Exploring the Potential and Challenges of Supersonic Technology for Commercial and Educational Use: Revolutionizing Air Travel and Scientific Research

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction:

Imagine soaring through the skies faster than the speed of thunder, breaking barriers and pushing the limits of what we thought was possible. Supersonics, with their ability to travel at incredible speeds, have captured the imagination of scientists, engineers, and aviation enthusiasts for decades. But beyond the thrill of speed, supersonics have a rich history of past uses that have contributed to fields ranging from military to commercial aviation. The military has been creating supersonic flight vehicles since the 1940's (Williams, 1992). To begin, a supersonic vehicle is classified as any vehicle that travels faster than the speed of sound and the first human-made plane to obtain this speed was the Bell X-1 Glamorous Glennis. This plane was piloted by the Air Force's "most experienced test pilot" Captain Charles Yeager to gather data for a "new generation of high-performance combat aircraft" (Linden, 2022). Since then, the military has continued to pursue supersonics by creating new designs and doing tests over cities to see if they affect everyday life.

On the other hand, as supersonics grew in popularity militaristically, a second wing of interest was created. This wing was created to mitigate domestic and international travel times. This led to supersonics reaching the public and private sectors of air travel. In 1976, the Concorde, the first and only supersonic commercial aircraft, was constructed. The Concorde was a joint effort between the French and British aeronautical industries. However, due to the Concorde's cost, it touched down for the last time in 2003: "The Concorde was so expensive that private jets were actually deemed a much more affordable and practical option for anyone who needed a quick, direct, and private mode of travel" (Papadopoulos, 2022). Additionally, as of 2022, the Concorde is the only successful supersonic commercial aircraft. Currently, Aerion's AS2, JAXA's S4, and Russia's Tu-444 (just to name a few) have been trying to curb the thought that supersonic vehicles only have militaristic uses. There are many problems with supersonics that constrain their uses and development. These include their noise pollution, their emissions, their cost, and their other environmental impacts.

The transition of supersonic technology from military use to commercial and educational use has the potential to revolutionize air travel and transform the way we approach scientific research and education, but it also poses challenges related to safety, sustainability, and cost-effectiveness that must be addressed through innovative solutions and strategic planning. This paper aims to cover the prior and in use applications of militaristic supersonics and transitions to provide newer applications of supersonics that are pulling away from the militaristic point of view and are focused more on their educational and environmental impact. Additionally, I will show new technologies and designs of supersonics in the commercial field that are trying to break down the barriers of pure militaristic applications.

Literature Review:

This argument can be made by answering the following, what are current or imagined designs and applications of supersonics that aren't militaristic? Currently, the Concorde is still the only successful supersonic commercial airliner. The Concorde was a breakthrough in new technology; however, its history is tainted with problems and ultimate failure. De Syon (2003) argues that the Concorde was a shameful step backwards in avionics. Since none of the work was collaborative, troubles that occurred between the French and British led to its failure (De Syon, 2003). Additionally, several authors argue that the Concorde did not think about environmental, economic, and social aspects which led to its downfall (Drake, 2001). However, due to them being a newer technology, supersonic flight posed major challenges that were resolved in the 1960's and the early 1970's. This was inevitably the breakthrough of the Concorde. "No supersonic transport could be designed without first breaking many fundamental and technical barriers" (Candel, 2004).

There were many problems with noise regulations and combustion emissions. The overall environmental impact of "supersonic airliners will have to be carefully evaluated and compared to subsonic air transportation systems" (Candel, 2004). Noise pollution has been a growing pandemic as "population growth, urbanization, and the associated growth in the use of increasingly powerful, varied, and highly mobile sources of noise" have become more prevalent in everyday life (Goines, 2007). Additionally, most planes use a mixture of gasoline and diesel to make jet fuel which releases different amounts of greenhouse gasses including CO_2, CO, SO_x, NO_x, HC, ect. (Masiol, 2011). There are multiple different ways to assess the environmental impact of air pollutants and their effects on the environment. This can lead to a lack of information but can be useful to obtain more data based on different tests (Kurniawan, 2011). Air pollution can affect children because they are vulnerable, and it can affect the environment through acid rain, haze, and surface-level ozone (Manisalidis, 2020). To combat this pollution, the United States and other countries have passed legislation and have been researching new sustainable practices for aircrafts. The newest of these legislations is the Clean Future Act: Decarbonization of The Transportation Sector and its goals are mostly focused on electric cars. However, electric vehicles can be seen in the avionic industry as well (Farakhi, 2019).

