Flying the manufacturer’s biggest and longest-range jet

by Matt Thurber

Just nine years after Gulfstream Aerospace unveiled its largest and longest-range business jet—the G650—and five years after certification, 250 G650s, 120 of them the ultra-long-range G650ER, are plying the world’s skies.

To say that Gulfstream’s timing could not have been better would be an understatement. The G650 tapped into a market that was shying away from smaller jets and eager for a large-cabin ultra-long-range jet that could connect city pairs never before considered.

The G650 also represents a transition for Gulfstream, into the realm of fly-by-wire (FBW) flight controls. While such a move was inevitable—every major business jet OEM has fielded or is developing FBW jets—the G650 is unusual because it’s likely the only FBW Gulfstream that will ever feature the traditional yoke-operated flight controls. The new G500 and G600 are equipped with sidesticks, the control of choice for most FBW designs, but also noteworthy in that their sidesticks are electronically tied to each other and move together as
The G650 design of two yokes mechanically connected as in traditional flight controls is a lot like Boeing’s FBW designs, thus far also employing yokes because Boeing’s philosophy is that it helps pilots maintain situational awareness when they can see the other pilot’s flight controls moving in concert with their own manipulation of the controls. The G500/G600 active sidesticks (a BAE design) also move in concert, thus maintaining the control-awareness philosophy.

There are advantages to FBW, independent of the type of cockpit control, and not just a smoother ride for passengers or better protection from exceeding certain flight parameters. For larger jets such as the G650, FBW allows designers to tune the handling of the airplane and give pilots something entirely different from what they might expect.

As a rough analog, after flying the G650ER and last year the G550, I was able to compare the handling of the two jets. The G550 has classic hydraulically operated controls, which does afford designers some latitude to improve handling, but the G550 is more work to hand fly, somewhat heavy on the controls and heavily dependent on trim to keep the workload comfortable. By comparison, I found the larger and heavier G650ER had much easier handling, something that I have also found with Embraer’s FBW Legacy 450 and 500 and Dassault’s FBW Falcon 8X.

**G650ER Features**

In most respects the G650 and G650ER are similar. In fact, the extra fuel in the -ER required no redesign of the wing as the fuel volume there was already able to accommodate an additional 4,000 pounds of fuel. The -ER’s total fuel capacity is 48,200 pounds, but that extra 4,000 pounds doesn’t benefit only range as it can also be used for added payload while carrying the 44,200-pound fuel load of the regular G650. All fuel is carried in the wings, and as in all Gulfstreams, the center of gravity won’t move out of the forward or rear limit as the fuel load varies.

“Some customers buy the -ER and don’t need maximum range, but they want the added payload,” said Kevan Jackson, director of the G650/G650ER programs. “It gives them a lot more flexibility or reserves.” No additional strengthening of the wings, fuselage or landing gear was needed for the -ER as the G650 had margin to accommodate the added weight, he explained.

While the G650 and -ER’s Rolls-Royce BR725 engines share the same core as the BR710s in the G550, the BR725 has a larger fan and delivers 16,900 pounds of thrust at sea level ISA while operating 17 percent more quietly than the BR710 and with lower emissions.

The G650, like all Gulfstream jets, carries on the clean-wing tradition, with excellent takeoff and landing and high-speed performance achieved without the added complexity of leading-edge slats. Unlike those on many other heavy jets, Gulfstream wings also benefit aerodynamically from simpler single-slotted Fowler-type flaps, without all the hardware and fairings that accompany more complex flaps systems.

Construction of the G650 is primarily traditional riveted aluminum, but Gulfstream has further developed the capability to more efficiently manufacture bonded structure, and that is how much of the fuselage and other components are made. “This all leads to a better cabin experience, longer range, higher speed and more quality and reliability,” said Jackson.

The incremental improvements that brought about the G650ER make it Gulfstream’s longest-range jet, and this performance doesn’t come at the expense of speed. At Mach 0.85, the G650ER can fly eight passengers 7,500 nm. Speed up to Mach 0.90, and the range drops to 6,400 nm, 350 nm fewer than the max range for the G550, but the G550 does that at Mach 0.80. By comparison, the G650 can fly 7,000 nm at Mach 0.85.

