# Flying the Falcon 7X

### The world's first purpose-built fly-by-wire business jet capitalizes on Dassault's Mach 2 technology.

*By Fred George*

**W**hat's it like to pilot the world's first fly-by-wire (FBW) business jet? Dassault provided *B&CA* with an exclusive opportunity to find out firsthand when we belted into the left seat of the Falcon 7X at its Istres Air Base Flight Test Center for a two-hour demo flight in mid-July.

This particular Falcon 7X, however, had some flight test development features you'll never see in a production aircraft. Most notably, it had two guarded switches on the instrument panel that, in essence, allowed

Dassault test pilots to perform a progressive, digital lobotomy on the Falcon 7X's fly-by-wire brains (see "Falcon 7X Fly-by-Wire System Architecture" sidebar).

We soon would learn that the first switch would enable us to disable the normal law mode of the FBW system so that we could fly the aircraft using alternate law in which some or all of the high-level FBW functions are not available. The second switch degraded the FBW system to its most basic direct law mode in which it functions essentially the same as a primitive hydromechanical flight control system. In direct law mode, there is no artificial feel, nor envelope protections or stability enhancements, such

as Mach trim, stall warning/recovery functions or fully operational yaw damping.

Using the two switches allowed us to sample some of the 7X's handling characteristics flying qualities that only will be duplicated in flight simulators after the aircraft is certified late this year.

We were accompanied by Yves "Bill" Kerhervé, Dassault's chief test pilot, in the right seat and Michel Brunet, another senior Dassault test pilot, on the jump seat. During the preflight briefing, Kerhervé explained that the Falcon 7X is one of the few Dassault aircraft that he has flown which is not inherently unstable and not designed for cruising above Mach 1. Kerhervé said that

snags. The company opted for FBW aboard the Falcon 7X to squeeze more performance out of the airframe.

Stability and performance are classic trade-offs in both civil and military aircraft designs. The more stable the aircraft, the more performance that must be sacrificed. Conversely, higher performance aircraft are inherently less stable. That's why virtually all aircraft designed to cruise as fast as 0.90 Mach, that are fitted with conventional flight controls, have large vertical fins and horizontal stabilizers. The main reason for this is the need to meet the dive speed stability standards spelled out by international airworthiness certification authorities. But the drag penalty associated with such a large empennage costs fuel and range. FBW enabled Dassault to fit the 7X with a considerably smaller and lower drag empennage and still meet regulatory dive speed stability requirements.

Maximum demonstrated dive speed, for example, is 0.93 Mach, just 0.03 above the 7X's 0.90 MMO. Without FBW, MMO would have been restricted to 0.86 Mach because of the regulatory 0.07 Mach buffer normally required by certification authorities. Similarly, maximum demonstrated dive speed, when not Mach limited, is 405 KIAS, only 35 knots above the Falcon 7X's 370 KIAS VMO speed. Using conventional flight controls, Kerhervé estimated VDF would have been at least 430 KIAS to validate the same VMO. In short, the protections offered by FBW flight controls enable aircraft manufacturers to push up maximum cruise speeds and yet offer equal or better high-speed safety margins when compared to aircraft fitted with conventional flight controls.

Improved low-speed handling, pitch and roll stability characteristics are other reasons why Dassault designed the Falcon 7X with FBW. The system's computers prevent the aircraft from exceeding safe angle-of-attack, airspeed/Mach or load limits, regardless of pilot inputs. They also limit maximum pitch angle to 45-degrees nose up and 20-degrees nose down. Bank angle is not limited, but the aircraft has artificial spiral stability so that it will slowly return to a bank angle of 35 degrees in steep turns if the stick is released. At shallower bank attitudes, the aircraft will maintain the bank angle last commanded by the flight crew.

As we would soon learn, FBW flight control is only one of many new technologies that are being introduced on the newest Falcon. The aircraft promises not only to be the easiest to fly and most comfortable Falcon yet introduced, but also the simplest to maintain and service, in spite of its advanced systems.

Dassault first developed redundant FBW flight controls more than three decades ago for the Mirage 2000, a very agile albeit unstable Mach 2-class replacement for the Mirage III. With FBW, the Mirage 2000 quickly earned a reputation as a docile handing machine, even in the demanding air combat maneuvering arena. Without FBW, it would have been virtually impossible to fly in the tactical environment.

Kerhervé next flew the Rafale, Dassault's second-generation, multi-mission FBW fighter designed to succeed the Mirage 2000, Jaguar strike fighter and the aging carrier-based Super Etendard. Rafale reached 1.3 Mach on its first flight and it soon topped 1.8

Mach. Notably, it also could fly slower on landing approach than the Super Etendard, enabling Dassault to build a beefed-up version for use aboard aircraft carriers. Without FBW, Rafale never would have gotten off the ground, let alone on to a carrier flight deck.

When it was time to develop a FBW flight control system for the new Falcon — which, like all its predecessors is inherently stable and a sub-sonic performer — Dassault Equipements, the division of Dassault Aviation that specializes in FBW technology, applied all the lessons learned from the Mirage 2000 and Rafale, thereby minimizing development time, cost and certification

The 7X's wing is thicker at the root and thinner at the tip than the 1970's-vintage Falcons' airfoil.

