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SUPERSONICS UPDATE

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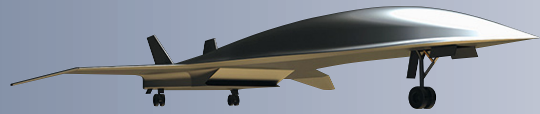
SUPERSONICS UPDATE



The resurgence of interest and activity around supersonic air travel continues to grow. And not just in supersonics: A startup has declared its ambition to develop a hypersonic airliner—an aircraft that could carry 20 passengers from New York to London in 90 min. at five times the speed of sound.

Challenges remain to be overcome—technical, financial, environmental and political. But progress is being made. Aerion, now backed by Boeing, is moving toward first flight of its AS2 supersonic business jet in 2023. Boom Supersonic now plans to fly its XB-1 demonstrator in 2020 and is targeting 2025-27 for entry into service of its 55-seat, Mach 2.2 Overture.

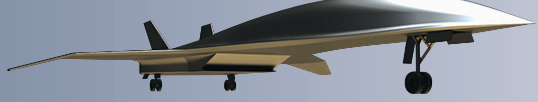
Lockheed Martin Skunk Works has begun assembly of NASA's X-59 QueSST low-boom supersonic flight demonstrator, with first flight scheduled by the end of 2021. In 2023, NASA plans to begin a series of flights over U.S. communities to collect data on the public acceptability of reduced sonic booms, a key step toward developing a noise certification standard that will allow supersonic flight over land.

But smooth sailing in not guaranteed. U.S. startups are leading the resurgence in supersonic transport development, and Congress has directed the FAA to develop regulations that will enable the sector to prosper, but Europe has voiced strong opposition to any relaxation of existing subsonic-aircraft noise and emissions standards to enable certification and operation of supersonic transports.

The scene is set for a vigorous debate within the International Civil Aviation Organization, which is working to develop global standards for a new generation of supersonic air transport.

The challenges are not discouraging startups that are targeting even higher speeds, led by Atlanta-based Hermeus with its Mach 5 airliner concept. And technology enablers are also advancing, with the UK's Reaction Engines reporting progress on its air-breathing high-speed propulsion concept.

Graham Warwick
Executive Editor, Technology
Aviation Week & Space Technology



Reaction Engines Pre-Cooler Passes Mach 3.3 Test

Guy Norris

It has been decades in the making but finally, on March 25 in rural Colorado, Reaction Engines achieved what could prove to be a pivotal moment in the advancement of air-breathing, high-speed propulsion when its pre-cooler technology was successfully tested at conditions representative of over Mach 3.

The breakthrough test—conducted at the company's newly opened TF2 test facility at Colorado Air and Space Port near Watkins—comes 30 years after Reaction Engines was quietly formed in the UK around an innovative engine cycle concept to enable access to space and hypersonic air-breathing flight from a standing start.

► Follow-on tests planned for Mach 4.2 and Mach 5

► High-temperature tests prove pre-cooler high-speed viability

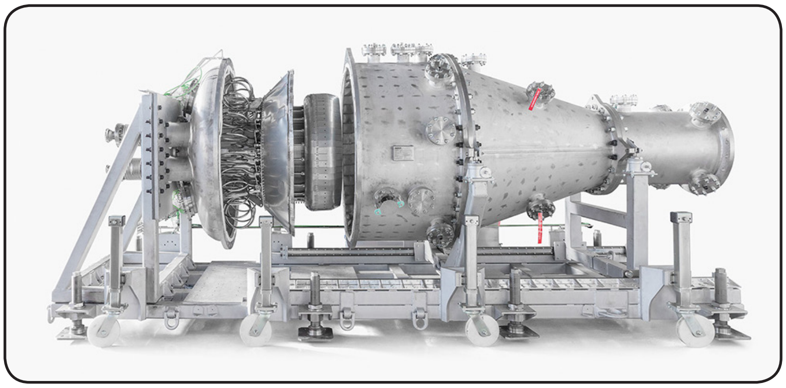
The lightweight heat exchanger (HTX) forms one of the main building blocks of the company's novel operating cycle and is designed to significantly reduce compressor delivery temperature (T3). This delays the onset of the T3 limit to a higher Mach number, maintaining sea-level conditions in front of the compressor over a very wide range of speeds, thus maximizing net thrust even at high speeds.

The HTX is designed to chill air in the inlet of high-speed turbojets for hypersonic vehicles and, ultimately, will form the basis for the company's Synergistic Air-Breathing Rocket Engine (Sabre) for low-cost repeatable access to space. In this role, the engine is designed to efficiently extract oxygen for rocket combustion from the atmosphere. In the fully integrated Sabre, the chilled air will be passed from the HTX to a turbo-compressor and into the rocket thrust chamber where it will be burned with sub-cooled liquid hydrogen fuel.

Now, after years of subscale development including the first runs of an operational pre-cooler in 2012, the company's first large-scale pre-cooler test unit has demonstrated the ability to rapidly chill incoming heated air generated by a donor General Electric J79 jet engine operating at full military power. Tests of the pre-cooler, which is made from 16,800 thin-walled tubes to provide high surface area with low weight, are being conducted under a DARPA research contract awarded in 2017.

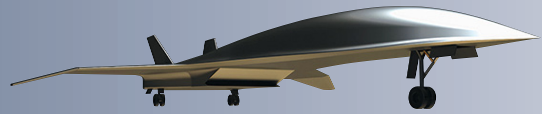
"We are adding a dial to the whole engine-optimization equation that you didn't have control over before, which is the inlet condition—not just the temperature," says Reaction Engines President Adam Dissel. The test result, which saw gas temperatures reduced from more than 800F (426C) to just above the boiling point (212F), boosts Reaction's confidence that follow-on tests with the J79 operating in full afterburner will see more dramatic reductions.

With the J79 operating at full power, the pre-cooler is expected to chill the mass flow from over 1,800F at inlet speeds representative of over Mach 5, to 200F in less than 1/20th of a sec. The higher-temperature test will stress not only the thermal expansion capabilities of the test rig but also each tube in the HTX, which are joined to an inlet and outlet manifold, thus allowing helium coolant to be cycled through.



REACTION ENGINES

The pre-cooler test unit, visible in the center of the image, contains 16,800 thin-walled tubes.