“Most customers fly at [Mach] 0.90 or 0.91,” Jackson said. But the flexibility the G650ER
offers means that fuel can be traded for payload without compromising range. “It gives them a lot more flexibility or reserves,” he said.

**Cabin Accoutrements**

At the maximum altitude of 51,000 feet, the cabin altitude in both G650 models is a low 4,850 feet, dropping to 3,290 feet at 41,000 feet, with 100 percent fresh air replenished every two minutes by the environmental control system. Eight windows on each side of the fuselage illuminate the interior, with more light available from windows that are 28 by 20.5 inches, 19 percent larger than the G550’s. “It makes a difference,” Jackson said, especially because even tall passengers don’t have to bend down to look outside.

The G650/G650ER cabin is Gulfstream’s widest and tallest, with a 102-inch width and 77-inch height. This compares to the G550 at 88 inches wide and 74 inches high. The new G500/G600 cabin splits the difference, with a width of 95 inches and height of 76 inches.

The cabin seating area is 47 feet 10 inches long, allowing buyers four zones to outfit to fit their needs. A variety of interior options are available, from a shower and special wardrobe/storage options in the lavatory to a forward galley opposite a crew rest area. The forward galley is illuminated with natural light from the windows. There is enough space for a real refrigerator with a freezer or a fridge-only option, and also for a stainless-steel appliance stack. The galley is

The G650ER’s spacious interior allows for a variety of optional layouts and equipment, including a shower, forward or aft galley and crew rest area.
fitted with a touchscreen control panel that can be used to manage all the cabin amenities from one location.

Gulfstream engineers have devoted a great deal of effort to silence jet cabins, and the G650ER’s is extremely quiet, so much so, Jackson said, “that we sometimes have to be careful about conversations we’re having in the cabin.” Adding to the quiet are pocket doors for the lavatory and one that covers the opening for the main door during flight.

Like all other Gulfstream current-production jets, the G650 is equipped with the Gulfstream cabin management system. Passenger control units are available at each seat and on iOS or Android mobile devices, allowing passengers to adjust temperature, lighting, window shades and entertainment options. Gulfstream’s CabinView is a customizable system for display of flight progress and points of interest as well as for delivery of passenger briefings. G650s now have optional high-definition external cameras, and these are a popular option, according to Jackson. Early G650s were available with standard-definition cameras.

Most G650 buyers are opting for Honeywell’s JetConnex high-speed Ka-band satcom. “[Broadband Internet access] is very important.”

Like the G450/G550, passengers and crew can access the G650’s baggage compartment in flight. The Gulfstream Aircraft Service Change for this feature was first approved by the EASA and is close to being approved by the FAA. Access is available anytime up to 40,000 feet, then for five minutes at 51,000 feet.

### Technology Benefits

While many of the systems in the G650 and -ER build on the architecture of the G550, Gulfstream took advantage of the opportunity to improve some of the design features, at a systems level and the pilot interface.

For example, in the cockpit, pilots will find the cold start procedures faster than in the G550.

### Gulfstream G650ER Specifications and Performance

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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<tbody>
<tr>
<td>Price (typically completed and equipped)</td>
<td>$67 million</td>
</tr>
<tr>
<td>Engines (2)</td>
<td>Rolls-Royce BR725 A1-12 16,900 lbs thrust</td>
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<tr>
<td>Avionics</td>
<td>Gulfstream PlaneView II (Honeywell Primus Epic)</td>
</tr>
<tr>
<td>Passengers (maximum)</td>
<td>3 crew + 19 pax</td>
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<tr>
<td>Maximum range (NBAA IFR, 200-nm alternate)</td>
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<tr>
<td>High-speed cruise</td>
<td>Mach .90</td>
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<tr>
<td>Long-range cruise speed</td>
<td>Mach .85</td>
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<tr>
<td>Fuel capacity</td>
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<td>Height</td>
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<tr>
<td>Cabin</td>
<td>Volume 2,138 cu ft</td>
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<tr>
<td></td>
<td>Width 8.5 ft</td>
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<td></td>
<td>Height 6.4 ft</td>
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<td>Length 46.8 ft</td>
</tr>
<tr>
<td>Baggage compartment</td>
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</tr>
<tr>
<td>FAA certification (basis, date)</td>
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</tr>
<tr>
<td>Number built (since 2014)</td>
<td>120 (July 2017)</td>
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thanks in part to more automation in the lengthy preflight systems tests procedures. There are fewer switches in the G650, and many features on the instrument panel have been relocated to improve ergonomics and make finding certain items faster during emergency situations.

