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SUPERSONICS

The Concorde, the iconic Anglo-French supersonic transport, took to the air for the first time on March 2, 1969, from Toulouse. The Soviet Union's Tupolev Tu-144 may have been first, getting airborne on the last day of 1968, but it is the Concorde that is remembered as inaugurating the era of supersonic air travel—and ending it, at least for now.

The Aerospatiale/BAC Concorde was a technical triumph and a commercial failure. Only 20 were built, and the aircraft was retired from service on Oct. 23, 2003. But those 27 years of commercial supersonic flight left a legacy that lives on to inspire a new generation of aircraft developers who see in technologies developed over the past 50 years ways to overcome the Concorde's shortcomings and bring back supersonic air travel.

The Concorde's legacy also lives on among environmental groups that argue the airport noise, sonic boom and cruise emissions of supersonic transports are not welcome in an aviation industry already facing significant challenges in reducing its environmental impact fast enough to make a difference.

It is against this background of inspiration and opposition that startups such as Aerion, Boom Supersonic and Spike Aerospace are working to develop a new generation of supersonic transports, one that can be economically viable and environmentally sustainable.

While they are leading the charge, their work is beginning to attract the backing of some big names in commercial aviation. Boeing has made a significant investment in supersonic business-jet developer Aerion, and Boom has pre-orders and investments from Japan Airlines and Richard Branson's Virgin Group.

These startups are all working to reopen the era of supersonic air travel by the mid-2020s. Aerion is already planning to make the first transatlantic test flight with its Mach 1.4 AS2 on Oct. 23, 2023, the 20th anniversary of the Concorde's last flight. It hopes to begin deliveries in 2026.

NASA, meanwhile, is tackling one of the Concorde's biggest issues—sonic boom—and developing technology for a future generation of quiet supersonic transports. Lockheed Martin is building the X-59A QueSTT low-boom demonstrator, which NASA plans to fly over U.S. communities in the early 2020s to gauge public response to its muted sonic "thump."

Amid these developments and to mark 50 years since the Concorde's historic first flight, we present here a compilation of stories that have appeared recently in Aviation Week & Space Technology. They paint a picture not only of the Concorde's life, but of the fate of its rivals in that first supersonic era and of the legacy that lives on with the startups planning the renaissance of high-speed air travel.

Graham Warwick
Managing Editor, Technology
Aviation Week & Space Technology

Boom Advances Overture Supersonic Airliner As Demonstrator Takes Shape

Graham Warwick

Boom Supersonic does not have many sacred cows, "but speed is one of them," says founder and CEO Blake Scholl. Maintaining a Mach 2.2 cruise is critical as the Colorado-based startup works to balance the high- and low-speed performance of its 55-seat supersonic airliner, now called the Overture.

Other supersonic transport projects have traded maximum cruise speed for lower airport noise, but Mach 2.2 is central to Boom's business case and to enabling transatlantic and transpacific flights that will fit in with existing airline timetables and allow higher aircraft utilization. "The Wi-Fi password here is Mach22ordie," he jokes.

Minimizing airport noise while maintaining cruise speed is central to efforts still underway to identify a powerplant for the Overture. Boom says its supersonic airliner will be as quiet on takeoff and landing as subsonic aircraft flying similar routes today.

► Aiming for airport noise level between Stage 4 and 5

► Not compromising on Mach 2.2 cruise-speed target

"We are comparing ourselves with the fleet of subsonic aircraft that will be in service at the time the Overture enters service," says Scholl. "You don't want to know the Overture is different from any other aircraft when it flies over."

Stage 5 noise certification standards that took effect at the end of 2017 require new aircraft to be a cumulative 17 dB below Stage 3 limits, or 7 dB below Stage 4. The cumulative figure combines the noise levels at three measurement points: lateral, flyover and approach.

Stage 4 did not require a minimum reduction at any of the measurement points, allowing manufacturers to spread the cumulative reduction over all three. Stage 5 requires aircraft to be a minimum of 1 dB below Stage 3 at each of the three measurement points.

Boom's target is to comply with the 1-dB-below-Stage-3 requirement at the individual noise measurement points and be somewhere between Stage 4 and Stage 5 on a cumulative basis, says Eli Dourado, head of global policy and communications.


BOOM SUPERSONIC

Boom continues to work with engine manufacturers to refine conceptual design of the Overture.

This will require a unique noise standard for supersonic aircraft, which Congress directed the FAA to develop in its 2018 reauthorization legislation. "We don't know what will be required of us, but we know what is economically reasonable and technically practicable," says Dourado.

"The details will need to be worked out in partnership with the FAA. [But] we are absolutely meeting that goal with margin," says Scholl. "We are deep with multiple engine suppliers, and it is an iterative process between the airframe and engine to get the right balance between performance and noise."

The Overture is in conceptual design. "Our engineering team will do a turn on the airplane and hand that back to the engine partner. They'll do a turn on the engine and provide it back to us, then we do another turn based on that . . . as we zero in on what's the right total package," Scholl says.

Boom has closed a $100 million Series B financing round that takes total investment raised to $200 million, which will allow the startup to make progress on design of the Overture in parallel with building and flying the XB-1 demonstrator, he says.

The one-third-scale XB-1 has slipped behind its original schedule, but fabrication is now under way and the aircraft is expected to fly late this year, Scholl notes. "We're fully funded through the end of 2020, which is basically the entire flight-test campaign on the XB-1."

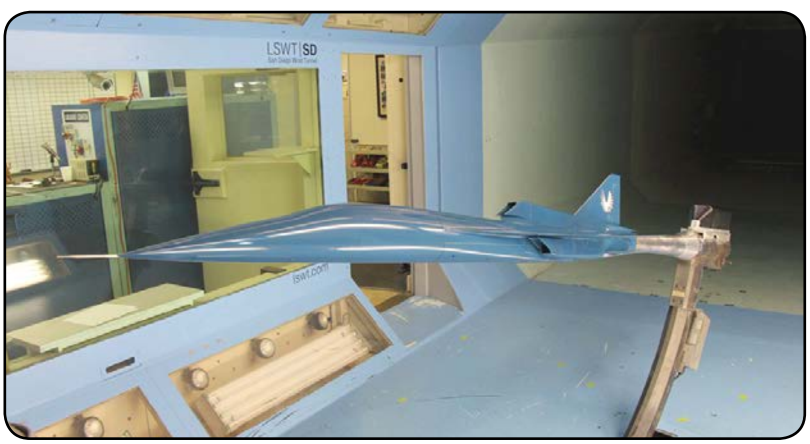
BOOM SUPERSONIC

Composite layup molds for the carbon-fiber forward fuselage of the XB-1 have been completed.

Boom originally planned to fly the XB-1 in 2017. "Frankly we were very ambitious and a little naive at the outset of the project," says Scholl. "What we learned was that the hardest part of supersonic transport design is balancing the high-speed performance with the low-speed performance.

"The high-speed performance is actually relatively easy. The trick is to get a high-speed airplane to also be controllable and stable on approach to landing," he says. Boom went through three campaigns of XB-1 wind-tunnel testing to get that balance right.

"The first iteration was about calibration data, and our predictions were off by about 30%," he says. "The second run was about confirming we were calibrated and we nailed it almost perfectly. Then we did a third iteration to confirm the safety of the final design."



BOOM SUPERSONIC

Boom has completed three campaigns of wind-tunnel testing to finalize the XB-1 configuration.

Tunnel testing finished in November 2018 and included takeoff and landing and the impact of gear doors on stability. "We came out of that with a clean bill of health," he says. Supersonic inlet testing has also been completed. "That test took a decade on Concorde to get it right."

Layup of the carbon-fiber fuselage halves will begin shortly, and Boom expects to have the forward fuselage in final assembly at Centennial in Colorado "in a couple of months," Scholl says. "We're fully funded through the end of 2020, which is basically the entire flight-test campaign on the XB-1."

Conceptual design "will continue through late 2019 to early 2020, and right about the time the XB-1 is taking flight we'll be locking in the configuration of the Overture." The additional investment also funds "everything we need to get the Overture launched in the traditional aerospace sense—engine selection, supply chain, production site, etc.," he says.

