Making the Small Supersonic Airliner a Reality: Obstacles and Solutions

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NASA Fundamental Aeronautics Student Competition
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Abstract

Making the Small Supersonic Airliner a Reality: Obstacles and Solutions

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Bringing supersonic travel to commercial aviation has been a goal for many years. A review of the pros and cons of supersonic travel is presented. The current target is to have the Small Supersonic Airliner in the air by 2020, with cruise speed of Mach 1.6-1.8, range of 4000 n.mi., payload of 35-70 passengers, sonic boom no higher than 65-70 PLdB, reduced airport noise, and improved fuel efficiency. Accomplishing this goal involves solving a number of technological and regulatory challenges. Key challenges are identified and described, and specific solutions are proposed for each based on the body of existing research.

A vision of the Small Supersonic Aircraft is presented, with particular attention paid to the critical issues of improving supersonic cruise efficiency, reducing sonic boom and airport noise, integrating the systems, minimizing high altitude emissions, assimilating into the air transportation system of the future, and implementing a new regulatory framework to permit overland supersonic passenger flight. The need to treat the challenges in an integrated manner is demonstrated. The conclusion is reached that based on the proposed solutions, the development of the Small Supersonic Airliner by 2020 is practical and realistic.

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1. Current State of Supersonic Passenger Flight

Sixty years have passed since the United States Air Force Captain Chuck Yeager broke the sound barrier flying his Bell X-1 aircraft in a program run by NACA, the predecessor of NASA. That was the beginning of the supersonic flight era. Since then, numerous advances have been made, from the introduction and design improvements of military supersonic jets to the innovation aimed at passenger supersonic flight. Even though development in the military has steadily continued, the use of supersonic jets for passenger travel has largely been a disappointment.

Bell X-1 First Generation Aircraft
(Image in the public domain, source NASA via Bell Aircraft)

The Concorde Jet
(Image in the public domain, photo taken by A. Pingstone)

Decades ago, there were several programs aimed at developing a supersonic passenger jet. Only one of them led to the introduction of a plane that became a commercial aircraft. The Concorde, the only supersonic passenger airliner ever in actual practical use, made its final flight in 2003 never to return to the skies. Even though it was a remarkable technological achievement, from the economic point of view the Concorde was an utter failure. This experience turned aircraft manufacturers toward simpler subsonic jets and away from the more challenging supersonic projects.

The supersonic passenger jet appears to be one of the very few areas of technology where we have taken a step backward. Inevitably, questions arise concerning the need for and feasibility of passenger travel faster than the speed of sound. Many efforts have been made, and continue to be made, to bring supersonic flight technology to general and commercial aviation. They have not succeeded. Numerous challenges have still to be addressed, and the bar is set very high. Even of the most committed professionals and enthusiasts, few expect to see passenger supersonic travel in the next two decades. General Yeager himself does not believe in the future of supersonic passenger travel unless major technological advances are made.[*] The challenges involved are truly formidable.

[*] Personal e-mail correspondence with Brigadier General Charles "Chuck" Yeager (February 9-16, 2009) in which he pointed out the prohibitive cost of fuel consumption as a critical barrier to passenger supersonic flight. Help of the General Chuck Yeager Foundation in facilitating the communication is gratefully acknowledged.

2. Need for Supersonic Passenger Travel

Before concentrating on technical challenges and ways to overcome them, it is important to consider whether there is a real need for such faster than sound modes of transportation as supersonic business jet aircraft, the Small Supersonic Airliner, and the most ambitious of all proposals, an efficient multi-mach aircraft. The answer to this question is unequivocally positive.

2.1. General Benefits

The introduction of supersonic commercial aircraft has the potential to bring revolutionary changes to U.S. competitiveness as well as provide broad economic benefits to the global economy.[1,2] As the world is becoming "flatter" and air travel more and more common, the availability of faster means of transportation could become a catalyst of growth. The benefits of supersonic passenger travel include reduced travel time for business leading to increased productivity, shortened travel time for leisure, the ability to provide rapid response in disaster situations, and faster delivery of time-critical goods.