Methods:

I used primary sources to gather information about newer commercial supersonic designs and technologies and educational uses of supersonics. Legal information about current bans on overland supersonic flights and information about how supersonics designs are causing and preventing pollution will also be addressed. The militaristic, commercial, and educational uses were all gathered from educational journals and articles about current supersonic designs, plans, goals, and test data. I looked to secondary sources to gather the impact of these new designs based on other's reports and their interpretations of these technologies. I used research from the 1940's to 2022 since that was when supersonics were introduced to show how far they have come.

Analysis:

Militaristic uses:

To understand the implications of the commercial and educational branches of supersonics we must look at their past uses in the military. The military not only designs supersonics, but they also do tests of these supersonics on cities to show their impact. These designs started as a means of defense. During World War II, Germany "had experimented then with swept-back and delta-shaped wings, which delayed transonic drag rise" meaning that the aircrafts could go faster for longer (Guilmartin & Taylor, 2023). This is a concern because an enemy bomber could take out multiple aircrafts without the concern of being shot down. As a result, the United States, and the Soviet Union each produced the F-86 Sabre and the MiG-15 respectively to counteract these bombers. However, both aircrafts were used in the Korean War against each other (Guilmartin & Taylor, 2023). As wars continued to happen, the need to go faster and faster grew. This led to the creation of the F-4 Phantom II and the MiG-21 during the Vietnam War (1955- 1975). These crafts could reach speeds upwards of twice the speed of sound. Currently, most supersonic aircrafts have been developed for future defense. One of these designs is the Cranked Delta. It is designed to fly over a variety of ranges with a variable payload (Iwanski et al., 2004). One example of this is that it can carry flares to intercept on coming missiles and it can travel transcontinental if needed. Additionally, newer supersonic vehicles have been designed in the form of drones. These supersonics are unmanned and are being primarily used for surveillance.

The military did not just design supersonic planes, but also missiles and rockets were developed to speed past enemy defenses. Most of these missiles and rockets fall into another category called hypersonics. They are classified as going five times faster than the speed of sound. They were first designed during the Cold War but were not heavily invested in because of "technological hurdles such as propulsion, control, and heat resistance" (Stone, 2020). This was until the early 2000s when John Hyten (former Vice Chairman of the Joint Chiefs of Staff and former Commander of U.S. Strategic Command General) stated "these weapons could enable "responsive, long-range, strike options against distant, defended, and/or time-critical threats [such as road-mobile missiles] when other forces are unavailable, denied access, or not preferred"' (Sayler, 2023). This led to the funding of hypersonics to try to catch up with the Russians and Chinese that have been continuously investing in them since the Cold War. In 2018, The China Academy of Aerospace Aerodynamics developed the Xingkong-2 "waverider" hypersonic cruise missile that can achieve six times the speed of sound. (Stone, 2020). As of 2020, the DOD is "pouring more than $1 billion annually into hypersonic research" to compete with the Russian and Chinese programs (Stone, 2020). Most of these projects under the DOD are labeled as classified for national security purposes. However, if I had to guess based on recent hypersonic video testing in Russia and China, most of these projects are about interception and defense against these developed hypersonic cruise missiles.

As the supersonic field grew, the government needed to do tests to see if they would be safe for use. They started to do experiments on their own people to determine the effects that supersonics have on civilians. One of these studies was done in Oklahoma City in 1965. The experiment was part of a large-scale program to build a supersonic transport (SST), an aircraft that would have produced sonic booms affecting many millions of people. They were an experiment by the US government to determine the effects of sonic booms on people and buildings over a prolonged period (Suisman, 2015). These tests included "some 500,000 test subjects—the city's whole population—none of whom volunteered to participate, and all of whom were intensely affected" meaning the government only wanted to find the results of these tests without having to deal with the adverse consequences that come with experimenting on their own population (Suisman, 2015). This study concluded that "booms of 1.5 to 2.0 p.s.f. would be acceptable to a general population. A final report… called unequivocally for additional testing of the psychological impact of sonic booms and noted the risks that attended the sonic booms' startle effect (e.g., the slip of a surgeon's hand, falling from a ladder, heart attack)" (Suisman, 2015). However, this study was cut short and abandoned because of damage to property, pressure from scientists, engineers, and others, damages to public wellbeing, and environmental concerns (Nwanevu, 2014).

