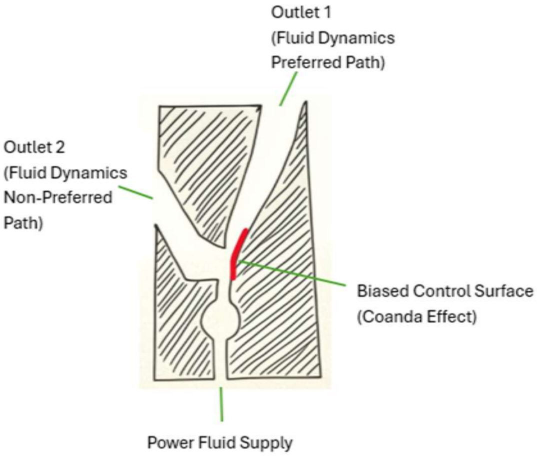


Figure A: Monostable Fluidic Element Cross-Section with Key Features Identified

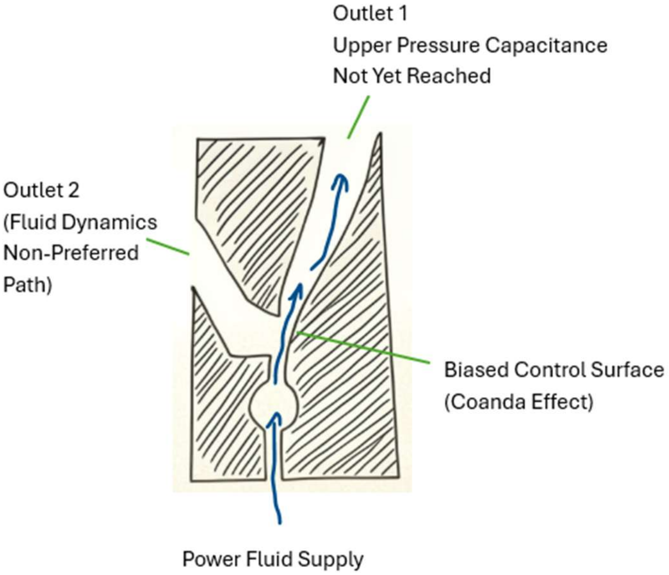


Figure B: Step 1 in Cycle-Monostable Fluidic Element (Outlet 1 Biased Flow)

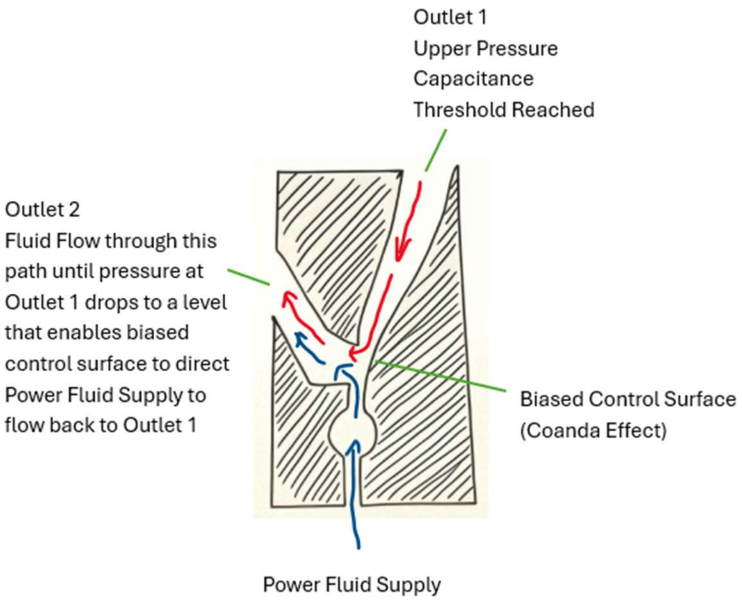


Figure C: Step 2 in Cycle-Monostable Fluidic Element
(Upper Pressure Capacitance Reached. Flow Switches to Outlet 2)

