The Amazing Story of Digital Fly-by-Wire

Darryl Sargent
Draper Laboratory

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Today, I’d like to tell you the story of Digital Fly by Wire, and start by taking you back to May 25th, 1972.

It was a typical day at Edwards Air Force Base. Blue skies, light winds. A great day for flying.

As NASA research pilot Gary Krier climbed into the cockpit of his F-8 Crusader, he did so with extra-ordinary anticipation, for this was no ordinary fighter jet.
F-8 In Fight

Aside from the NASA markings on its tail, to all outward observers it looked like a normal F-8. Built 14 years earlier as the Navy’s first carrier-based supersonic fighter jet, F-8’s had seen extensive action in Vietnam engaging North Vietnamese Mig-17s.

On the inside, this aircraft was very different from all other airplanes. The F-8, and all other aircraft of its day, had mechanical linkages that connect the pilot’s stick and rudder pedals to the rudder, ailerons, and other aerosurfaces. Moving the stick or pedals moved mechanical and hydraulic linkages that in turn moved the control surfaces. But on this aircraft, all of these mechanical connections had been removed.

*For the first time there was no direct connection between the pilot and the control surfaces, not even as a backup system.*

In this F-8, the mechanical system was replaced by a digital computer that sensed the pilot’s inputs, and then commanded remote hydraulic actuators to move the aerosurfaces.

*For the aircraft to fly at all, the computer had to work.*

As Gary Krier took off that day, he had confidence that he could fly this new kind of airplane. After all, he had flown un-modified F-8s to learn their flight characteristics, and had flown 200 hours in the simulator with the new fly-by-wire systems. *He thought it would work, but would it? He wouldn’t know until he got the bird into the air.*
This is the story of Digital Fly By Wire, and the crucial role that Draper Laboratory played in developing and fielding this technology.

It is a story that starts with the first free flight of the Wright Brothers, and extends into every human-rated spacecraft and modern aircraft. It is a story of how a few individuals with extraordinary vision changed the future of aviation.
Why use a computer to fly an airplane?

The first reason is that using a computer and electrical signals transmitted over wires is much lighter than using a series of mechanical control linkages, so that the airplane is lighter, faster, and more fuel efficient. All very good things if you are building an airplane.

The second reason is more subtle. Using a computer in the control loop allows you to augment the pilot’s inputs to the point where you can safely fly even an unstable airframe. Unstable means that without control inputs, small disturbances can cause dramatic loss of control. Perhaps the easiest demonstration of this is when you try to balance a stick in your hand.
Balancing Stick

Unless you move quickly and precisely to keep the base of the stick underneath its center of mass, your stick is going to fall over. If you can sense the motion of the stick and react quickly, you can keep it balanced. This is what computers are very good at – doing rapid and precise calculations.

*By now you are asking – why would you want to fly an unstable airframe? It turns out that aircraft that are marginally stable or unstable can maneuver very quickly, which is of great value when you are a fighter pilot trying to out-gun an enemy fighter. But some instability is good even for conventional aircraft.*
This is not a new concept - in fact it was first discovered in the earliest days of aviation by the Wright Brothers. Before their historic flight in 1903, most of the basic problems of flight had been worked out. We knew how to make strong, light weight structures, and wings capable of generating enough lift to get them into the air.

We also knew how to make engines with enough power to overcome drag and generate enough speed to cause them to become airborne.

We knew how to make the airplanes inherently stable so that they would return to level flight after a control input.

All the pieces of the puzzle were solved, and many teams were engaged in an intense competition to be the first to achieve human flight. Yet time and again the vehicles would crash whenever the wind would veer or gust. The problem was that the aircraft were too stable – so stable that the pilot could not respond to the changes in the wind. It was the Wright Brothers who first understood this problem, and deliberately made their airplane with negative stability - depending on the human pilot to make it stable. This gave them both the control they needed to direct the aircraft and the agility to respond quickly to winds and gusts.
Our own Doc Draper chose to tell this story in great detail when he gave the prestigious Wilber Wright Memorial Lecture in 1955 to the Royal Aeronautical Society in London. At the time of his talk, there were a wide variety of electro-mechanical autopilots and stability augmentation systems being developed, and Doc laid out the history of flying unstable aircraft and his vision for an “All-Manoeuvre Flight Control System” where some day - with the aid of advanced instrumentation “Manoeuvres of all kinds would be realized to the ultimate performance limits of fast and fantastically powerful aircraft”. That vision became a reality with the F-8 Digital Fly by Wire program.

All-Manoeuvre Flight Control System

“Manoeuvres of all kinds must be realized to the ultimate performance limits of fast and fantastically powerful aircraft”. - Charles Stark Draper
In the early 1970’s a small team at NASA’s Dryden Flight Research Center decided to take up the challenge of flying an airplane with a computer. They worked out their plan and flew to NASA headquarters to try to get funding for their project. There they met with the Deputy Assistant Administrator for Aeronautics, who happened to be Neil Armstrong.

Neil was very excited about the project, but balked when he heard that they planned to use an analog computer. When told about the difficulty of finding a reliable digital computer, he said “I just went to the Moon in one” referring to the highly reliable Apollo Guidance Computer. He suggested that they contact Draper Laboratory about using modified Apollo hardware and software for the F-8 program, which led to a long and successful collaboration between Dryden and Draper Laboratory, with Draper supplying the sensors, computers, and software for the program.
Over the course of the next 12 years, the heavily modified F-8 flew 211 times. Initial flights used a single highly reliable Apollo Guidance Computer and an independent analog backup computer. With only a $1M of funding in the first year, they demonstrated that a computer could fly a complex aircraft using digital control augmentation.

The program then moved on to demonstrate a more commercially viable approach – using three IBM AP-101 computers voting as a redundant set, and effectively operating as a single computer to control the aircraft. At the tail end of the program, the F-8 became a test bed for the Space Shuttle’s avionics. Total spending on the program was less than $12M, but it left an impressive legacy of technology that formed the basis of the avionics for all future advanced aircraft and spacecraft.
In military airplanes, the obvious advantages of improved maneuverability caused this technology to be immediately adapted in the F-16 and all subsequent fighter aircraft, and enabled the first use of stealth technology in the F-117A and the B-2, neither of which could fly at all without active control. It also found a home in commercial airplanes for its weight savings and reliability, first implemented in the Airbus 320 and later in the Boeing 777.
In spaceflight, the F-8 system was a direct predecessor to the AP-101 based Space Shuttle avionics, and various versions of this technology have been employed in all of America’s human spacecraft since the Shuttle, including the systems Draper has developed for the X-38, Space Launch System and the commercial systems that will ferry cargo (Cygnus) and crew (DreamChaser) to the International Space Station.
The real significance of the F-8 Digital Fly By Wire program is its human legacy – showing what a small team with vision, team work and a little bit of funding can accomplish.