### Improved Aerodynamics, Systems and Maintenance Features

New wing aerodynamics were the largest single factor in making possible the 7X's 5,950 nm maximum range. The wing is about 35 percent more efficient than that of Falcon 900 because of its refined super-critical airfoil, five degree greater sweep angle and higher 9.72:1 aspect ratio. It's also thicker at the root and thinner at the tip than the 1970's-vintage Falcon 50/2000/900 airfoil. There is a noticeable increase in bottom surface, trailing edge reflex, as indicated by the pronounced S-curve in the trailing edge of the wings, flaps and ailerons. The Falcon 7X will be the first Dassault business jet fitted with standard winglets, but they only add about 2 percent to maximum range. The decision to fit the aircraft with winglets was made about six months into program development when Dassault elected to increase range from 5,700 nm to 5,950 nm. Larger winglets would have increased maximum range more, but the wing would have required a beefier structure to handle the additional loads. This would have added weight, time and cost to aircraft development.

The overall package of wing improvements make it possible for the Falcon 7X to climb directly to FL 410 at MTOW in ISA+10° conditions and fly efficiently at 0.80 Mach during long-range cruise. Range at 0.85 Mach is 5,200 nm, so it's likely that many operators will opt for higher cruise speed on most intercontinental missions.

Full-span leading-edge slats and slotted trailing-edge wing flaps will provide the Falcon 7X with exceptional low-speed performance. Even with the 7X's newly increased weights, Dassault engineers forecast a 104 KIAS VREF landing speed when landing with eight passengers and NBAA IFR reserves.

The Falcon 7X incorporates several

system improvements to increase dispatch reliability, enhance redundancy and reduce maintenance burden. Almost all systems are designed with sufficient redundancy to permit dispatch with single component failures.

The electrical system features brushless DC generators on all three engines and most motors are brushless designs. To meet the additional redundancy needed for FBW, the Falcon 7X is fitted with both a ram-air turbine generator (RAT) and permanent magnet alternators (PMAs) on engines one and two. Add in the two lead-acid batteries and the aircraft has a total of eight sources of DC electrical power. You can still launch if you lose any one of the generators or PMAs prior to takeoff. The APU also may be used as an electrical power source, but only on the ground.

Gone from the cockpit are the left and right circuit breaker panels. Primary and secondary power distribution boxes, closely located to the components they supply, are fitted either with monitored, mechanical circuit breakers or solid-state power controllers (SSPCs). The status of all circuits can be monitored on an EASy screen display in the cockpit and individual circuit breaker functions, hosted by the SSPCs, can be "pulled" or "reset" from the cockpit. The status of each circuit/circuit breaker during the flight is recorded by a central maintenance diagnostics unit for later use in troubleshooting.

The Falcon 7X also will have a dedicated ground service bus that will power only certain required components. It's designed to conserve battery power during routine servicing and refueling.

The latest Falcon retains Dassault's proven engine-driven 3,000 psi hydraulic pump design. Previous Falcons had "A" and "B" hydraulic systems. Aboard the 7X, a third or

"C" system, powered by the number two engine is added for enhanced redundancy. Each engine-driven pump now has its own miniature accumulator to dampen hydraulic shocks in the plumbing. The aircraft also has a 2,800 psi electrically driven standby pump. Systems "A" and "B" are newly fitted with automatic isolation valves that preserve flow to the primary flight controls in the event of system leaks caused by non-flight-critical components. Dassault retains its legacy of using mineral-based MIL-H-5606 hydraulic fluid, stored in "boot strap" reservoirs that are pre-charged to suppress foaming when the pumps are running. All the filters for each system are concentrated on a single manifold and any filter clogging is monitored on an EASy screen in the cockpit.

This will be the first purpose-built business jet to be fitted with Goodrich SmartProbe units. The four SmartProbes sense angle-of-attack, angle-of-slideslip, pitot and static pressure and they're fitted with integral miniature digital air data computers. All four probes are augmented by total air temperature probes, thereby enabling them to compute true altitude, Mach and airspeed. They're also all linked together so the aircraft has four separate, RVSM-compliant digital air data computers. SmartProbes eliminate all of the plumbing associated with legacy air data computer systems. In addition, the AOA and slideslip sensors have no moving parts. All air data are digitized at the probes and then sent to the FBW system, integrated standby instrument display and other avionics equipment.

The new Falcon's fuselage has a heavier duty substructure, enabling cabin pressurization to be increased even though it has larger cabin windows than the Falcon 900. Maximum cabin altitude now is 6,000 feet at FL 510. Two dual-channel control, electrically powered outflow valves control pressure differential. Three-zone temperature control is standard, with one thermostat used for the cockpit and galley areas and the other two dedicated to the passenger cabin. This design feature makes it possible to select different temperatures for the forward and aft sections of the cabin. Air conditioning is supplied by a single air-bearing air cycle machine pack, backed up by an emergency pressurization system having a large heat exchanger cooled by ram air that makes it possible to maintain a comfortable cabin temperature at high cruise altitudes. An optional humidifier and HEPA bacteria filter are available.

Each engine now has its own bleed-air pre-cooler and dispatch is permitted with a loss of any single source of bleed air, even in icing conditions. Cabin pressurization is still available in the event that two of the three sources of bleed air are lost, but the aircraft

must avoid or exit icing conditions. Dual ice detectors are standard and the aircraft may be dispatched with one inoperative. Bleed air flow to the wings, center engine S duct and engine inlets is modulated by computer to maintain a specific temperature, thereby using the minimum amount of bleed air required. This feature improves climb performance in icing conditions. Brake heaters are an option.

