After Concorde, who will manage to revive civilian supersonic aviation?

By François Sfarti and Sébastien Plessis
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Commercial aircraft are flying at the same speed as 60 years ago. Since Concorde, which made possible to fly from Paris to New York in only 3h30, no civilian airplane has broken the sound barrier.

The loudness of the sonic boom was a major technological lock to Concorde success, but 50 years after its first flight, an on-going project led by NASA is about to make supersonic flights over land possible. If successful, it will significantly increase the number of supersonic routes and increase the supersonic aircraft market size substantially.

This technological improvement combined with R&D efforts on operational costs and a much larger addressable market than when Concorde flew may revive civilian supersonic aviation in the coming years.

Who are the new players at the forefront and the early movers? What are the current investments in this field? What are the key success drivers and remaining technological and regulatory locks to revive supersonic aviation?
EXECUTIVE SUMMARY

Commercial aircraft are typically flying between 800 km/h and 900 km/h, which is between 75% and 85% of the speed of sound. It is the same speed as 60 years ago and since Concorde, which flew at twice the speed of sound, was retired in 2003, there has been no civilian supersonic aircraft in service.

Due to a prohibition to fly supersonic over land and large operational costs, Concorde did not reach commercial success.

Even if operational costs would remain larger than subsonic flights, current market environment seems much more favourable: since Concorde was retired in 2003, the air traffic has more than doubled and the willingness to pay can be supported by an increase in the number of high net worth individuals and the fact that business travellers value higher speed levels.

The loudness of the sonic boom was with high operational costs a major technological lock to Concorde success, but 50 years after its first flight, NASA’s on-going Low-Boom Flight Demonstration mission is about to collect data that could make supersonic flights over land possible.

In this context, several important supersonic aircraft projects have been launched over the past few years and there are already early airline clients (Japan Airlines, Virgin Group and Flexjet, a US business jet service provider), which soon may offer a new dimension to differentiate themselves from competitors: speed.

There is a significant change in players compared to Concorde: some current projects are led by young companies in the US. On their side, historical OEM and OAM are staying involved through industrial partnerships.

The on-going projects are targeting premium travellers first (high net worth individuals and business class travellers) with business jets and commercial aircraft. Commercial supersonic aircraft projects under development aim at giving airlines the possibility to charge the same fare as business class. If they manage to do so, we can expect supersonic flight to become a segment within the business class market.

For now, we are still at the early stage of development. Innovation needed in supersonic flights is still important, not only to reduce the operating costs to enlarge the addressable market, but also to tackle new environmental concerns: noise regulation during take-off and landing and NOx and CO2 emissions.

Short-term R&D and a larger addressable market could enable a revival of civilian supersonic aviation in the coming years:

- Several routes across oceans already have a large enough traffic to support supersonic flights. Some aircraft under development (e.g. Boom Overture and Aerion AS2) will be able to address premium travellers on these routes.
- By the end of the 2020s, NASA’s on-going R&D could enable supersonic flight over land, which will significantly increase the number of supersonic routes and increase the market size substantially. It will give the opportunity to develop new quiet supersonic aircraft (e.g. Exosonic, Spike S-512).
- In the future, continued investments to keep on reducing operating costs and continued air traffic growth should contribute to a larger development of supersonic flights.
Aircraft are flying at the same speed as 60 years ago and since Concorde was retired in 2003, there has been no civilian supersonic aircraft in service.

Commercial aircraft are typically flying between 800 km/h and 900 km/h, which is between 75% and 85% of the speed of sound.

First commercial aircraft with jet engines were introduced in the 1950s and their speed were already very close to current typical cruise speed. Civilian aircraft speed has not increased since the end of 1950s, except with supersonic aircraft.

Exhibit 1: Aircraft typical cruise speed over aeronautics history

Concorde was in service between 1976 and 2003; it was the most famous commercial supersonic aircraft.

Aside from Concorde, Tupolev Tu-144 was the only other civilian supersonic aircraft, but commercial passenger flights stopped after less than 1 year of operation.

Concorde was developed in the 1960s by a French and UK consortium and entered into service in 1976. It flew at twice the speed of sound (Mach 2, ~2200 km/h), which made it possible to fly from Paris to New York in only 3h30 (compared to about 8h20 with current aircraft).

Concorde did not reach commercial success: due to large operating costs (escalated by the 1970s oil crisis), only 2 airlines (Air France and British Airways) operated a total of 14 aircraft, between 1976 and 2003, almost exclusively on 2 routes: London-New York and Paris-New York. Indeed, Concorde were not allowed to fly supersonic over land due to the noise caused by the sonic boom.