Commercial uses:

As shown, the military has invested a lot of resources into supersonics and some of the results have led to a spillage into the commercial realm and caused more companies to work on commercial supersonics. A design for a quiet supersonic aircraft was constructed under the U.S. Defense Advanced Research Projects Agency (DARPA) Quiet Supersonic Platform (QSP) program by a team from Northrop Grumman Integrated Systems and Raytheon Aircraft. It was intended to serve as a technology evaluation platform that was sufficiently like both the strike aircraft and the business jet (Bruner et al., 2002). While designing this aircraft, dual requirement parameters had to be agreed upon every step of the way to ensure that these companies were abiding by civil and military standards. One of these balances was the takeoff balance where the "resulting dual-relevant requirement was for 7000 ft, not the 7250-ft average of the two input requirements. The reason for this was that the military requirement was not a hard requirement while the civil requirement was based on being able to operate from typical general aviation airports" (Bruner el al., 2002). In the end, this design proved to be a success. However, it was never developed any further and didn't have a name. Currently, NASA, Lockheed Martin, and Skunk Works are developing the X-59 QueSST. This is the next generation of quiet supersonic aircraft. Its goal is to "Collect community response data on the acceptability of a quiet sonic boom generated by the unique design of the aircraft. The data will help NASA provide regulators with the information needed to establish an acceptable commercial supersonic noise standard to lift the ban on commercial supersonic travel over land" (Lockheed Martin, 2022).

Although commercial supersonic travel over land is banned in the United States, companies are still trying to work through and eventually lift this ban. Additionally, the "key technologies" for supersonic aircrafts have advanced significantly over the past 30 years and newer companies like Boeing and McDonnell-Douglas have indicated a "viable commercial market" has been reached and "focused R&D programs are already underway in Europe and Japan" (Harris Jr., 1992). One of the Japanese aircrafts is the JAXA's S4 Supersonic Low-Boom Airliner. This aircraft was designed by Japan Aerospace Exploration Agency (JAXA) and assessed by the German Aerospace Center (DLR) to "obtain key technologies realizing an environmentally friendly and economically viable supersonic transport" (Ishikawa et al., 2020). In the design of the S4 Supersonic Low-Boom Airliner, they focused primarily on the reduction of sonic boom loudness, the lift-drag ratio, and the structural weight. Their analysis focused on the "economic and political environments that a supersonic airliner has to comply with are summarized by considering the main stakeholders: passengers, airlines, the manufacturer, and the public" (Ishikawa et al., 2020).

Another country that has been working on civil supersonics over the past 50 years is Russia. One of their newest aircraft designs is based on the development of airliners for no more than 20 passengers and will have a hybrid power unit consisting of a turbojet and a supersonic ramjet engine. They based this design on past supersonic aircrafts including the Russian Tu-144, United States' Aerion AS2 aircraft, Spike S-513, and Quiet Supersonic Transport. This design focused on observing "environmental requirements on sonic booms, noise around airports, and air pollution" and the "economic terms, supersonic passenger planes are only viable if the need for speed outweighs the operating costs" (Kraev et al., 2019). Both studies mean that for every supersonic aircraft that is being developed currently they all have the same goal of lowering the sonic boom loudness and decreasing the cost of them. Both issues were the eventual downfall of the Concorde.

Educational uses:

As shown, the commercial realm of supersonics is growing. To continue this trend, new advancements in technology will need to be made to obtain these goals and educating the next generation is a pivotal step in this process. Stanford University has an Aerospace Vehicle Environment that can design and optimize small-scale, supersonic, and unmanned aerial vehicles (UAVs). Academic designs for supersonic UAVs developed at Stanford are then analyzed and compared to a design from the University of Calgary, for a variety of metrics. They compare data and they discuss the "potential pitfalls related to conceptual design accuracy" (Dalman et al., 2021). This is important because it gives students the opportunity to get hands-on experience in the classroom before applying their theoretical knowledge in the industry. However, currently this software can only be used to optimize “aerodynamics, stability, and propulsion” (Dalman et al., 2021). This means that these tests aren’t taking into consideration the environmental impact or the cost of these designs. Another university that has been working with supersonics is the University of Washington. They “designed, analyzed, ground-tested, and built advanced research UAVs for the flight testing of low-speed flight characteristics of tailless supersonic aircraft” as a capstone for their Aircraft Design Program (Livne, 2017). This shows that universities are also committed to creating supersonic aircrafts. However, universities are placed in a gray area in how their research is applied because of where their funding comes from. Some of their funding comes from the Airforce and Navy (military) while some come from companies like Boeing and Lockheed Martin.

Other than universities, non-avionic companies are also committed to helping create supersonics. Tools have been developed to help students learn about conceptual designs for supersonics. One of these tools is 3D CAD. This allows students to “verify the feasibility of alternative solutions, which stem from the project technical data, and/or to compare them with each other” without having to build prototypes of these supersonics (Chiesa et al., 2000).

Acknowledgements and Drawbacks:

Although supersonics are being bred for commercial and educational uses, they still have drawbacks that plague them to this day. Their banning, development, cost and public impacts, and environmental impact are four key factors in this discussion.

