Taking Control by Wire

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The Falcon 7X's pioneering fly-by-wire system is the future here today.

By Ross Detweiler

About three years ago, I flew a Falcon 900EX from San Francisco to Columbus, Ohio. Arriving late at Lane Aviation, the good folks of the night staff quickly and competently “flushed and fueled” the three-holer.

Inside the FBO, there was a silver-haired gentleman with a Segway, one of those two-wheeled transporters upon which the rider merely stands, holds the handlebars, leans in the direction toward which he wants to travel and moves out. How hard could this be to master? I asked for a turn and was granted a ride down the long hallway.

I didn’t do well. It seemed to me a hard machine to control smoothly, and I wiggled and tortured my way about halfway down the hall and managed to turn it around without damaging the doors of various offices or knocking any pictures off the wall. When I got back to the front, the old man was shaking his head.

“Quit trying to balance this thing. It balances itself. Just stand on it, think about which direction you want to travel, and go. It’s that simple,” he said. “My five-year-old granddaughter doesn’t have the problems that a pilot does because she doesn’t try and control it. Pretend it has four wheels and just stand on it.”

With that advice, it was, instantly, a lot of fun and easy to maneuver in precisely small radii. Keep this story in mind. I didn’t realize it at the time, but it was a breakthrough that I would use later.

We Are FBW

At Dassault Falcon Jet’s big annual breakfast at the NBAA Convention several years before the above incident, the inventor of the Segway transporter, Dean Kamen, spoke. A quiet-spoken genius in my estimation, Kamen’s not just smart, but he has the ability to make his genius understandable to the rest of us. He’s working on numerous projects including water
controls. Pull too hard at too high an airspeed and you can overstress the airplane, or pull too hard at too low a speed, and you can stall it. Thus the pilot is connected mechanically to the flight controls of the airplane. Regardless of the speed of the airplane, or outcome of the input, the controls will respond to the pilot, the only “brain” in the operation.

Ask someone about the difference between fly-by-wire and conventional control systems and they’ll likely respond, “The controls are commanded by electrical impulses instead of cables.” That’s true, but the real difference in an FBW system is the computers that receive control inputs and direct control movement. Wire is just the medium for transporting those commands. The Falcon 7X has three main computers that protect against overspeed, stall and overstress; provide stability augmentation; auto-trim the airplane; “consider” pilot inputs to the flight controls; and optimize configuration. Three secondary flight computers back up the main computers.

In the god-awful event that all six of these digital computers fail, there is an analog computer that controls the two flight spoilers with rudder pedal displacement and the trimmable horizontal stabilizer with the pitch trim switch.

You don’t land the airplane in this analog computer “manual” reversion. You keep it right side up while you “reset” the digital computers. The odds of that happening are 10 to some incredibly negative exponent, but it’s nice to know you never reach a point where you have no control. An engineer told me that.

I think of these computers as aids, not replacements for my brain. I like to relate a story about a cardiac surgeon who was a passenger on a Global Express I was flying. He was a private pilot with his own light twin. (Don’t you love the way these guys become the “expert” in the back, telling all the folks what you’re doing up front and why?) Nevertheless, he made the comment, “It’s all done with computers these days. Believe me, I know.”

I asked him if he operated at one of those hospitals that used computers for different surgeries.

“Why, yes. It’s the latest state of the science.”

“That means I could be a heart surgeon then, right?”

“Well, not exactly,” he said condescendingly.

“The doctor still has to know what the computer’s doing to his patient and know and be proficient in the intricacies of whatever procedure is being performed. He’s still the surgeon.”

Exactly.

In the 7X, computers “judge” what I want to do with the airplane. They guard against my getting too slow or too fast. I don’t have to “tickle the stall” to get max performance in a wind shear or terrain avoidance maneuver. I just pull as hard as I can, in the direction I want to go, and I’m obtaining the maximum performance I can get toward my goal. I don’t have to crosscheck all my attitudes with airspeed. I should, but if I don’t, I can neither stall, nor pull the wings off. I don’t have to remember to retract the flight spoilers or extend or retract certain high-lift devices at

purification, but at the time Dassault was trying to get the attendees more comfortable with the fly-by-wire (FBW) concept, and Kamen was the perfect person for the task.

