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Supersonics Project Advanced Curriculum Contest

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Abstract

This document details the design of a small supersonic airliner, with a cruise speed of around Mach 1.7, and a cruising altitude of 20,000 feet. The aircraft will carry a maximum of 65 passengers (depending on the seating configuration), and will be operation by the year 2010. Modern construction techniques and innovative materials have been incorporated into the design to make the aircraft efficient enough to be sustainably commercially viable. The aircraft emissions have been reduced, allowing the aircraft to travel at high altitudes around the ozone layer, without as much emissions as current subsonic airliners. The aircraft will also be extremely quiet, both in the air and on the ground during takeoff and landing, due to the use of a variable cycle engine. The sonic boom signature is minimal, and the pressure wave produced by the aircraft is less than 2 pounds of pressure per square foot. All this will allow the aircraft to be extremely commercially viable, and future versions of such an airliner will help replace current subsonic airliners completely.

Objective: To build a delta-winged small supersonic airliner that is efficient, and commercially viable and sustainable. This airliner is to have a cruise speed between Mach 1.6 and Mach 1.8, cruising altitude of 55,000 feet. It is to be designed to carry minimum of 65 passengers in a two class configuration.

Goals:

- Create low sonic boom levels.
- Achieve a level of fuel efficiency near to that of current commercial subsonic aircraft.
- Have low ground noise, to enable operation at existing airports near residential communities.
- Minimize emissions, as the aircraft will have a cruising altitude in or around the delicate ozone layer.
- To create an aircraft that is easy to maintain, without requiring special repair facilities, at existing airports.
- Keep the landing distance under 10,000 feet, to allow operation at most of the world's airports.

Non goals:

- To be constrained by the cost of new materials

Design Guidelines:

- Decrease Conventional fuel usage to reduce takeoff weight.
- Use innovative, lightweight materials without compromising passenger safety.
- Use low-maintenance material and technologies to replace or augment current technologies.

Aircraft specifications:

Length: 46m

Width: 2.8 m

Height: 2.4m

Wingspan (at longest points): 20.5 m

Capacity: 65 passengers (2+2 in standard class, 1+1 in first class)

Efficiency: 2.5 passenger-miles per gallon

Sonic Boom Signature: ~ 1.6 psf

Introduction

The airliner will have a speed of around Mach 1.6 – 1.8, with a cruising altitude of around 55,000 ft above sea level.

Although the thinner atmosphere reduces air resistance (resulting in increased efficiency), this demands that the airframe has high structural strength, as there is a greater pressure difference between the interior and exterior of the plane. To prevent an explosive decompression at altitude, I propose the usage of high strength titanium alloy for areas wherever high structural strength is needed, such as window and door frames, and the wings, canard, and tail roots. The usage of lightweight carbon-fiber composites in areas such as the main fuselage, wing surfaces, and fuel tanks has also been proposed. The airplane doors will be smaller than those on normal jetliners, as a smaller door means that there is a lesser chance of the door being blown off.

In my design, the large delta wings will be mid-fuselage (vertically), with a slightly downwards camber. The wings will have a natural high angle of attack, eliminating the need for complex and heavy machinery in the nose of the plane to allow the pilots to see the runway during takeoff and landing. The high angle of attack is needed as delta wings need a high angle of attack to generate lift at low speed. The outer edges of the wing will flare up slightly, as this helps reduce the impact of sonic boom. The volume and lift area of the aircraft have been evenly spread out, as each lift surface creates its own pressure wave, which can be cancelled out if these surfaces are correctly placed. This reduces the sonic boom significantly. (Three-View)

Thus, in the front section of the aircraft, canards will be used (which are relatively larger than those used on other airliners). These canards also increase control of the aircraft, as there are no rear horizontal stabilizers for attitude (pitch) control. The wings will be of a high sweep delta structure, with multiple, smaller delta-shaped ogive shapes at the front of the wing where it joins the fuselage (similar to Concorde). They will have titanium leading and trailing edges, with temperature sensors that will automatically reduce speed if the temperature is too high. (Top view)

The wings will start slightly ahead of the middle-point of the plane. They will have a lattice beam structure, made of a lightweight steel alloy. Self-sealing carbon-fiber fuel tanks will fill the large area within the wings, as they have high strength, and are also significantly flexible, so in the event of a crash they will remain intact and not leak, reducing the chance of aircraft fires or explosions.

