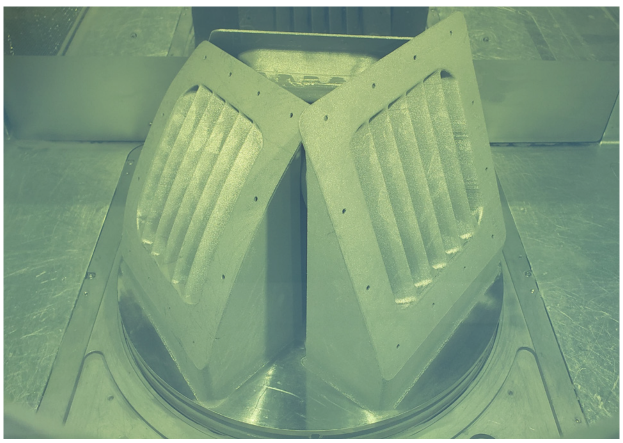
3D Printing Flight Hardware for Supersonic Aircraft

Challenging titanium parts for XB-1 demonstrator aircraft successfully 3D printed on VELO3D’s Sapphire system



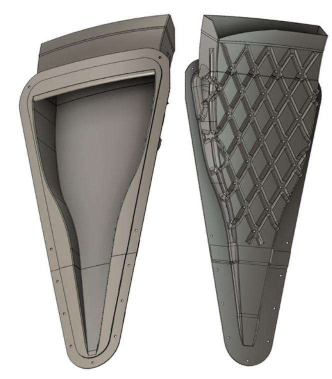
Three parts for the Variable Bleed Valve (VBV) system waiting for unpacking in an inert Sapphire build chamber.

Boom Supersonic’s XB-1 supersonic demonstrator aircraft, revealed on October 7, 2020 at the company’s Denver hangar, brings supersonic air travel closer to reality. Unlike the earlier Concorde, XB-1 and Overture (the company’s future supersonic airliner), present their creators with an opportunity to explore more advanced designs and manufacturing technologies than those available to engineers in the past.

Early on in the project, knowing that 3D-printed parts are already flying in many current aircraft, the Boom Supersonic design and engineering team started thinking about employing additive manufacturing (AM) to produce some of their most complex part designs.

Why AM? “There are many reasons for choosing that technology over others,” says Boom Engineer Byron Young. “There’s a great deal of design flexibility in using 3D-printed materials. You might be able to achieve similar results by making multiple parts and welding or bolting them together, or by using complex carbon-fiber tools. But that requires a lot of engineering time, and often more manufacturing time as well.”

“Engineers are always trying to implement time-savings into a job. Much of the time and effort in aircraft design goes into joints, the interfaces between components. By designing directly for AM, we can reduce the number of parts and joints, which also reduces time and net effort. And part consolidation cuts out significant amounts of weight, something that’s a major priority in aircraft design.”



NACA ducts are frequently used in high-speed aircraft to capture exterior air and channel it into the aircraft to cool the engine

Manufacturing Uncompromised Geometries

Many of Boom's 3D-printed parts are related to channeling air, and contain complex vanes, ducts and louvres. Some of the air being routed through these parts exceeds 500 degrees Fahrenheit. The geometric complexity of these parts required a surface-based design approach. "If fast moving air is touching it, we care about that surface from an efficiency and performance standpoint," says Young. "So when designing these parts, you generally start with aerodynamic profiles and then trim, fillet, and thicken surfaces to create the solid part itself. The resulting parts are very complex—which meant they definitely needed to be fabricated through AM."

Duncan Machine Products (DMP) was the manufacturing partner that led the 3D printing and machining of all the parts for Boom. DMP is AS9100, ISO 9001, and ITAR certified.

VELO3D's Gene Miller, Applications Engineer agrees with the sentiment, and worked closely with both Boom Supersonic design engineers and Duncan Machine Products (DMP), the supply chain partner that handled both printing and post-processing. "Boom designed all these parts specifically for their novel aircraft," he says. "The unique types of geometries they created for directing flow, with a focus on weight savings, couldn't be done with sheet metal or casting or any other way. To reap the benefits of complex design and weight reduction together, the only option was to do it with metal AM."