The $200 million secured so far is only a small part of the $6 billion Boom estimates will be needed to develop and certify the Overture and its engine, and has been raised from individuals and investors that support startups with tens of millions of dollars, not billions.

"We didn't start [this funding round] by talking to Series B investors. We started talking to the Series C investors, the folks who would write multi-million to billion-dollar checks," says Scholl. "We said: 'We're not raising from you now, but in a couple of years we will be, so tell us what you need to see.' They told us what the key milestones are, and we worked backward from that and raised enough money in the B round to hit all those milestones," he says.

"And those milestones are what you would expect: Prove the technology by flying the demonstrator; further prove the market by growing the orderbook; lay out the supply-chain strategy including taking in key partners on engines, aerostructures and avionics; and lay out the details of the certification process."

Boom filed its type-certificate application with the FAA late in 2017. The proposed certification basis draws on past experience with Concorde and other high-flying aircraft such as Gulfstream business jets. "There are going to be a lot of special conditions on this airplane, but we've deliberately avoided doing anything for which there is not some precedent," says Scholl, adding "The FAA has been phenomenal."

Boeing's Aerion Investment Brings Supersonic Air Travel A Step Closer

Graham Warwick

For a company developing a sleek and speedy aircraft, Aerion has been forced to follow a slow and twisty road. But now that Boeing has invested in the 15-year startup, its path to certifying and delivering the AS2 supersonic business jet in 2025 looks straighter and smoother.

Neither company is putting a number on Boeing's "significant investment." But the fact that Aerion's new five-person board includes two senior Boeing executives makes the scale clear—one is Mike Sinnett, vice president for product strategy and future aircraft development at Boeing Commercial Airplanes.

Boeing is not the first major name to be associated with Aerion, but it may prove the most significant. The startup has courted all the main aerospace players since it was formed in 2003. It approached high-end business-jet makers Bombardier and Dassault with no success. But John Holding, who had led design of the Global Express as Bombardier's head of engineering, joined Aerion in 2008 to lead advanced design.

In 2014, Airbus agreed to help with design of the AS2. The assistance came from Airbus Defense and Space in Germany and helped sustain the supersonic design skills for its engineers. But Airbus completed its involvement in 2016.

AERION

Aerion's biggest issue was finding a suitable engine. Its original design was conceived around a pair of Pratt & Whitney JT8D-200s, an older turbofan suited to supersonic flight because of its relatively large core and medium bypass ratio. But with introduction of the trijet AS2 in 2014, Aerion needed a quieter, cleaner, more efficient engine.

Toward the end of 2017, the company revealed it was working with General Electric to define an engine. Aerion also announced an agreement with Lockheed Martin Aeronautics under which its Skunk Works would provide assistance with preliminary design. The Skunks' civilian experience includes design of the QSST quiet supersonic business jet, which was never built, and NASA's X-59A low-boom flight demonstrator.

All along the way, Aerion was being backed by American billionaire Robert Bass. Now the startup was paying the Skunk Works for engineering assistance while Lockheed evaluated whether to invest in the program and assemble the AS2. Aerion was also paying GE for the engine design work.

In November 2018, GE Aviation unveiled its Affinity engine for the AS2. Designed to enable the aircraft to meet stringent Stage 5 airport noise limits yet provide supersonic cruise performance, this is an 18,000-lb.-thrust engine based on the core of the CFM56 with a new two-stage fan and medium bypass ratio.

The bigger diameter of the Affinity reduced the AS2's cruise speed to Mach 1.4, from the original 1.6. But its improved fuel efficiency increased subsonic range and enabled Aerion to offer a supersonic business jet that will be no noisier than competing subsonic aircraft entering service in the mid-2020s.

Behind the scenes, meanwhile, Lockheed's contract to vet the technical viability of the AS2 expired on Feb. 1, with "no plans to renew," says the Skunk Works. "We have moved on from [that] relationship," Aerion said, just ahead of the Boeing investment being announced.

Under the new deal, Boeing will provide engineering, manufacturing and flight-test resources, "as well as strategic vertical content," to accelerate aircraft design and bring the AS2 to market. The content is not specified, but Boeing's vertical businesses include avionics, actuation, auxiliary power units (with Safran), landing gear, seats and analytics. That another Aerion board member is Ken Shaw, vice president of supply chain for Boeing Global Services, suggests the major part it plans to play in supporting the AS2.

Boeing engineers will begin arriving at Aerion within days to participate in the preliminary design review, and the OEM's investment will unlock a slew of key program decisions. Announcement of aerostructures and other suppliers and selection of an assembly site are expected over the course of this year, Aerion says.

For Boeing, investment in Aerion represents an early chance to participate in a return of supersonic air travel. Since the government-funded Boeing 2707 was canceled in 1971, the company has continued to study supersonic transports, from the 300-seat transpacific High-Speed Civil Transport of the 1990s to small, low-boom airliners more recently.

Why a supersonic business jet? In part because Boeing Business Jet operators are potential customers for a high-end aircraft like the AS2. And also because Aerion sees the aircraft as a technology platform, with larger versions to follow. Unique natural-laminar-flow aerodynamics allow the AS2 to cruise efficiently both supersonically at Mach 1.4 and subsonically at Mach 0.95 and may hold the key to a sustainable return of high-speed air travel.

Final Testing Will Clear Way For Assembly Of Supersonic X-59A

Guy Norris

In a corner of its Skunk Works facility in California's high desert, Lockheed Martin is gearing up to start assembly of the X-59A, a unique research aircraft for NASA designed to shape sonic booms as well as, potentially, the destiny of the reborn commercial supersonic aircraft industry.

Configured with a sharply swept delta wing spanning 29.5 ft. and measuring 93.8 ft. in length, the slender X-59A is highly unusual, even by Skunk Works' standards. Designed to reduce its sonic boom by shaping that will prevent shockwaves from the airframe coalescing into a conventional, loud N-wave "double-bang" sonic boom, the Quiet Supersonic Technology (QueSST) X-plane instead will produce a muted S-shaped sonic "thump" (see graphic below).

At least that is the plan. Following first flight in 2021, the single-engine Low-Boom Flight Demonstrator will be flown the following year faster than sound over a variety of rural and urban U.S. communities to measure public response to its reduced sonic signature. If the design works as hoped, the slender aircraft, flying at around Mach 1.4 and 55,000 ft., will generate only a reduced boom loudness of about 75 PNLdB, far below the 109 PNLdB produced by the Anglo-French Concorde supersonic airliner that was retired in 2003.

► Major assembly of X-59A begins in May

► First flight remains on track for 2021

Public reaction to the overflights will provide data to help formulate regulations enabling civil supersonic flight over land. In the U.S., these have been banned by the FAA since 1973, and it was only in 2008 that, after an emerging wave of interest in reviving commercial supersonic capability, the agency made the first supportive moves that helped launch the QueSST effort. "It needs thorough research to serve as the basis for any regulatory decisions" to address a change in operational restrictions, the FAA said at the time. "Public involvement will be essential in defining an acceptable sonic boom requirement," it added.

LOCKHEED MARTIN/NASA

Lockheed Martin plans to begin assembly of the X-59A in May, while NASA is targeting first flight in late 2021.

The Skunk Works was awarded a $248 million NASA contract in April 2018 to build the X-59A Low-Boom Flight Demonstrator. In October, just a month before Lockheed marked the official start of manufacturing with a "first chip" ceremony, Congress passed the FAA Reauthorization Act, which directs the agency to reopen the case for civil supersonics. The legislation specifically requires the FAA to "develop and issue noise standards for sonic boom over the United States and for takeoff and landing and noise test requirements applicable to civil supersonic aircraft."

Although Lockheed Martin had been working with NASA on civil supersonics for more than a decade, and on preliminary design of the X-59A since 2016, the November milestone "was a really big deal for us," says Peter Iosifidis, program manager for Lockheed's Low-Boom Flight Demonstrator. "It brings a level of realism to the program, because it is one thing to put something on the drawing board and never leave the PowerPoint slides, but it is another to now be building this airplane. Since then, we have released a lot more drawings and a lot more parts and are steadily moving toward first jig load in May." Referencing the installation of the initial major structural parts into the tooling assembly, Iosifidis says, "We are meeting all the commitments we made to NASA."