The Falcon 7X's fuel system is simplified compared to legacy Falcons. Each engine is fed from a specific set of tanks, all having close to the same fuel quantity. The center group holds 374 pounds more fuel than the outside groups, providing additional fuel for running APU on the ground. Total system capacity is 31,940 pounds, about 3,000 pounds more than the original 5,700-nm range aircraft would have carried.

The fuel quantity management computer is a dual-channel design, but only one channel is required for dispatch. Each of the fuel probes is individually monitored by the aircraft's central maintenance computer. If one fails, the computer will identify it immediately, thus making it possible to replace it without troubleshooting the system.

Each tank group and engine has one normal and one standby brushless DC fuel boost pump, enclosed in canisters for quick removal/replacement without draining the tanks. Similar to earlier Falcons, the tanks are pressurized to assure adequate engine fuel supply in the event of loss of all boost pumps. The flight crew can select cross flow or cross feed between tank groups with a single button push that activates the appropriate combination of boost pumps, valves and flow manifolds.

The Falcon 7X is the first Falcon since the Model 10 and 20 to have trailing-link main landing gear. It's also the first Falcon to have the nosewheel steering (NWS) entirely controlled through the rudder pedals, so either pilot has full authority NWS capabilities. Dual proximity sensors monitor gear position. The brake-by-wire system also is a dual channel unit, with only one channel required for dispatch. Similar to early Falcons, the 7X has a parking/emergency brake system powered by the System "B" hydraulic accumulator. The aircraft also has a tire pressure monitoring system that speeds up preflight inspection chores and enables the crew to keep an eye on tire pressure in flight. This feature might be particularly useful when deciding whether to divert to an alternate airport with a long runway.

The fire protection system has been improved. Fire detectors now are more immune to dust and pressure switches warn of depleted fire extinguishing bottles.

The Falcon 7X is fitted with a new oxygen system, one that eliminates high pressure



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lines from the cockpit, thus reducing the potential for leaks. Computer-controlled pressure regulators on the flight crew masks conserve available oxygen based upon cabin altitude. Bottle quantity is displayed on the EASy screens.

### Flying the First FBW Business Jet

The Falcon 7X has an even more capable version of Dassault's signature EASy cockpit than the Falcon 900EX. Mastering this revolutionary approach to avionics, navigation and airframe systems control and display requires a major training commitment on the part of flight crews making the transition from conventional EFIS cockpits or more evolutionary versions of Honeywell's Primus Epic platform.

We lacked that opportunity prior to flying the Falcon 7X, but fortunately for us, Kerhervé was one of Dassault's most proficient pilots with the EASy cockpit. Primarily using the cursor control device on the center console, Kerhervé configured two center display screens with systems synoptic pages, navigation charts, engine instruments and CAS message windows appropriate for each phase of flight. During the process we noted that EASy makes strong use of its point-and-click graphic user interface while minimizing emphasis on traditional button push, key stroke and knob twist data entry conventions.

Four Falcon 7X aircraft are being used for development and certification. About two-thirds of the flight test program had been completed by late June 2006, with certification slated for late fourth quarter. We flew Falcon 7X s.n. 2, which first flew in July 2005; ours was its 89th flight. It was fully aerodynamically conformed to the final production configuration, including winglets and elimination of the secondary

rudder system. There were no flight envelope limitations, except for a 20 KTAS crosswind limit, five knots below the limit for production aircraft. The aircraft did not have the current production-spec fuel system, so it held 3,000 pounds less fuel. It also didn't have operative slat down-locks, so climb and cruise performance were negatively affected by excess drag. As a result, we elected not to record detailed cruise profile performance numbers.

Serial number 2 had a 37,700-pound BOW the day we flew it, about 3,500 pounds heavier than a production-spec airplane. The computed ZFW was 40,100 pounds, including the safety pilot and 2,200 pounds of water ballast aft. With 10,000 pounds of fuel, the computed takeoff weight was 50,100 pounds and the c.g. was 25.0 percent MAC.

The day was near perfect for a complete FBW evaluation. The air mass to FL 250 and above was cloudy, unstable and full of embedded rain showers. The ceiling at Istres was 5,000 to 6,000 feet overcast, so pattern work could be completed in VFR conditions.

Computed $V_1$ and $V_R$ were 108 KIAS, $V_2$ was 113 KIAS and clean wing speed was 144 KIAS, based on a slats/flaps 2 (20 degrees) configuration, Istres' 79-foot field elevation and an OAT of 26°C. Computed takeoff field length was 3,300 feet. The FBW system in production aircraft automatically will set horizontal stab trim to six degrees nose up for takeoff. We positioned the stab to that setting manually in s.n. 2. Initial pitch attitude was computed as 16 degrees nose up.

Compared to previous Falcons, the 7X has much shorter checklists because its systems are more highly automated. The prestart checklist, for instance, had only 15 items and one-third of those were dedicated to flight test procedures.