Having established a relationship with VELO3D on some trial parts in 2019, the Boom Supersonic team chose the company's next-generation laser powder-bed fusion (LPBF) technology to produce a number of printed titanium components (a right and a left version for many of them) located in critical areas of the plane. These included manifolds for the Variable Bypass Valve (VBV) system that routes air released by the engine compressor to the aircraft's outer mold line (OML); exit louvers for the environmental control system (ECS) that cools the cockpit and systems bay; louvers that direct the center inlet's secondary bleed flow to the OML; and NACA ducts and two diverter flange parts. NACA ducts are frequently used in high-speed aircraft to capture exterior air and channel it into the aircraft to cool the engine bays. All parts were printed on the VELO3D Sapphire system.

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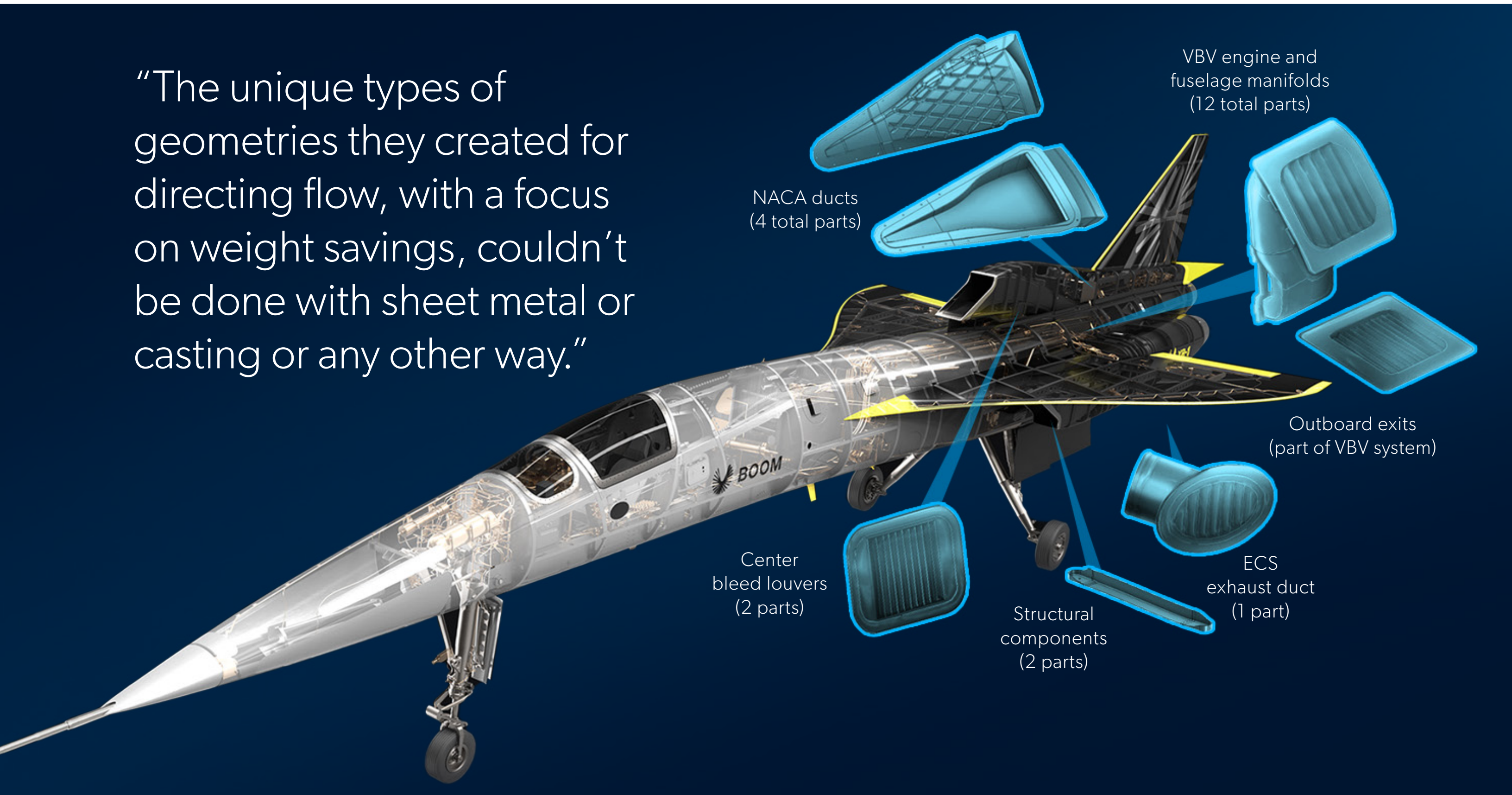
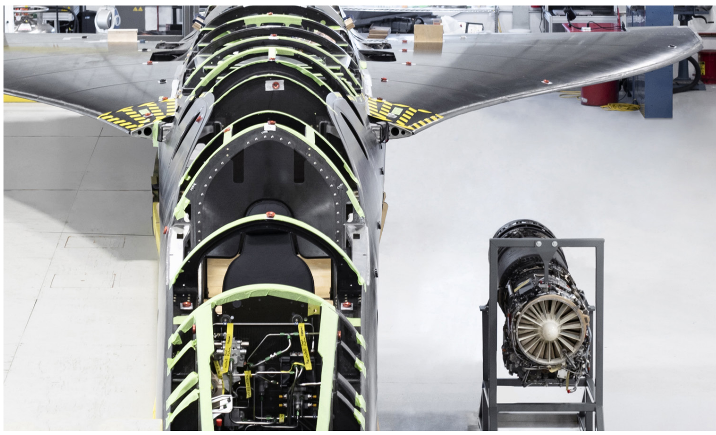