This loudness of the sonic boom was one of the main technological locks to Concorde success. Reducing that noise and allowing supersonic flight over land will significantly increase the number of supersonic routes and increase the market size substantially. It is in this direction that NASA is conducting the Low-Boom Flight Demonstration mission.

Within this context, several supersonic aircraft projects have been launched.
Several concrete supersonic aircraft projects have been launched over the past few years. Still, we are at the early stage of supersonic aviation revival

Young US companies are the most active in terms of supersonic aircraft development

3 segments of projects are currently under development:

1. **Business jets**: Aerion and Spike (both US-based) are targeting a launch in the 2020s.

2. **Commercial supersonic aircraft**: Boom (also US-based) is targeting a launch around 2025 and Exosonic is working on a project for the early 2030s. JAXA (Japan Aerospace Exploration Agency) is leading R&D for a commercial supersonic aircraft in the 2030s.

3. **Hypersonic aircraft**: current R&D is also addressing a longer-term generation of aircraft flying up to Mach 5, enabling intercontinental flights in 90 minutes. Airbus and Boeing have announced projects for the 2040s and 2050s. Very recently, Hermeus has started developing a hypersonic aircraft for the 2030s.

**Exhibit 2: Main supersonic aircraft projects under development**

Historical aircraft and equipment manufacturers are staying involved through industrial partnerships

Historical aircraft and equipment manufacturers (OAMs and OEMs) have announced much longer-term projects, but remain active on this R&D segment through industrial partnerships:

- **Airbus** initially partnered with Aerion from 2014 and 2017. Lockheed Martin joined the Aerion project in 2017 after Airbus exited. Finally, in February 2019, Boeing replaced Lockheed as a partner with Aerion on the AS2 development.

- Aerion is relying on GE for the engine design (GE Affinity) and announced end of December 2019 a partnership with Safran for the design of the complete AS2 braking and landing gear system, and the AS2 nacelles.

- Boom is also working with GE, for the propulsion of its XB-1 demonstrator and with other major US equipment manufacturers such Honeywell for the avionics.
Regarding NASA’s Low-Boom Flight Demonstration, Lockheed Martin has been selected as the primary subcontractor for the X-59 Quiet SuperSonic Technology aircraft.

Exhibit 3: Supersonic aircraft industrial partners

Supersonic aircraft projects are funded mainly by VC companies and are on their first financial rounds.

Boom raised between 2017 and 2018 a total of $140M from mainly US venture capital companies. Even more recently, Hermeus raised seed funding in May 2019 from a US venture capital company as well.

While funding is growing, we are still at the early stage of supersonic technology development. Current players are at the demonstration phase of their program, necessary to trigger the investments needed: Aerion AS2 future aircraft is assessed to cost ~$4B to develop and the start-up Exosonic presented a development plan which costs ~$6B.

Exhibit 4: Investors in supersonic aircraft projects
There are already a few early airline clients which placed orders or options for supersonic business jets and commercial aircraft.

On the commercial aircraft segment, 2 identified airlines (Japan Airlines and Virgin) have placed orders with Boom, which plans to start delivering the aircraft by mid-2020s.

On the business jets segment, Flexjet (a US business jet service provider) placed orders for 20 Aeron AS2, for which the delivery has been announced for 2025.

Thanks to this type of innovative exposure, these early clients should benefit from a large marketing effect. In addition, by cutting flight time in half commercial airliners can offer a new dimension to differentiate themselves from competitors: speed. Such a differentiation factor could have a huge impact in a market where there are limited differentiation means.

These pre-orders are a promising start, but it is small compared to the enthusiasm at the time of Concorde: 10 years before its entry in service, about 15 airlines had already placed orders or options (most of them were cancelled between 1972 and 1973 due to the oil crisis).

Exhibit 5: Supersonic aircraft known clients

<table>
<thead>
<tr>
<th>Known clients</th>
<th>Client profile</th>
<th>Pre-order date</th>
<th>Aircraft</th>
<th>Not exhaustive Scope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexjet</td>
<td>American provider of fractional ownership aircraft</td>
<td>2015</td>
<td>AERION (Aerion AS2)</td>
<td>Order for 20 aircraft</td>
</tr>
<tr>
<td>Virgin</td>
<td>Multinational conglomerate company which includes the airline Virgin Atlantic and the spaceflight company Virgin Galactic</td>
<td>2016</td>
<td>BOOM (OVERTURE)</td>
<td>Partnership + Options for 10 aircraft</td>
</tr>
<tr>
<td>JAL</td>
<td>International airline, Japanese flag carrier</td>
<td>2017</td>
<td></td>
<td>$10M investment and 20 aircraft pre-order</td>
</tr>
</tbody>
</table>

Factors which prevented Concorde from a commercial success are still present to date, but one of the major technological hurdles is about to be overcome.