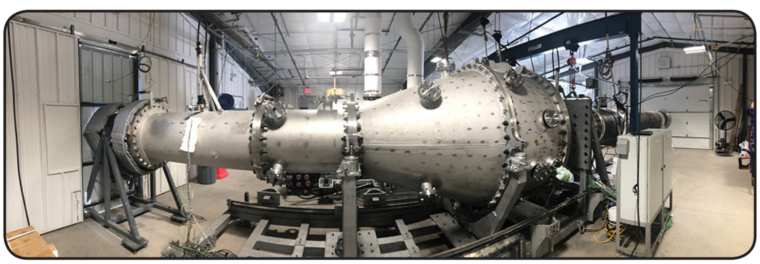
"This is the first test ever of our pre-cooler at highly elevated temperatures, and the performance looks to be right in line with predictions and the data quality exceeded expectations," says Dissel. The evaluation was particularly significant for an operationally representative system because it "featured a temperature ramp profile analogous to the flight conditions that would be experienced from takeoff and acceleration up to a flight speed of Mach 3.3, the cruise speed of a Lockheed SR-71 Blackbird," he adds.

Sized to match the mass-flow requirements of a potential flight-test demonstrator engine, the HTX run was also the first chance to wring out the TF2 facility. "All the various facility and ground support systems performed well during their first fully integrated test setup; this was a great accomplishment, as several systems could not be fully checked out until they were actually operated at high temperature," says Dissel.

The March 25 evaluation, which also marked the first high-temperature test at the Colorado site, will be followed in coming months by tests at Mach 4.2 and Mach 5. The exact timing will depend on the outcome of test rig conditioning for runs with the engine in full afterburner. "The last thing we want to do is put an unknown condition into the pre-cooler," says Dan Larson, Reaction Engines engineering project manager. The connections and piping in the test setup experience thermal expansion in the order of several inches during powered runs, and may show even greater movement at higher thrust settings, he explains.

The fully instrumented pre-cooler is "assembled in a manner so that we can deeply analyze the behavior of that unit when it is subjected to hypersonic enthalpies," says Reaction Engines CEO Mark Thomas. "We will be progressively building up to those extreme test levels. TF2 is capable of running full simulated missions for the pre-cooler so we can run it effectively in temperature terms from the ground to ultimate flight conditions and back again over a sustained period of time," he adds.

The facility uses a complex helium circulator and control systems to deliver the appropriate conditions during the simulated flight cycle. "That's a unique capability when you think about that volume of hot gas being transferred for that duration. We are not aware of any other facility that could safely do that in any areas we could safely test. So this is a very prized capability, and a lot of investment has gone into it from the UK and the U.S., both private and public," comments Thomas.



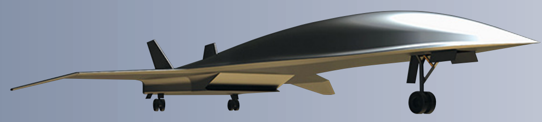
REACTION ENGINES

Heated air enters the test unit from the plenum (left), and exits through an outlet (right).

"We are stepping through the test campaign in a progressive manner. Phase 1 went to the ultimate conditions we could get to in maximum military (dry) power, and Phase 2 takes us into afterburning temperature levels," he comments. The Colorado facility is designed to test to Mach 5-equivalent temperatures. "That suits the immediate need and the proof-of-concept. If we want to go beyond, the facility is versatile and there are things we can do," says Thomas, who adds that TF2 is also intended to be used for other propulsion and hypersonic test work in the future.

The recent test result is also positive news for the company's plans to develop nearer-term commercial opportunities from the highly scalable pre-cooler. Through a newly established applied technologies business arm, Reaction is studying various additional uses for the heat exchanger across a broad swath of aerospace, automotive and industrial applications. These range from boosting turbojet and turbofan performance to increasing power-station efficiency and enhancing racing car engines.

"We have an eye on what might come downstream of this work, and there is potential to combine our pre-cooler with a conventional gas turbine," says Thomas. "This could enable faster jet engines, and we have designed it with that in mind." The pre-cooler could, believes the company, enhance the performance of turbojets as well as provide elements of an advanced thermal management system for future more electric aircraft, or next-generation combat



platforms with adaptive propulsion and directed-energy weapon systems.

"If this heat-exchanger technology is heading into the territory of ultra-lightweight, high-performance, minimum pressure drops and lower drag, and the form factor is adaptive, then it becomes attractive in an aero engine context for arguably the first time. That means we have to look at that as a serious opportunity," says Thomas. "We are actively engaged with industry on that topic," he adds.

To bolster its search for commercial applications, Reaction has brought in expertise from the Red Bull Racing Formula One racing team advanced technology group to lead that initiative. According to Thomas, it is on course to find early applications for miniaturized versions of the pre-cooler in high-end automotive applications, as well as in the energy sector.

"On the aerospace side we see other potential applications in the similar territory of thermal management. That's a big challenge and so will require more novel solutions," says Thomas, who notes the emerging needs of civil supersonics and hybrid-electric propulsion as two potential markets. "In terms of hybrid-electric, I think we really have something to offer there. The heat exchanger is a very relevant technology for that application. We have the great benefit now of being backed by BAE Systems, Rolls-Royce and Boeing, and between the three of them they have a lot of things on their plates that we can talk to them about."

Thomas notes that the three aerospace giants are among several groups showing growing interest in the Sabre concept and the pre-cooler technology at its core. Reaction Engines has raised over £100 million ($130 million) in the last three years from public and private sources. In addition to the UK government, which announced a £60 million commitment in 2013 to assist with the demonstrator engines, BAE Systems made a strategic investment in 2015, while a further £26.5 million was raised in 2018 from other investors, including Rolls-Royce and Boeing's venture capital arm, HorizonX.

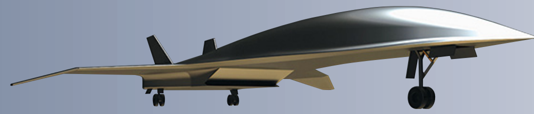
But for now, "it's fair to say all eyes are on the prize and the results we achieve in this test campaign," underscores Thomas. "We are that close to it now that people, in both industry and government agencies, are watching this closely. This is all great because it is exactly where we want to be."

Test progress in Colorado comes on the heels of a recent positive assessment of the design of the Sabre demonstrator core conducted by Reaction in collaboration with the UK Space Agency and European Space Agency. The preliminary design review clears the way for a follow-on critical design review and the subsequent development and test of the core at Reaction's newly built facility in Westcott, England, planned for 2020.

REACTION ENGINES

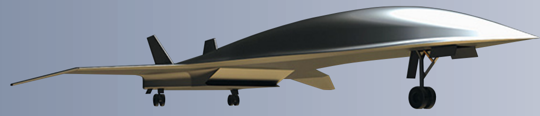
Heated air mass from the GE J79 under the cover (left), is conditioned by the plenum (center) before being ducted to the pre-cooler in the building.

The demonstrator core will consist of an axial air compressor driven by a closed-cycle helium loop, with a liquid hydrogen heat-rejection system. Reaction, which is building up the test infrastructure at the Westcott site through the remainder of this year, says the core will be fully representative of the Sabre thermodynamic core cycle. Fueled by liquid hydrogen, the unit will incorporate heat exchangers, combustion and turbomachinery modules. The complete follow-on demonstrator engine, a final test site for which has yet to be determined, will build on the core to incorporate the pre-cooler, rocket engine and ramjet.