In almost every case, the Sapphire was able to print parts directly from Boom's CAD data, preserving original design intent. "We did use our system's Flow pre-print software to add some structural ribbing on the thinner walls of the NACA ducts that had to be constrained," says Miller. "But for the most part the other components all printed as is, with no compromise to the design."

Boom's Young was impressed with the ability of the Sapphire to accurately produce the extremely thin-walled designs of the parts. "The Sapphire system allowed us to print walls as thin as 20 thou (0.02 inch, or 750µ), with a surface finish that didn't require additional machining in most cases," he says.

The high aspect ratio (height to width) made possible by the VELO3D machine's non-contact recoater system (which distributes each new layer of powdered metal to be fused by dual lasers) was another plus. In order to remove mass, the vanes on the center inlet's bleed louvers were printed hollow, and the parts were designed with high aspect ratios (very thin walls along long spans). "Because our technology provides the ability to print that very high aspect ratio in this kind of design, we didn't need excess material for strength inside the structures and we could grow those duct vanes up very high without any interference from the recoater," says Miller.

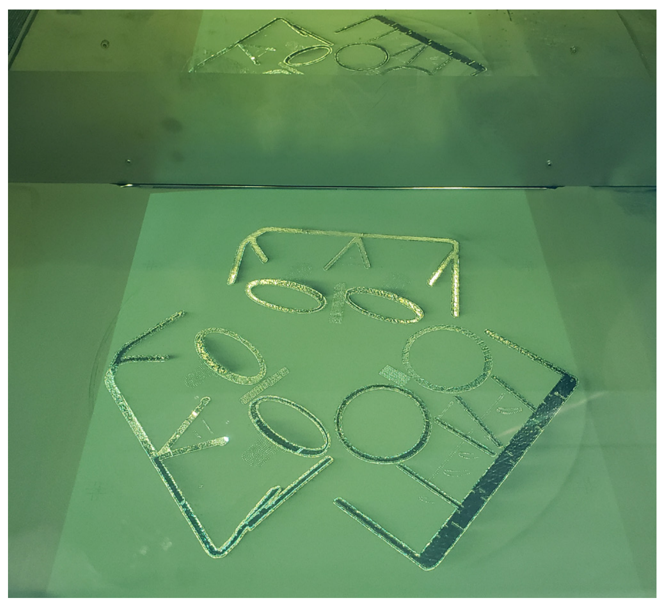


"Supersonic flight introduces a number of different phenomena and stresses you generally don't see with conventional air travel."