At one point he held up a hand and wiggled his fingers. “Fly-by-wire,” he said. “Electrical impulses from my brain travel down my arm to receptors where that electrical impulse is changed into a mechanical motion. That’s fly-by-wire.”

By gosh, he was right. We don’t have cables running up the length of our arms and connected to a turnbuckle on the side of our neck. We don’t set a line of machinery in motion just to move a finger. Rather, we “think” the movement electrically and it happens. We are fly-by-wire.

Dassault got its money’s worth out of that plate of scrambled eggs.

In a conventional flight control system, the pilot moves a wheel or stick and rudder pedals to input commands to flight controls. Those commands go mechanically into tensioned cables that move over numerous relay pulleys, bell cranks and artificial feel inducers. This input eventually arrives either directly at a flight control or, in boosted systems, at a hydraulic actuator where it moves valves that port fluid to the piston of that actuator and move the flight control connected to that piston.

Pilots are responsible for cause and effect in terms of the amount of force they apply to the
critical times. My thinking is backed up by a computer that is programmed with pre-set limits.

**From Input to Control Movement**

In Dassault's FBW system, control inputs first go to Flight Data Concentrators. These electronically gather the wants and wishes of the pilots through their inputs to the side-stick controllers and the rudder pedals. If the autopilot is on, the concentrators gather the flight director's wants and wishes.

When I say they "gather" the input, I'm using pilot jargon, not engineering terminology. For instance, there are 20 potentiometers in each side-stick controller that electronically measure the controller's direction, rate and length of time of displacement. This is an extremely sophisticated system. Gathering is done through electrical impulses fed to all six flight control computers.

To allow the airplane to respond to the commands appropriately, the computers must first ascertain the airplane's current performance.

In conventional aircraft, the pilot determines an aircraft's condition by gathering information gathered from various sources including pitot pressure, static pressure, slip and temperature. The pilot reads this information as it is displayed on instruments in the cockpit.

In an FBW system these air data inputs have to be transmitted electronically to the computer. On the 7X, the electrical inputs come from four ADS (air data system) "smart" probes — number one to the pilot, number two to the copilot, number four to the backup airspeed and altitude indicator, and number three backs up any of the other three positions. A reversionary panel allows the pilot to move ADS one, two or three to either the pilot's or copilot's side. These ADS smart probes are information gatherers of the computerized FBW system. They're important.

Other computer inputs come from the IRSes, the AHRSe, the flaps, wheel speed and WOW sensor.

Output from the flight control computers goes to four Actuator Control and Monitoring Units. The purpose of these is to receive the inputs from the operating Flight Control Computers and send the electrical commands to the desired flight control actuators. Later in the process these same components monitor flight control movement. The electro-hydraulic actuators' ports are opened in response to electrical signals telling them how much and how fast to operate.

There is also a maintenance and avionics interface computer that monitors the performance of all the components and determines how "well" they are, which is to say how many of the components that should be operating are doing so.

**Why So Many Computers?**

There are three sets of flight control laws at work in the Falcon 7X's FBW system. The three main "dual lane" (lane A controls, lane B monitors) computers are dominant. The secondary computers take control only when all three of the main computers have failed.

With all three of the main computers in control, the system is in "normal" mode. All the protections of the system are available. If one of the main computers is lost, the pilot may still maintain the "normal" laws profiles. If two of the main computers are lost, the system goes to "alternate" laws, which means that some of the protections are unavailable. If all three of the main computers fail, the pilot is in direct mode, basically flying an airplane with the secondary flight control computers, which are single-channel design with no monitoring of the demanded inputs for compliance with the protections. When in direct mode, a careless pilot can overstress or stall the airplane — Hell-o — as has always been possible with cable controls.

To ensure there is always electricity to run through the wires, the system can be controlled with just one of three generators functioning. If no generators are working, the system still can be electrified through batteries or inputs from a PMA on either the number one or two engine. If all that fails, there is a RAT for power. You must have some hydraulics.