"We are trying to find out what the leanest approach to testing out all the elements is and are still on the path ultimately to a Sabre flight engine. We think we've reached that the sweet spot after considerable effort and having gone through this technical design and development process," says Thomas. Referencing the core demonstration, he adds: "It will be a progressive buildup and, as well as accomplishing the final confirmation of the Saber cycle, it will allow us to use that same facility as a rig for demonstrating components and subsystems technology."

The final full-up demonstrator Sabre will be sized for around 20,000-lb. thrust when combined with the pre-cooler, core engine, thrust chambers and rocket nozzles. This thrust level will enable potential flight testing on a relatively small vehicle, while at the same time—when clustered with up to three other Sabre engines—it could provide sufficient thrust levels for a mission-capable vehicle.



Hermeus Targets Mach 5 Sweet Spot For Hypersonic Project

Guy Norris

Amid the ongoing surge in civil supersonic aircraft projects, Atlanta-based startup Hermeus has unveiled details of its ambitious plan to develop a higher-speed passenger aircraft with, potentially, double the speed advantage.

Provisionally sized to carry around 20 passengers over transatlantic ranges at speeds up to Mach 5, the newly revealed aircraft project is targeted at entry into service by the late 2020s. Despite the aggressive schedule and ambitious performance targets, the company believes existing and near-term technologies are already capable of supporting the venture.

► Aircraft planned for 20 passengers, 4,000-nm range and Mach 5 cruise speed

► It will have a turbine-based, combined-cycle engine with ramjet

The decision to limit the vehicle to Mach 5, the defined boundary between supersonic and hypersonic, is a key factor in the near-term feasibility of the project, says the company. "Once you get above Mach 5, the stagnation temperatures within the combustor, as well as what we'd experience at the leading edge and the like, are really hot," says Hermeus Chief Technical Officer Glenn Case. The X-15 hypersonic research aircraft, for example, recorded temperatures at Mach 5 of 1,110F and 1,325F on the nose cone and wing root, respectively, while predicted equilibrium temperatures in the same zones on a hypersonic cruiser at Mach 8 are 4,000F and 3,100F.

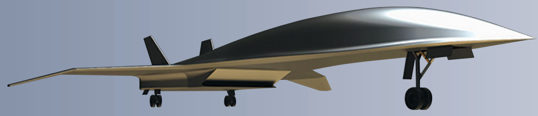
"Current materials will work at Mach 5, but once you get out of the range of lightweight materials, you have to go to nickel-based materials, and beyond that you have to start making major airframe structures out of ceramic matrix composites," says Case. "That's not in the technology wheelhouse we want to operate in. We want to be engineers, not scientists."

By limiting the top speed to Mach 5, Hermeus also hopes to develop a viable propulsion system that depends on a combined turbine [either a turbojet or turbofan] and ramjet, but which crucially does not require a supersonic combustion engine, or scramjet. "That's one of the things we don't want to tackle, and that is where the science comes in," says Chief Product Officer Mike Smayda. Scramjets are no longer just science fiction, he says. "They are right there on the horizon; but there again we've all being saying that for 20 years."

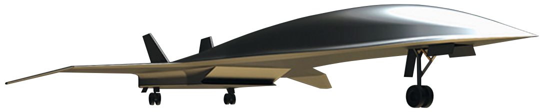
Although several turbine-based combined-cycle propulsion concepts are under evaluation by the U.S., China, Russia and others for proposed air-breathing hypersonic vehicles and weapons, the majority incorporate a dual-mode ramjet that transitions to scramjet mode at Mach 5.5 or 6. Around this speed and above, the flow passes through the combustor supersonically.

Although the Hermeus aircraft would utilize a propulsion system in which shock compression replaces mechanical compression, a ramjet would still be able to achieve efficient operation at Mach 5 by decelerating and compressing the incoming flow to subsonic speeds. "It will take a government level of investment to get an operational scramjet off the ground, but to get an operational ramjet off the ground we are talking venture capital. So we are going to stay with subsonic combustion and deal with the higher temps, but at conditions where the ISP [specific impulse, or measure of fuel efficiency] of a ramjet is still very good," adds Smayda.

"We do believe the technology is there to develop a Mach 5 vehicle. The key is going to be the transition to the ramjet," he adds. The baseline propulsion system, like much of the vehicle, is in the initial study stage but "generally we are looking at a turbofan or turbojet," says Case. "More likely we will go to a turbofan because of the bypass ratio for operating on the lower side of the Mach range from zero to about Mach 3," says Case.



Referencing previous operational high-Mach systems such as Pratt & Whitney's J58 turbo-ramjet developed for the Lockheed SR-71, the company says the technology is well established. "But we need to relearn it, and we haven't had an engine that is operated there commercially. It is a development challenge, but I don't think it will take a miracle," Casey adds.



HERMEUS

Currently portrayed with a simple 2D inlet, Hermeus says the final configuration will continue to evolve.

Hermeus, which revealed its presence in mid-May after announcing a seed-round investment led by Khosla Ventures, with additional participation from private investors, has "been in contact with primes as regards turbomachinery, and we are looking at potential partners there," says Case. Although unidentified for now, he adds that the potential partners are engaged in high-speed turbine studies both internally and through U.S. government programs. "We have had some high-level talks," he says. "There is a lot of government push but not a lot of industry pull, and that is what we represent. That is very beneficial not only to customers but also because the government wants an industry."

One such effort is the U.S. Air Force Research Laboratory-led (AFRL) ATTAM (Advanced Turbine Technologies for Affordable Mission Capability) initiative. Targeting technology development for a range of next-generation small-, medium- and high-power turboshafts and combat engines, the ATTAM program has so far awarded Phase 1 contracts to General Electric, Honeywell, Pratt & Whitney and Rolls-Royce, as well as Lockheed Martin and Northrop Grumman.

The baseline vehicle configuration indicates twin tails, a 2D waverider inlet and a large wing with outer sections angled down at a relatively modest anhedral. However, the final product could look significantly different, says Case. "The drawings we have released so far are conceptual at this stage, and we are still 8-10 years away from flying something like this. But we are going through a handful of outer mold lines and crunching through computational fluid dynamics to see which configurations are the most optimal. You have to start somewhere," he says.

"The company's been around for six months, so there is a lot to still be decided. But it is important to us that we use existing aviation infrastructure," says Chief Operating Officer Skyler Shuford. "We want to be able to land on existing runways, and we also want to be able to run on jet fuel. We don't want to have to completely change the infrastructure to be able to run our vehicle."

Hermeus is targeting the high-end business traveler and corporate markets. "We are talking about a mostly transatlantic-type range of 3,800-4,000 nm or so with 20 passengers," says Smayda. "Compared to Concorde, the interesting thing about Mach 5, compared to Mach 2 or so, is that the faster you fly you can provide the same service to the same number of people with a smaller aircraft."

