CIVIL SUPERSONIC

Concorde is a museum piece, but the allure of speed could spell success for one or more of these projects.

by Nigel Moll

Fourteen years have passed since British Airways and Air France retired their 13 Concordes, and for the first time in the history of human flight, air travelers have had to settle for flying more slowly than they used to. But now, more so than at any time since Concorde's thunderous Olympus afterburning turbojets fell silent, there are multiple indications of a supersonic revival, and the activity appears to be more advanced in the field of business jets than in the airliner sector.

Aerion continues to be the most enduring player, and the company's AS2 design now has three engines (originally two), the involvement of Airbus and an agreement (loose and non-exclusive, but signed) with GE Aviation to explore the supply of those engines. Spike Aerospace expects to fly a subsonic scale model of the design for the S-512 Mach 1.5 business jet this summer, to explore low-speed handling, followed by a manned two-thirds-scale supersonic demonstrator "one-and-a-half to two years from now." Boom Technology is working on a 55-seat Mach 2.2 airliner that it plans also to offer as a private SSBJ. NASA and Lockheed Martin are encouraged by their research into reducing the severity of sonic booms on the surface of the planet.

Shaping the boom

The sonic boom produced by a supersonic aircraft has long shaped regulations that prohibit civil supersonic flight over land, presenting aircraft designers with no choice but to remain below Mach 1 over land and exceed the speed of sound (760 mph at sea level) only over water. But research over the past decade or so is bearing fruit toward revealing how to shape the aircraft to muffle the sonic boom.

"We call it sonic boom shaping because it shapes the acoustical signal of the shockwave that reaches the ground," says Peter Coen, project manager for the commercial supersonic technology project at NASA Langley. "All aircraft flying to date create what is called an N-wave sonic boom: if you plot the pressure distribution that you measure on the ground, it looks like the letter N. You get a large pressure impulse, a gradual decrease to below the local atmospheric pressure and then another impulse back to the atmospheric level. You hear bang-bang, and you don't hear the gradual pressure change in the center of the signal. The reason you have the two impulses is that the air doesn't know the airplane is coming, so the pressure changes instantly. Near the airplane there are shockwaves on the canopy, the wing, the nose, the engine nacelles and the tail, and they're all different strengths, randomly spaced along the airplane. Because they have different strengths

Half a century ago, engineers designed Concorde with slide rules. Today, they have an arsenal of computing tools to solve the Anglo-French SST's shortcomings: boom noise, engine noise and fuel thirst.

they travel at slightly different speeds, so as that wave travels away from the airplane the energy coalesces into the two spikes; as that signal travels through the atmosphere it gets attenuated (the pressure gets lower) but it still maintains the N shape until the sonic boom reaches the ground.

"You want to shape the airplane so that the shockwaves formed near the airplane have a specific pattern in which they are relatively consistently spaced and of the same strength. If they're the same strength they travel at about the same speed and they tend not to coalesce. Or if they do they coalesce into a pattern that you want on the ground: instead of a spike, a series of small pressure changes. The atmosphere has worked on them and in effect rounded them a bit, so what we're aiming for is something that looks more like a sine wave than an N shape. With a gradual pressure change, your ear does not hear it and the disturbing crack or bang is gone. You'd hear it as a double thump."

Aircraft designers' predicament is not made any easier by the absence of hard numbers in the regs, which do not provide actual figures for decibels or strength of pressure wave that the FAA would deem acceptable for overland supersonic. This is what is driving NASA's low-boom flight demonstration program: it will produce measurable evidence of the reductions made possible by boom shaping.

In addition to shaping airframes, the researchers have also been studying how people respond to different impulsive sounds such as sonic booms, indoors and outdoors. "Using simulators, large rooms with large speakers attached to the walls, as well as flight-test work where we fly the airplane in a dive maneuver to produce in a very small area the signal we're looking for, we have an idea that at somewhere between 60 and 70 dBA the noise begins to fade into the background, which might be acceptable. The proof is when we leave the lab and take the dive test off range and see how the average person, going about their business on the average day, responds to this sound."