Engine start is straightforward, requiring
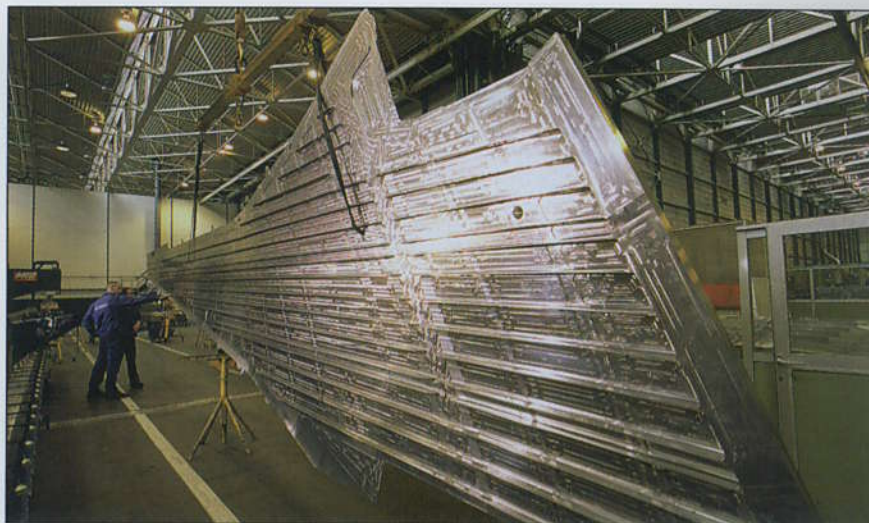
*The wing of the Falcon 7X is entirely new, featuring more sweep and a higher aspect ratio.*

Dassault Falcon Jet

only turning on each engine "run" switch and turning a centrally located start mode knob to the start position in sequence. APU bleed air automatically is rerouted from the ACM pack to the engine starter and fuel boost pumps are activated as needed. After the start, APU bleed air is redirected to the pack.

Brake-by-wire action was very smooth and progressive, but the dual-rate steer-by-wire (SBW) system, activated through the rudder pedals, was overly sensitive, in our opinion. Production aircraft will be fitted with an improved three-rate SBW system.

We lined up on Runway 33 for takeoff, held the brakes, ran up the engines and engaged the auto-throttles. The throttle levers are back-driven, providing excellent tactile feedback. We released the brakes and the lightly loaded aircraft accelerated sportingly. We rotated to about 15 degrees

nose up after a takeoff roll of about 2,500 feet. Required back pressure on the side-stick controller was light. There was no pitch command cue. We simply rotated until the flight path vector symbol climbed above the horizon line, indicating that the aircraft was leaving the runway. We also monitored the airspeed trend vector tape next to the flight path vector. As long as it showed acceleration, we knew that the aircraft was both climbing and gaining necessary speed for flap/slat retraction.

Pitch response to fore/aft stick movement was agile, but proportionate and easy to control. Any time we released the side stick, the aircraft's flight path vector remained constant, at least in smooth air. We also noted that roll control force was noticeably lighter than pitch force. Gentle inward/outward pressure on the side stick is

all that was needed to roll the aircraft moderately. With full left or right deflection of the side stick, roll control authority was very brisk. The Falcon 7X's FBW system seemingly shares its digital DNA with Rafale.

After takeoff, we accelerated to a 260 KIAS/0.78 Mach climb speed. We adjusted nose attitude to the appropriate degree and just let go of the side-stick controller. Stab trim was automatic. But as we entered turbulence in the clouds, we observed that the FBW system isn't designed to hold attitude as solidly as some larger FBW aircraft we've flown. Moderate turbulence will cause a change in flight path vector that must be corrected with side-stick inputs, if the aircraft is being flown manually.

It may be possible to generate aircraft/pilot coupling (APC) oscillations when correcting for turbulence-induced perturbations in some older FBW aircraft. This is because of excessive time lag between control inputs and control surface response. The phenomenon is similar to pilot-induced oscillations in a conventional flight control aircraft, but it's caused by slow computers rather than pilot error.

We observed no such behavior in the 7X when hand-flying, even in moderate to heavy turbulence. Dassault engineers explained that the inherent short-period pitch stability of the 7X requires no faster than a 50 millisecond response time to dampen such APC oscillations completely. The actual FBW system response time aboard the 7X is 12.5 milliseconds, the same as in the short-coupled Rafale fighter. So it's extremely improbable that pilots will find themselves out of synch with the FBW system of the Falcon 7X, even in the most demanding circumstances.

During the climb, Kerhervé demonstrated the effect of dual left and right side-stick controller inputs. Vibrators in both side sticks activate, warning the pilots of the dual control inputs. Both inputs are summed algebraically and warning lights alert the crew as to which has priority. Either pilot can take priority by pressing a thumb button on the side stick, but only one pilot at a time is permitted to make control inputs.

Kerhervé also engaged the autopilot at about 15,000 feet. This locks the side stick in place, thereby providing a tactile cue to the crew. Moderate pressure on the side stick, in any direction, causes the autopilot to disengage so that the aircraft can be flown by hand. The autopilot also can be disengaged by pressing a button on the side stick, the same button that's used to take control priority.