Clicking on certain items on the electronic checklist pulls up the synoptic diagram for that system automatically, saving pilots a step.

Pilots can more easily see their respective wingtips from the cockpit, thanks to larger side windows. The airplane has a wingspan of 99 feet, 7 inches (about six feet longer than the G550’s), so keeping visual track of the wingtips’ position is vital.

From the outside, the G650 and -ER have a lower look about them, as the G650’s trailing-link landing gear design puts the wing closer to the ground than the G550’s. The Kollsman enhanced vision system camera is now positioned on top of the nose to give the proper view for displaying EVS imagery on the Rockwell Collins head-up display (HUD).

Gulfstream has upgraded to proximity switches on the landing gear instead of regular electromechanical weight-on-wheels switches. The proximity switches are more reliable and less prone to gathering contaminants that could render the switches inoperative at a critical time. All external
lights are LEDs except for a brighter xenon landing light.

The main cabin door is closed by an electrically operated hydraulic pump powered by the forward emergency batteries, and it closes by draining the hydraulic fluid. It is much easier to open than the somewhat intimidating (for first-timers) traditional door, with none of the older Gulfstreams’ primary and secondary door handles.

Fly-by-wire Flight Deck
The G650 cockpit is familiar enough that a G450/G550 pilot will feel instantly comfortable. There is nothing that overtly signals that this is a FBW airplane; the yoke looks completely normal, the tiller for the steer-by-wire nosewheel steering is just like that on the G550 and the avionics, while updated, look almost exactly the same.

There are subtle differences. Gone are the small standby displays (separate ones for attitude and heading) parked next to the landing gear handle on the G550. These are replaced by a clever doubling-up of functions by the standby multifunction controller (SMC) on either side of the G650’s guidance panel. On the G550, these are called display controllers, and they are used for setting up the PFD and map, managing checklists, making HUD selections, baro settings and so on. The G650’s SMCs do much of the same, but their screens are larger and prettier, with color output instead of the G550’s monochrome.

The biggest difference is a “standby” button on the bottom of the SMC’s controls; pushing this turns the display controller into a big beautiful standby display with typical PFD layout. The advantage of this setup is twofold. Not only is the standby display now much easier to see because it is mounted just below the glareshield in the pilots’ normal field of view, but it is much larger than the G550’s standby displays.

Another handy button on the SMC is the “utility” function. This reveals softkeys for checking tire pressure, refueling, engine oil and hydraulic fluid levels and the cabin pressure control system.

The avionics are Honeywell’s Primus Epic-based Gulfstream PlaneView II advanced flight deck, with the same four 14-inch displays as the G550. Eliminating the extra standby displays cleans up the tilt panel and leaves room for the control for a great new G650 feature: autobrakes. These are now standard on the G650 and -ER, and Gulfstream is offering free retrofits to owners of earlier G650s.

The G650 guidance panel is much the same as the G550’s except for placement of the baro setting knob on the guidance panel instead of on the display controller panel. On the G550, I found myself occasionally grabbing the baro knob when trying to change a setting on the display controller, when I should have been using the setting knob that is mounted just below the baro knob. This resulted in me twisting the baro knob and setting an incorrect baro number a few times—something that also happened with my classmates—when I thought I was twisting the display controller setting knob.

The G650 guidance panel/SMC setup is much simpler and less prone to that ergonomic error, with a range/set knob clearly placed on the bottom right corner of the SMC. This may seem like a small item to complain about, but Gulfstream human factors engineers are clearly working to keep improving the product.

PlaneView II in most other respects was comfortably familiar in the G650, with synthetic vision available on both PFDs, the latest version of the Kollsman EVS II playing on the HUD and MFD, three FMSs, Honeywell’s 3D digital RDR-4000 radar, ADS-B out, FANS and CPDLC (datalink communications). Gulfstream is also working on gaining approval for no natural vision landings under the FAA’s new enhanced flight vision system regulations. “We’re hoping to be first out the door [with EFVS approval],” said Jackson.
Fly-by-wire Controls

“This is truly a clean-sheet airplane,” Jackson explained. Gulfstream took a conservative approach, opting for yoke controls that are mechanically connected, and waiting for the next-generation G500/G600 to install BAE active sidesticks that are electronically connected. This decision adds to making the G650 a comfortable transition for the G450/G550 pilot, and it underscores the FBW control philosophy that Gulfstream elected to adopt.