The value of time has been growing, resulting in a premium being placed on the ability to get to the destination faster. Quicker delivery of time-critical cargo could save lives, as in the case of organ transplants. Cutting the time of travel in half could expedite diplomatic negotiations, which also saves lives. The benefits are numerous.

If supersonic travel becomes available at a reasonable cost, the effect could be as great as that experienced by society when subsonic passenger jets were first introduced. The United States has the chance to boost its technological leadership and in the process provide enormous economic benefits both domestically and globally. Economic benefits to the country and companies "first to market" with supersonic passenger jets fully justify the development cost.[3,4]

2.2. Existence of Demand

While the current difficult economic conditions have somewhat dampened the demand for air travel in general, this decrease in demand has been largely offset by the lower cost of fuel leading to reduced airfares. More importantly, the current recession, no matter how severe, does not change the long-term projections of growing demand for air transportation and the general worldwide trend for increased need to transport passengers and cargo faster.

With any technology, the first products are relatively expensive and target an upper tier of the market. Supersonic travel is no exception; the logical first customers are business people who would require supersonic business jets. As with other technologies, the next stages of development would target a broader universe of consumers. In case of supersonic air travel, this would mean the Small Supersonic Airliners and, at some point in the future, "jumbo" supersonic jets for mass travel. Initially, however, it is important to ascertain demand for the first product, the supersonic business jet. Several studies have been performed to determine the level of demand for supersonic planes, with the focus on supersonic business jets. These studies provide a reference point for the demand for the Small Supersonic Airliner that will follow.

Market Study	Demand for Supersonic Business Jets (Number of Jets)
Gulfstream Aerospace – Study 1[2]	180 over 10 years (not including "fractional ownership")
Gulfstream Aerospace – Study 2[2]	350 over 10 years
Meridian / Teal[5]	250-450 over 10 years
Teal Group 2007 Study[6]	400 over 20 years
StrategyOne Consulting / Aerion[7]	220-260 over 10 years
Supersonic Aerospace International (SAI)[8]	300+

Table 1: Projected Demand for Supersonic Business Aircraft

While there have not been detailed studies of demand for the Small Supersonic Airliner, it is logical to assume much higher demand than for the business jet, and that if the price differential is relatively small, many if not most would prefer supersonic to the traditional subsonic travel. At 20% difference in airfare, the estimate of 200 planes a year appears to be very conservative. The demand clearly exists, but the aircraft to meet the demand remain to be developed. We can safely assume that the demand for the Small Supersonic Airliner is a significant multiple of that for small business jets. This demand provides financial justification for aircraft manufacturers; general benefits to the economy are an excellent reason for the government to allocate appropriate resources and assume a leadership role in the development.

2.3 The Vision for 2020: Summary of Specific Requirements for Supersonic Jets

Both the input from industry and the goals established by NASA suggest that a supersonic airliner in commercial use could be a reality by 2020. Significant research by the industry leaders has most recently been focused on the development of a small supersonic civil craft. While there is no clear consensus on the exact system metrics for such jets – such metrics being impossible to formulate precisely until specific advances have been made – the NASA supersonic-system-level metrics present a well thought-out target and include even progression beyond the Small Supersonic Airliner, the focus of this analysis, to a larger and faster supersonic aircraft.

	2015 (N+1)	2020 (N+2)	2030-2035 (N+3)
	Supersonic Business Class Aircraft	Small Supersonic Airliner	Efficient Multi-Mach Aircraft
Cruise speed	Mach 1.6-1.8	Mach 1.6-1.8	Up to Mach 2
Range (n.mi.)	4000	4000	4000-5500 (up to 6000)
Payload (passengers)	6-20	35-70	100-200+

Table 2: **NASA's Initial Targets and Performance Goals for Future Supersonic Civil Aircraft**[9,10]

NASA, based on internal research and feedback from the industry, has also identified specific environmental and technological performance objectives that have to be met in order to achieve these goals. These objectives are just as important as the parameters contained in Table 2.

Some in the industry espouse a more optimistic view that the technology needed to achieve this vision – at least the first step, the supersonic business jet – has already been largely developed, and believe that their development efforts are almost at the point where supersonic flight can be moved into commercial use. Aerion and SAI* seem to hold this view. Their technological achievements are noteworthy; however, it is clear that there remain numerous obstacles to overcome to make supersonic business travel a reality. The barrier for the Small Supersonic Airliner is set even higher.