The research agency says first flight is still on track for 2021. "We had a baseline review at the end of October and made a first-flight commitment date of early 2022. But we are still holding our original 'work to' date of 2021, and the difference between those two dates is the schedule reserve. Nothing has actually slipped," says NASA Low-Boom Flight Demonstrator Project Manager Craig Nickol.

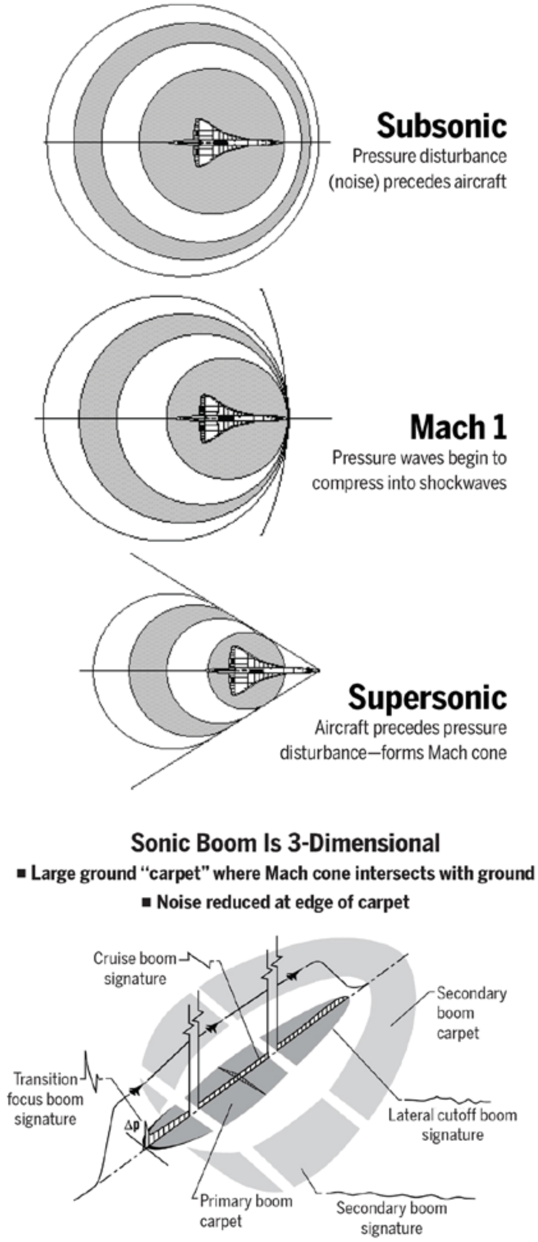
Even though assembly is slated to get underway in May, NASA and Lockheed Martin will continue to hold a series of critical design reviews (CDR) through early fall. "We will hold subsystem CDRs before the major system CDR. Initially, this was planned in August, but because of the government shutdown, this looks like it will probably be in September, and we are pretty confident we will hit that," says Nickol.

On the NASA side, these reviews will focus on the flight-test instrumentation package and development of the high-definition external vision system (XVS), which will be mounted in a fairing in front of the cockpit. The XVS will peer ahead of the X-59A's long slender nose, which is shaped to reduce its shockwave signature and sonic boom but which also blocks the pilot's forward view. The XVS works in combination with the Collins Aerospace EVS-3600, a multispectral imaging system, which is mounted beneath the nose and designed to enable the pilot to land in nearly all conditions using long-wave infrared visual sensors.

"We are testing the off-the-shelf-components of [the XVS], including a high-definition monitor in the cockpit and high-definition cameras and computer hardware as well. We need to make sure they pass environmental specifications, so we are doing temperature and vibration tests. Once we get through that, we will go into more integrated testing, starting with flight tests in late spring or early summer at NASA Langley Research Center using our King Air. This evaluation of the hardware, and also the software in the

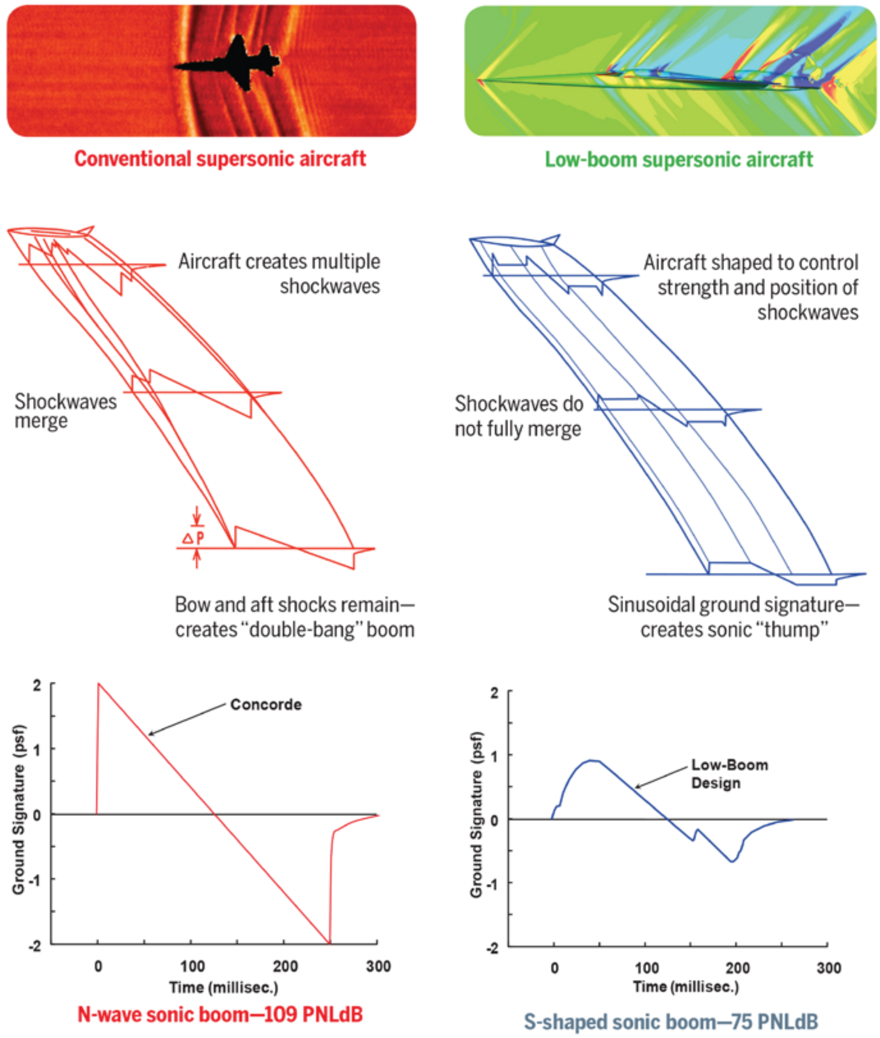
Anatomy of Low-Boom Supersonics

NASA has led development of technology to reduce the sonic boom of supersonic aircraft through airframe shaping. The X-59A QueSST low-boom flight demonstrator is being built by Lockheed Martin to gather data on the public acceptability of reduced sonic booms. The goal is to gather data to enable regulators to agree on a noise certification standard that enables the ban on supersonic flight over land to be lifted.



real-time operating system, will be our final major test before CDR," says Nickol.

A follow-on high-speed wind-tunnel test also is planned at NASA Glenn Research Center to verify predictions of inlet performance. The X-59A will be powered by a centrally positioned General Electric F414 with a top-mounted inlet. "We have to worry a bit about flow into the inlet," says Nickol. "There are some features that could create vortices, and we have to make sure we don't have distortion at certain conditions. It is a unique installation and is important for low boom. That is the reason it is there. It is a trade-off. It is good for the boom, but it is not an ideal location for flow. That is why we are being very careful about the detailed testing, to make sure we are good before we go to flight test."



The tests will take place in Glenn's 8 X 6-ft. wind tunnel using a 9.5%-scale model. "Working with GE, we decided we wanted additional inlet data, though we are pretty confident with our inlet design," says Nickol. "There isn't a problem; we just want more resolution so we have greater confidence in that data and to ensure we are not going to [have] any problems when we go into flight."