**Why the Side Stick?**

FBW offers a chance to make a big change in the way the pilot interfaces with the control of the airplane. When I first saw FBW technology, it was in the F-16. Although I never got the opportunity to fly that machine, I cannot imagine any setup more natural to a pilot. A reclining seat, a throttle in one hand, stick in the other, the pilot's shoulders relaxed, and arms supported in side rests to help accommodate the g forces. Perfect.

Ever since seeing that first F-16, it has been my opinion that there can be no better fly-by-wire setup than the way General Dynamics, or Dassault, or Airbus have designed theirs. You can't improve on the natural position of the hands and arms with side-stick controllers. To take this marvelous technology and attach it to a yoke or a stick between the pilot's legs is like putting a three-speed shifter on the steering wheel column of a new Corvette. A word of advice to any manufacturer planning on "improving" FBW: The center yoke, or the center control stick, is dead. Move on.

That, of course, is my opinion.

**Let's Fly It**

Any pilot who has flown a fighter, a helicopter or even a Cub with a control stick knows not to "grab" the thing. Rather, you put your right wrist on your right leg and "touch" the stick. When learning to fly formation or to refuel in flight, the proximity of the other aircraft typically
causes students to overcontrol because they're holding the stick too tight. A crutch that often helps students ease up is to place a pencil in their hand and explain, "If you feel that pencil, you're holding the stick too tight."

In formation flying, precise fore and aft movements of the stick are made with the wrist. Left and right movements are usually made with the thumb in back and two fingers touching the front of the stick. The extension-retraction of those two fingers is roll control in formation. The familiar advice is, "Put it where you want it and trim off the pressure." The trim button on most high-performance aircraft is located on the top of the stick. The thumb is used to trim off forward pressures being held by the two fingers or rearward pressures held by the crook between the thumb and two fingers.

Obviously you need not have flown fighters to easily maneuver the 7X, but that experience gave me a good point of reference to start my FBW indoctrination. Work the stick with the thumb and tips of two or three fingers. Put the airplane where you want it and just wait a second. It trims off the pressure to stay there.

The 7X will coordinate my turns and trim off the pressures caused by my changes to the flight path or speed. It is a "flight path stable" airplane. Remember that flight path is the track the center of gravity of the airplane makes through the air. It is not pitch.

In addition to the 7X's adjustable pilot seat and pedals, there's a soft pad behind the side stick that adjusts to relieve any tension from your hand.

Take off and rotate the airplane into the flight director cue. Gear up, hold attitude for a second and then let go. The airplane stays right there. When you get to 400 feet, clean up, lower the flight path and pull the power back to climb. If the departure calls for a turn, roll into it, neutralize the aileron pressures, hold for a second and let go. The airplane stays there. On final you roll out, aim the airplane at the end of the runway, set the power and relax; it stays aimed at the end of the runway. Only wind can change its destination.

**How Not to Fly a Control-by-Wire Airplane**

Since the 7X maintains flight path, its attitude may change in the doing, especially if you're hand flying the airplane with the auto throttles off. This can require some mental adjustment, especially among experienced pilots.

We've all been taught that when flying attitude instruments, all changes in airplane motion are made with reference to attitude. We don't push forward on the stick while looking at the altimeter. We reference the attitude indicator and lower the pitch to correct altitude excursions. We reference the attitude indicator when adjusting power, and again when correcting changes in our flight path caused by the changes in power.

But, again, to maintain its flight path the 7X may automatically change attitude — slightly, but perceptibly. The pilot would also have changed the attitude to accomplish what FBW did automatically, but since the change was uncommanded, the pilot might reflexively return the aircraft to its former attitude.

At that point, the pilot would cross-check performance instruments only to discover they're moving because he's now disrupted the attitude needed to maintain the stable flight path he requested in the first place. He re-corrects and the oscillations continue.

In effect, the pilot is trying to balance the Segway.

Don't fight the fly-by-wire. Let it maintain the airplane's flight path. The 7X cannot be flown the same as any other airplane, but once you let it maintain flight path and change only performance, piloting becomes as easy as riding a Segway.

The Falcon 7X fly-by-wire system, derived from years of Dassault fighter experience, is a pioneering technology for business aviation. That others will follow is a given since this is the way that future airplanes will be controlled. There is no going back to non-computer monitored flight controls at this stage. Fly-by-computer is here to stay.