We leveled off at FL 200 for a series of maneuvers in normal law mode at 250 KIAS. Rolling the aircraft up to 35 degrees in either direction and releasing the stick causes the



*The cockpit section of the 7X is manufactured in Argenteuil using an entirely robotic process.*

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FBW system to hold bank angle, but some back pressure on the side stick is needed to keep the flight path vector on the horizon line, thus preventing altitude change. We also flew steep turns up to 60-plus degrees, noting that light lateral and back pressure on the side stick were required to hold bank angle and altitude. Leveling the wings, we pulled back smoothly on the side stick to the back stop. Positive load stabilized at 3.5 g's. Push forward on the side stick to a soft stop unloads the aircraft to 0.5 g's. Pushing all the way to the forward hard stop unloads the aircraft to -1 g with flaps up and 0 g's with flaps extended.

Next, we flew a series of minimum speed maneuvers designed to illustrate the FBW system's low-speed protection functions. Pulling power to idle, we attempted to stall the aircraft in every possible slat/flap configuration, including landing approach. Approaching the stall in the clean configuration, the middle and outboard slats automatically extend to energize the flow over the roll spoilers and ailerons, in keeping with long-standing Dassault design practice. We held the side stick in the full aft position and the nose just mushed down near the stall as the FBW system stabilized the angle-of-attack near $C_L$ max.

The approach-to-stall behavior was virtually the same with slats out and flaps extended to any position, except that the stall speeds obviously were slower.

Then, Kerhervé switched off the normal law mode of the FBW system so that we could evaluate handling characteristics in alternate law mode without the benefit of angle-of-attack limiting. In everyday operations, only a total loss of redundancy in any FBW computer, sensor or input device would prevent functioning of the normal law mode.

In alternate law mode, low- and high-speed envelope protection may not be available, so it's up to the crew to hold close to a 1-g load limit and fly the aircraft no faster than 260 KIAS/0.80 Mach. The relatively low VMO/MMO limits in alternate law speak reams about the 7X's relaxed stability characteristics and the role that FBW plays in making possible its 390 KIAS VMO/0.90 Mach MMO limits.

We flew the aircraft at 250 KIAS in a series of steep turns. It was as stable in pitch, but yaw and roll stability were degraded, as were pitch and roll automatic trim. We also flew a series of low-speed maneuvers, observing that the air data computers increase the low-speed redlines on the airspeed tape by a few knots compared to the redlines depicted for normal law mode. The FBW system introduces a bit of extra low-speed margin in the alternate law mode. The aircraft should be flown at lower maximum angle-of-attack limits in any slat/flap configuration because
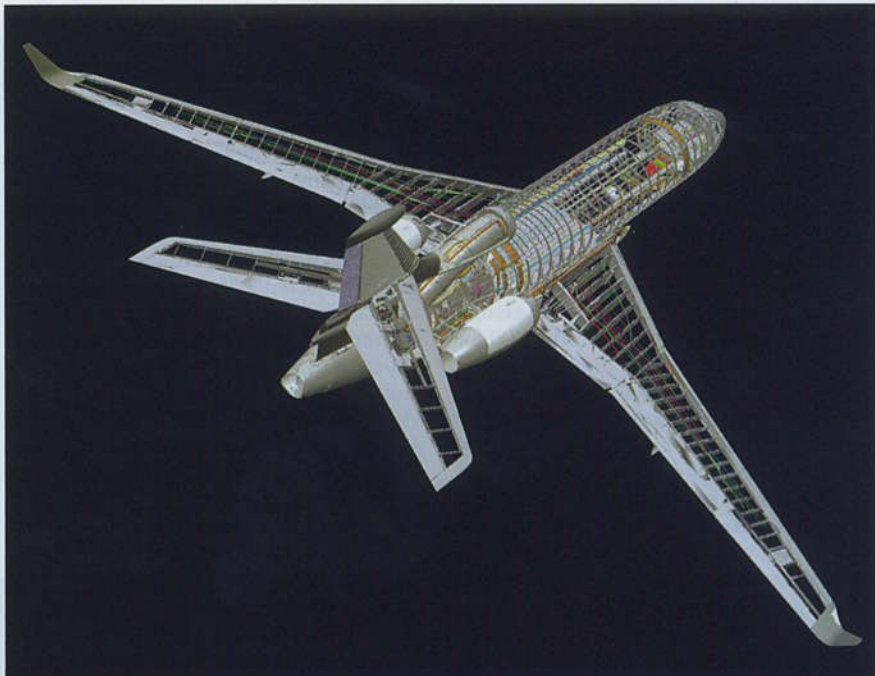


The new Falcon's fuselage has a heavier duty substructure, enabling cabin pressurization to be increased even though it has larger cabin windows than the Falcon 900.

of the lack of low-speed protections. We flew as slow as 1.1 Vs in the clean configuration and five knots slower on-speed for each slat/flap configuration. This put the aircraft into the yellow angle-of-attack warning section of the airspeed tape, but kept us clear of low-speed redline.

Then Kerhervé turned off both switches, putting the aircraft's FBW system into the direct law mode. In operational service, there will be a $10^{-7}$ probability of degradation from normal to direct law due to a FBW system failure. In the direct law mode, pitch, roll and yaw stability were further degraded, all flight envelope protection was lost and auto trim was not available. The aircraft had to be trimmed manually using switches on the center console because the side stick has no trim switches.