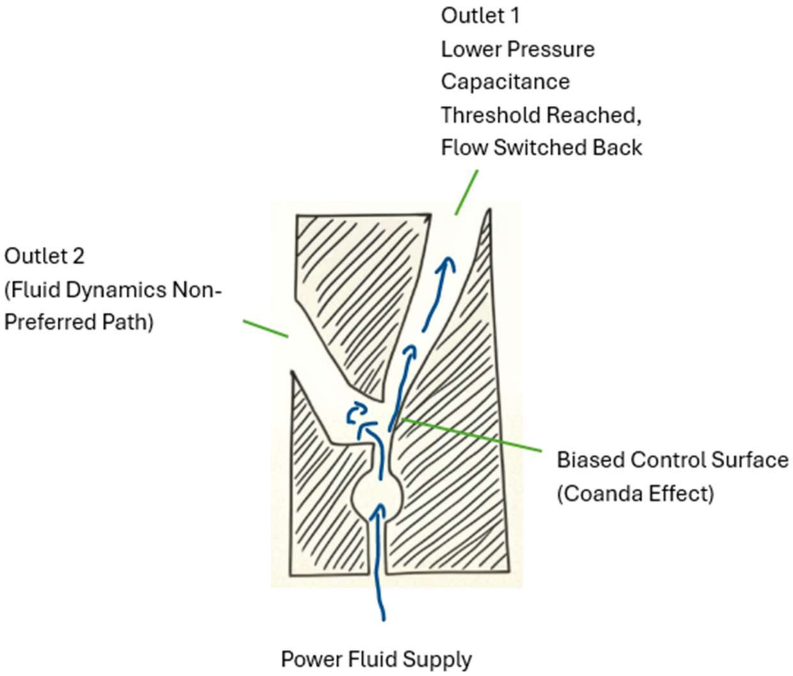


Figure D: Step 3 in Cycle-Monostable Fluidic Element
(Lower Pressure Capacitance Reached. Flow Switches Back to Outlet 1)

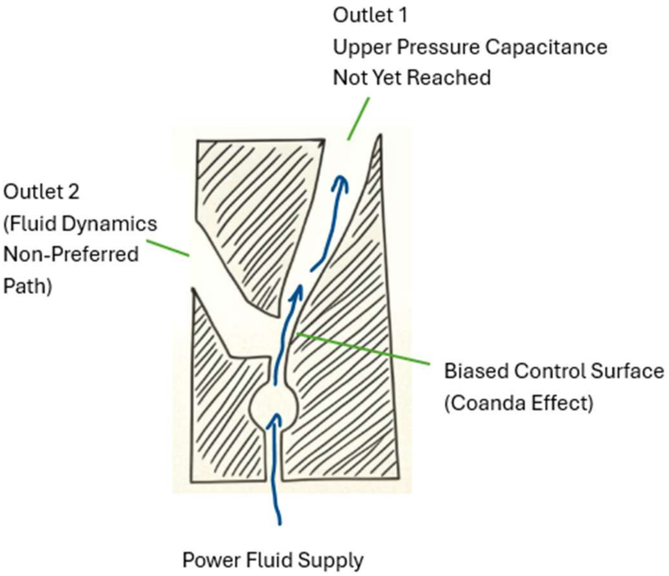


Figure E: Back to Step 1 in Cycle-Monostable Fluidic Element (Outlet 1 Biased Flow)
Cycle Repeats

2. History of Fluidics

The history of fluidic technology is a fascinating journey that began in the mid-20th century, driven by the need for reliable control systems in aerospace and defense applications. Fluidics as a formal discipline emerged in 1959 at the U.S. Army Harry Diamond Laboratories (HDL) in Washington, D.C., which was then known as the Diamond Ordnance Fuse Laboratory. Dr. Bowles, based out of the Baltimore area, made significant contributions to the field of fluidics during this time with the teams he led, establishing fluidics as a new discipline. It was at this time that the first fluid amplifiers were developed, marking the birth of fluidic technology. These early devices demonstrated the potential to control fluid flow without moving parts, using only the dynamic properties of fluids to achieve amplification and switching functions. This breakthrough sparked significant interest across government and industry, particularly in the context of the space race and military advancements during the Cold War era.

In the early 1960s, fluidics gained traction as a promising technology for control systems in aerospace applications. Agencies such as NASA, the Department of Defense (DOD), and the Atomic Energy Commission (AEC) invested heavily in fluidics research, recognizing its potential to address challenges in environments where electronic systems were vulnerable, such as high-radiation settings or extreme temperatures. NASA played a pivotal role in advancing fluidic technology through its various research centers.

The mid-1960s saw a surge in enthusiasm for fluidics, with the technology being heralded as a potential solution to a wide range of control system challenges. However, this period also marked a phase of overselling, where fluidics was promoted as a panacea for all control needs, leading to unrealistic expectations. In effect, it became a technology in search of a problem to solve. While fluidics has some distinct uses, it has limitations in terms of its cycle speeds and miniaturization scale, which prevent it from effectively competing against transistors in many applications. As a result, some attempts at applying fluidics failed to deliver the anticipated performance, causing disappointment among early adopters. Despite these setbacks, other implementations proved highly successful, particularly in aerospace and industrial automation. By 1972, when the NASA survey "NASA Contributions to Fluidic Systems" was published, fluidics had matured into a viable technology with operational systems in place across multiple sectors.

Key milestones in the evolution of fluidics include:

- **<u>Aerospace Innovations (1960s)</u>**: Fluidics was integrated into NASA programs for critical applications. For instance, a fluidic oscillator was used to measure total temperatures exceeding 1667°K (3000°R) on the X-15 rocket plane during a flight test on October 3, 1967, demonstrating its reliability at high Mach numbers. Similarly, fluidic servo valves were developed for nuclear rocket engines, operating in high-radiation environments where electronic systems would fail.