To test this theory, NASA and Lockheed Martin are designing a new airplane called the Quest, for quiet supersonic technology. It's a single-seat Experimental airplane, some 100 feet long and with an mtow of 25,000 pounds, shaped to produce this low-boom signal. "For the dive testing we have been using an F/A-18, instrumented to repeat a dive profile precisely but not modified in any way to shape the boom," says Coen. "We start the dive subsonic at 50,000 feet and allow the airplane to achieve supersonic just briefly in a steep dive so that the signal comes off the top of the airplane at about 45,000 feet at a shallow angle and travels a long distance through the atmosphere before it reaches the ground.

"In a small area of the ground, you end up with a signal that is kind of rounded and has a low peak pressure, the sort of signal we're looking for with our low-boom design. The signal hits the ground about 30 miles from the aircraft. Right below the aircraft you get an intense, focused boom. This maneuver is effective as a research tool as long as you've got a big desert to fly over—we've done all this testing at NASA Armstrong [the former Edwards AFB] and the test community we've used is the base housing community—a small area surrounded by desert. The people we're exposing to this sound depend for their livelihood on aircraft that regularly make sonic booms. They're not anti-sonic boom—for them it's the sound of freedom. We don't really get true data that we could give to the FAA to prove that we've achieved the right level, but we can use it to test the procedures and fine-tune the surveys and how we record the noise in the community."

The low-boom flight demonstrator is slated to fly in 2021, at which time researchers can do tests in other, average communities anywhere in the U.S. Lockheed is doing the preliminary design of the aircraft for NASA, and that phase ends this summer. "We will then have a new competition for the actual detail design and development of the aircraft. It's a clean-sheet airframe that uses a lot of existing components, mostly from existing military aircraft. The Lockheed design uses F-16 landing gear and a GE F414 engine. The canopy and cockpit area is the aft cockpit of a T-38. To maintain the desired supersonic shape, you can't have a forward-vision window, so we're going to use a synthetic external vision display to give the pilot essentially VFR-equivalent vision."

Is Lockheed's end goal some sort of airliner? "I can't say for certain," ventures Coen. "My guess is they want to position themselves to be a technology provider. I don't see them getting back into the airliner business. They might partner with somebody to do an airliner design. Lockheed is not involved with Aerion or any other SSBJ project. A few years ago they were partnered with SAI [Supersonic Aerospace International] on the design of an SSBJ, but that design has languished. The NASA effort is focused on a longer-term goal of airliner-type transportation. But there is significant overlap in the technologies we're working for business jets too. We still have a no-funds-exchanged agreement with Gulfstream under which we share information about understanding the community response to low-noise supersonics."

A few years ago Gulfstream took out patents on a nose spike designed to mitigate the boom. "They haven't shown anything relative to that in a while," observes Coen. "The breakthrough that we came up with by shaping really just happened

BAC-Aerospatiale Concorde	
Passengers (max)	100
Supersonic cruise	Mach 2.02/1,340 mph
Supersonic range	3,908 nm
Takeoff field length	11,800 feet
Max takeoff weight	408,000 lbs
Operating empty weight	173,500 lbs
Max fuel	210,000 lbs
Engines (four)	R-R/Snecma Olympus, 38,050 lbs each for t/o
Wingspan	84 feet
Length	202 feet 4 inches (+5.5 inches at Mach 2)

in 2009-2010. We tunnel-tested it in 2011. The mathematicians who started this research a long time ago proposed essentially two target ground signals to achieve a low boom. For the longest time, people were trying to produce a signal like that. The breakthrough came when we learned that we don't really care what the shape of the signal is on the ground as long as it produces the loudness level that we like. So Gulfstream was the first to exploit that with its quiet spike, but very rapidly NASA working with Lockheed and Boeing realized you could also do it with a more conventional nose shape, for less mechanical complication. Gulfstream has not shown any designs publicly, and I'm guessing they're also looking at other approaches." Coen notes that Aerion is not pursuing a low-boom design.

