Quiet boom could revive supersonic air travel

Realizing overland supersonic flight is likely to proceed at a subsonic pace.

Take the boom out of sonic booms, and civilian supersonic flight could make a comeback. For that to happen, not only does the boom have to be suppressed, but public acceptance of the quieter boom has to be won and regulations have to be changed to permit supersonic flight overland.

The Concorde, a commercial jet that flew from 1969 to 2003, had a devoted following of transatlantic commuters. But it was allowed to fly supersonically only over water because its boom annoyed people on the ground.

Theoretical approaches for suppressing the sonic booms that occur when planes fly faster than the speed of sound have been around for three decades. But advances in computational fluid dynamics, plus a recent proof-of-principle flight, have made the prospect of an acceptably quiet sonic boom seem within reach. Business jets would be the first step.

Shaping the boom

In 2003 a Defense Advanced Research Projects Agency-NASA-industry partnership flew a US Navy F-5E plane with a modified nose. The Shaped Sonic Boom Experiment's boom was not quiet, but it did match predictions based on the modifications. "They were able to produce the wavefront they wanted on the ground. It was the proof in the pudding, and it got things stirred up," says Victor Sparrow, an acoustical physicist at the Pennsylvania State University in University Park. The SSBE results "helped a lot of people get past a lot of unknowns in the atmosphere," adds John Morgenstern, a Lockheed Martin engineer who works on shaping planes to produce quiet booms and still meet takeoff, landing, and other aviation requirements. "On average, turbulence reduces the strength of sonic booms. But many people were skeptical of shaped booms' persistence through turbulence."

When a craft exceeds the speed of sound, shock waves form at its surface and emanate outward. The shock waves coalesce into a characteristic N shape; the "boom-boom" heard on the ground comes from the abrupt pressure increases. Boom amplitude scales with craft size, as does financial and technical risk, so, at least for now, the focus is on small business jets. Beyond scaling down the size, says Morgenstern, "it's difficult to get rid of the sonic boom, and it would be impractical from an energy standpoint. What we do is change the shape of the waveform to make it far less audible."

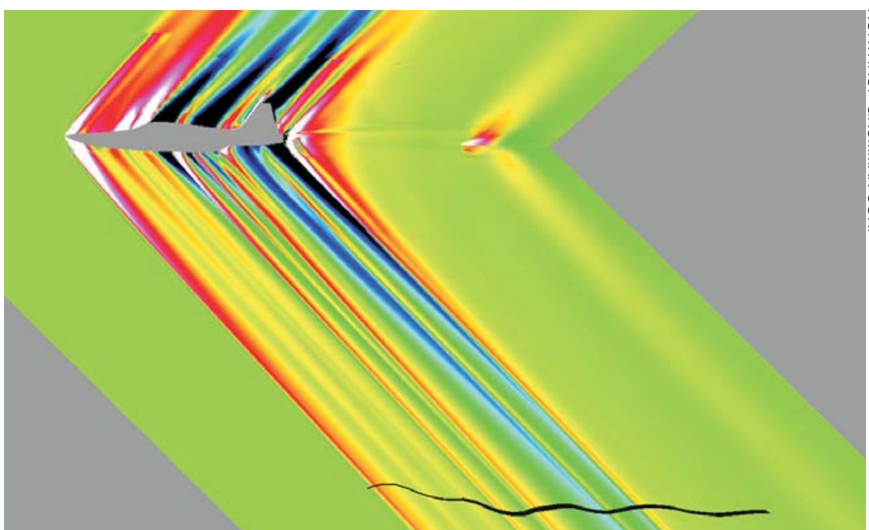
"Viscous dissipation and thermal conduction make a small contribution" to the shock wave's structure, says Sparrow. "The largest factor is the molecular relaxation process. We know the quantum mechanical properties of oxygen and nitrogen, but how will they affect the waveform? How do we shape the airplane to have a number of smaller shocks instead of one larger one? The idea is to delay the coalescing of the little shock waves into an N wave."

That's where computational fluid dynamics comes in. In the past, says Peter Coen, principal investigator for NASA's fundamental aeronautics supersonics project, "we were using fairly simple linear-theory-based analyses to start our sonic boom predictions. Now we are using CFD techniques to get flow fields all around the craft. In order to create a low-boom signature on the ground, we use this analysis to control the position and shape of the shock waves so that as the pressure signal propagates away and is affected by the atmosphere, it forms the signal we want." The shapes of the wings and other lifting surfaces play a role in sculpting the sonic-boom signature, he adds.