Smayda, as are co-founders Case, Shuford and CEO A.J. Piplica, are former employees of Generation Orbit, where they most recently led the development of the X-60A, a rocket-powered hypersonic testbed vehicle. The company's board of advisors includes Rob Meyerson, former Blue Origin president; Rob Weiss, the recently retired vice president and general manager of Lockheed Martin Skunk Works; Keith Masback, former CEO of the U.S. Geospatial Intelligence Foundation; Katerina Barilov, founder of Sparkplug Capital+ and managing director of Shearwater Aero Capital; George Nield, former FAA Associate Administrator; and Mitch Free, former director of technical operations for Northwest Airlines.

FAA Chief: How We're Accelerating Safety Standards For Supersonics

Dan Elwell

AERION

Describing supersonic transportation as "the challenging new frontier in commercial aviation," and "essential to a strong and forward-looking nation," President John F. Kennedy, on June 5, 1963, called for a joint government-industry effort to develop a supersonic transport aircraft.

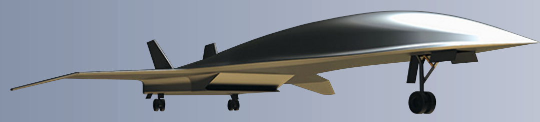
Over the next 50-plus years, the U.S. led the world in the development of commercial spacecraft, unmanned aircraft and electric aircraft - yet we have been unable to get a supersonic transport aircraft over the horizon. Now the FAA is reviewing and updating existing regulations to help enable innovation through the development and certification of new, commercially viable and environmentally responsible, civil supersonic aircraft.

Today, we're taking an important step to accelerate the effort to re-introduce supersonic aircraft. The FAA is issuing a Notice of Proposed Rulemaking (NPRM) to streamline the process for obtaining approval for flight testing of new supersonic aircraft. This paves the way for domestic supersonic aircraft manufacturers, startups, and investors to continue their work and secure approval for supersonic flight testing in the United States, and is a signal to the rest of the world that the U.S. is making a serious regulatory commitment to the future of quieter and commercially viable supersonic aircraft.

New aircraft designs, propulsion systems and airframe materials offer promising benefits and, at the same time, require thorough assessment and evaluation for safety, as well as environmental impacts, such as noise and emissions – just as with every new aircraft we certify. The process to develop and approve these aircraft will take time. We won't see them overhead tomorrow, but we're committed to putting in place the regulatory framework to reenergize this exciting technology.

While there remain challenges ahead, don't bet against this group of high-flying entrepreneurs, experimental aviators, and rocket scientists from launching a new era of supersonic travel. Years of research, investment, and technological advancement have paved the way for a new generation of commercially viable supersonic aircraft. Our goal is to enable U.S. innovators to safely open new aviation frontiers. As these supersonic entrepreneurs bring the world closer, they will create jobs, economic prosperity, and aviation growth for all Americans. Let's open the skies for them.

Dan Elwell is acting administrator of the FAA.
The views expressed are not necessarily those of Aviation Week.



Lockheed Martin Begins Assembly Of X-59 Low-Boom Demonstrator

Guy Norris

Assembly of the X-59, the first purpose-designed piloted NASA aeronautics research X-plane since the X-31 nearly 30 years ago, is getting underway inside the cavernous Lockheed Martin Skunk Works facility in Palmdale, California.

Although only the first few sections of aluminum wing spars and keel beam have so far been loaded into the jigs, the outline of the assembly support structure reveals how the slender planform of the highly swept aircraft will eventually look. With a stiletto-like nose and a cockpit set amidships, the X-59 QueSST low-boom flight demonstrator is one of the most unusual designs to emerge from the Skunk Works.

Measuring 96 ft. 8 in. in length and with a wingspan of just 29 ft. 6 in., the X-59 is designed to validate whether careful airframe shaping can transform the traditional sonic boom of a supersonic aircraft into a publicly acceptable muted "thump." Flying at Mach 1.4 and 50,000 ft., the X-59 is designed to produce a sonic thump of less than 75 PNLdB, compared with the 105-110-PLdB "double-bang" sonic boom produced by the Concorde supersonic airliner.

► Critical design review on track for September

► Wing assembly set for completion in 2020

If the test program can prove that shaping will prevent shockwaves from the airframe coalescing into a conventional, loud N-wave boom, this could open the door to the development of environmentally acceptable commercial supersonic aircraft.

But before that can happen, the law in the U.S. must be changed. In October 2018, just a month before Lockheed marked the official start of parts manufacturing for the X-59 with a "first chip" ceremony, Congress passed the FAA Reauthorization Act, which directed 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."

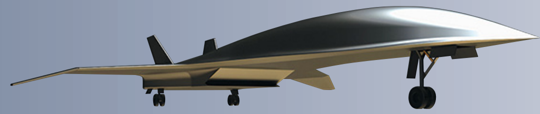
"It's all about overturning that regulation," says Peter Iosifidis, Lockheed program manager for NASA's Low-Boom Flight Demonstrator. "There are a lot of challenges to supersonic flight, but this is the primary goal. NASA is taking the lead on what is really going to allow aircraft manufacturers to go out and ultimately build commercial supersonic products."

LOCKHEED MARTIN

The cockpit will be dominated by the large upper XVS conformal display and twin Collins Pro Line Fusion displays.

Although companies such as Boom and Aerion are pressing ahead with designs that circumvent the law by only flying supersonically over water, or by flying at transonic and low Mach-number speed to minimize sonic boom, others including Lockheed Martin are waiting in the wings for the regulatory landscape to change. "They won't move forward and make the investment without that rule change in place, and that's what this is really about," adds Iosifidis.

Lockheed is meanwhile moving toward a critical design review (CDR) in September, having completed crucial inlet distortion tests in the NASA Glenn Research Center's 8 X 6-ft. supersonic wind tunnel. "The results were in line with predictions, so we don't



have to change the design of the inlet and won't have restrictions on engine operability during the mission. It is also probably the last wind tunnel test we will have to do for this airplane," says Iosifidis.

The tests, which were conducted at supersonic speeds covering all mission parameters, verified the centrally mounted inlet will not ingest the fuselage boundary layer or suffer from inlet buzz, a condition in which a violent oscillation of the supersonic shock system can occur inside the inlet.

With clearance in hand to freeze the inlet design, Lockheed recently completed manufacturing readiness reviews for all major sections of the aircraft, including the forebody, wing and empennage. The review "validates the fact that the big bones of the airplane aren't going to change, so manufacturing is in place and parts are being made," says Iosifidis. "We are pumping out drawings at a regular rate and, [beyond CDR], the next major milestone is first flight in the first half of 2021."