The Falcon 7X exhibited poor yaw stability, although some FBW yaw damping was still available. There was noticeable yaw/roll coupling (Dutch roll), but the aircraft still was quite controllable. We flew a series of 30-degree bank turns in each direction. The lack of the auto pitch trim



Another section of the 7X wing that is manufactured in Martignas located a few miles from the Bordeaux-Merignac facility where all Falcons are manufactured.

function and natural spiral stability became evident. But the flight path vector cue was a significant aid to controlling the aircraft. We also flew a simulated landing approach with gear, slats and flaps fully extended. In alternate and direct laws, indicated approach speeds actually are higher at slats/flaps 3 (40 degrees) than at slats/flaps 2 (20 degrees). The boost in low-speed margin is necessary to provide sufficient static pitch stability in the landing configuration.

Kerhervé then restored full FBW system functionality and we climbed to FL 400 for a quick check of handling qualities. At a weight of 47,000 pounds, we performed a series of wind-up turns at 0.80 Mach to probe Mach buffet margins. The Falcon 7X was buffet free up to 2.5 g's at this weight, indicating that it has much higher high-speed buffet boundaries than Falcons fitted with the last generation wing.

Heading back to Istres, we performed a simulated emergency descent by reducing thrust to idle and fully extending the airbrakes. Nose attitude changed almost imperceptibly, but the sudden loss of wing lift and moderate buffet were quite apparent. Accelerating up to 300 KIAS, the aircraft initially descended at more than 18,000 fpm, stabilizing in a 10,000-plus-fpm descent.

We entered the VFR traffic pattern from the west side of the airport and prepared for a touch-and-go landing to Runway 33. The Falcon 7X is very easy to fly in the pattern because of the light side-stick control pressures and linear response of the Pratt & Whitney Canada turbofans to throttle movement. We elected not to use autothrottles for this approach.

The weather was bumpy, so we had to make constant adjustment to the flight path vector in an attempt to maintain altitude. We

called for landing gear abeam the touchdown point and full flaps while turning base to final. The auto pitch trim function virtually eliminated configuration-induced pitch changes, but there was a noticeable increase in drag as Kerhervé extended the flaps to the 40 degrees position.

We pulled the throttles to idle at 30 feet agl and started a gentle flare. The long-travel, trailing-link main landing gear produced flattering results at touchdown. We consciously had to fly the nose down to the ground because the FBW's derotation algorithm, a feature that mimics the aerodynamic behavior of a conventionally controlled aircraft on touchdown, has yet to be perfected.

Kerhervé selected slats/flaps 2 (20 degrees) for the takeoff on landing roll-out. We took off and turned crosswind for another circuit, this one being a full stop. We repeated the same technique as before, but we extended

## Falcon 7X Fly-By-Wire System Architecture

Dassault elected to fit the Falcon 7X with one of the most redundant fly-by-wire (FBW) systems ever installed in a civil jet. It's highly fault-tolerant so its master minimum equipment list will be long and complete. Dispatch will be permitted with multiple single components faults, including failure of one channel of each side-stick controller, one SmartProbe inoperative and loss of a single flight data concentrator, one channel in a main flight control computer (MFCC) or in an actuator control monitoring unit.

FBW systems are critically dependent on electrical power, so three engine-driven generators, two engine-driven permanent magnet alternators and a ram air turbine generator are available for power supply. Two batteries can power the system, if all other power sources fail. The APU only supplies electrical power on the ground.

The Falcon 7X's FBW system may be divided into five areas: (1) sensors, (2) data concentrators, (3) flight control computers, (4) actuator controllers and (5) actuators. As illustrated in the accompanying diagram, pilot control and sensor inputs are fed to the flight data concentrators. The data acquisition units supply three, dual-channel main flight control computers (MFCCs) and three single-channel secondary flight control computers (SFCCs). Location of these computers is split between forward and aft ends, and left and right sides of the fuselage for maximum isolation. The routing of FBW wiring harnesses also is widely separated for optimum damage tolerance.

The first level of the FBW system is comprised of pilot controls and sensors, the intelligence gatherers of the system. Each group of sensors supplying the FBW system has multiple channels. Most individual boxes are at least dual-channel designs. Each SmartProbe, for instance, is dual-channel. Each side-stick controller is a five-channel unit because of its critical functionality. The redundancy is so complete that operators will be able to dispatch with a single failed channel in multiple groups of sensors and still have plenty of backup in the case of a subsequent channel or box failure.

The second level of the system is dedicated to data concentrating, processing all the inputs for use by the flight control computers. The input sensors actually feed analog, digital and discrete signals to five, dual-channel flight data concentrators, although there's only one box depicted on the accompanying diagram. The data concentrators digitize all the inputs and forward them to the flight control computers, the brains of the system, for decision making.

The brains of the system are at the third level. This is the flight control computer section. Normally, the three dual-channel main flight control computers handle all chores. Each channel in the MFCCs runs different software. Each channel either generates flight control laws or monitors the results, with roles alternating at each power up. MFCCs are capable of normal, alternate and direct law modes. Any one of the three MFCCs can provide complete FBW normal law mode functionality. All the stability enhancements, envelope protection functions, auto trim and auto flight control configuration features remain available in the normal law mode so long as redundant input, sensor and interface inputs are available. Normal law, in other words, needs a "second opinion" from every input source to verify the integrity of the primary input, plus a "second opinion" from the alternate channel of at least one MFCC.