Overview of main constraints to supersonic flights development

Supersonic aircraft has been a proven technology for several decades: for civilian applications, Concorde entered into service more than 40 years ago and since Concorde was retired supersonic aircraft are still used for military applications.

However, looking at the Concorde’s experience, any future supersonic aircraft project will face several important constraints, in order to reach commercial success. The main difficulties will be:

1. Supersonic route limitation due to the sonic boom
2. More operational costs mainly due to a higher fuel consumption
3. A limited range compared to current subsonic aircraft
4. Environmental concerns which are becoming stronger: NOx and CO2 emissions, and noise during take-off and landing
Exhibit 6: Supersonic aircraft main constraints for Concorde and future projects development

The sonic boom created by the aircraft when flying supersonic (> Mach 1) creates such noise on the ground that supersonic flights are currently not allowed over land.

When flying supersonic, an aircraft creates a sonic boom that can be very noisy on the ground, even if the aircraft is flying at high altitude.

It was one of the major reasons which prevent Concorde from reaching commercial success:

- It made the US ban Concorde landings in the US. Landings in New York would start only almost 2 years after Concorde entered into service.
- Concorde flights inside the US would have to remain subsonic. It was the case for the flights to Dallas: flights were subsonic between Dallas and Washington.
- Concorde flights to Singapore were also affected: Service stopped after a few years due to noise complaints from Malaysia and India.

Noise created during take-off and landing is also a challenge.

When Concorde flew, it caused large disturbances around airport during take-off and landing. Since Concorde, subsonic aircraft became lighter and noise regulation became tighter. There are on-going discussions with the FAA to adjust noise regulation for supersonic aircraft.
Environmental factors are becoming more important with the intent to limit NOx and CO2 emissions. Concorde generated 3 times more NOx and CO2 than today's subsonic aircrafts. It was not such an important concern at this time. Today, it is becoming a strong factor to be considered for any new supersonic project: innovation in supersonic flights will be required to address this issue.

In this frame, some countries are talking about special taxes on aircraft fuel. In addition, “Flight-shaming” is becoming more popular: this new trend aims at limiting companies’ use of air travel and reduce their carbon print, through the use of high-quality video conferencing systems for example.

Despite these concerns for emissions, air traffic is continuously growing including business travels, and it is expected to continue to grow substantially in the next 15 years.

In addition, current subsonic aircraft design is based on an architecture defined several decades ago when CO2 emissions was not as central as today. Now OEMs and OAMs are trying to optimize current design to reduce emissions. For supersonic aircraft we can expect to be in a more favorable situation, as this constraint is taken into account from the early stage of development. For instance:

- Aerion announced its goal to design an engine for 100% biofuel operations
- Boom plans to use carbon neutral fuel for its demonstrator aircraft XB-1

### A larger addressable market and short-term R&D could make supersonic aircraft projects successful likely starting by business jets

The demand for supersonic flights is likely to be much more important than for Concorde, given the increase in both air traffic and the number of high net worth individuals. As for Concorde, future supersonic aircraft will have larger operational costs than subsonic aircraft. However current market environment is much more favourable to reach a commercial success. Since Concorde was retired in 2003:

- **Air traffic has more than doubled** (in passenger-kilometers) and it is expected to continue to grow at fast rate. For instance, the number of passengers who flew between Paris and New York almost doubled since 2003.
- **Business air travel** has also significantly increased since 2003.
- The number of **high net worth individuals** has more than doubled since 2003.

From a technological and market perspective, the business jet segment is more likely to grow first. Supersonic aircraft will probably first grow with supersonic business jets, with an “intermediate” speed increase (Mach 1.4 or 1.6). Such a speed combined with the limited size of business jets (compared to commercial aircraft) make a more reasonable technical challenge for the first step of supersonic aircraft development.
Afterwards, commercial supersonic flight is likely to become a strong segment within the business class market.

