7E7

When "E" means everything

As designers add more new features to the 7E7, some say the E stands for "everything"—especially efficiency

In a little more than four years, Boeing plans to begin delivering an airplane whose middle name will be "efficiency." The 7E7, which the company has been marketing with great fanfare, would burn 20% less fuel on long routes (and 10% less over shorter distances) than other aircraft in its class.

Actually, Boeing says it even will be more efficient than some planes out of its class, including the Airbus A380 superjumbo. But the 7E7 is not designed to be some kind of Toyota Corolla of the sky, a stripped-down machine that sacrifices comfort and speed for better gas mileage.

In that respect, the E might just as well stand for "everything."

For passengers, the 7E7 provides wider seats and aisles, and a quieter, more comfortable cabin that is humidified, pressurized at 6,000 ft instead of the typical 8,000, and stocked with electronic entertainment goodies. For operators, the plane offers not only fuel efficiency but also easier maintenance, lower life-cycle costs, and a logical fit among its 777 and 747 siblings. For the environment, it features quieter engines, reduced emissions, and cleaner manufacturing processes.

All of that would be pointless without efficiency—the heart and soul of Boeing's first new passenger jet since the 777 of 1990. To achieve the 20% efficiency goal, Boeing engineers have taken a four-pronged approach that will offer some radical changes over previous designs, as well as evolutionary improvements. In general terms, new engines will get Boeing halfway to its goal. To reach its final target the company will combine incremental improvements in aerodynamics, a totally new systems architecture, and heavy reliance on composite materials.

"They have a very ambitious goal…but to me it doesn't appear to be unrealistic," says Hans Weber, an aerospace technology consultant at Tacop International in San Diego. "Boeing has a history of meeting its targets; they're highly regarded."

Despite considerable in-house talent and an array of international partners helping in the design, Weber says Boeing Commercial Aircraft has not been associated with risk taking of late.

"Boeing is more known for a cautious and rather conservative approach, and the 7E7 isn't," he says.

by **Ron Laurenzo**
Contributing writer

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Battered by the same post-September 11 storm that has stunned its airline customers, and by loss of market share to Airbus, Boeing Commercial Aircraft is staking its future on the broad wings of the 7E7. Over the next 20 years, the company is predicting sales of 2,000 base and stretch models, plus another 500 short-range versions.

It's fast, too

Ironically, at least in light of the stillbirth of Boeing's Sonic Cruiser, the 7E7 would also be one of the fastest airliners in the sky, cruising at 0.85 Mach, a tick faster than the 777 and a smidgen slower than the 747, the fastest airliner in the post-Concorde era.

"The 7E7 is intended to do its efficiency magic at the same high speeds as the fastest airplanes flying today," says Walt Gillette, Boeing's vice president of engineering, manufacturing, and partner alignment for the 7E7. The A380 too will cruise at 0.85 Mach, says Gillette, noting that this "is going to be the speed regime for the really efficient twin-aisle airplanes out there."

Put it all together and the 7E7's moniker, Dreamliner, starts to make sense, although among skeptics it has acquired a secondary meaning quite unintended by Boeing.

As chief engineer, Gillette is one of the main people responsible for bringing the Dreamliner into reality. Gillette, who joined Boeing in 1966 as an aerodynamicist, has spent his entire career preparing for such a challenge, and he speaks with relish about the project. He has helped develop just about every Boeing airliner after the 707. In the early 1990s he was chief project engineer on the 777. Prior to that he was top technology man on the 737 and 757.

He also led the team that pioneered the 7E7 concept, as well as the Sonic Cruiser and the 747X. Before that he headed the engineering team for the entire Commercial Airplane Div.

For clarity's sake, the 20% efficiency figure comes from comparing the 7E7's per-passenger fuel costs with those of other airplanes in its class, basically the 767 and A330 families. Gillette says 20% is an average number that can vary depending on whether you compare it to a 767-300 or -400, or an A330-200 or -300.

In simple terms, Boeing is initially aiming

The first round of high-speed wind tunnel testing for the Boeing 7E7 was recently completed. Four different wing configurations were tested during the effort. Additional wind tunnel tests will continue through 2006.

the 7E7 at the middle of the airline market, with the base version flying roughly 7,800 n.mi. carrying about 200 passengers seated in three classes. By comparison, the 767-300 has the same seat count, but offers only about 80% of its new sibling's range and a noticeably slower cruise speed.