Key structural elements, including the nose section and inlet, are being built by California-based Swift Engineering, a specialist company involved in aerospace composite manufacturing and the development of technologies for autonomous systems, robotics, urban mobility and power management. The chines are being built by aerostructures specialist San Diego Composites, while Moog is supplying actuators for the T-tail, ailerons and motors for the flaps.

The vertical tail is provided by aerostructures specialist D-J Engineering, while Lockheed is building the small T-tail, which is designed to help shape the sonic boom signature. "We are also building the forebody, as well as the upper and lower empennage and nacelle. We are doing most of the spine and wing," Iosifidis adds. Buildup of the first composite skin panels began on the Skunk Works' large fiber-placement machines in mid-June. The wing is due to be structurally complete by February 2020.

LOCKHEED MARTIN

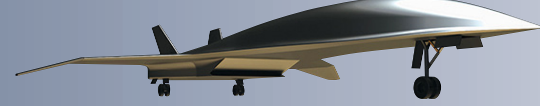
First spars in the jig emphasize the pronounced gulling of the inboard wing for low boom.

The relatively thin wing section has also driven Lockheed to pursue alternate options for monitoring fuel quantity, the correct measurement of which is made more vital because of the aircraft's relatively restricted mission capability. It is only designed to be able to perform two back-to-back 50-mi. supersonic runs up to 100 mi. from a takeoff-and-landing site. Vermont-based Liquid Measurement Systems, which specializes in graphite composite fuel quantity measurement probes, is providing the X-59 system.

Collins Aerospace will provide flight deck avionics based on its Pro Line Fusion system and a dual-camera multispectral infrared enhanced vision system (EVS), the EVS-3600. Together with Lockheed, the companies are jointly developing software for the flight deck avionics. Pilot forward visibility is reduced because of the X-59's long nose. The EVS—mounted beneath the nose—will be used primarily for landing and will work in conjunction with an external vision system (XVS), a forward-looking 4K camera system in development by NASA that will be mounted on the upper surface of the nose.

"We have stabilized the cockpit design, and now we are nailing down the configuration," says Lockheed Martin X-59A chief test pilot Dan Canin. Referencing the reuse of many other aircraft parts and components in the supersonic project, ranging from the standby instrument from an F-16 to the entire rear seat and canopy from a T-38, he adds: "In spite of the fact we have cobbled together parts from various legacy systems, very little of this looks like the airplane it came from.

Along with a large-format upper display system for the XVS and test-related instrumentation, the X-59 cockpit also includes some unusual features such as a U-2-derived hydrazine air-start system and a thermal battery system taken from a T-50 trainer that will run the aircraft's emergency fuel-pump system.



Flight-control laws are also in development for the aircraft, which will be tuned to govern up-and-away handling qualities as well as adapted to the approach and landing characteristics of the unusual aircraft closer to the ground. “We have the basic control-law mode, which is like a fighter with pitch-rate and roll-rate command as well as sideslip with the pedals, but the greatest focus areas are on safety and working synthetically through the displays,” says Canin. Pilots should quickly get used to not having a forward window to look out of and instead using the displays, he adds. “It should not be spooky as long as we have depth perception,” he notes.

LOCKHEED MARTIN

Lockheed Martin’s X-59 cockpit mockup is set to become the systems integration lab with Collins Aerospace and NASA-provided equipment.

In the cockpit mockup, which is soon to become the systems integration lab with real Collins and NASA-provided equipment, Lockheed is also developing backup safety procedures in case of display failures. “Pilots would like to be able to land with no avionics at all,” says Canin. “Maybe with a chase aircraft and a spotter on the ground, and using the side windows for peripheral cues, we think we’ll be able to do that safely. Everyone will feel happier going into the development program if that’s possible.”

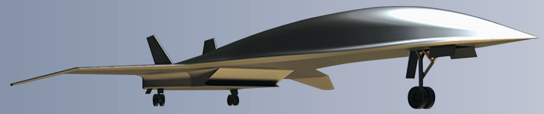
The sheer length of the aircraft, added to the aft location of the 17-ft. 6-in.-wheelbase landing gear, is driving careful consideration of flight-control laws for landing. “The amount of aircraft that’s aft of the gear gives us tailstrike potential after about 9.2-deg. pitch and on approach about 6 deg.” says Canin. The aircraft will therefore come in at a nominal 2.5-deg. approach angle and, although Lockheed estimates it will come over the fence at about 160 kt., Canin says: “We don’t want to get into a situation where we overrotate and get into a pilot-induced oscillation.”

To guard against this, the X-59 may take a leaf out of the Lockheed Martin F-35C control-law book. “Our initial concept for landing is going to be flightpath command with speed hold, in which we lock in the angle of attack and the flight path,” he adds. “So basically, we do a very shallow carrier landing where we don’t flare, and we just let it fly onto the deck. Flightpath command has changed the game for carrier aviation with the F-35C.”

Planning for the uncertainties of first flight is already underway. “The aircraft is very unstable longitudinally in pitch and very sensitive to crosswinds. The very high sweep angle gives us a lot of rolling moment with a bit of sideslip, so the more augmentation modes I can have for first flight the better,” says Canin. “The whole idea of the first flight is to get it back safely. So we are not going to move the gear and, after we take off, we will do practice approaches to make sure we can get back. Therefore, we want to have as many other options for that control law in case basic is not perfect.”

Lockheed plans to conduct initial airworthiness tests with a series of 10 or fewer flights out of Palmdale before taking the aircraft to the nearby NASA Armstrong Flight Research Center at Edwards AFB for an envelope expansion program expected to encompass 30 flights. These will be flown with NASA as part of the first of three main phases planned by the research agency.

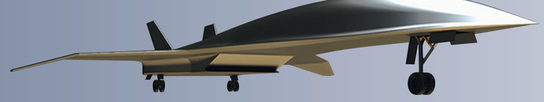
Phase 1 covers aircraft development “from critical design all the way through envelope expansion flights, both subsonic and supersonic,” says Heather Maliska, associate project manager for the Low-Boom Flight Demonstrator at NASA Armstrong. Phase 2 is an acoustic validation phase in which NASA will evaluate whether the aircraft can be flown over communities for noise testing, while Phase 3—which is expected to run from late 2023 to 2025—will focus on community response testing.



For the acoustic validation phase, NASA is gearing up to prepare tools to be able to compare its models to real flight data to make sure the sonic boom level is acceptable. This will involve measurements of the boom signature in the near, mid and far field. For the near-field measurements, "we are instrumenting a NASA Boeing F-15 with a shock-sensing probe that we will take up and fly alongside the X-59 to measure the static pressure of the sonic boom," says Maliska.