Cruising altitude is also a factor. From higher up, a shock wave has more time to be attenuated by the atmosphere on its way to the ground, but it can also coalesce more into an N wave. And a higher-flying jet requires larger wings and a bigger engine. Another tradeoff is between an airplane's speed and its engine size and other design parameters. "When you put everything in the mix, the optimum Mach number is about 1.6 to 1.8"—or a speed of 1.6 to 1.8 times that of sound, says Coen. At those Mach numbers, he adds, the optimum cruise altitude is about 50 000—55 000 feet.

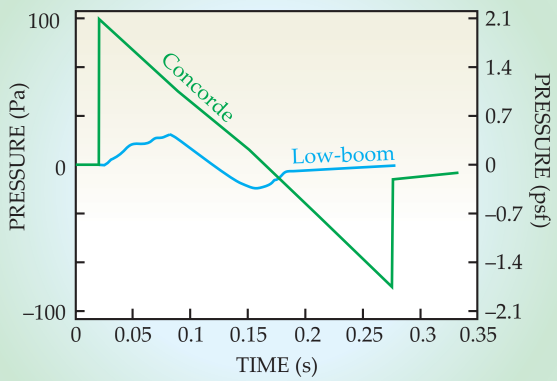
Sonic puff

The market for business jets is growing, according to a 13 February article in the *Financial Times*. Besides business executives, says Supersonic Aerospace International (SAI) founder Michael Paulson, small supersonic jets "will have



NORTHROP GRUMMAN CORP

Pressure contours from computational fluid dynamics calculations matched actual measurements for the Shaped Sonic Boom Experiment. Colors represent pressure, going from high (white and red) to low (blue and black). The black trail is the path taken by a NASA probing airplane during the SSBE's actual supersonic flight.



Shaping shock waves. The N-wave form of a sonic boom from the Concorde is compared here to a prediction of a shaped, low-boom waveform. (Waveforms courtesy of Gulfstream Aerospace Corp and adapted by Victor Sparrow and Lance Locey.)

utility for governments and for medical emergencies such as transporting organs for transplants." The projected price tag is around $80 million apiece, or about double a subsonic business jet.

Paulson's company is working with Lockheed Martin Corp and is one of a handful in the worldwide aviation industry—another is Gulfstream Aerospace Corp, which was founded by Paulson's father—pursuing quiet supersonic flight. An inverted V-tail attached to the wings "allows us to place the engines very far aft on the wings. It's what we need for shaping the sonic boom," says SAI's Paulson. The boom from SAI's design would be hundreds of times quieter than that of the Concorde, he claims, adding that the company aims to do its first test flight in 2013.

Last year, Gulfstream's "quiet spike," a 24-foot telescopic nose, was test flown by NASA on an F-15B aircraft. The spike dampens the boom by breaking the shock wave into many smaller ones. "Our computerized design shows us that we can reduce the boom energy by 10 000 times to produce a sonic puff," says Gulfstream spokesman Robert Baugniet. Acoustic laboratory tests, he adds, show a 40-decibel reduction in boom sound compared to the Concorde. Neither Gulfstream nor SAI–Lockheed Martin has yet tested a full-scale model of their supersonic design, and they present their boom suppression claims in terms that are difficult to compare.

Many challenges

But even sonic puffs would require new regulations. "Under our current regulation, there is an explicit prohibition on supersonic flight over the continental United States," says Carl Burleson, director of the Federal Aviation Administration's office of environment and energy. But thanks to inquiries from industry and the SSBE flight, the FAA began funding some research on noise and human perception of sonic booms. With NASA and the Environmental Protection Agency, the FAA also formed a team to explore high-altitude emissions and other issues related to supersonic flight. And it started a task force at the International Civil Aviation Organization, the United Nations agency that sets aircraft standards, to "see if supersonic operations and noise certification

KATHLEEN HODGDON AND VICTOR SPARROW

People listen to unannounced sonic booms for research on sound perception.

NASA DRYDEN FLIGHT RESEARCH CENTER

Test flights with Gulfstream Aerospace Corp's "quiet spike" were completed in February.

should be revised," says Burleson. "The most important thing right now is developing a metric to judge whether the booms are acceptable or not. We hope to have a metric in 2008."