Aerion Supersonic Business Jet Design
(Image from Aerion Corporation's press kit photos)

Quiet Supersonic Transport (QSST) Designed by Lockheed Martin's Skunk Works® for SAI
(Image from the Supersonic Aerospace International LLC press kit)

* Technically, the jets proposed by Aerion and SAI do not fully meet the requirements for the small business class aircraft and certainly not for Small Supersonic Airliner. However, they do represent a significant step forward in the supersonic flight development.

3. Challenges and Solutions

3.1 Key Challenges

The key challenges to overcome in order to make the Small Supersonic Airliner a reality span a range of issues[11,1,2]:

- Efficiency challenges
  - Supersonic cruise efficiency
  - Light weight and durability at high temperature
- Environmental challenges
  - Airport noise reduction
  - Sonic boom suppression
  - Reduction of high altitude emissions
- General performance challenges
  - Aero-propulso-servo-elastic (APSE) challenges
  - System integration and optimization
- Integration of supersonic aircraft into commercial air traffic and the next generation air transportation system (NextGen)
- Accomplishing all of the above in a way that makes the cost of supersonic travel comparable to that of traditional subsonic air travel
- Building new regulatory framework for overland supersonic flight
  - Overcoming public opposition
  - Developing appropriate environmental standards
  - Formulating and adopting new regulations

It has been widely recognized that the technological challenges are formidable. However, the challenges that have to do with policy issues and public opinion are not to be underestimated. Exclusive focus on technology is not going to realize the dream of seeing non-military supersonic jets in the air.

The vision of the Small Supersonic Airliner in 2020 and the specific solutions to existing challenges are summarized below. However, some of the more important topics – either because they involve the most difficult challenges or because they have not received sufficient attention – are intentionally described in greater detail than others.

3.2 Need to Develop New Regulatory Framework for Supersonic Flight

Before any discussion of the technology enabling the future Small Supersonic Airliner, it is important to focus on the legal framework that would allow supersonic travel. The vision is to have an affordable supersonic alternative to modern air travel. This means that the airliners have to comply with noise and other restrictions both at the airport level and during supersonic cruise overland. Overland flight is critical to the vision; all demand projections assume the ability to fly over land. Currently, this would be a direct violation of U.S. laws.

3.2.1 Current Regulatory Framework

The current regulations in the US effectively prohibit supersonic overland flight except for military aircraft in designated corridors. It is a blank prohibition; there are no standards that supersonic aircraft could satisfy in order for the FAA to allow supersonic flight. The only passenger supersonic technology was the Concorde, for which certain exemptions were made. Currently, the prohibition on supersonic flight stands both in the U.S. and in numerous other countries, even though there do exist overland corridors such as the ones in Siberia and Australia where supersonic flight is allowed.

3.2.1 Required Regulatory Changes

In order to enable supersonic passenger flight, the FAA and its sister organizations in other countries have to establish clear standards to be met by supersonic planes to be allowed to fly overland. Without such standards, supersonic flight will remain a dream regardless of the technology development.

Specific standards that it is reasonable to establish are similar to those for the traditional subsonic aircraft and should include the following:

- Noise level at takeoff/landing (airport)
- Noise level at transonic speeds
- Noise level at supersonic cruise (sonic boom)
- Pollution at takeoff/landing and low altitude
- Pollution at high altitude

3.2.1 Ways to Bring about the Required Regulatory Change

The FAA has done some work toward introducing regulations for supersonic passenger flight. A recent policy update on the noise limits for future civil supersonic aircraft is part of this work.[12]

Changing any regulation is a challenge involving not only convincing the policymakers but also getting public support for the changes. The way to bring about the required regulatory changes is to clearly demonstrate the new technology will not have the negatives of the loud sonic boom or significant NO_x pollution at high altitude. Convincing the public is probably the hardest part of this challenge, and it is important to use new means – innovative and creative – to gather public support. These ways could include working together with leading environmental organizations; positioning supersonic flight as a solution to a number of societal problems as opposed to a source of environmental and other problems; educating the public about supersonic flight and technology; working on preventing supersonic flight from being seen as one of the excesses of the corporate culture; working with regulatory organizations at the international level as opposed to having a strictly US focus.