The F-15 will also carry a pod to collect schlieren imagery. "This will give us a better look at the fine details of the shockwaves because sometimes the computational fluid dynamics do not see that sort of fine detail. Such imagery will give us validation of the shockwaves and help us compare all our data to the models. We will also take ground measurements across the desert over large sound arrays to measure the sound on the ground," she adds. "Once all that is validated and accepted, then we'll go through an acceptance review and make sure we are ready to move into Phase 3."

The community response phase will involve surveying up to six towns and cities, the locations of which have yet to selected. The surveying process will be similar to tests conducted last November over Galveston, Texas, during which a NASA BoeingF/A-18 was used to simulate the reduced shockwave signature by flying a special supersonic dive profile off the coast. The maneuver resulted in a muted sonic boom reaching the community-response survey area onshore and anecdotally "sounded like a car door closing in the distance," says Maliska, who was in Texas to witness the event.



Lockheed Martin Floats Supersonic Airliner Concept

Guy Norris

Boosted by development of the X-59 low-boom demonstrator for NASA and sensing the potential for an early jump-start in the emerging commercial supersonic market, Lockheed Martin has unveiled details of a Mach 1.8 concept capable of transpacific routes with up to 40 passengers.

The company believes its baseline design can economically operate on routes up to transpacific in length while simultaneously defeating the problems of sonic boom and airport noise that killed off the Concorde 16 years ago. Unlike earlier supersonic transport (SST) attempts by the industry, including by Lockheed , this time the concept builds on new enabling technologies in design, propulsion, aerodynamics and systems that were either not previously available or sufficiently advanced.

The design breakthroughs owe much to the X-59 QueSST, in addition to leveraging studies conducted earlier this decade under NASA's N+2 quiet supersonic initiative, which preceded the low-boom demonstrator. These studies proved for the first time that low boom could realistically be combined with good supersonic-cruise lift-to-drag ratio and established the fundamental building blocks of both NASA's latest X-plane and Lockheed's newest large supersonic concept.

► Twin-engine quiet supersonic transport concept is 225 ft. long

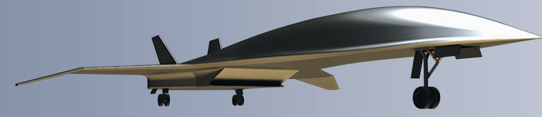
► 40-passenger design is aimed at transpacific ranges at Mach 1.8

"We now have the technology to dramatically reduce the impact of those sonic booms that were completely unacceptable from the Concorde," says Michael Buonanno, Lockheed Martin air vehicle lead for X-59. With the new demonstrator, which is targeted for first flight in 2021, "we are shifting the whole design space and proving we can shape sonic booms to make them dramatically quieter," he says. "Leveraging data from X-59, regulators may replace the current boom with standards that future manufacturers of supersonic airliners could design to. So, this could really usher in a new age of commercial transportation."

The sharply swept delta-wing quiet SST design is 225-ft. long with a span of 73 ft., making it significantly longer than the Concorde but slightly narrower in span. Almost 70 ft. of the overall length is made up of the nose section, while the cabin occupies the central 78-ft. section of the fuselage. Twin tail-mounted nonafterburning engines, rated at 40,000-lb.-thrust, are located between V-tails. "We've gone back to V-tails, which we studied early on for X-59. They're best for the shaped-boom criteria, but we had challenges from a stability and control standpoint. We have now figured out the nuances of how to integrate those to get the benefit," says Buoanno.

LOCKHEED MARTIN

Lockheed Martin's 40-passenger quiet SST concept (foreground) draws on NASA's X-59 low-boom demonstrator (background).



To get the most from the technology Lockheed conducted a rigorous SST market analysis, which established a set of basic requirements for range, takeoff field length, passenger capacity, sonic-boom loudness at the start of cruise, over water and overland cruise Mach number, and airport noise. These were each given minimum threshold values, below which the concept would not be viable, and objective values for optimum performance.

"We know it's going to be very difficult to come up with an airplane that meets all the design objectives, so as we went through the process we looked at those trade-offs to see where we could give a little, though still not be worse than the threshold," says Buonanno. "But it did enable us to come up with a sweet spot in terms of the design."

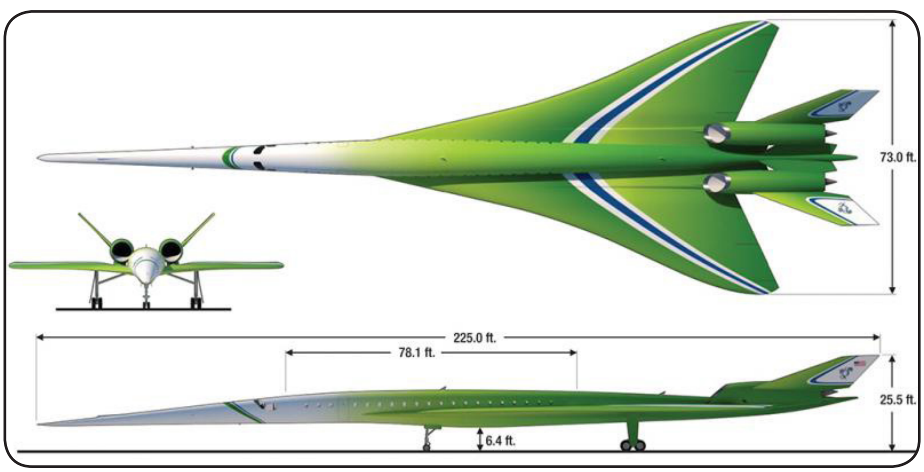
Threshold range was set at 4,200 nm, which the company believes is sufficient for most top city pairs, while an objective range of 5,300 nm will enable nonstop transpacific missions. Target takeoff field length is less than 10,500 ft., though under 9,500 ft. is preferred, while the sweet spot for passenger capacity is set at 40. Using Concorde as a reference, "we explored different markets and looked at load factors, and thought 40 [passengers] would be a good place," says Buonanno. The minimum viable payload is 19, below which seat-mile costs are considered unrealistic.

For sonic boom loudness, the threshold requirement was set at less than 80 PLdB, with less than 75 PLdB as the optimum target. Whether these values are realistic depends on the outcome of the upcoming community acceptance tests with the X-59, says Buonanno. The latest round of performance trades has projected a design with 5,200-nm range and a boom loudness of 80 PLdB. "So that's slightly louder than the X-59, but still much, much quieter than Concorde. It's an area we want to explore further, but until we get data from flight testing it will be hard to gauge where the threshold of acceptability really lies," he adds.

For overland cruise Mach number, Lockheed's design is optimized for Mach 1.7 or higher. Speeds of Mach 1.6 or lower adversely affect aircraft utilization and cruise efficiency. For flight over water, Mach 1.7 or greater is preferred, but speeds above Mach 1.8 begin to get challenging on sonic boom loudness.