Like Boeing, Gulfstream chose the speed-stable platform, where the G650 essentially handles like a normal airplane with hydraulically actuated controls or just mechanical controls (cables, rods and pulleys). Pulling the G650 into a climb requires the pilot to change the trim to set the trimmed airspeed, which might require the FBW computers to adjust the moveable horizontal stabilizer to a new angle to relieve pressure on the controls during the climb. The pilot of the G650 is either flying in a trimmed condition or using trim to return to a trimmed condition or just accepting the control pressure perhaps temporarily in a maneuver that won’t last too long, just like any conventionally controlled airplane.

Airbus, Dassault and Embraer fly-by-wire designs are flight-path stable, where the airplane remains in whatever flight path the pilot selects. Because the G650 is a FBW airplane, there are additional benefits besides the weight savings of computers and wiring versus cables, pushrods and hydraulics. FBW allows engineers to extract more performance from the airplane while tuning the
ride for passenger comfort. Built-in envelope protection helps pilots keep out of dangerous corners. Flight control surfaces can be manipulated by the computers to continually optimize aerodynamics for minimum drag, and in the G650's case this amounts to a 1 percent drag reduction, according to Jackson.

The speed-stable philosophy means that pilots transitioning into the G650 will not have to learn a new way to fly but can bring their muscle memory from previous conventional airplanes to the new airplane.

The FBW system architecture relies on two hydraulic systems, either of which can operate dual hydraulic actuators for each aileron, elevator and rudder control surface. Spoilers on each wing have a single hydraulic actuator. If both hydraulic systems fail, electric backup hydraulic actuators mounted on each aileron, elevator, rudder and outboard spoiler panel provide full backup control. A change on the G650 is using hydraulic dampening to protect flight control surfaces from gusts while parked, so there is no mechanical gust lock system as found on the G550 and earlier Gulfstreams, yet another way the cockpit is less cluttered.

The FBW controls operate in four modes: normal, alternate, direct and backup. While normal mode feels, well, normal, there are some subtle features that adjust the control feel in this mode. During takeoff, for example, the FBW system adjusts control sensitivity to prevent overcontrol, and the pitch trim switch moves the stabilizer. Once the airplane is in the air, the controls transition, and the pitch trim switch adjusts elevator position while the stabilizer then moves to remove the load from the elevator.

In normal mode, angle-of-attack (AOA) is limited, and the stickshaker activates at AOA .94, and the FBW will not allow the airplane to stall, even if the pilot pulls the yoke all the way back. The FBW also prevents a high-speed excursion by limiting nose-down authority when exceeding Vmo. Other protections: maneuver load alleviation, which prevents loads of more than 1.5 g by controlling aileron deflection; speed brake auto retract at high power settings; dynamic rudder limiting to prevent the pilot from overstress ing the airframe by using the rudder incorrectly; and elevator split limiting, for protection against large torque forces when operating in split elevator mode.

Normal mode relies on all systems operating normally with two flight control computers, each of which has two separate channels. One channel can run the entire flight control system.

If the required air data or inertial data is not available or the flight control computers lose communications with the horizontal stabilizer control unit, the control system switches to alternate mode. In this mode, the autopilot and high- and low-speed protections become unavailable and the stickshaker activates at AOA .85 instead of .94 (but only if air data is still available). Pilots can attempt to reset the flight control computers in alternate mode using the flight control reset switch on the center pedestal.

If all four flight-control channels of the computers fail, the system reverts to direct mode. In this mode, the speed brakes won’t automatically retract, the stickshaker won’t work and the pilot can’t revert to either alternate or normal mode until power has been cycled.

The same is true in backup mode, which is the worst case (and was tested extensively during the flight-test phase). In this mode, the mid-spoilers used for roll control are unavailable and the speedbrakes and ground spoilers do not work. The pitch trim switch on the yoke doesn’t work, and pitch trim can be controlled, at one-third the normal rate, only via the backup trim switch.