The manufacturers strategy is to design a supersonic aircraft which gives airlines the option to charge the same fare as business class. If they manage to do so, supersonic flight is likely to become an important segment within business class market. Market research shows that corporate travellers value speed over in-flight service (e.g. comfort, connectivity, …), as opposed to leisure travellers. Depending on how the demand evolves, airlines could later be able to charge a premium for supersonic flights.

Since Concorde, the diversity of the major routes is more favourable to the development of supersonic flights across oceans: flights between Asia and U.S., or flights through Middle East hubs were less developed when Concorde flew. Now, some countries have a strategic geographical position to offer supersonic flights across oceans. Thus, they have the opportunity to develop this market, without waiting for further R&D. As an example, Japan Airlines placed 20 pre-orders with Boom.

With prohibitions on supersonic flights over land, players estimate that supersonic airplanes could address up to 500 routes, which corresponds to a market for 1 000 to 2 000 aircraft according to Boom.

NASA is leading a government-industry team that could make supersonic flight over land possible and lead to a new era for civilian supersonic aviation.

The Low-Boom Flight Demonstration led by NASA is probably the most important development for commercial supersonic flights. This mission aims at flying a Low Boom Flight Demonstrator (the X-59 Quiet SuperSonic Technology aircraft) with 2 objectives:

1. Validate the design process used to define the aircraft shape to reduce the loudness of the sonic boom
2. Provide ICAO (International Civil Aviation Organization) all the data needed regarding community responses to quiet supersonic flights, in order to set the noise regulation for supersonic aircraft

The X-59 is a large-scale supersonic experimental aircraft with technology that reduces the loudness of a sonic boom. Flight tests are planned to begin in April 2021. Flight tests above US cities are planned between 2023 and 2026, in order to assess community responses to supersonic travel. Based on these flight test campaign results, the target is that ICAO defines the noise regulation for supersonic aircraft in 2028.

Depending on the manufacturers’ design timelines, the first aircraft allowed to fly supersonic over land with a design based on NASA’s results could enter into service in the early 2030s.

- Boom is targeting an entry into service around 2025. Thus, their first aircraft design will focus on routes across oceans.
- Aerion is following another design approach, which avoid the sonic boom to reach the ground up to Mach 1.2 (Aerion Boomless Cruise technology). Thus, they will manage to fly supersonic over land, but they will have to reduce speed, compared to the aircraft typical cruise speed (Mach 1.4).
- Spike and Exosonic are targeting a design based on NASA’s on-going research to allow their aircraft to fly supersonic over land.

The number of viable routes and aircraft could be significantly increased if NASA’s on-going mission is successful. Supersonic flights would no longer be limited to routes across oceans. Thus, supersonic commercial aircraft and business jets could address:

- long domestic flights, such San Francisco-New York, which would become a day trip
- transcontinental flights with an important part of the flight above land, such Chicago-London, San Francisco-London or Paris-Hong Kong
- intra-Asian flights which have been significantly developed since Concorde

Enabling supersonic flights over land could add several hundreds of potential routes (1300 additional potential routes according to Exosonic). Many of them would not be economically
viable, but it brings a potential for a much larger number of commercial supersonic aircraft on the market.

**Exhibit 7: Strategies regarding sonic boom**

<table>
<thead>
<tr>
<th>Supersonic aircraft project</th>
<th>Strategy regarding sonic boom</th>
</tr>
</thead>
<tbody>
<tr>
<td>AERION (Aerion AS2)</td>
<td>Boomless Cruise technology (different than NASA the Quiet Supersonic Technology project): reduced sonic boom up to Mach 1.2:</td>
</tr>
<tr>
<td>SPIKE (S-512)</td>
<td>Quiet Supersonic Technology (NASA): design progress will be based on NASA’s research to allow supersonic flights over land</td>
</tr>
<tr>
<td>Boom (Overture)</td>
<td>Focus on routes across oceans</td>
</tr>
<tr>
<td>SABRE (JAXA)</td>
<td>Quiet Supersonic Technology (NASA): design progress will be based on NASA’s research to allow supersonic flights over land</td>
</tr>
</tbody>
</table>

The market size should continue to increase thanks to technological improvements and the continued growth in air traffic.

**Air traffic will continue to grow at a fast rate.** In passenger-kilometers, it is already more than twice the traffic in 2003 and it is expected to double in the next 15 years.

Supersonic aircraft under development should be much less fuel consuming than Concorde but should remain more expensive to operate than current aircraft.

In the future, continued investments to keep on reducing operating costs and continued air traffic growth should contribute to develop the supersonic segment further.
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