Lockheed Martin expects to have 80-90% of the drawings released to engineering by the time of the final CDR. Initial assembly will already be taking place in parallel, "because if not, we would never meet the schedule," Iosifidis explains. "But that also makes sure we do not have risks. We also have manufacturing readiness reviews for major elements, including one for the wing in November 2018, one for the forebody [in February] and one for the empennage in March. Those events say major structural pieces are not going to change, so by the time we get to CDR we essentially have a product."

Return Of High-Speed Air Travel Faces Environmental Headwinds

Graham Warwick

For the hopefuls developing a new generation of supersonic transports (SST), the Concorde is both an inspiration and a problem. The speed and elegance of the Anglo-French aircraft still appeals to many, but its noise and cost polarized public opinion on high-speed air travel.

"Concorde was a beautiful aircraft, way ahead of its time, but there were some serious shortcomings. And that makes us think about how we can have a sustainable resurgence of supersonic flight versus the short period that Concorde brought," says Tom Vice, CEO of Aerion.

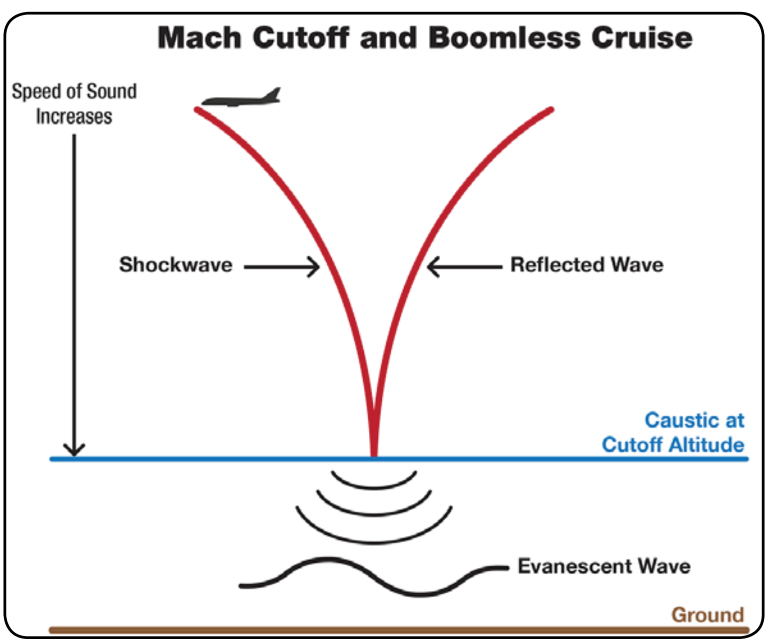
One of three startups in supersonic civil aviation, Aerion is developing the AS2, a Mach 1.4 business jet scheduled for delivery in 2026. The others are Boom Supersonic with the Mach 2.2 Overture, a 55-seat airliner planned for service in the mid-2020s, and Spike Aerospace with the S-512, a Mach 1.6 low-boom business jet aimed at introduction around 2025.

► U.S., Europe disagree on supersonic noise standard

► Aerion, Spike aim to meet Stage 5 subsonic standard

While Boom has raised $141 million, Aerion has secured a "significant investment" from Boeing, which will provide engineering, manufacturing plus flight-test support for AS2 and unspecified "vertical content." Aerion and Boeing engineers are working together to complete the preliminary design review in mid-2020, and first flight is on track for June 2023, says Vice.

As the benchmark for Aerion, Vice looks back not to the Concorde, but two decades earlier, to the Boeing 707, "because it was a speed jump that was sustainable," he says. "We have to meet today's strict regulatory and certification requirements while we also build sustainable supersonic flight that not only the regulatory agencies can accept but the public will embrace."



AERION

For Aerion, making the return of supersonic flight sustainable meant taking a step back and redesigning the aircraft to reduce not only landing and takeoff (LTO) noise but also inflight noise and emissions. The three-engine AS2 is designed to meet the same Stage 5/Chapter 14 LTO noise standards as apply to new subsonic transport-category aircraft certified after the end of 2017.

Meeting Stage 5 required a higher-bypass-ratio turbofan and made integration with the airframe more challenging. "It was excruciatingly difficult to extract every fraction of a decibel, but that was our commitment," says Vice. The selected engine, GE's 18,000-lb.-thrust Affinity, is based on the core of the commercial CFM56 turbofan mated to a new two-stage medium-bypass fan.

By filing its FAA type certification application before the end of 2017, Boom potentially grandfathered the Overture under Stage 4 noise standards. The startup's stated intent is to be between Stages 4 and 5. This assumes there will be a new noise standard developed for supersonic aircraft.

But the Trump administration's push for special noise rules for SSTs was rejected at the latest meeting of the International Civil Aviation Organization's Committee on Aviation Environmental Protection (CAEP). The U.S. must now set a domestic LTO noise standard as required by the 2018 FAA Reauthorization Act, says the nongovernmental International Council on Clean Transportation (ICCT).

"Instead, [CAEP] will conduct a comprehensive review of the likely increased noise, air and climate pollution from supersonics and consider how the existing LTO noise requirements for subsonic aircraft can be applied to supersonics," says the ICCT. "[European] industry agrees that LTO noise for supersonic should be based on Chapter 14 subsonic standards," Vincent De Vroey, director of civil aviation at the Aerospace and Defense Industries Association of Europe, said in a Feb. 18 tweet.

Boom, which has yet to select an engine, is not deterred. "CAEP is moving forward with a supersonic work program that we expect to eventually harmonize with the U.S. standard," says Eli Dourado, head of global policy. "Our view is that subsonic and supersonic standards are in fact clearly distinct." But for Spike, like Aerion, meeting Stage 5 noise limits is "critical," says CEO Vik Kachoria.

For Aerion, minimizing carbon emissions was a factor in design and integration of the engine. "We're committed to responsible cruise carbon-dioxide [CO2] standards for supersonic aircraft," says Vice, noting there is a proposed standard for subsonic aircraft, but not yet for supersonic transports.

"Our fuel burn and emissions numbers are something we have worked extremely hard on," he says. "And even with the first new supersonic engine in 55 years, Aerion continues to look at even further reduced CO2 emissions . . . [and] so is focused on the future utilization of alternative jet fuel."

As for en route noise, the AS2 is not a low-boom aircraft and is designed to be economically viable flying supersonically only over water. "We do not advocate the lifting of the restriction on overland supersonic flight without there first being an acceptable technical and operational approach that attenuates the noise generated by the sonic boom," says Vice.

"We actively oppose any company that takes an irresponsible approach to the elimination of Mach 1 overflight restrictions," Vice says. He believes there are only two valid approaches that will lead to supersonic flight over land: "low boom and no boom."

NASA and Lockheed Martin are building the X-59 to demonstrate the low-boom approach, but Vice believes there are significant technical, operational and economic issues with the current state of low-boom technology. "I think it will take decades for this technology to find its way into production aircraft," he says.

Low-boom aircraft will have a higher fineness ratio, and therefore a higher takeoff weight for the same cabin volume, than traditional supersonic designs. "Therefore, they will likely burn more fuel and emit more CO2 in flight with

AERION

Noise and emissions concerns drove design of the AS2's GE Affinity engine.

current engine technology," Vice says. "These aircraft will probably trade lower en route noise for greater en route CO_2. Our approach is no boom and lower CO_2, and I believe strongly that no boom will win out over low boom for the foreseeable future."

Boom, like Aerion, says its business case does not require supersonic flight over land. But the startup has called for a "reasonable and practical" sonic boom standard—one significantly lower than the Concorde's 109 PLdB but not as low as the 75 PLdB NASA plans to demonstrate. Spike, however, is aiming "quite a bit below" 75 PLdB with its smaller aircraft, says Kachoria.

Aerion, meanwhile, plans to certify the AS2 to fly over land at Mach 1.2 without producing a boom on the ground. Called boomless cruise, this exploits a phenomenon called Mach cutoff, which occurs when the aircraft flies at a speed that is supersonic at its cruise altitude, but not on the ground, because the local speed of sound reduces as air density decreases with altitude.

As shockwaves from the aircraft propagate down through the increasingly dense atmosphere, refraction causes them to curve until they turn upward away from the ground. The altitude at which these rays turn parallel to the ground is called the caustic. In the shadow side of this caustic, only weak evanescent waves travel to the ground, and there is no sonic boom.