Gulfstream's only input for this article was this: "Unfortunately, we don't have anything new to report in terms of supersonic. We have a small team dedicated to researching sonic-boom mitigation and working with other organizations to remove the ban on flying supersonically over land. It's important to remember that we already offer an aircraft that can fly at nine-tenths the speed of sound!"

Even if, like Aerion, you choose to fly supersonic only over water, a supersonic aircraft still has to meet engine noise requirements for takeoff and landing. "Right now the NOx emissions requirement applies only to takeoff and landing," says Coen, "so a Concorde-type turbojet is not going to cut it. Our vision at NASA is a little

NASA and Lockheed Martin are teamed on the design of the Quest, slated to fly in 2021. It will test theories about how the design of the airframe can shape and muffle the sonic boom as it is perceived on the ground.

farther out, but we are looking at engine cycle designs, nozzle and inlet configurations that meet at least the existing regs and, longer term, the proposed Chapter 14 stringency. That's an important area of our work that the business jet folks need to pay attention to. In conjunction with our subsonic research efforts, one of the big areas of focus is on the reduction of emissions and fuel consumption. We've developed some interesting concepts for the combustor, which should reduce emissions even at altitude to a point that is compatible with preserving the ozone layer in the upper atmosphere. This sort of technology should be available to the likes of GE and Rolls if they're providing the power for supersonic business jets. GE and Rolls do seem to be the two engine OEMs most involved in possibly powering an SSBJ today. Pratt & Whitney is out there as the biggest manufacturer of supersonic engines now, but it doesn't seem to be showing anything related to commercial aviation."

Is it still assumed at this stage that an SSBJ or SST will be powered by something burning jet or bio fuel? Is there any radically different engine technology at a stage now that would convince someone to design a supersonic airplane around it? Coen: "I would have to say no. Anything other than jet fuel that can offer the energy density required by a supersonic aircraft is a long way in the future. Some of the weirder hybrid things that have been proposed…They rely on some new physics. But I will give credit to the English hypersonic folks who would essentially use fuel to cool the inlet air. It looks a little weird, but they're making good progress on it. That's a hypersonic propulsion system, but it might be closer than you think. Considering the era in which it was designed, the Concorde engine inlet is really an amazing achievement. Not only did it work, but it did so with a great deal of efficiency." In cruise, the inlet was responsible for about two-thirds of the net thrust required by the aircraft.

Each of Concorde's four Rolls-Royce Snecma Olympus 593 turbojets breathed through its own 11-foot-long inlet equipped with a complex system of ramps, actuators, valves and spill doors that with precise manipulation were able to slow the intake air to Mach 0.5 from Mach 2. "If you slow down from Mach 2, to 1.7 or 1.8," notes Coen, "you can design a pitot-type fixed-geometry inlet that has a normal shock that stands off a little way in front of it for what we call an external compression inlet that rivals the efficiency of Concorde's engines but without any moving component."

Supersonic Shove

GE Aviation has been working with Aerion "for some time now and doing studies around different configurations and options," according to Shawn O'Day, marketing general manager for GE Aviation business and general aviation and integrated systems. The agreement with Aerion (announced at EBACE this spring) "involves working together to define a configuration that makes sense for the program." At this stage scant detail about the agreement has been released. "We don't have a timeline drawn out. We've been talking for years, and this is the next step. Talks will get more serious about what the next stage is. It's tough to paint a picture here because a lot of what we face now is diving in to see what these next steps are. Those are going to be determined over the summer and beyond."