Tests of human sound perception include using sonic boom simulators, in which people compare recorded and simulated booms; having people listen to sonic booms outside; and rigging a house with microphones and accelerometers during sonic booms. "We don't know all the fundamental physics of boom interactions with structures," says Kevin Shepherd, head of structural acoustics at NASA's Langley Research Center in Hampton, Virginia. "But we have reason to believe that how people react indoors and outdoors is quite different. Inside you hear objects rattle and walls creak. This will influence people's perceptions." The time of day, frequency of sonic booms, and ambient noise also play a role.

But computations, wind-tunnel tests, and noise and rattle measurements only go so far. "If we are going to argue to change the rule, someone is going to have to build an actual aircraft to demonstrate, as there [are] likely to be considerable community concerns," Burleson says. That someone, he adds, will have to come from industry. No one has stepped forward yet. "There is no way we as an industry are going to invest a whole pile of money into developing airplanes until we know that the regulatory groups are going to move off of ground zero. There has to be some kind of agreement," says an industry engineer who insisted on anonymity.

"There are so many challenges," says NASA's Shepherd, "and a lot of places where [a revival of supersonic flight] could fall down—the sonic boom is not the only problem you can imagine. There is fuel efficiency, global warming, airport noise. . . . If there was enormous pressure on oil consumption, then producing a new supersonic aircraft would probably be poor timing. It would look crazy." Although some industrial researchers claim they can make engines for supersonic jets that do not pollute more per mile than subsonic planes, those data are not open to the public, and most researchers believe the opposite is true.

A more detailed look at the repercussions of flying at 50 000 feet is needed, Burleson says. But, he adds, "aviation is a relatively small contributor to greenhouse gas emissions, 2 to 3%. If you have 12 000 to 14 000 aircraft flying around the world, adding a couple hundred more"—the projected number of supersonic jets is 400 to 500—"is probably not going to add a huge [emissions] inventory burden."

As for when supersonic flight overland might become a reality, predictions start at about six years from now. Besides the uncertainties of setting a metric and building and testing a prototype plane, says Burleson, "once you get into the rule-making process, it's anyone's guess."

Toni Feder

International Linear Collider gets reference design and cost estimate

But DOE warns that the design team's hope for completion of the 31-kilometer-long machine by 2019 may be too optimistic.

For more than five years now, a linear electron–positron collider big enough to explore the so-called terascale (collision energies of order 10^{12} electron volts or 1 TeV) has topped the wish list of the international community of particle physicists (see Physics Today, September 2004, page 49). Given the present state of accelerator technology, the collider's two face-to-face linacs would need a combined length of about 30 km to achieve a first-phase collision energy of 0.5 TeV. The cost of such a gargantuan facility dictates that the undertaking—from R&D and design, to construction, to operation—be thoroughly international from the start. Appropriately, the project carries the name International Linear Collider. The ILC is regarded as an essential complement to the Large Hadron Collider (LHC) ring at CERN, which should begin providing 14-TeV proton–proton collisions next year.

Now the ILC has its first estimated price tag, based on a reference design prepared over the past two years by the Global Design Effort, a 60-member team headed by Barry Barish of Caltech. GDE's report of its design and cost estimate (http://media.linearcollider.org/rdr_draft_v1.pdf) was released at the February meeting in Beijing of the International Committee for Future Accelerators, GDE's parent organization. Although the report doesn't give the estimated total cost as a straightforward sum, it comes to roughly $7.5 billion in 2007 US dollars.

Sample sites

Because it will be several years before a site is chosen for the ILC, the reference design and cost estimate are not site-specific. But civil-engineering cost estimates are included for three sample sites: in the mountains west of Tokyo, near CERN on the Swiss–French border, and near Fermilab in Illinois. Despite the obvious geological contrasts, it turns out that the tunneling and other civil-engineering costs for the underground machine, about $1.8 billion, are much the same for the three sites. That's because each site has different difficulties and compensating advantages. The problems posed by the mountainous terrain of Honshu, for example, are balanced against the virtues of horizontal access and a granite substrate that, unlike the Illinois prairie or the Rhone valley, requires no concrete lining of tunnel walls.

A possible site near the DESY laboratory in Hamburg was much discussed in previous years when DESY pioneered the superconducting RF acceleration technology that was selected in 2004 for the ILC. But Hamburg was not included among the sample sites because a machine there could not sit nearly as deep as at the other three sites. That would require significant changes in the reference design. Furthermore, if the collision point were at DESY itself, the Elbe river would obstruct the ILC's eventual extension to 50 km for 1-TeV collisions in a later upgrade foreseen