"We have a unique way of harnessing the phenomenology of Mach cutoff in a real-time operational capability," says Vice. "Our business case does not require the supersonic overflight rules to change, but I believe boomless cruise will be the first operational capability that will reliably achieve supersonic flight over the U.S. that the regulator will accept and the public will embrace."

Boomless cruise will be a mode of the AS2's autopilot. "It takes the burden off the crew," says Vice. "The aircraft understands where it is in relation to the air column ahead of it. It understands temperature gradients, and vertical and horizontal winds, and it creates an algorithm that goes into the flight control laws to ensure the aircraft does not boom—and, really importantly, with high reliability."

Aerion plans to develop and test its technical and operational approach to Mach cutoff during certification and deliver the AS2 in 2026 with boomless cruise capability. "And if regulators around the world allow supersonic flight over land, we will have demonstrated we can do it reliably," he says.

Redesigning the AS2 to meet Stage 5 noise standards has affected performance, reducing cruise speed to Mach 1.4 from the original Mach 1.6. Supersonic range has been reduced to 4,200 nm, but increased to 5,400 nm subsonic. Aerion has looked again at travel-time savings between city-pairs, and the aircraft still "meets the market needs," says Vice.

While both the Bombardier Global 7500 and Gulfstream G650 subsonic business jets have a maximum operating Mach number of 0.925, the AS2 will cruise at Mach 0.95 for its full subsonic range, he says. "It is the fastest subsonic aircraft and able to fly efficiently subsonic in the Mach cutoff region and supersonic. We can fly Mach cutoff New York to Los Angeles and be the fastest by an hour," Vice says.

With Boeing's backing, Aerion plans to move ahead with supplier announcements and, in late summer, selection of the final assembly site for the AS2. This will be a "global center of excellence for supersonic aircraft design, production and support," says Vice. More money will be needed to take the program through flight test and certification. "We still have future rounds of funding to go, but we are fully funded for the next several years," he says.

Aerion plans to follow the AS2 with other supersonic transports. "We at Aerion, and at Boeing, have continued to study the market, economics and technology required for commercial airliners," he says. "I believe it is going to take time to address the issues and create a sustainable commercial supersonic airline market. And Aerion airliners—Aerion Boeing airliners—will have to be as environmentally responsible as our business jet."

Concorde's 50th Anniversary Marked Amid Civil Supersonic Revival

Guy Norris

As the drive toward sustainable commercial supersonic aircraft begins to accelerate, it seems remarkable that half a century ago the first supersonic airliner prototypes were already entering flight testing and the coming high-speed leap in civil aviation was viewed as a near-term inevitability.

Yet none of these programs lived up to their promise and, despite the technological success of the Concorde, the economic and environmental barriers proved too great to overcome. Their legacy endures, though; and today all these initiatives, audacious as they were, inspire the new generation of supersonic aircraft developers as well as provide an invaluable source of lessons learned.

► Despite challenges, the Concorde proved the technical viability of high-speed civil flight

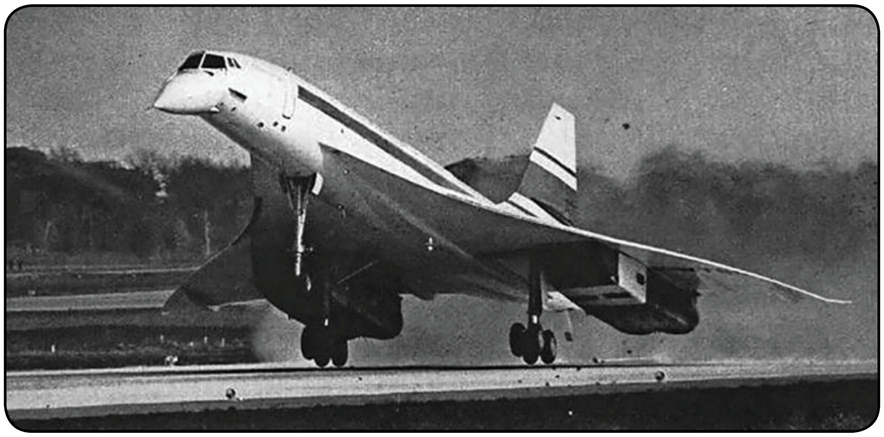
► Typical New York-London flight time for the Concorde at Mach 2.5 hr.

Fifty years ago, civil supersonic development was at its peak. The Soviet Union's Tupolev Tu-144 supersonic airliner made its first flight on the last day of 1968, and just over two months later, on March 2, 1969, it was the turn of the Anglo-French Concorde. In the U.S., General Electric's GE4 engine was undergoing ground tests as part of plans aimed ultimately at powering Boeing's much larger and faster 2707-300. Supported by the U.S. government, the 2707 had by this stage been refined with a large delta wing, succeeding an earlier but controversial variable-geometry configuration.

In contrast to the Soviet Union's Tu-144, whose flight had occurred behind the Cold War-era Iron Curtain, the Concorde's maiden sortie in France was a global media event. Aviation Week's Donald Fink was among those on hand to report on the flight of prototype 001 from Sud Aviation's (later Aerospatiale) facility in Toulouse.

After delays caused by strong winds the day before, and then by slow-clearing morning fog, Concorde 001 took off at around 3:30 p.m. following a 22-sec. takeoff roll along the 11,500-ft. northerly runway. "The aircraft, which weighed over 250,000 lb., accelerated rapidly, its nose-down attitude accentuated by the drooped visor which was left lowered in the landing position," wrote Fink.

The first flight, which reached a top speed of 250 kt. at an altitude of 10,000 ft., was commanded by Sud Aviation's flight-test director and chief pilot, Andre Turcat, with Jacques Guignard as co-pilot. Flight-test observer Henri Perrier and flight-test engineer Michel Retif made up the rest of the flight crew. Escorted by a Gloster Meteor chase aircraft on the right side and a Sud/Potez Paris photo chase plane on the left, the Concorde "was put through a series of banks during the climb out to evaluate handling characteristics at various speeds," Fink noted. "Maximum roll angles of 30 deg. were reached during the flight.



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After a 4,900-ft. takeoff roll, the Concorde's distinctive drooped nose rises into the air for the first time at Toulouse-Blagnac on March 2, 1969.

"Turcat kept the aircraft on the 330-deg. runway heading for about 7 min., then made a 90-deg. turn to the left," Fink continued. "After 2 min. on the 240-deg. heading he turned back to a downwind of 150-160 deg., which returned him to the Toulouse-Blagnac Airport in a wide left-hand pattern."

However, not everything went perfectly to plan. "The crew had a tense moment during the flight when the landing drag chute jettison warning light flashed," said Fink. Flight-test control had just told Turcat that the wind was strengthening and that, on landing, he could expect a 10-kt. tailwind with gusts up to 14 kt. With a high landing speed and a tailwind, the brake chute was considered essential to ensure a safe landing this early in the test program. Although the aircraft was restricted to takeoffs and landings to the northwest to avoid the city of Toulouse, the crew considered switching to the 150-deg. upwind direction.

"The chase pilot reported the chute door in the normal position, and the jettison warning was attributed to a faulty circuit. The drag chute functioned normally on the landing, which was made on the 330-deg. heading," reported Fink. Although the plan included a potential low-level flyby, Turcat elected to land on the first approach because of the worsening wind conditions. The first flight lasted 28 min. and was followed by a longer 61-min. test mission on March 8, which saw the landing gear retracted for the first time.