Does the agreement provide exclusivity to GE? Is there anything to prevent Rolls or Pratt jumping in? O'Day: "Aerion and GE are working together now; let's just leave it at that. Ask Aerion if there is any exclusivity to GE." Aerion chose not to elaborate on this and other questions, among them whether any money has changed hands yet and to what extent GE would be expected to be a risk-sharing partner putting skin in the game: "We expect to have more to say as we progress with the engine development process. Engineering teams at Aerion and GE currently are working jointly in an engine definition phase."

Has any particular GE engine, such as the Passport, caught Aerion's attention as a strong candidate to serve as the core of a supersonic engine? O'Day: "We're not disclosing that at this point. We're using existing capability and technology to address the need. Aerion requires somewhere in the region of 17,000 pounds from each engine for takeoff, but really what you're designing for is high-altitude thrust. Unlike a traditional airplane, the thrust levers on an SSBJ go forward for cruise at altitude. The engine is actually operating at a higher power at altitude, and it needs a lot of air flowing through the core. Bypass ratio is lower than on a traditional business jet engine, so the core has a lower-bypass fan attached to it and is bigger than what you'd normally have. Technically it's still a turbofan rather than a turbojet." Aerion did confirm to **AIN** that the AS2 will have fixed engine inlets, but "we need more engine data before we finalize the design. Concorde had variable inlets, but the challenges are fewer at Mach 1.5."

Will military engine people and expertise be formally assigned to this project? "We have people with both military and civil program experience," said O'Day, "so we will be drawing on them. But we have to be careful not to get into materials, technology and know-how that fall under export control laws. It has to be a commercial engine."

The other engine manufacturer publicly interested in getting on board the next generation of supersonic civil aircraft is Rolls-Royce, which can claim to have civil supersonic propulsion experience equaled only by Olympus 593 partner Snecma (Safran). The British company is looking into supersonic concepts and following supersonic business aircraft development programs. Dr. Dean Roberts, market analysis executive for business aviation at Rolls-Royce, said "We have supersonic civil aircraft experience, and can draw on our fighter experience as well." He noted that until regulatory hurdles can be overcome to allow supersonic flight over land, the "halfway house" will be a hybrid SSBJ.

The company has done detailed analysis, Roberts said, that showed the hybrid approach is "quite an attractive proposition—looking at the routes you could fly there are very clear benefits." On the economic side, R-R's analysis suggests "the greater the distance you can go, the more people will pay for speed. What we think is that if you radically increase speed, you will get an exponential not a straight-line relationship so you can substantially raise the price," a prerequisite to make such programs viable. Thus "it will not destroy the subsonic world" as the number of aircraft would be small, tying in with the growing number of billionaires.

Spike, Boom, Pow, Zap

Spike founder Vik Kachoria has put his own money into the S-512 SSBJ program but he also has investors, "all U.S. individuals and commercial entities so far, but we have also talked with investors in the Middle East and Asia."

The all-composite S-512 is being designed to cruise at Mach 1.6, which Kachoria defines as "a sweet spot for boom, airframe temperature and range." His background is in physics and math and he has worked at NASA and GE Aircraft Engines, "and our chief engineer was at NASA for 20 years and at Boeing for 20 years, specifically working on supersonic and hypersonic vehicle design."

Kachoria is playing his cards close to his chest at this stage and reveals little detail about the S-512 beyond what is on the website. He does say, however, that "we have talked with two of the three engine manufacturers." GE is already under an agreement with Aerion but the partnership appears to be loose on ties; maybe the two are Rolls and Pratt, maybe not. "Our engines will not be afterburning—too much noise, too much fuel burn—and boom shaping is the number-one priority for our program. We're talking with NASA and Lockheed Martin."

Boom is working on the design of a small supersonic airliner, and the company says the design "can also be configured as ultra-VIP personal or business aircraft." Declaring that "a major problem with Concorde was that it had more seats than could be filled at the required prices," Boom says its aircraft will have just 55 seats, similar to the number of seats in the premium cabin of a typical widebody airliner: "Final ticket prices will be set by airlines, but we are designing the aircraft so that airlines can operate profitably while charging the same fares as today's business class."