Airport noise targets are "consistent with future standards" and, although the exact requirements are still being decided by regulators and the International Civil Aviation Organization, Buonanno says the design and its propulsion system will be capable of meeting whatever is defined. "Noise regulations are still in development, but are kind of a moving target and we are aware of those," he says.

To meet the requirements, the Lockheed design embraces four key enabling technologies; shaped-boom design; integrated low-noise propulsion; swept-wing supersonic natural laminar flow; and the external vision system (XVS) for visibility from the cockpit. "These are things that have really changed in the past 10–20 years as a result of investments by the government and industry," Buonanno notes.



LOCKHEED MARTIN

From its boom-shaping nose to the lifting V-tail, the design is longer than the Concorde but with a shorter span.

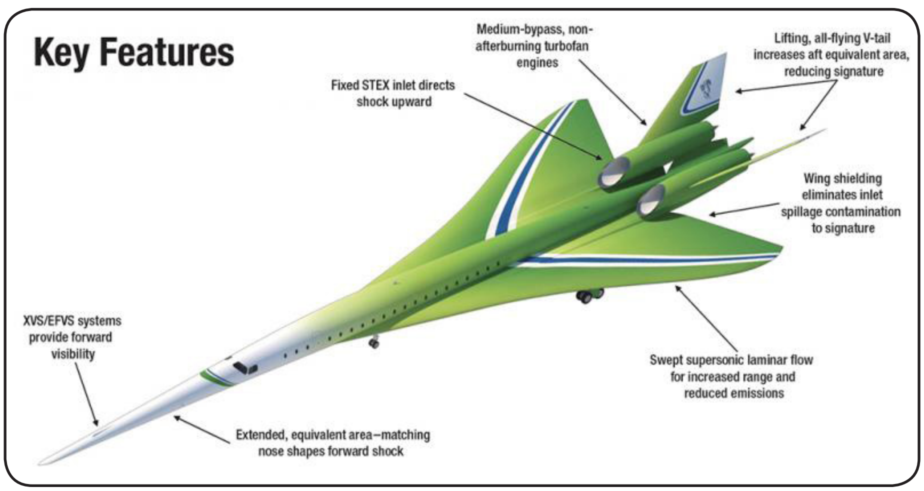
The shaped-boom design technology is one of "the key ingredients as to why we think it's a good time to move forward," he says. "Ten years ago the technology wasn't there to truly hit low boom, and back 20 years ago low boom was thought to be 85–90 PLdB. So, the investment that NASA made to build up to the X-59 has become critical here, and the tools and methods we have used to shape the design of the X-59 are 100% transferable to a larger-scale commercial design."

Major strides to tailor for low boom while minimizing the impact on supersonic cruise efficiency were made starting almost a decade ago during Lockheed's work with NASA on a high-speed N+2 design. Advances in CFD (computational fluid dynamics) capabilities enabled more accurate modeling of the flowfield, while a new generation of geometry manipulation tools allowed designers to explore complex 3D flow perturbations. In addition, a new set of optimizers provided a means of quickly identifying realistic configurations. At the time, these tools were applied to a concept aimed at NASA's N+2 goals for a 35- to 70-seat, Mach 1.6-1.8 jet with an 85-PLdB boom and airport noise 12 EPNdB below Stage 4, all of which came close to Lockheed's 2019 quiet SST concept.

The second enabling technology, integrated low-noise propulsion, addresses the issue of airport noise, "which hamstrung Concorde just as much as its sonic boom," says Buonanno. "Tackling that problem is going to be critical to having an acceptable future commercial supersonic transport. Lots of building blocks are now in place in terms of fundamental research that's taken place over the past decade or so. When we put together those pieces we can come up with an integrated propulsion system that will allow us to be successful."

Elements include recent developments in advanced plug-nozzle designs, noise shielding concepts and distortion-tolerant fan blades that operate at high efficiency yet cope with the turbulent flow in inlets designed for low boom. One such design is the STEX (streamline-traced external compression) inlet which, in NASA tests, showed it could direct the shockwave from inlet flow spillage up and away from the aircraft, providing both noise shielding and reduced boom.

Optimized for speeds of Mach 1.6 or slightly above, the STEX design incorporates an external supersonic diffuser and an inward-turning inlet that produces external cowl angles with low wave-drag compared to conventional axisymmetric spike inlets. The inlet leading edge is scarfed and, as the terminal shock was seen in tests to be located near the end of the diffuser, subsonic spillage was localized to a small part of the cowl lip. This feature could enable the inlet to be integrated with the overall aircraft to control the interaction of the spillage with the upper-wing surface.

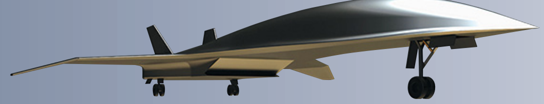


LOCKHEED MARTIN

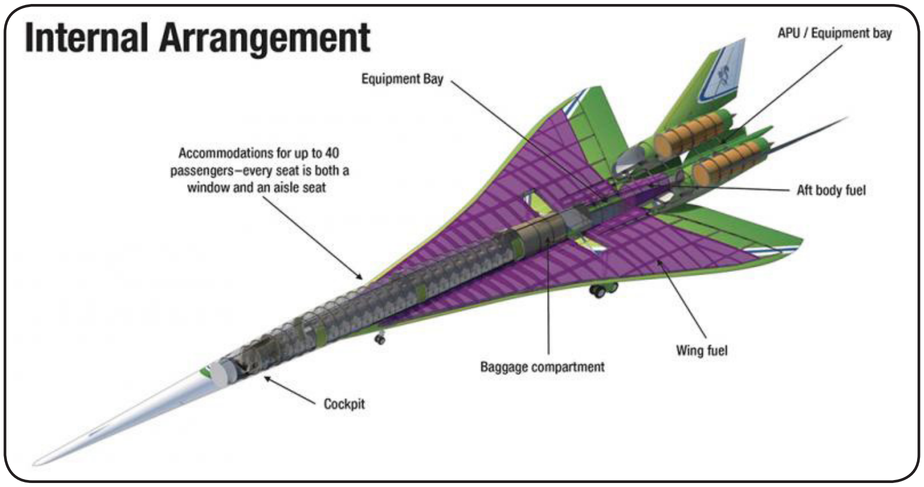
The SST's design features include top-mounted engines with scarfed inlets to help shape the boom.

Researchers also found that the low external cowl angles and localized subsonic spillage helped reduce external pressure disturbances that contribute to sonic boom. However, the STEX has challenges that will require further study. For instance, in tests it was found that interaction between the terminal shock and the boundary layer led to lower total pressure recovery and higher total pressure distortion compared to an axisymmetric-spike inlet designed for the same conditions. Potential solutions could include adding bleed to the throat section or introducing vortex generators.