SEE ALSO

► State-backed Supersonic Projects Pitched East Against West

► Final Testing Will Clear Way For Assembly Of Supersonic X-59A

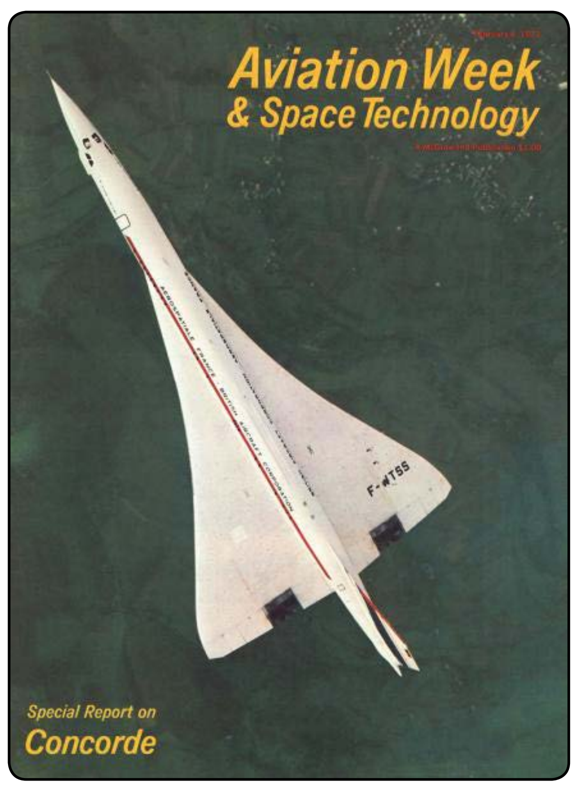
► Return Of High-Speed Air Travel Faces Environmental Headwinds

► Photo Gallery: Concorde At 50: Faster Than A Speeding Bullet

► Photo Gallery: Concorde At 50: Droop Snoop

By the time the first British-built Concorde prototype 002 made its 22-min. maiden flight from British Aircraft Corp.'s Filton, England, facility to RAF Fairford on April 9, 1969, the French-made aircraft had made nine flights. Test pilot Brian Trubshaw, who commanded 002's first flight, had by then flown one sortie with Turcat on 001 and told Aviation Week's Herbert Coleman of the "great aid" it had been in preparing him for the British-based test flight, particularly given the aircraft's unusually high angles of attack for takeoff and landing.

As flight tests finally got underway, a year later than originally planned, Aerospatiale and BAC also revealed in March 1969 that the entire program was expected to break even at the 200-aircraft mark. However, with the U.S. supersonic effort apparently lagging five years behind the Concorde, the two companies predicted up to 250 sales might be possible if the lead could be maintained. Looking further ahead, BAC believed



The production wing planform and tail were revised compared to the prototypes, one of which was pictured on Aviation Week's Feb. 8, 1971, cover.

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a larger, follow-on Concorde derivative might also be required as a successor in the 1980s. At the time, in 1969, the Concorde was set to enter service in 1973, and 74 aircraft had been optioned by 16 airlines.

The future looked optimistic, but even as flight testing began, the storm clouds were gathering. Development costs had skyrocketed, in part because the joint program was based on two parallel production lines, in France and the UK. In 1971, the British government estimated overall development costs would be around $1.98 billion (almost $13 billion in current dollars), but this proved unrealistically low. By late 1977, with additional deliveries increasingly unlikely beyond the initial batch of aircraft to Air France and British Airways, the British government acknowledged it would incur losses up to $350 million on the first 16 production aircraft, not counting the UK's initial contribution of $980 million toward development.

Delays also caused setbacks and additional costs, some of which were due to development issues with the variable-geometry inlet doors for the aircraft's Rolls-Royce/Snecma Olympus 593 engines, as well as numerous attempts to suppress aircraft noise. Notwithstanding the issue of the sonic boom, which would eventually limit the Concorde's regular supersonic operations to over-water routes, the low-bypass engines and the use of afterburners for takeoff made the aircraft noisier overall than second-generation jet airliners around airports.

Although a gradual reduction in overall engine noise of about 15 EPNdB (environmentally perceived noise decibels) was achieved over the initial configuration, the production-standard aircraft at its maximum takeoff weight of 400,000 lb. and maximum landing weight of 245,000 lb. still generated a lateral noise of more than 113 EPNdB, almost 118 EPNdB at takeoff and just under 115 EPNdB on approach. Some of the higher noise levels were avoided by modified operations, but the acoustic problem remained simply insurmountable and forced the Concorde into an operational compromise from which it could never hope to be economically viable.

Eventually, after nearly seven years of testing, development and route proving, scheduled commercial flights began simultaneously on Jan. 21, 1976, when a British Airways aircraft flew from London to Bahrain and an Air France Concorde flew from Paris to Rio de Janeiro (via Dakar). The main market for the Concorde was to the U.S., however, and it was not until May 1976 that both airlines began restricted service to Washington's Dulles International Airport.

Service to New York's John F. Kennedy International Airport, the most important U.S. destination in terms of business-traveler revenue, started in November 1977 after victory by Air France and British Airways in a bitter legal battle with the New York Port Authority. The aircraft was finally granted type approval for U.S. operations in January 1979.

Despite the aircraft's ability to operate safely and reliably at its Mach 2.04 cruise speed (1,354 mph at cruise altitude) and with seating configurations for up 128 passengers, the rising cost of fuel and ever-present challenge of noise scuttled any chance of additional production. Of the 20 aircraft built, only 14 were used for passenger service, with seven each delivered to Air France and British Airways. Most of the other airlines that placed options for the Concorde canceled their commitments in 1972 (Air Canada and United Airlines) or 1973 (Pan American World Airways, Conti-

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After the first flight, Concorde Chief Test Pilot Andre Turcat barely contains his glee as he stands alongside (left to right) Jacques Guignard, co-pilot; Henri Perrier, flight-test observer; and Michel Retif, flight engineer.

nental Airlines, American Airlines, Trans World Airlines, Middle East Airlines, Japan Airlines, Sabena, Eastern Air Lines, Braniff Airways and Lufthansa). Air India canceled in 1975 while CAAC Airlines of China and Iran Air both confirmed cancelation of their options as late as 1980.

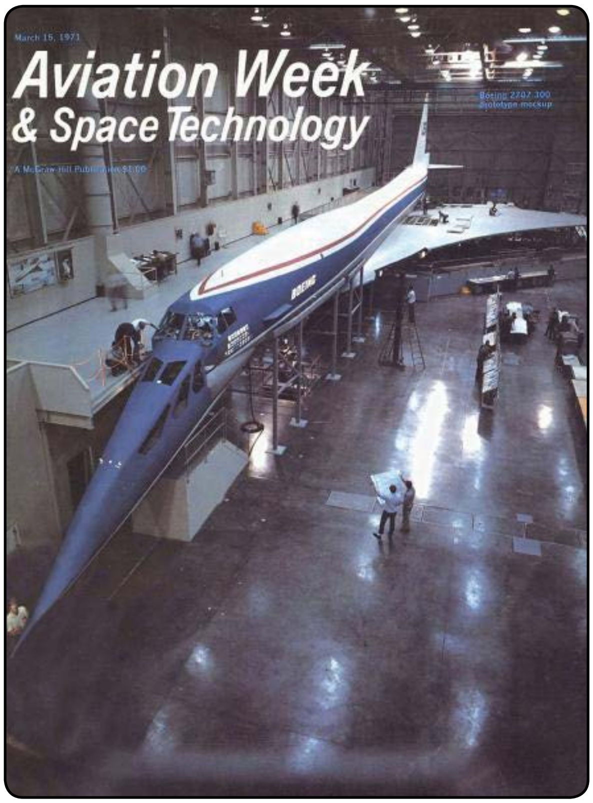
The aircraft was finally retired from service in 2003, after a series of setbacks starting in July 2000 with the type's only crash following takoff of an Air France charter flight from Paris Charles de Gaulle Airport. The downturn in the global aviation market following the September 2001 terrorist attack on the U.S. also hastened its demise, which finally came when Airbus, by then the engineering design support organization for the Concorde, announced its intent to discontinue maintenance support.

State-backed Supersonic Projects Pitched East Against West

Guy Norris

As the developers of tomorrow's high-speed aircraft reflect on the 50th anniversary of the Concorde's first flight, they can also draw on lessons learned from two costly civil supersonic failures of the same era: the Soviet Union's ill-starred Tupolev Tu-144 and the aborted U.S. Supersonic Transport (SST) program.

Both projects were officially launched in 1963 and, just like the space race between the two superpowers, quickly assumed importance as a matter of national pride and prestige, particularly in Europe, where the Tu-144 was pitched in head-to-head competition with the similarly sized Anglo-French project.