**Time To Fly**

Demonstration pilot Tony Briotta and Scott Curtis, senior international caption, briefed our planned flight on a warm summer day at Gulfstream’s Savannah, Ga. headquarters. The plan
was for Briotta to fly left seat and Curtis right seat from Savannah to Columbia, S.C., while I flew jump seat, then switch so I would fly left seat back to Savannah.

Weather was typical heat-generated scattered thunderstorms that threatened to join up later in the afternoon and produce a tropical downpour, but for our flight there were no immediate threats. It took Briotta and Curtis just 10 minutes to run through the pre-start checklist, which was much faster than the process in the G550.

We took off from Savannah’s Runway 10 fairly light, at 67,084 pounds, 36,516 pounds lower than the 103,600-pound mtow. Outside air temperature was 31 degrees C, and the FMS calculated our runway required at 3,335 feet to stop after a rejected takeoff or 3,184 feet to go. Briotta explained that I’d find it necessary to use the
thrust reversers to slow our taxi as the BR725 generates a lot of thrust at idle. Curtis said that the G650’s FBW “flight controls feel like the difference between a sports car and a luxury car. It’s very responsive.” It took just 24 minutes to fly to Columbia, and before I took the controls, Curtis explained that landing the G650 is different from landing the G550, in that the newer jet’s nose doesn’t need to be help up after touchdown. “You have to push the nose down,” he said, “and it won’t tend to slam down.”

During the takeoff, Briotta explained that the airplane is “more responsive on the rotation. Most pilots tend to pull back too hard, and it jumps off the runway. Just pull back nice and smooth to nine to twelve degrees [nose up], and don’t chase the flight director.”

The biggest difference that I would probably notice between the G550 and G650 is that no matter how much it weighs, the G650 will handle the same, Briotta said. “You can be smooth or aggressive, whatever the weight.”

One control that Gulfstream pilots should take care not to be too aggressive with is the nosewheel steering tiller; on the G650 it’s just as sensitive as the G550’s, with the ability to turn the nose up to 80 degrees. On takeoff, the rudder pedals provide up to 7 degrees steering, which worked just fine to keep the nose on the centerline. The G650ER’s brakes were not at all grabby and help the pilot keep things smooth for the back-seaters.

On takeoff from Columbia’s Runway 29, the BR725s accelerated the big jet quickly as the autothrottles smoothly advanced the power. At 107 knots I pulled the yoke back to rotate while trying to avoid letting the nose rise too rapidly as we accelerated past the 124-knot V, speed. The controls did indeed feel precise, and I was able to put the nose exactly where I wanted and trim for the climb with little extra effort.

It took just 15 minutes to reach FL430, and we leveled off at FL450 for a performance check. With fuel flowing through each engine at 1,480 pph at ISA -7 degrees C, speed settled at Mach 0.91.

Our route took us northwest nearly to Knoxville, Tenn., then southwest over Augusta, Ga., and back to Savannah. On the descent, Briotta demonstrated the high-speed envelope protection, which kept the nose from drooping as we sped up to Vmo.

I slowed down at a lower altitude to get a feel for the G650ER’s low-speed handling, and indeed it was crisp at any speed. As we neared Savannah, I steered around some building thunderstorms, carving pathways between the burgeoning cloudscape like a Red Bull racer turning to avoid hitting one of the raceway pylons.

We elected to hand-fly a visual approach to Runway 10, backed by with the glideslope information on the HUD, which I prefer to use whenever possible. I brought the big Gulfstream in a little high, but Briotta noted that when the flaps are fully out and gear down, “you can point the nose down and not pick up speed,” and sure enough I captured the glidespath easily and held it solid right to the runway. The G650ER felt amazingly solid and responsive even on short final, and I was able to stick it on centerline and within the landing zone parameters that the FlightSafety instructors hammered into me during my G550 training.

After a barely perceptible touchdown of the main gear, I did as instructed and pushed forward—not too quickly—on the yoke, and the nosegear touched down gently. We had selected the autobrakes to the “low” setting, and once the nose was firmly planted, the brakes brought us to a smooth stop, aided by a touch of reverse thrust.

The G650ER exceeded my expectations in all respects, but mainly in the handling. This is among the largest jets that I have flown, and Gulfstream engineers have done a marvelous job making the G650ER a pleasure to fly. The precise handling at all speeds and in all configurations makes the G650 and G650ER the pinnacle of the Gulfstream flying experience.