While designing its airliner to have a boom 30 times quieter than Concorde's and takeoff noise quieter than required by Stage IV, Boom rails against the ban on overland supersonic operations in the U.S.: "This ban should be reversed and replaced with a commonsense noise standard, set to promote efficient, affordable supersonic flight while disallowing nuisance. In the meantime, Boom will focus on routes that are primarily overwater—such as New York to London or San Francisco to Tokyo, flying subsonically when over land. More than 500 routes benefit immediately and significantly from supersonic speeds."

Spike S-512	
Passengers (max)	18
Supersonic cruise	Mach 1.6
Supersonic range	5,580 nm
Subsonic cruise	Mach 0.95
Subsonic range	4,050 nm
Takeoff field length	6,000 feet
Max takeoff weight	115,000 lbs
Operating empty weight	47,250 lbs
Max fuel	56,000 lbs
Engines (two)	20,000 lbs each for t/o
Wingspan	58 feet
Length	122 feet

Boom plans to fly the XB-1, a supersonic two-seat concept demonstrator under construction at Denver Centennial Airport, next year. It will be powered by three GE J85 turbojets. The airliner is intended to cruise at Mach 2.2, at which the nose and leading edges of the carbon-fiber structure will reach as much as 345 degrees F (174 degrees C.) on a hot day. Concorde's speed limit of Mach 2.02 was defined by its aluminum structure: at that speed at 60,000 feet, the nose was 260 degrees F. (127 degrees C.) and the wing leading edges were 210 degrees F. (99 degrees C.), and sustained forays into temperatures above those harm the molecular structure of aluminum. Boom emphasizes that modern composites are a more suitable material for building a high-speed airplane.

The Allure of Speed

I think back to one of my seven rides in Concorde for a case study in the allure of speed. One

of the passengers was about as close as humanly possible to Mr. Creosote, the impossibly portly restaurant patron in the Monty Python movie, *The Meaning of Life*, who, after consuming every item on the menu and washing them down with two jeroboams of wine and a crate of ale, exploded. This passenger's decidedly non-aerodynamic frame was blistering through the dwindling atmosphere at the muzzle velocity of a .22 rifle bullet, wedged cattawampus in one of the SST's modest chairs with a seatbelt extender. He had a choice and would have been way more comfortable spending seven hours in a 747's first-class throne, but the allure of extreme speed for three hours of discomfort was more powerful. I had only admiration for his enduring such contortions to log the ride of his life.

This anecdote perhaps partially addresses a question raised by some about the ultimate market

Aerion AS2	
Passengers (max)	Nine
Top-speed cruise	Mach 1.5
Top-speed range	4,000 nm
Long-range cruise	Mach 1.4
Long-range range	4,750 nm
'Boomless' cruise	Mach 1.2
'Boomless' range	3,750 nm
Transonic cruise	Mach 0.95
Transonic range	5,300 nm
Takeoff field length	7,500 feet
Max takeoff weight	121,000 lbs
Basic operating weight	57,801 lbs
Max fuel	Approx. 61,000 lbs*
Engines (three)	15-17,000 lbs each for t/o
Wingspan	61 feet
Length	170 feet

*With approx. 2,000 pounds for eight passengers and bags

Boom Mach 2.2 airliner	
Passengers (max)	55
Supersonic cruise	Mach 2.2/1,451 mph
Supersonic range	4,500 nm
Subsonic cruise	Mach 0.95
Subsonic range	Not announced
Takeoff field length	8,500 feet
Max takeoff weight	Not announced
Operating empty weight	Not announced
Max fuel	Not announced
Engines (three)	Not announced
Wingspan	60 feet
Length	170 feet

Boom XB-1 demonstrator	
Crew	2
Supersonic cruise	Mach 2.2/1,451 mph
Supersonic range	1,000+ nm
Takeoff field length	8,500 feet
Max takeoff weight	13,500 lbs
Operating empty weight	Not announced
Max fuel	Not announced
Engines (three)	GE J85-21 turbojets
Wingspan	17 feet
Length	68 feet

size for an SSBJ. They question whether spending fewer hours in a relatively small cabin will trump spending more hours in the sumptuous, connected surroundings of a modern subsonic large business jet or private airliner, literally a home and office in the sky, complete with multiple different zones, among them a bedroom with en suite marble/granite bathroom with shower.