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- Boeing's 2707-300 design reached full mock-up stage before cancellation by U.S. Congress
- Russia's Tu-144 flawed by structures, systems and propulsion shortcomings had a short service life

In the U.S., the FAA-initiated SST program aimed to overtake the Tu-144 and Concorde efforts by focusing on a larger and faster Mach 2+ design capable of carrying approximately 300 passengers with intercontinental range. The U.S. project therefore immediately faced greater technical challenges and required the design and development of more costly advanced materials, structures, systems and propulsion.

Boeing, which was selected to develop the 2707 SST over the competing Lockheed L-2000 in January 1967, also hit major hurdles early on and, to reduce weight and complexity, was forced to redesign the airliner with a fixed delta wing, tails and canards in place of the variable-geometry wing of the original configuration. The redesign delayed the program by two years, and more concerns began to emerge over wing flutter and noise from the GE4 engine being developed by General Electric for the 2707.

In 1971, shortly after Boeing's impressive prototype mockup was pictured on Aviation Week's March 15 cover (above), the mounting costs, environmental concerns and uncertainty over the commercial feasibility of the aircraft led Congress to cancel the program.

The Tu-144 development, by contrast, was driven by the urgent demands of the Soviet government, which stipulated a first-flight target of 1968. Ultimately, the Tu-144 did succeed in becoming the first supersonic airliner to fly, at the end of December 1968, and the first to exceed Mach 1, in June 1969. Despite also becoming the first commercial transport to exceed Mach 2 in May 1970,

the design was flawed. Rushed through to meet an unrealistically tight schedule, inevitable shortcomings emerged in structural integrity, engine power and stall margin, inlet and engine control at supersonic speeds as well as control authority and landing speed.

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► Final Testing Will Clear Way For Assembly Of Supersonic X-59A

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► Photo Gallery: Concorde At 50: Droop Snoop

This was exposed to the world in the worst way when the first production-standard Tu-144, newly configured with a revised double-delta wing and canards, broke up in midair at the 1973 Paris Air Show, killing six in the aircraft and eight on the ground. The disaster slowed development and, along with budget issues, delayed service entry to November 1977, almost two years after the Concorde.

Following the crash of an improved Tu-144D variant in May 1978, the fleet was permanently grounded after having completed only 55 scheduled flights. Although the aircraft continued to be used for limited cargo service, that was eventually halted in 1983, by when 102 commercial flights had been completed.

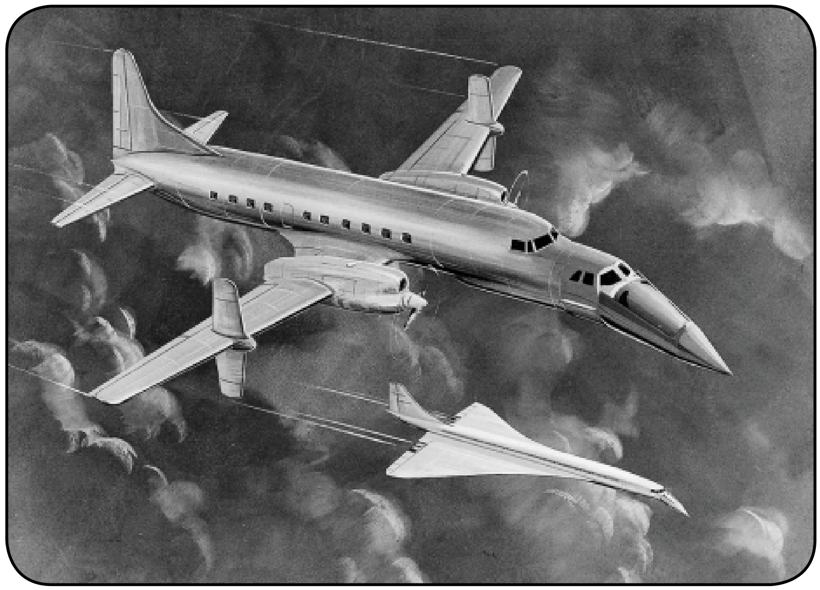
Concorde At 50: Droop Snoop

Guy Norris

The Concorde's variable-geometry nose fairing and retractable visor were unique design features, introduced to give pilots comparable forward vision to conventional airliners during takeoff and landing. With the development over recent decades of high-fidelity multispectral imagery systems, such as those designed for the NASA X-59 low-boom demonstrator, it is unlikely that similar "droop snoop"'configurations will be required on next-generation commercial supersonic aircraft.

Unusual Concorde Trainer Concept: Aero Spacelines

In the late 1960s, Unexcelled, the parent company of Aero Spacelines (maker of the Boeing 377-based Guppy and Super Guppy outsize cargo aircraft) formed Tex Johnston Inc. (named for the Aero Spacelines president and former Boeing test pilot) to produce Total Inflight Simulation. One of the proposed concepts was a Concorde trainer with a cockpit section of the supersonic transport, along with the movable nose, mounted on a Convair 580 (AW&ST May 27, 1968, p. 93). The project was never completed.



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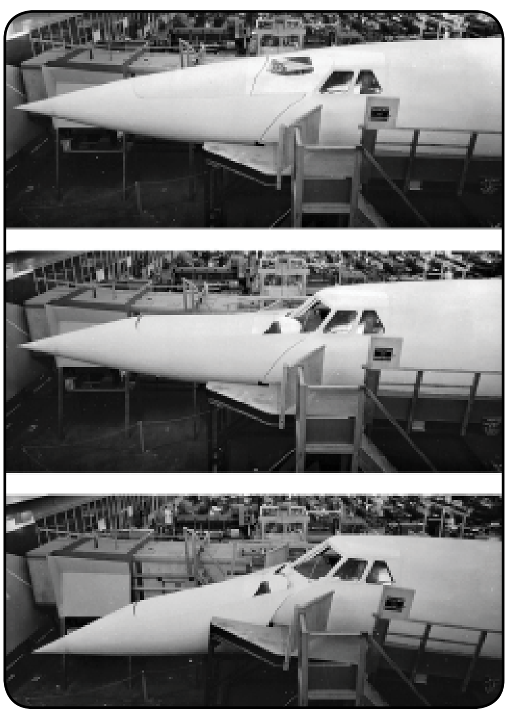

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Early Nose and Visor Design

An early mockup of the Concorde's original variable-geometry nose and visor is pictured in the supersonic, subsonic and approach-to-land positions. The design was changed, largely at the direction of the FAA, to include a transparent visor—a design challenge, since the visor also protected the main windshield panels from the effects of kinetic heating.

Approaching To Land

In this classic image of the Concorde landing at the Farnborough Airshow in 1974, the nose is fully drooped by 17.5 deg. (AW&ST Sept. 9, 1974, p. 23). On a 3-deg. glideslope approach, this permitted an angle of vision 15 deg. below the horizon and gave the crew visibility of the ground about 420 ft. ahead of the main landing gear legs. The movable nose fairing and retractable glazed visor were developed by Marshall of Cambridge in England.

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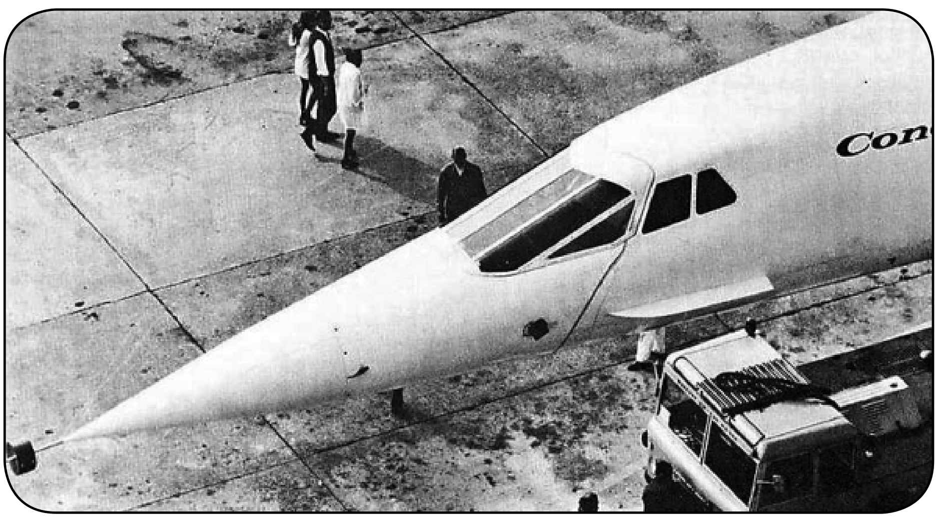
Overhead Visor View

Powered by two hydraulic systems, the nose could be fully drooped in 12 sec. and raised in less than 19 sec. (AW&ST Sept. 27, 1971, p. 25) The aircraft normally would be flown with the visor up, but for takeoff the nose would be drooped 5 deg. and the visor lowered. Both would be raised for the start of acceleration to Mach 1 and beyond; for landing, the visor would be lowered again and the nose fully drooped.