If there's only one signal from any group of input sources, then the system automatically degrades to the alternate law mode. Some or all of the normal law functions may be lost, depending upon which input source has been lost.

The MFCCs' direct law mode only is invoked if all signals from certain critical sensors are lost. At that point, the pilot is flying the aircraft with simple electrical links to the flight controls that emulate the mechanical linkages of a conventional flight control system. The Falcon 7X isn't shy about demonstrating its relaxed static and dynamic stability characteristics in direct law mode, but there's only a $10^{-7}$ probability of the level of degradation occurring.

The single-channel SFCCs are only capable of operating in the

the airbrakes once we had weight on all three landing gears and deployed the center thrust reverser. It's not advisable to use the airbrakes or thrust reverser with weight only on the mains because of the attendant nose-up pitching moment.

During the next takeoff, Kerhervé retarded the right engine to idle five knots below V1 to simulate an engine failure on takeoff. There was a very mild right yaw that was easily countered with light left rudder pedal pressure. The FBW system also provides slight left wing down roll input to help prevent yaw/roll coupling. At a weight of less than 47,000 pounds, the OEI climb rate was impressive, a testimonial to the efficacy of the 7X's three-engine design.

Once we were stabilized downwind in the pattern, Kerhervé turned off the FBW normal and alternate law modes and we prepared for the final landing approach in direct law. He returned use of the right engine and we engaged the autothrottles, a procedure the 7X AFM will recommend when published later this year.

Shifting and gusting winds, along with moderate turbulence, preceded an encounter with a small, concentrated downdraft on downwind. Turning final to Runway 33, the tower instructed us to go around to the west and set up for right traffic to Runway 15. A 15 KIAS left crosswind developed at that point.

Having very relaxed static stability, the aircraft wallowed around as we maneuvered for landing approach. It would have been uncomfortable for passengers, but we in the cockpit felt assured about complete aircraft controllability in direct law mode. But we were busy because we had one hand on the side stick and the other on the trim switches on the console. We crabbed into the crosswind, making the transition to wing-down/top rudder on short final. Touchdown was smooth and uneventful.

It was only fitting that a Rafale landed immediately behind us, thereby reminding us that Dassault's military airplane FBW technology now flows through the nerve network of the Falcon 7X.

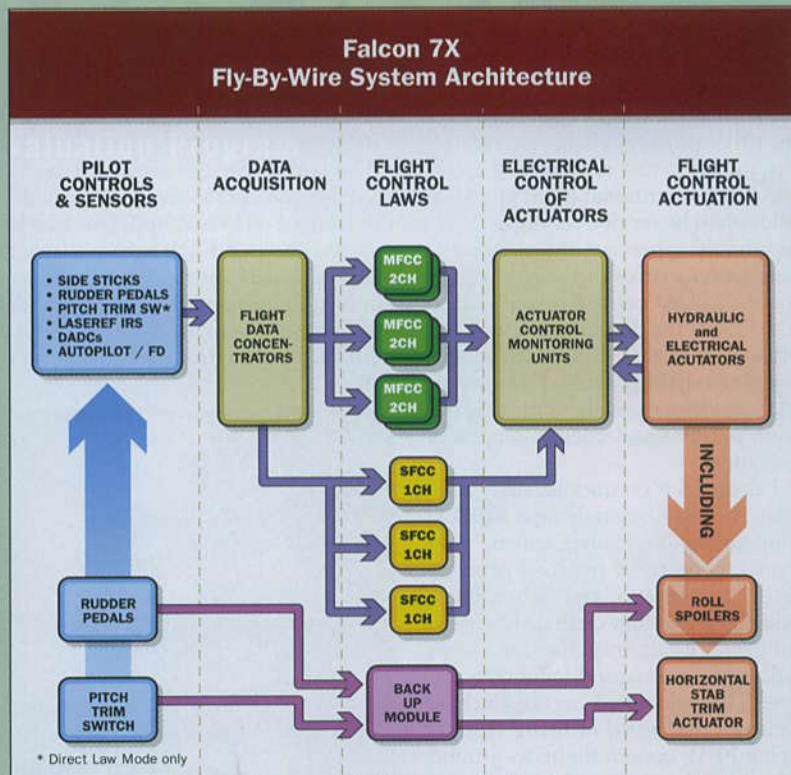### Home Stretch to Certification and Production Deliveries

We concluded that FBW makes the Falcon 7X the nicest flying Falcon ever, an impressive accomplishment considering that the handling manners of Falcons always have been the envy of others in the business aviation industry. There will be a lot of pilots who only begrudgingly turn over control of the Falcon 7X to the autopilot above FL 290 because of RVSM airspace rules, in our opinion.

direct law mode. That's because they lack a second channel needed to verify the integrity of the decision-making process of the primary channel. However, the SFCCs have different microprocessors than the MFCCs and they run completely different software. Their function is to provide simple, but triple-redundant critical flight control functionality in the event that all three MFCCs fail.

Control law signals from the MFCCs or SFCCs are sent to the actuator control monitoring units. The ACMUs command the positioning of the primary and secondary flight control actuators, in essence replacing the mechanical links to the servo actuators that would be found in a conventional flight control system. Position data from the actuators is fed back to the ACMUs to verify that the commanded position occurred. The ACMUs also perform reasonability checks on signals received from the main and secondary flight control computers.

