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Propulsion Control Technology Development in the U. S. – A Historical Perspective

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Extended Abstract

ABSTRACT

This paper presents a historical perspective of the advancement of control technologies for aircraft gas turbine engines. The paper primarily covers technology advances in the United States in the last 60 years (1940 ~ 2002). The paper emphasizes on the pioneering technologies that have been tested or implemented during this period. The paper assimilates knowledge and experience from industry experts, including personal interviews with both current and retired experts.

Since the first United States-built aircraft gas turbine engine was flown in 1942, engine control technology has evolved from a simple hydro-mechanical fuel metering valve to a full-authority digital electronic control system that is common to all modern aircraft propulsion systems. At the same time, control systems have provided engine diagnostic functions. Engine diagnostic capabilities have also evolved from pilot observation of engine gauges to the automated on-board diagnostic system that uses mathematical models to assess engine health and assist in post-flight troubleshooting and maintenance. Using system complexity and capability as a measure, we can break the historical development of control systems down to four phases: 1) the start-up phase (1942 – 1949), 2) the growth phase (1950 – 1969), 3) the electronic phase (1970 – 1989), and 4) the integration phase (1990 – 2002). In each phase, the state-of-the-art control technology is described; the engines that have made historical landmarks, from the control and diagnostic standpoint, are identified. Then the historical perspective of the engine controls in the last 60 years is presented, in terms of control system complexity, number of sensors, number of lines of software (or embedded code), etc.

This paper is dedicated to all those who have contributed to the advancement of air breathing propulsion control capabilities in the world.

1.0 INTRODUCTION

This year commemorates 100th anniversary of the Wright brothers' flight. The Wright brothers' flight was the first *powered* flight, where both the airplane and the engine were designed and built by the Wright brothers. This first powered flight sparked enthusiasm about aviation in the world. It created a mature industry that has revolutionized transportation. In the past 100 years, aviation has become a symbol of innovation with record-setting breakthroughs, many of which have been contributed by advances in engines, or propulsion systems. During this period, propulsion systems have evolved from piston engines (the first generation, 1903-1945, [1]) to jet engines [2, 3] (1942-present). This paper provides a historical perspective of the development of jet engine control technologies; specifically, it focuses on the technical advancements of turbofan and turbojet engines in the United States during the past 60 years. This historical period is further divided into four controls developmental phases as follows:

1. Start-up phase, 1942 – 1949.
2. Growth phase, 1950 – 1969.

3. Electronic phase, 1970 – 1989.
4. Integration phase, 1990 – 2002.

In each phase, a brief description of the key technologies is first presented, then the engines that have made historical contributions are tabulated. Section 6 presents a global view of the evolution of the controls technologies in the last 60 years. Before we look back in history, a brief review of the gas turbine engine control principle may be helpful.

A simple engine control system computes the amount of fuel needed for the engine to produce a desired power (or thrust), based on pilot's power request through a throttle (or a power lever); then it meters the right amount of fuel to the engine's combustion chamber(s); and it maintains the engine power at the desired level in the presence of air flow disturbance and changes in flight conditions. Figure 1.1 illustrates this *fuel* control system and identifies the various components needed to make the system work. The valve is usually called an *actuator*, whose position changes with the fuel flow command, and the fuel flow is called a *controlled variable*.

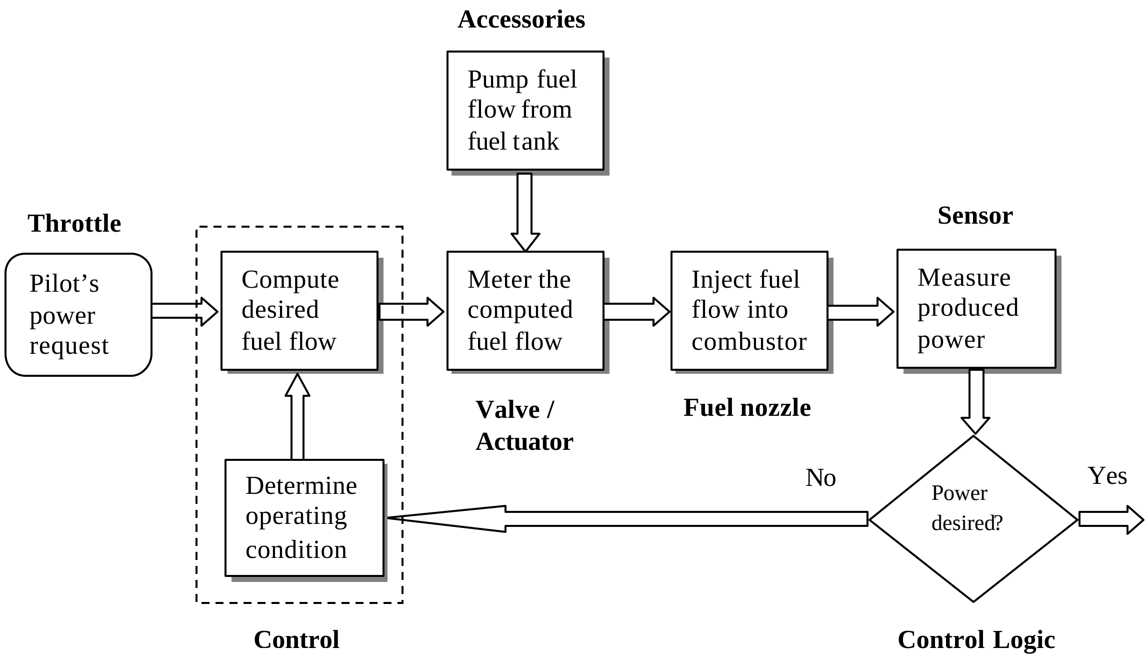

Figure 1.1: Functional process diagram of a simple engine control system

If we change "power" in Figure 1.1 to "turbine temperature," then the process represents a temperature control system, or a temperature governor. Likewise, if we change both "power" and "fuel flow" to inlet guide vane angle (IGV), then the diagram becomes an IGV control system.