Printing with Titanium (TI6AL4V)

All parties involved agree that one of the biggest challenges of the project was working with the titanium material Boom chose for the 3D-printed parts. "One of the positive aspects of using titanium is the material allowables at temperature," says DMP additive manufacturing engineer Aaron Miller (no relation to Gene). "There's less loss of strength at high temperatures compared to aluminum or carbon fiber, and it has a higher strength to weight ratio."

But lightweight, extremely heat-resistant titanium—widely used throughout the aerospace industry for critical components—also has a reputation for being delicate and difficult to work with no matter how it is manufactured. If titanium is cooled too rapidly it becomes brittle and is prone to cracking. Jokes Aaron, "Titanium is on that list of things that machinists don't like, right behind engineers and Inconel [a superalloy]."



Dual 1 kW lasers trace the geometry and melt the Titanium powder into a near-net shape part, in this case, for XB-1's VBV fuselage manifolds.

A Variable Bleed Valve (VBV) system is installed on each of XB-1's engines. This system is critical to engine operation as it discharges compressor air to prevent engine stall. CAD image on left is from Flow™ pre-print software, with external support structures indicated in blue. Notice that the airfoils of the guide vanes are printed without support structures, preserving a leading edge that optimizes the air flow performance. Middle image shows three nestled parts, as printed, and still attached to the build plate. Right image is a close-up of the airfoils, as printed.

Titanium parts can be manufactured conventionally via casting, which has a slower cooling rate to prevent cracking, notes Gene. But the extremely thin walls in the aircraft hardware designs would have been nearly impossible to cast. "That's really one of the driving forces behind using 3D printing for these parts because we can print large, thin-walled titanium sections without the high scrap rate of cracked cast parts," he says.

"This was a learning process on all sides," Gene acknowledges. "Boom designed a part family that was new to us, really pushing the envelopes for weight reduction and thin-wall geometries, and we had a lot to learn as far as printing these components out of titanium and what to expect from the physics of printing. How it is going to move? How is it going to shift? What can be printed without supports and what areas needed to be supported so the result is nominal?"

Laser Focus	Value	Status	Timestamp
Spot Size Center Focus			
Laser 1	2.32	✓	2019-10-10 11:11 AM
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From VELO3D's Assure quality assurance software, users are able to monitor and measure part quality characteristics such as layer height and laser focus in real-time. All data points are summarized in an informative build report.

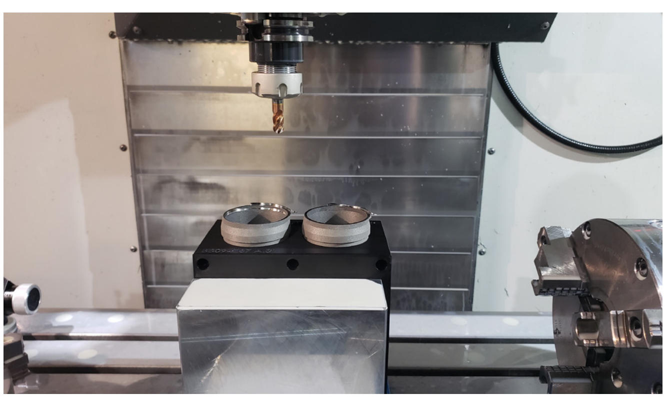
This is where process control is critical. VELO3D's semiconductor heritage provides an intense focus on quality control. The team has developed a unique, proprietary AM process that optimizes the print parameters and sequences to produce robust titanium parts. "This reduces the amount of internal stress in the substrate as the material is being built up in the Z build-direction," Gene explains. "It diminishes the possibility of cracking by mitigation of internal stresses formed during cooling."