3.3 Sonic Boom

The problem of overcoming "noise pollution" created by the sonic boom is arguably the most challenging in creating the Small Supersonic Airliner.[2] At supersonic speeds, pressure waves from the nose and the tail of the aircraft coalesce into two shock waves that propagate in a cone behind the aircraft, and at the ground level are perceived as a loud sound (or two loud sounds heard in rapid succession) usually called sonic boom. At long distances from the aircraft (far field) such as at the ground level, the pressure waves are more pronounces as two shocks from the nose and the tail of the aircraft because all the other pressure waves end up being combined into them. The resulting acoustic disturbance is an environmental concern and a violation of FAA regulations.

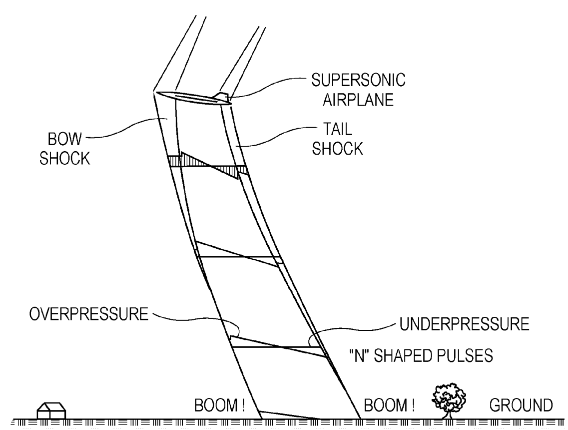


Figure 1: Sonic boom created by a conventional supersonic aircraft (per Henne[15])

3.3.1 Current State of the Art

Significant research efforts have gone into reducing or eliminating the sonic boom, some originated by the government (NASA, DARPA, AFRL), some by the industry (from Lockheed Martin to Gulfstream to Dassault), and some by academia. A number of approaches have been proposed to reduce the sonic boom to acceptable noise levels. It is worth noting that there is no consensus on what constitutes acceptable noise level. Even the currently used PLdB and EPNdB units of measurement are not universally accepted by regulators, and PLdB measurements are generally not part of the FAA noise regulations. The current noise pollution goals for Small Supersonic Airliner (N+2), as well as the N+1 and N+3 generations of supersonic aircraft, are shown in Table 3.

	2015 (N+1)	2020 (N+2)	2030-2035 (N+3)
	Supersonic Business Class Aircraft	Small Supersonic Airliner	Efficient Multi-Mach Aircraft
Sonic Boom (PLdB)	65-70	65-70	65-70 low boom flight 75-80 unrestricted flight
Airport Noise - cum below Stage 3 (EPNdB)	10	10-20	20-30

Table 3: **Noise Targets for Future Supersonic Civil Aircraft**[9,10]

The approaches that have been proposed to reduce or eliminate the sonic boom generally involve one or a combination of the following[13,14,15,16,17,18]:

- Introduction of passageways through the aircraft
- The use of components that modify, deflect, or cancel shocks
- The use of active systems to modify, deflect, or cancel shocks

All three, either separately or in combination, typically increase either the weight of the aircraft or the drag, or lead to the deterioration of some other parameter affecting overall performance and efficiency. We include the shaped sonic boom approach here as well, even though it is sometimes differentiated from these "standard" design methodologies.[13]

3.3.2 Solutions to the Sonic Boom Problem

The vision for the Small Supersonic Aircraft includes significant reduction in the sonic boom achieved through the sonic boom shaping approach.

Sonic boom is characterized by the N-wave acoustic signature created when air pressure rises sharply because of the shock wave coming from the aircraft nose, followed by a gradual decrease in pressure below the ambient level, and then a rapid increase in pressure back to the ambient level. While the amplitude of the "N" is relatively high, the abruptness of the pressure changes is an even greater contributor to the loud boom effect audible on the ground. The approaches to decreasing sonic boom listed above focus on both the amplitude of the N-wave signature of the boom (ΔP) and the speed of change in the pressure ($\Delta P/\Delta t$) at ground level. The goal is to "shape" the sonic boom in such a way that both the pressure differential and the rate of its change are reduced, making the "N" look more like as sideways "S."