The first drawback of supersonics is them being banned over land use due to the loudness of the sonic boom they create. This ban was applied as a part of The Aircraft Noise Abatement Act of 1968 by the Federal Aviation Administration (FAA) and the Department of Transportation (DOT). This law currently “prohibits flight in excess of Mach 1 over land unless specifically authorized by the FAA for purposes stated in the regulations" due to the noise caused by the sonic boom (Federal Aviation Administration, 2020). However, the FAA is investigating the new technologies associated with mitigating noise impacts for overland flights. If these technologies are deemed to be adequate in their biennial review the FAA can "determine whether to amend the current ban on supersonic flight by civil aircraft over land in the United States" (Federal Aviation Administration, 2020).

Most of these designs are still in the design stages therefore, no development has been made for them. As of January 2023, "NASA now expects its delayed X-59 Quiet Supersonic Technology (Quesst) demonstrator aircraft will make first flight in 2023 following completion of still-outstanding system evaluations" (Hemmerdinger, 2023). This was a delay from their previous goal of having their first launch in 2022. Lockheed Martin stated that "supply chain and labour issues as holding up the complex development effort" (Hemmerdinger, 2023). For the JAXA's S4 Supersonic Low-Boom Airliner, no dates have been published for its maiden flight. However, "The Japanese research agency is now working with Boeing to evaluate and verify the low-boom design technology" (Warwick, 2020). This means that either the project will survive and go into production, it will be redesigned, or it will be scrapped completely. In Ishikawa et al.'s study they found that tickets will be very expensive due to development and operation costs, airliners will have a hard time adding them to their fleets because of resizing of subsonic premium cabins, and "supersonic aircraft inevitably burn significantly more fuel and cause more atmospheric emissions than their subsonic counterparts" (Ishikawa et al., 2020).

The last of their major drawbacks is their effect on the environment. Impacts of supersonic vehicles first start with their noise pollution. Noise pollution "will continue to increase in magnitude and severity because of population growth, urbanization, and the associated growth in the use of increasingly powerful, varied, and highly mobile sources of noise" (Goines, 2007, 287). As the popularity of supersonics continues to increase, the amount of noise pollution created will also increase. Emissions are also of large concern when it comes to supersonics. These aircrafts emit nitrogen oxides (NO_X) that can cause "changes in atmospheric processes and chemistry that lead to a radiative imbalance, a radiative forcing (RF) change" (Matthes, 2022). Additionally, another study by Dubey showed that supersonic transport "can cause the predicted local O_3 loss of 1.5% to be uncertain by up to 3% in regions of large aircraft NO_X injection" (Dubey, 1997). Both studies show that the emission of nitrogen oxides can lead to a depletion of stratospheric ozone. Another way to think about this is to imagine a hole being created in the ozone layer. Another key drawback with supersonics is the emission of CO_2. Currently, supersonics "have higher relative fuel burn (FB) than current subsonic aircraft flying the same routes. Burning more fuel while having less passengers (pax) on board per trip yields significantly higher FB per passenger for these operations" (Weit, 2020). This leads to an increase in CO_2 emitted from the transport. Since climate change has become an omnipresent issue, supersonics are faced with the task of limiting the amount of greenhouse gasses (GHG) emissions they produce. One keyway that society has been involved in this process is by legislation. To "curb the growth of GHG emissions from air travel, the U.S. Federal Aviation Administration (FAA) has created a policy to achieve carbon neutral growth by 2020 relative to the 2005 baseline" (Arul, 2014). Additionally, certain studies have shown the impact of placing a carbon tax on air traffic and on automobiles. Lastly, as climate change awareness has increased some studies have revisited "the previous debate surrounding Concorde to explore the potential for current initiatives to overcome the public's anxiety of further environmental degradation" (Drake, 2001, 501).

Conclusion:

Supersonics are seen as a militaristic technology. However, with new designs and technologies of supersonics, the aviation industry is almost at the tipping point where their applications will be used in commercial flights and for educational purposes. After reading this, companies that are producing these supersonics (Boeing, Northwell Grumman Corporation, Japan Aerospace Exploration Agency, Gulfstream Aerospace Corporation, ect.) can narrow down their studies to address these main concerns and produce new technologies that allow for supersonics to be viable. This in turn will allow competitors pursuing commercial supersonics to be inclined to also manufacture supersonics to gain an edge in the commercial market. Additionally, they can cooperate with other industry tycoons to manufacture commercialized supersonics faster. Educationally, universities will see this research to further educate their students on the major problems currently with supersonics. Additionally, future research should look at public opinion of supersonics. This will prove if there is a need for them and it should look at different challenges faced by supersonics. Pollution and cost are the two major issues with supersonics, however there are always more problems which can make them less viable in the commercial and educational realms. Hopefully, this research will motivate companies to work together to create the next Concorde. However, this time it will be successful and here to stay. Military funding will be necessary to continue the transition of supersonics from militaristic uses to commercial uses. However, new investors and new companies can minimize the funding and create a natural environment. This environment will fuel competition creating better and more affordable supersonics.

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