Looking at smaller distances, especially in the cutthroat U.S. domestic market, Gillette is confident a short-range version of the 7E7, which would seat 290 passengers in two classes, can replace the 757-300, 767-300, and Airbus A300-600 aircraft flying routes in the 500-1,500-n.mi. range.

"The real trick here is to utilize the intrinsic efficiency of the 7E7—which is designed as a very long-range airplane—and make it the best short-range airplane in history in terms of efficiency," Gillette says. "Well, it turns out we've done all that."

One way they did it, says Gillette, was to design a wing with a removable, replaceable tip. With a wingspan of 193 ft, the long-range base and stretch versions will not fit in the airport gates used by 757s, 767s, and A300s. To fix that, the short-range model will have a 172-ft wingspan.

Choosing engines

Start discussing better fuel efficiency and most people will think immediately of engines, which indeed will account for the biggest chunk of the 7E7's improvement in this area.

To get the engine design it needs, Boeing worked closely with General Electric, Rolls-Royce, and United Technologies' Pratt & Whitney, and after months of study, the company announced its selection on April 6.

Boeing settled on two engine types, General Electric's GENX and the Rolls-Royce Trent 1000. In a first, both engine types will use the same standard interface with the airplane.

7E7's engines will be "right at the edge of the technology that's available for entry into service in mid-2008," he says. By themselves, Gillette adds, they will provide 7-8% of the plane's improved efficiency.

However, because the aircraft and engines are being designed as a single entity, Boeing sees an additional 2-3% gain. That comes from a process called cycling, in which engine improvements lead to airframe and wing improvements, and vice versa.

In other words, if an engine is more fuel efficient, the plane does not need to carry as much fuel, which means the wings do not have to lift as much weight, so they can be smaller. That, in turn, means the engine can be a bit smaller, allowing a smaller wing, and so on until the right balance among engine, wing, and airframe is reached.

Gillette says the 7E7's engines will have a bypass ratio of 10, with a fan the size of the 777's and a core the size of the 767's.

Another logical suspect for improved efficiency in aircraft is a more slippery slipstream. Gillette says the company will eke 2-3% out of the new plane's aerodynamics thanks to advanced computational fluid dynamics. The process is an extension of what Boeing did with the 777, the first digitally designed airliner. CFD at that time allowed for analysis of the wing and body, or of the wing, nacelle, and strut with boundary layer at transonic speeds. The process yielded results in 3D, but was still lacking in detail. Also, until recently, an aerodynamicist would propose a shape, analyze it with the computer, and then, based on the computer analysis, tweak the shape and start the process over.

Now, CFD codes are advanced enough to analyze airflow over the entire aircraft, and aerodynamicists can propose the result they want and let the computer propose the shape. The new method is highly precise, says Gillette, with predicted results usually coming within 1% of the real thing in wind tunnel tests.

Staunching the bleed

Another 2-3% efficiency will come through equipment that is hidden from view. "The systems in the 7E7 are considerably different from [those in] any other airplane," Gillette says. "The first thing we did was completely remove the high-pressure bleed air system."

Typically, jet aircraft use bleed air—air pulled from the engine core and piped all over the plane by a system of ducts—to pressurize and control climate in the cabin and to deice the wings and engine inlets.

That air, of course, is extremely hot—around 1,000 F straight out of the engine, which is enough to melt the wing if something goes wrong. Hence, a heavy, complex system of valves, temperature sensors, and control units is necessary to cool the air to a maximum of 400 F.

By the time it reaches the fuselage, the air is still at 300 F and has to be cycled through air-conditioning packs that spin at more than 120,000 rpm before it can be used for pressurizing or heating the cabin. Thus bleeding air off an engine not only requires much ancillary equipment but also reduces the engine's efficiency and lowers power output.

"We've gotten rid of the least reliable system on the airplane," Gillette says.

Instead, the 7E7 will use electric motors and air compressors that Gillette says are lighter and more reliable for cabin pressurization. Eliminating the ducting system provides more space inside the wing leading edges and more flexibility in slat and wing design.

Gillette says companies that make these kinds of electric motors and controllers are doubling the capacity of their products every 18 months, rivaling Moore's law for computer technology advances.

"The whole world's working on them, so there's much more of a future for increased efficiency, lower weight, and higher reliability in electrically powered devices than in pneumatically powered devices," he says.