Electric and electro-hydraulic actuators are the brawn of the system. Three hydraulic systems supply the actuators. The aircraft is controllable with two of the three systems inoperative.

The basic FBW system architecture has a $10^{-9}$ probability of failure, thus meeting the most stringent certification requirements. That wasn't good enough for Dassault. The Falcon 7X was fitted with an emergency backup flight control system that uses discrete inputs from the rudder pedals and pitch trim switch. These inputs are separate from the redundant channels that feed the normal FBW system and they bypass all other second-, third- and fourth-level components. The backup module electrically trims the position of the horizontal stabilizer for pitch control. Inputs from the rudder pedals command the position of the roll spoilers — not the rudder! The



**Falcon 7X Fly-By-Wire System Architecture**

PILOT CONTROLS & SENSORS — DATA ACQUISITION — FLIGHT CONTROL LAWS — ELECTRICAL CONTROL OF ACTUATORS — FLIGHT CONTROL ACTUATION

• SIDE STICKS
• RUDDER PEDALS
• PITCH TRIM SW *
• LASEREF IRS
• DADCs
• AUTOPILOT / FD

FLIGHT DATA CONCENTRATORS

MFCC 2CH
MFCC 2CH
MFCC 2CH

SFCC 1CH
SFCC 1CH
SFCC 1CH

ACTUATOR CONTROL MONITORING UNITS

HYDRAULIC and ELECTRICAL ACUATORS

INCLUDING

RUDDER PEDALS

PITCH TRIM SWITCH

BACK UP MODULE

ROLL SPOILERS

HORIZONTAL STAB TRIM ACTUATOR

* Direct Law Mode only

roll spoilers use "C" system hydraulic power supplied by the number two engine-driven pump. But if the engine-driven pump is inoperative, electrically powered backup hydraulic actuators in the wings power the roll spoilers. The intent of the backup system is to provide the crew with additional time to reset or recycle the MFCCs and SFCCs, thereby restoring a higher level of FBW control.

Bottom line? There's a $10^{-11}$ probability, a one in 100 billion chance, that you'll lose all flight control functioning aboard the Falcon 7X.

Pilots new to the EASy cockpit also will be making the transition to point-and-click avionics and display control.

FBW also is one reason why the 7X will have the nicest ride for passengers of any Falcon yet built. While the 7X doesn't have active load alleviation like some Airbus models, FBW provides pitch, yaw and roll stability manners just not possible in an aircraft with conventional flight controls. That adds up to better ride comfort.

Pilots should appreciate the point-and-release characteristics of the flight path vector-based flight control system. Once you've achieved the desired trajectory, the aircraft will hold that flight path within engine and aerodynamic limits. Folks new to the EASy cockpit also will be making the transition to point-and-click avionics and display control.

The Falcon 7X is on track for early 2007 deliveries. All certification flying is slated to be completed by November, leaving only paperwork tasks to be finished prior to earning TC by year-end. The flight and c.g. envelopes have been fully cleared, the engine operating and restart envelopes have been verified and initial natural icing tests are complete. The main remaining tasks include increasing crosswind landing limits, improving FBW system flight-to-ground detection and derotation algorithms for landing, plus some control smoothing.

During our visit there was no mention of last year's pitched battle between Dassault and Honeywell regarding alleged performance shortcomings of the Primus Epic avionics suite. Indeed, Dassault claimed that "general systems/avionics behavior has been checked and was found to be generally satisfactory." But in contrast to Embraer's E-Jets, Dassault also has shunned any dependence upon Primus Epic to host fly-by-wire functions aboard the Falcon 7X. Fitting the aircraft with separate fly-by-wire computers may be a major reason why Dassault claims no weight savings with the FBW system.

Dassault officials claim that "aircraft behavior is at least as good as expected." By the time of our visit, no flight had been canceled due to an FBW failure or fault, they said. Cruise performance has been validated, but final range numbers won't be available until full testing of s.n. 4, the first aircraft with final production-configuration fuel tanks.



Dispatch will be permitted with multiple single components faults, including failure of one channel of each side-stick controller,

Overall AFM performance is equal to or better than Dassault's predictions. Final AFM performance testing now is under way, with final certification tasks slated to start in September.

When customer deliveries begin in 2007, the commercial success of the Falcon 7X will depend less on its FBW sophistication and more on its cruise speed, range, fuel economy and airport performance, plus its cabin comfort, dispatch reliability and maintainability.

The Falcon 7X has the most range of any aircraft in the $40 million class, but the Gulfstream G500 is a very close competitor. Gulfstream could change that simply by upping the G500's maximum fuel quantity by a few hundred pounds. Dassault officials counter that the 7X has a considerably wider cabin cross section and that it burns at least 10 percent less fuel on most missions. It also burns less fuel than the Falcon 900EX on missions of equal length.

So will the best Falcon yet built triumph over all existing 6,000-nm-class competitors? Will the 7X's unprecedented technical innovation yield a concomitant increase in market share in the large-cabin business jet class? The market reaction is pointing that way. Over 80 copies of the 7X have been sold, making it the most successful Dassault Falcon aircraft at this point in the life of the program. The company says the next available delivery position is in the middle of 2010, and that to accommodate the demand, production will increase to three per month during the second half of 2007. We're looking forward to following this story and flying the 7X again next year for a complete *B&CA* Analysis. **B&CA**