Quality control is integrated throughout the entire build, starting with Flow pre-print software, executed through the Sapphire system and validated with Assure's quality assurance. Pre-build machine calibration is achieved with a single click, automatically checking critical variables like laser alignment, beam stability, powder-bed quality, and much more. In-process metrology monitors a wide variety of key metrics and flags these anomalies. Comprehensive build reports for all parts are compiled and saved for future reference.

The internal flow passages on XB-1 's VBV fuselage manifolds were printed entirely without support structures, saving material, post-processing time, and labor. Left is the top of the manifold and right is the bottom .

Simplified Post-Processing

Once Boom's titanium parts were 3D printed, they were easily sliced off the build plate with sawing or wire-cutting EDM. The DMP machinists found post-processing to be relatively straightforward, compared to parts made in other AM systems they've worked with, remembers Aaron. The part geometries brought an additional challenge when creating fixtures for holding the parts during finishing. "There's pretty much no surface that's perfectly flat or round on an aircraft, which makes them difficult to grab on to," says Aaron. "But we just used the parts' CAD models and quickly designed and 3D printed custom plastic fixtures (on a separate FDM printer) that were appropriately squared or rounded for us to grab on to with our finishing tools."



A ball-nose end mill ensures that the cylindrical hose barb of this VBV engine manifold is smooth. All post-processing was performed at DMP.

Part finish right out of the machine was tested with a profilometer, registering about 250 RA on average. "If the customer wanted to go to 125 RA it would take just a few minutes with a vapor hone to achieve that," says Aaron. "So far Boom hasn't asked us to dial-up the surface finish on their parts; they're concentrating on geometry and part strength at this point, but if a smoother surface is needed that's easy to accomplish."

Finished parts were heat treated and /or HIP (hot isostatic press) processed to enhance fatigue life. "Doing this is always a good idea, especially when you have flight components that may be cyclically loaded during takeoff and landing," says Gene. "Supersonic flight introduces a number of different phenomena and stresses you generally don't see with conventional air travel." Adds Young, "The main forces being applied aren't generally pressure loads from, say, breaking the sound barrier. In many cases it's induced strain caused by the overall structure of the aircraft flexing around your part. When parts with dissimilar thermal expansion coefficients are mounted to each other, significant stresses can also result (this include carbon composites and aluminum in addition to titanium). Designing these 3D printed parts to be very thin and flexible can actually mitigate some of these issues."

The three companies that put their heads together to successfully produce the 3D printed parts for Boom Supersonic's XB-1 supersonic demonstrator clearly learned a lot from their collaboration. The Boom team found that AM was more complex than they had envisioned—but could also deliver on their original design intent. And Duncan Machine Products expanded their 3D printing expertise significantly, going on to purchase a third Sapphire machine. Says Aaron, "We're getting a lot of new business because of our capabilities in additive manufacturing."

An additive-manufacturing machine operator at Duncan Machine Products (DMP) about to unpack a build on a Sapphire metal 3D-printing system.

The Future of Supersonic Travel

Commercial flights for Overture, the company's future SST, are scheduled to begin before the end of the decade. Hundreds of potential routes have been identified, and two major airlines—Virgin Group and Japan Airlines—have already pre-ordered 30 airliners.

Boom's Overture airliner will include a carbon-composite airframe, and is exploring the use of quiet and efficient Rolls-Royce jet engines that don't use afterburners during supersonic cruise.

Boom Supersonic's XB-1, the one-third scale demonstrator for Overture, rolled out in October of this year, with flight testing slated to begin in 2021. The full-sized Overture will debut in 2025, and passenger flights are due to commence before the end of the decade.