The 7E7 will be "more electric" but not "all-electric," relying on hydraulics to do the heavy work of raising and lowering the landing gear, as well as moving the ailerons, elevators, and other flight control devices. While hydraulics provide the muscle, Gillette says the system will also feature electrical signaling and some electrical powering as well.

Subcontracts are still being distributed for the system, and Gillette says Boeing will be able to talk more about its final architecture in coming months.

The hydraulics also will be lighter and more localized than current types, and the 7E7 will be one of the first two airliners to have a 5,000-psi system, as opposed to 3,000. The other is the A380, which isscheduled for first delivery in 2006.

Higher pressure means a weight savings from carrying less hydraulic fluid, as well as smaller, lighter pipes and controllers. For safety, the 7E7 will have three hydraulic systems, although one could do the job in an emergency.

The carbon fiber advantage

The 7E7 gets another 2-3% fuel efficiency through the use of composite materials on a scale previously unseen in an airliner. In strength applications, carbon fiber is 20-30% lighter than conventional aluminum, and about 15-20% lighter than advanced aluminums that could be available during 7E7's development period.

"The news is not that we're going to build a wing out of carbon fiber, because we've been doing that a lot," Gillette says. "The news is to build a fuselage out of carbon fibers."

It will be Boeing's biggest carbon-fiber project ever, but one for which it is well prepared, Gillette says. He adds that the firm has built and delivered more carbon-fiber structures than any other aircraft company in the world—6 million lb, in airliners, military planes, launch vehicles, and satellites.

The 7E7 wing box, wing center section, and fuselage pressure vessel will be made of the same substance used to make almost 500 horizontal and vertical stabilizer sets for the 777. The material is extremely robust and has survived hail storms undamaged.

A pressurized fuselage typically endures more stress than the aircraft's wings, considering that during every flight it gets pumped up to around 55-60% of its design load, says Gillette. In addition to fatigue, it is subject to corrosion from lavatory and hydraulics fluids. Wings, on the other hand, are designed for 2.5 *g* and typically stay at 1 *g*, or about 40% of their load. Over time, Gillette points out, the industry has figured out how to build and maintain aluminum fuselages, but they are "fairly complicated structures."

The 7E7 is promising passengers wider aisles and seats.

Since carbon fiber does not fatigue or corrode, it is a logical choice for making the body of the plane. Previously, however, it had been considered too expensive.

"We have figured out how to produce a fuselage at cost levels that are very, very competitive with aluminum, so that's really the big step forward here," Gillette says.

Aside from weight savings, there also is the prospect of much lower long-term maintenance costs. In carbon fiber, moreover, the company sees a growing technology sector, as it did when it moved toward more electrical systems. The rapid advances taking place in the development of this material will benefit 7E7 in the future, Boeing believes. As carbon fiber improves, it is easy to introduce into production processes.

Only the aircraft industry uses aircraft-grade aluminum, making it a "boutique" business where the industry alone bears all the R&D costs. Carbon fiber has been expensive, but is used in products ranging from golf clubs to bridge beams.

"We believe nanotechnology is going to move the cost and efficiency of carbon fiber much faster than it's going to move metals," Gillette says. "By going to carbon fiber, we're sure we can meet our weight [and cost] targets…and we'll be with a material that will see lots of advantage gained in the future."

The wing and fuselage will feature composite materials in a traditional design. However, Gillette says carbon fiber may allow Boeing to use a new structural concept for the empennage, though the details are still being worked out.

Despite Boeing's history of using composites, rival Airbus is more highly regarded in this area. That will change if Boeing gets it right with the composites, from the design board to the manufacturing floor and to maintenance on the flight line.

"This 7E7 will make Boeing leap way ahead of Airbus," predicts Weber, who says the company will benefit from all the work it has done on military composites since the 777 launch, as well as on upgrades to its current airliner fleet.

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Bill Dane, senior aviation analyst at Forecast International in Newtown, Conn., is confident the 7E7 project will succeed, because it addresses what users want, he says. Succeeding in the high-efficiency department could leave the middle market to Boeing for several years, considering Airbus is tied down with the A380 and could not respond with a direct competitor to 7E7 until 2010, Dane says.

Sonic Cruiser was "the only thing they've done wrong," says Dane, who believes Boeing should have listened harder to the airlines. With 7E7, he says, "If they can come up with a 15% operating cost reduction, they're going to have a real winner."