Together with the plug nozzle, as well as modern engine cores from high-bypass-ratio turbofans adapted with new low-pressure systems, Buonanna says, "We can thread the needle. For efficient supersonic operations, we tend to want smaller fans and higher fan-pressure ratios, but for low noise we want bigger fans with lower fan-pressure ratios. Now we have the key ingredients that let us come up with a solution that gives us good performance at supersonic flight, and in the takeoff and landing environment. A big part of this is the Mach 1.6-1.8 sweet spot, where we think we could come up with a good solution with today's technology to meet those noise constraints."



Another key enabler is the potential for swept-wing supersonic natural laminar flow (NLF). "[NLF] is at a fairly low technology readiness level, but we have identified it as having significant potential," says Bounanno. Although Lockheed previously studied laminar flow with Aerion for application to that company's AS2 supersonic business jet, "that technology would not be compatible for our low-noise or shaped-boom criteria," he says. "However, NASA has done research in the past few years looking at the possibility of significant amounts of supersonic NLF with swept wings, and that would be highly swept. It would significantly help achieve our upper-range goals. The key is to get drag reduction without compromising the shaped-boom characteristics."



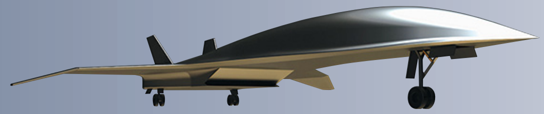
The passenger cabin occupies a 78-ft.-long central section of the slender, shaped fuselage.

Natural laminar flow can be created by designing the wing with a favorable pressure gradient to delay the transition of flow from laminar to turbulent. However, all previous practical NLF wings have been applied to either small aircraft or designs with low sweep. Lockheed's challenge is that with increased sweep angle the now 3D flowfield becomes susceptible to a form of boundary-layer instability called crossflow vortex instability. This causes the boundary layer to become turbulent closer to the wing leading edge.

The fourth enabler is the XVS high-definition camera and display system being developed by NASA for the X-59. As swept wings require higher angles of attack for takeoff and landing, the long nose obscures the view from the cockpit. Concorde got around this with a droop-nose design, "but now we have the benefit of modern technology and can avoid that weight and complexity with an XVS," Bounanno notes.

So what does Lockheed Martin hope to achieve by releasing the concept? "We've been making investments to reduce sonic boom for decades and now we are taking it to the next level," says Peter Iosifidis, Lockheed program manager for NASA's Low-Boom Flight Demonstrator. "We are taking those results and considering how we can leverage that learning into developing a supersonic product in partnership with somebody or perhaps to license it. We will explore all options.

"We are closer now than we have ever been, and with our work with the X-59 we are probably in the best position to put something forward to meet the demand for faster travel times," he continues. "How that's going to happen has not been determined, but this is the next step. We have put some significant engineering resources into creating a concept with some validity to it, although there's a lot more work to be done," Iosifidis says. "With this concept we are putting our toe in the water to say we are open to explore those opportunities, wherever they might be."



Speed Game

Graham Warwick

For an X-plane, NASA's X-59 QueSST supersonic low-boom flight demonstrator is under unusual schedule pressure. Industry needs data from the aircraft's first community-acceptance flights by 2024 if it is to stay on track to establish long-awaited noise standards permitting supersonic flight over land.

Without data on what level of sonic boom the public would find acceptable, civil supersonic aircraft could continue to be prohibited from flying above Mach 1 over land. This would limit the economic viability of the new-generation supersonic transports industry aims to deliver within the next 5-10 years.

NASA

NASA's X-59 staying on schedule is critical to plans for sustainable supersonic air travel

The schedule is tight. NASA expects Lockheed Martin's Skunk Works to fly the X-59 from Palmdale, California, late in 2021, but it could slip into early 2022. Envelope expansion, acoustic validation and initial public-response data collection flights will follow at Edwards AFB in California.

NASA needs to conduct the first community-acceptance flights beyond the Edwards test range in 2023, likely over a location in Southern California, if it is to meet its commitment to deliver an initial dataset to the International Civil Aviation Organization (ICAO) by the end of 2024.

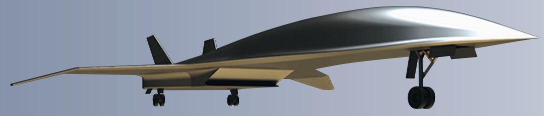
That deadline is set by the need to collect and analyze the data before the 13th meeting of ICAO's Committee on Aviation Environmental Protection (CAEP) early in 2025. CAEP is developing a standard for en route noise that will enable aircraft to be certified for supersonic flight over land.

This has already been a long road. ICAO has been working on sonic boom—which regulators now prefer to call en route noise as advances in aircraft design have reduced the boom to a thump—for 15 years, and it will be another 10 years before the final certification standard will be ready.

The reason it is taking so long is complexity. Existing regulations for certifying aircraft landing and takeoff noise involve measuring sound levels at the ground and then, by analysis, working back to the source noise and propagating that through a reference atmosphere to produce the data required by the certification authorities.

That will not work for sonic boom. "As the boom propagates through the atmosphere, it loses features. We can't backtrack to the source, then propagate that noise under reference conditions," says Robbie Cowart, director of supersonic technology development at Gulfstream. "Certification procedures require measurements at reference conditions," he told the American Institute of Aeronautics and Astronautics Aviation conference in Dallas in June.

Close to an aircraft cruising supersonically, the sonic signature is a ragged mix of shock and expansion waves. Farther from the aircraft, at mid- and far-field, features start to coalesce and become fewer, but then the boom enters the Earth's boundary layer, where low-altitude turbulence reintroduces high-frequency content to the signature, even causing localized focusing and strengthening of the boom.



"With turbulence, you can get a radically different signature just 20 ft. away," says Cowart. This raises the question of where the boom should be measured: at the ground, above the turbulent layer or at a mid-field altitud? There is also the issue of which noise to certify—the cruise boom that NASA has set out to reduce or the focused boom that is generated when the aircraft accelerates, decelerates or maneuvers? And do you measure noise only under the aircraft's track or across the entire 20-mi.-wide boom carpet?

When an aircraft is designed to minimize the under-track boom, it can increase the noise off-track and off-design. "How do we do this in a uniform, robust and consistent manner?" asks Cowart. "How do we measure boom and keep it economically feasible? We have to think about economic reasonableness. If we have to spend 20% of our flight-test budget on measuring en route noise, that's not reasonable."

These are just some of the issues being tackled by CAEP experts as they work to develop the first-ever certification standard for sonic boom. But to ensure a sustainable return to supersonic air travel, the most critical step remains determining what level of en route noise the public will deem acceptable.

For that, NASA is under the gun to begin collecting community-response data by 2023 and to complete 4-6 flight campaigns across the U.S. by the end of 2025. "It's a very tight schedule," acknowledges Dave Richwine, deputy program manager for technology. The X-59 is an X-plane program with a deadline.