Bob Witwer, vice president of advanced technology at Honeywell Aerospace, has some thoughts on this: "Aerion's cabin is nice, it's pretty, but it's not that roomy. It's about like a super-midsize. [The AS2's cabin is 30 feet long from the cockpit divider to the rear of the lavatory. For good fuselage shaping, cabin width varies: about 66 inches immediately aft of the cockpit divider in the forward lav/galley area; 87 inches in the forward seating area; 90 inches in the aft seating area; and 96 inches in the aft lav. By contrast, a Challenger 350 super-midsize cabin is 25 feet 2 inches long and 84 inches wide.]

"The laws of aerodynamics and the cost of making and operating such an aircraft mean that you want to keep it as narrow as possible. Think about the choice between that airplane, which gets you there a couple of hours earlier and then you get stuck in traffic at the destination, and a bigger cabin with connectivity as seamless as being on the ground. Setting air transport aside for a second, there's been a push in the bizjet market forever to try to make the aircraft a flying office, with all its comforts and amenities, to the point that the transition is transparent to the executives flying. If we go down the path of providing much greater bandwidth for connectivity in the air, using satellites for oceanic flights, such as with Honeywell's GX Aviation, and it keeps growing in bandwidth just like it has on the ground, then how much bigger a deal is it to go from NY to Johannesburg and save three hours of flight time?"

Witwer also shared his thoughts on some avionics-related nuts and bolts facing SSBJ developers: "I'm sure there are going to be subtleties as we dig into a supersonic aircraft. Flight controls become more complicated, especially when you remain in the transonic region (Aerion is supersonic but not high Mach [and is being designed to cruise efficiently at Mach 0.99]), and that introduces some design complications. When they're done right they'll be transparent to the pilot—that's just the nature of bridging the gap from subsonic to supersonic. As far as other avionics and systems go, such as FMS, I don't know that there would be a need to intrinsically change the design. FMSes do efficiency calculations, so modeling for those would change, and to a greater degree than they do today when we go from one subsonic aircraft to another. We collaborated with NASA Langley on a pilot-friendly intuitive cockpit presentation for an SSBJ to show the effective sonic boom from a geographic point of view in relation to where the airplane was. If the NASA and Lockheed work in mitigating the boom pays off, we'd have to revisit depicting the boom; NASA did all the algorithmic work there. I don't know if Aerion has chosen an avionics supplier but they haven't talked with us."

Laura Smith-Velasquez, a sonic-boom display researcher at Rockwell Collins, does see a place for certain new capabilities in an SSBJ's avionics suite: "You can develop a low-boom aircraft but you can't develop a no-boom aircraft. There will always be a sonic boom if you are traveling faster than the speed of sound. The resulting sonic boom is managed (dependent on atmospheric conditions, which are highly dynamic) via the flight plan/profile an aircraft will fly. A sonic boom footprint display is necessary to predict (based on atmospheric conditions) where the footprint will reach the ground and allow pilots to modify their flight plan and mitigate the sonic boom, keeping it at either an 'acceptable level' or flying at a Mach cut-off airspeed and altitude so it does not reach the ground. Since sonic boom propagation depends on the area of atmosphere from the aircraft to the ground through which the pressure wave travels, it will greatly depend on the weather you are flying through and above. Currently we have forecast data we can use to characterize the atmosphere the pressure wave is traveling through. This is highly dynamic and can change in flight. The sonic boom display system will need to monitor these changes for negative impacts and alert the pilots to resolve any issues by modifying the flight plan." ❑