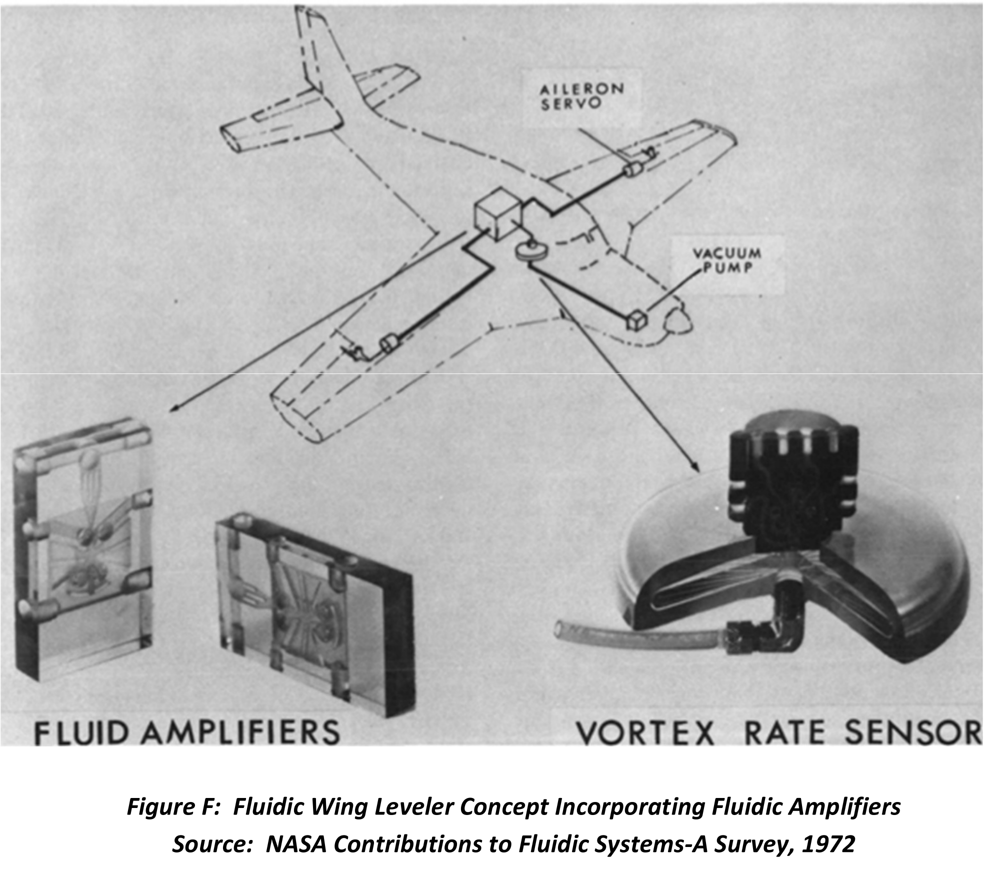


Figure F: Fluidic Wing Leveler Concept Incorporating Fluidic Amplifiers
Source: NASA Contributions to Fluidic Systems-A Survey, 1972
(National Aeronautics and Space Administration)

- **Industrial Adoption (1960s–1970s):** Fluidics found its way into industrial automation following NASA technology utilization conferences. In 1964–1965, Bardons & Oliver, a machine tool manufacturer, adopted fluidic controls for automatic turret lathes after attending a NASA conference at Lewis Research Center. This adoption was driven by the reliability, simplicity, and cost advantages of fluidics over electronic controls.

- **Medical Applications (1970s):** Fluidics began to make inroads into the medical field, particularly in devices that required operation without electricity. One notable example of its application was the Bowles/MSA breathing assistor, a fluidi evice that supported respiration in emergency settings, highlighting the technology's pote auster ditionally, the RETEC Breathing Assistor also ente sitive Pressure Breathing eans to ventilate patients

- **Automoti** idic technology in windshie ating, fan- shaped spra les use pressurized n cleaning across the w es visibility, promotes lon

The evolution of fluidi reduced costs and improved sca olding and precision casting enable chnology more accessible for com acturing), additional manufacturing luidics continues to inspire innov , such as emergency medical soluti esponse. The historical trajectory of fluidics under chnology, overcoming early challenges to establish itself as a reliable and vers olution across multiple domains.

3. Analogy Between Fluidic and Electrical Circuits

One of the most effective ways to understand fluidic systems is by drawing an analogy to electrical circuit logic, which is a framework familiar to many engineers. Just as electrical circuits use components like resistors, capacitors, and transistors to manipulate electrical current for functions like amplification, switching, and logic processing, fluidic systems use fluid dynamic phenomena to manipulate fluid flow—either gas or liquid—to achieve similar functions. This analogy not only simplifies the conceptual understanding of fluidics but also highlights its potential as an alternative to electrical systems in specific applications.