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Concorde At 50: Faster Than A Speeding Bullet

Guy Norris

March 2, 1969, marks the 50th anniversary of the first flight of the Anglo-French Concorde, the world's first and—so far—only supersonic civil airliner to see prolonged service. As plans advance for a 21st-century generation of civil supersonic aircraft, we take a trip back through Aviation Week & Space Technology's archives to highlight some of the Concorde's earlier years.

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Concorde 001 Landing

The first French-built preproduction Concorde, No. 01, flew to the British Aircraft Corp. (BAC) final-assembly site in Filton, England, where British Concordes were completed, in the summer of 1972 for installation of production-standard Rolls-Royce/Snecma Olympus 593 Mk. 602 engines and variable geometry inlets (AW&ST Aug. 21, 1972, p. 22). The aircraft was retired to the French Air Museum at Le Bourget in October 1973 after 4.5 years of flight-test work. Although Turcat joked that the aircraft was retired because "the ashtrays were full," he openly eulogized the prototype. "It had given us the biggest thrills of our careers and heralded a new transport era for the world. In return, we just loved it."

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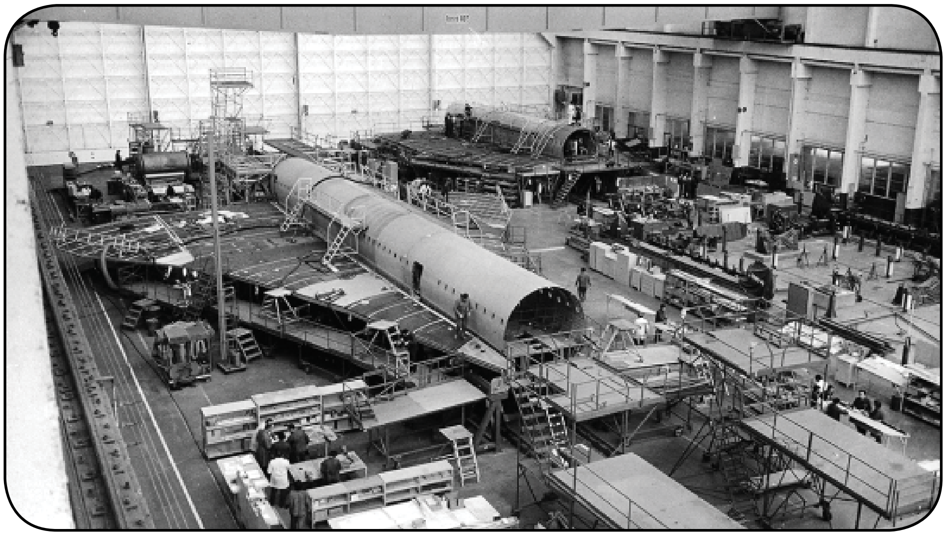
Concorde 002 at London Heathrow

With certification and the start of commercial service still more than six years away, the first British-built prototype, 002, made an unplanned visit to London Heathrow Airport in September 1970 (AW&ST Sept. 21, 1970, p. 32), providing an early meeting between the supersonic jet and its eventual nemesis, Boeing's 747—the first widebody airliner. The aircraft was flown by BAC Chief Test Pilot Brian Trubshaw, who in later years recalled the thrill of working on the program: "When we went supersonic, it was like being at the controls of a rifle bullet, just amazing." Concorde 002 was retired to the Fleet Air Arm Museum in Yeovilton, England, in 1976 after 438 flights, 196 of which were supersonic.

Concorde Production in Toulouse

Concorde 102, the first of the family in the final production shape and dimensions, was built in France in 1972 and flew in January the following year (AW&ST Feb. 7, 1972, p. 44). With a redesigned tail section incorporating added fuel space and a longer cabin, 102 was the first Concorde to visit the U.S., when it flew to Texas for the opening of Dallas/Fort Worth International Airport in September 1973.



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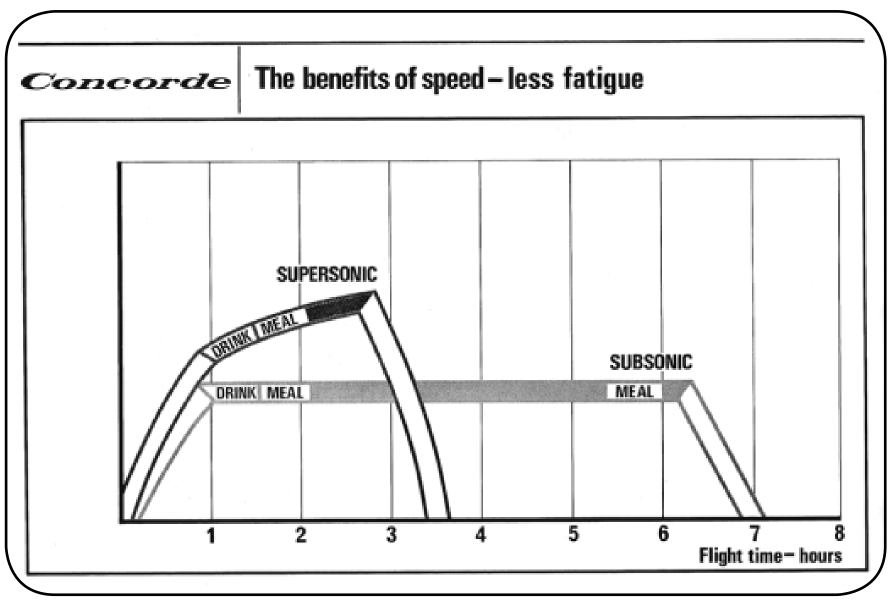
Concorde 102 in Alaska

Concorde 102 underwent a gauntlet of extreme-temperature testing in early 1974, including 12 days in Fairbanks, Alaska, where it remained outdoors for several nights in temperatures as low as –44C (–47F). Retired from flight-testing in May 1976, 102 is today preserved at Paris Orly Airport.

The Benefits of Speed—The Hard Sell

Despite the aircraft's ability to operate safely and reliably at its Mach 2.04 cruise speed (1,354 mph at cruise altitude) and with seating for 128 passengers, the fuel crisis of 1973 and the ever-present challenge of noise killed off any chance of additional production beyond those committed to France and the UK. Although Air Canada and United Airlines had already canceled their commitments in 1972, the real body blow followed in 1973 when Pan Am ditched its orders, followed in quick succession by Continental Airlines, American Airlines,



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Trans World Airways, Middle East Airlines, Japan Airlines, Sabena, Eastern Air Lines, Braniff International Airways and Lufthansa. The marketers desperately tried to revive interest by advertising the benefits of speed, but it was too late. Air India canceled in 1975, while CAAC of China and Iran Air both confirmed cancellation of their options as late as 1980.

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Supersonic Service—Route-proving

In the buildup to service entry, Air France and Aerospatiale pilots and crews flew a series of 35 route-proving flights during the summer of 1975. Up to 70 invited passengers were carried on the flights, which flew between Paris and Gander, Newfoundland. Here, cocktails are served as the aircraft cruises at 54,000 ft. over the North Atlantic at Mach 2.04.

Commercial Services

Concorde 206, the first to operate a commercial service for British Airways in January 1976, flew proving trials in December 1978 for U.S.-based Braniff International Airways before the short-lived services with the Concorde began between the two airlines in 1979. The aircraft, which was also the first to fly a commercial supersonic flight to New York after the city's ban on the Concorde was lifted in 1977, is pictured at Las Vegas during the 1978 trials. Flown by Braniff and British Airways crews, the aircraft visited 16 U.S. cities during the tour, 13 of them for the first time. This aircraft last flew in 2000 and is preserved in East Lothian, Scotland.

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