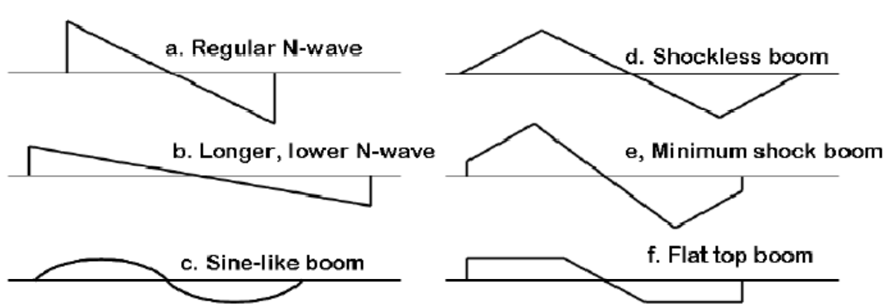


Figure 2: N-wave boom and potential shaped booms (per Plotkin[19])

The shaping of the sonic boom involves constructing the frame of the aircraft to create shock and expansion zones in such a way that they partly cancel each other. For example, the fuselage could be intentionally shaped to create shock and expansion zones that will compensate for the shock and expansion zones produced by the wings of the aircraft and its engine nacelles.[13,15] A number of other approaches have also been proposed and could be utilized for shaping the sonic boom. A blunt-nosed spike extended from the front of the aircraft, or extendable on a boom, could deflect air pressure and to some degree disrupt the air flow patterns that contribute to the sonic boom.

Another approach to sonic boom shaping is constructing the frame in such a way that during supersonic flight, when the landing gear is retracted, the low profile of the aircraft is substantially linear or slightly concave downward.[15] In both cases the nose of the aircraft coincides with the bottom of the fuselage. When such an aircraft flies at supersonic speeds, the pressure distribution is asymmetric and the shock waves propagate toward the ground with lesser intensity than in other directions. Based on detailed computational fluid dynamics (CFD) and propagation analysis, it has been shown that such a design results in a demonstrably weaker sonic boom at ground level. Experiments have also demonstrated that low boom shaping technologies do result in a change in the acoustic signature and reduction of the sonic boom.[19] DARPA QSP / NASA SSBD provided experimental support for the theoretical results, even though they included testing only of some limited elements of sonic boom shaping.

Figure 3: An example of structural configuration of an aircraft that incorporates design elements to shape the sonic boom (based on an illustration in Henne's patent[15])

The main approach to implementing the vision of the Small Supersonic Aircraft is to expand on the research that has already been performed on shaping the sonic boom. Further research is necessary because the most advanced approaches developed to date probably do not yet provide sufficient reduction of the sonic boom, and also because the current research is focused primarily on small business jets. Since the Small Supersonic Airliner is larger in size and weight, its sonic boom level is also higher. This creates a greater challenge and the need for further developments of the sonic boom shaping techniques for the Small Supersonic Airliner. The use of new materials enabling morphing geometry appears to be very promising. In addition, most of the research has been focused on the nose portion of the sonic boom signature, and it is likely that additional progress could be made in shaping the aft portion of the sonic boom.

3.4 Propulsion Systems, Efficiency, and Related Environmental Issues

Improved propulsion efficiency is critical to the vision of the Small Supersonic Airliner primarily because otherwise supersonic travel will be prohibitively expensive. Efficiency goals need to be addressed in conjunction with the environmental issues. Two of the environmental issues, airport noise and the sonic boom, have already been discussed. It is also important to ensure that pollution, primarily at high altitude, is minimized. This includes NO_x, H_2O, and CO_2 emissions.[2] In particular, emissions of nitrogen oxides have to be reduced to limit their impact on the ozone layer.

It is undeniable that there remain significant challenges in improving propulsion system efficiency. The lift/drag ratio of a supersonic jet is much lower than that of a subsonic aircraft. Reducing the drag could in part be accomplished by reducing the weight of the aircraft. The use of new light weight materials could be part of the solutions. Therefore, the vision of the Small Supersonic Aircraft incorporates the use of innovative composite materials, in particular those that can withstand high temperatures. It is one of the ways to reduce fuel needed per passenger-mile.

Supersonic cruise efficiency needs to be combined with efficient performance in the transonic and takeoff/landing regimes.[20,2] The optimization problem of improving propulsion efficiency includes design and optimization of the inlet, fan, core engine, bypass duct, nozzle, and other system elements as well as improving airframe aerodynamic efficiency. It is envisioned that a variable cycle engine (VCE) system will be utilized, which will change the bypass ratio[21] (fan airflow to core airflow) from the higher levels during takeoff/landing to the lower levels best suited for supersonic cruise conditions.[22]

Although not a necessary condition, the general goal is also to reduce dependency on traditional carbon-based fuels. Initial experiments in using alternative fuels have already been conducted, with synthetic fuels successfully used to power supersonic jets.[23,24] Hydrogen fuels appear to present problems both with the weight and with the ability to fit into the wings sufficient fuel volume for long-range flight (up to 4,000 n.mi.). However, if more efficient propulsion systems are created, smaller amounts of hydrogen fuel could be used for the same flight distance. While hydrogen fuels do not eliminate pollution, their use significantly reduces its level.[25] Development of new synthetic fuels that are highly efficient, produce less pollutants, and are inexpensive appears to be very promising.[26] These fuels are part of the overall vision of the Small Supersonic Airliner, but they are not absolutely necessary for its development.

3.5 Integration into the Overall Air Traffic Flow in 2020

The airspace system in 2020 will bear little resemblance to that of today. The changes will be qualitative in addition to a simple growth in size and complexity, and the vision of the Small Supersonic Aircraft includes its functioning within the next generation of the air transportation system.

The Small Supersonic Airliner will need to be fully integrated into the Next Generation Air Transportation System (NextGen). NextGen will have a number of characteristics and capabilities relevant to all air transportation and to supersonic transportation in particular.[1] These include network-enabled information access; position, navigation and timing services; aircraft trajectory based operations; super density arrival/departure operations; equivalent visual operations; weather assimilated into decision-making; and layered, adaptive security. Predictive modeling technologies for air traffic control systems will play a critical role given greater air traffic density as well as the greater speed of supersonic aircraft.

Given the increase in air traffic volume, density, and speed, it is envisioned that the Small Supersonic Airliner will have computer systems directly integrated with those of NextGen, leading to the reduced chance of human error. A significant level of system redundancy will be implemented both onboard the Small Supersonic Airliner and within NextGen, with a focus on effective communication between the two. Intelligent adaptive systems will be used to accomplish these goals. Advanced systems onboard and on the ground will integrate information from multitudes of sensors on the aircraft, on the ground, and on other aircraft, in part utilizing the research being done by the Department of Defense and other government agencies.[27]

3.6 Need to Consider the Development as Integrated Challenge

The numerous technological challenges described in Section 3.1 can only be solved in combination and have to be treated as an integrated challenge. In the context of achieving performance, noise, and emission goals, propulsion systems, airframe shape, overall vehicle design and other aspects of Small Supersonic Airliner development should be treated as an integrated challenge due to their high level of interdependency.

The "blind cockpit," likely part of the vision of the Small Supersonic Airliner, is a simple example of the interdependency of the numerous issues involved in making this vision a reality. As well as being a challenge in and of itself, it will create significant challenges for aircraft system integration and additional automation for efficient linking with the NextGen systems of traffic control and airport operations. It will also require new regulations by the FAA and similar agencies in other countries.

Not only are the efficiency and environmental challenges difficult to overcome, but for most of the proposed or contemplated designs there is also a certain tradeoff between the two, with improvements in environmental impact such as noise and emissions leading to a deterioration in efficiency, and vice versa. This once more underscores the need to treat the creation of the Small Supersonic Airliner as a truly integrated challenge. Simultaneous optimization of several parameters is the only appropriate approach. Currently, computer models and other research do not fully utilize this approach due to its inherent complexity. However, such integrative models are needed, in addition to and not as a substitute for the specialized models that are currently utilized in each of the individual areas of aircraft design, and that are now integrated primarily on a conceptual level rather than on a detailed modeling level. The addition of the enhanced modeling component to the process could only be beneficial.

The combined task of improving efficiency, reducing the sonic boom, and minimizing high altitude emissions is by definition an integrated challenge and could only be solved as such. Changes in propulsion systems and airframe reinforce the need to search for strong materials that are able to withstand high temperatures. The need to reduce the aircraft weight, which is even greater for the Small Supersonic Airliner than for the supersonic business jet, also necessitates the search for light composite materials that would also be able to withstand the operating conditions. The need for efficient fuels is tied to the need to reduce the fuel contribution to the weight of the aircraft, both in terms of fuel weight and the weight of the rest of the aircraft using this fuel for propulsion, because the weight is a major contributor to the sonic boom and the drag. The fuel and propulsion system also affects the emission levels of NO_x at high altitudes as well as the cruise efficiency, leading to changes in aircraft configuration. Considered in the aero-propulso-servo-elastic (APSE) framework, all of the above clearly demonstrate the need to consider the development of the Small Supersonic Airliner as an integrated challenge. This, in turn, implies multi-disciplinary teams working in close collaboration.

4. Toward Small Supersonic Airliner: Paths Not Anticipated

Technology often develops in unpredictable ways. While it is important to have a roadmap to the Small Supersonic Airliner development, introduction and adoption, it is also important to recognize that long-term plans always have to be adjusted to incorporate advances in science and technology.

4.1 Advances in Basic Sciences

Advances in basic sciences are the most unpredictable in the way they affect technology development. While it is tempting to speculate about the possible directions of such advances, this kind of speculation is almost always perceived as science fiction bubble and a sign of ignorance of the existing research. Often, such opinion is justified.

The "Beam me up, Scotty" type of technology might, in fact, become the preferred mode of transportation in the future. Quantum "teleportation" of photons has been accomplished,[28,29] but the teleportation of anything else contradicts modern science. Could it be completely ruled out? No, it cannot.

More realistic are the advances in basic sciences that will enable wide-spread supersonic travel by easily addressing one of the already identified challenges. While any speculation in this area is dangerous, here are three examples of the areas of potential breakthroughs:

- Revolutionary advances in the development of new fuels that could dramatically improve the efficiency of supersonic flight and reduce pollution
- Advances in basic sciences that would lead to easy ways to suppress sound propagation by use of techniques not yet proposed or developed, such as the creation of a "field" around the aircraft that would dampen any sound propagation
- Scientific advances that would enable the development of qualitatively new propulsion mechanisms applicable to supersonic flight

The list could continue, but its usefulness is diminished by the very unpredictability of revolutionary advances in basic sciences. It is important, however, to encourage basic research and to closely monitor scientific developments to see if any of them could be applied to supersonic flight.

4.2 Other Types of Breakthroughs

Breakthroughs could also come from "normal" technological development, as opposed to being based on Nobel Prize-level scientific research directly affecting aeronautics.

One such type of breakthroughs is the steady progression in research and development affecting every aspect of the technology. In the case of the Small Supersonic Airliner, this would involve successful implementation of every step of the current NASA plan to develop a supersonic jet by overcoming the obstacles already identified. Advances along this path, some of them quite unpredictable, could in combination lead to a result that could be considered a true breakthrough and lead to the successful development of supersonic passenger flight. The areas where such unpredictability is the greatest are probably improving efficiency of supersonic flight and dramatic reduction of the sonic boom and general noise of the aircraft. Breakthroughs in other areas, on the surface having little to do with supersonic flight, could also lead to such advancements. For example, realizing the improbable but nonetheless possible idea of developing a quantum computer[30,31] would permit comprehensive computational fluid dynamics (CFD) analysis at a totally new level, which could bring unexpected solutions to the current challenges facing the development of the Small Supersonic Airliner. Such advances in computing technology would permit the creation of a true "simulated" wind tunnel and the ability to test millions of possible configurations without the need to sacrifice precision and taking into account every important variable, which would literally be a quantum leap from the current state of the art.

Another type of breakthroughs would involve the application of an existing technology or already known scientific research to the supersonic flight challenges in a way that has not previously been considered. A famous example from a different area is the invention of the Internet as a way to share information. The technology had existed for some time before the Internet in its current form appeared and became what is arguably the main means of information sharing. It is possible that there is already a technology or scientific foundation for a technology that could be used to solve some of the challenges of supersonic flight but has not been considered for this application. Speculation about any specific technology is almost sure to be wrong. Still, the area of high frequency laser research might hold potential to affect the propagation of shock waves and disrupt the sonic boom. It is also possible that high frequency sound emitters could have such an effect. Having a source of safe ionizing radiation on board and pointing toward the ground might change pressure patterns and disrupt or smooth out the N-signature of the sonic boom. Another potential area of research is in finding a way to move most of the sonic boom to the frequency levels inaudible to the human ear.[*] Most or part of the sonic boom would then be at the ultrasound or infrasound levels. While some of the sound shaping techniques effectively do reduce the frequency to less audible levels, the idea of moving it to the ultrasound territory has not been explored.

We do not know where the main advances will come from. While the emphasis should be on research and development along the established path that has been to a significant degree outlined, it is important to closely monitor advances in other areas of science and technology to see if they could be applicable in aeronautics in general and the development of the Small Supersonic Airliner in particular.

[*] In all likelihood, the ideas that the author believes to be "original" and "creative" and that are presented in this and other sections of the paper would prove implausible upon examination by experts. However, if some of these ideas actually are plausible and have in fact already been proposed in the past by others, the author's failure to reference this prior work is the result of lack of knowledge of its existence.

5. Conclusion

The real barrier wasn't in the sky but in our knowledge and experience.
Chuck Yeager

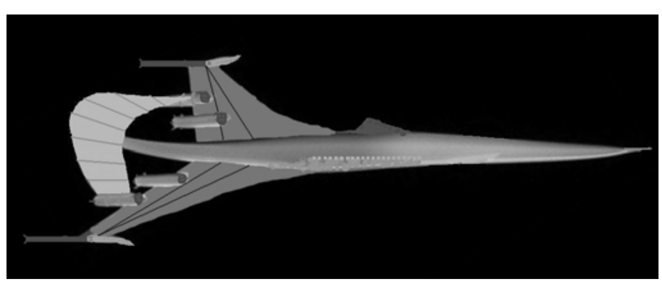
There are numerous barriers to making the Small Supersonic Airliner a reality. The plan to build the Small Supersonic Airliner has significant implementation challenges, both at the technology and policy levels. However, the feasibility of the plan has been established. While the overall path to making this vision a reality cannot be predicted with absolute certainty, its key elements have been clearly defined. Both specific challenges and a number of possible ways to solve them have been identified. There is every reason to believe that the vision of the Small Supersonic Airliner will become a reality.

The following are the main conclusions of the analysis:

- The program aimed at having the Small Supersonic Airliner in the air by 2020 is realistic and its main goals are achievable
- There remain significant challenges to overcome in order to see this goal realized
    - The efficiency challenges have to be resolved in conjunction with satisfying environmental constraints
    - The regulatory and policy challenges must also be resolved as they present a barrier to supersonic passenger flight
- Specific paths of technological progress and public policy solutions have been identified and promise to make the Small Supersonic Airliner a reality

Certain financial and policy measures could facilitate the development. Some such specific measures include:

- Increased funding for NASA to enable the agency's being the coordinator and focal point of the development
- Building effective government-industry partnership to overcome the technological challenges, in particular those related to cruise efficiency, sonic boom suppression, and the reduction of high altitude emissions
- Additional funding and support of basic research related to aeronautics
- Close coordination with other government agencies and intergovernmental organizations
- Building up public and political support for the required policy and regulatory changes



Sketch by the author with fundamentals based on the designs already proposed (primarily Lockheed Martin and Gulfstream Aerospace, with modifications)

The main technological paths are clearly established,[32] and there is every reason to believe that by 2020 the Small Supersonic Airliner will be in the air, with its use growing exponentially after this point and allowing for the development of the next stage of supersonic travel. The key to accomplishing this exciting goal is the concentrated effort and cooperation of scientists and engineers, government agencies and private corporations, to bring this vision to fruition with benefits for both technology and the economy. It will happen!

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Making the Small Supersonic Airliner a Reality: Obstacles and Solutions

Gail M. Krutov

Statement from Supervising Adult

I confirm that the student's work is original.

Alex Krutov