The cockpit of the aircraft will be an all-glass cockpit, with one large windscreen facing forward, and several smaller ones facing towards the side, allowing all-round visibility. (Front View)

Efficiency

High efficiency, in both the aerodynamic shape of the aircraft, and the fuel consumption by the aircraft powerplant are essential for the economic viability of any supersonic airliner. This is because the cost of the fuel saved due to high efficiency, over time, offset the fairly high construction costs demanded by the advanced materials that will be necessary on such aircraft.

Efficiency at high supersonic cruise speeds will be achieved by a combination of aerodynamic modeling and by the usage of lightweight composite materials (including carbon-fiber composites), and by installing energy-efficient Variable Cycle Engines (VCE).

This VCE will be of tandem fan design. In normal operation, both of the fans (mounted on the same shaft with a large axial gap between them) operate in 'serial' mode, similar to a normal (axial flow) turbofan. During takeoff and landing, the two fans will work independently, using auxiliary intakes and exhausts, to increase the total airflow, simulating a high-bypass ratio engine. The engines will also be made lighter, by the usage of lighter titanium alloys in most of the structure.

To increase fuel efficiency, the weight of the aircraft has been reduced by around 10% and following power saving measures have been introduced:

- Making the aircraft seating lighter by reducing the amount of aluminum used-using honeycomb ribs instead of traditional hollow ribs, and replacing the current seat padding with lighter foam. This will meet the fire safety norms while reducing the dead weight.
- Reducing the amount and thickness of plastic paneling in the interior of the aircraft. As these interior surfaces have no role in maintaining aircraft integrity, they can be reduced in thickness.
- The usage of large amounts of carbon-fiber composites and titanium alloys in areas such as the engine fan blades, areas of the upper and lower fuselage, to name a few.
- Reducing the number of paint coats to two – An initial coat (primer), followed by a colored coat with a water-resistant polymer coat mixed in.
- The introduction of a large battery bank in the rear of the plane, which will power the lighting and temperature control systems of the aircraft when the main engines are not turned on (during taxi, parking, etc.)
- The APU, which used to perform these tasks, will now be used to generate power only to charge the batteries and start the engines. The reduction of the APU's size (and consumption) will mean that more fuel is used by the engines for flight, as APU's are grossly inefficient.
- In addition to this, thermocouple power-generating devices will be used in the engines, as the large temperature differences between the engine interior and exterior will be harnessed to generate some amounts of power.

Photovoltaic Technology

Thin Photovoltaic panel 'sheets' will be used to charge aircraft's the battery bank. These Solar Panel sheets generate relatively small amounts of electrical power, compared to the amount generated by the engines. However, if allowed to collect solar energy for a long period of time, these panels can charge up the aircraft's Lithium-ion battery bank.

Similar technology has been developed by NanoSolar Inc, based in Silicon Valley, California. They have developed thin photovoltaic cell 'sheets' which are made of a treated layer of aluminum foil, surrounded by any thin, clear polymer. These sheets are very light, and will be used on various surfaces, like the large area of the delta wings, and the curved area of the upper fuselage. These sheets can be manufactured very cheaply, as the whole process has been likened to printing a sheet of glossy paper. The sheets can be bent, and can be applied to almost all surfaces. They can also be able to resist the high temperatures of supersonic flight, as the treaded foil layer can be covered with heat-resistant clear polymers.

Propulsion efficiency

The airliner will use Variable Cycle Engines (VCE), which achieve both low and high-speed performance. This VCE will be of the tandem fan design. In normal operation, both of the fans (mounted on the same shaft with a large axial gap between them) operate in 'serial' mode, similar to a normal turbofan.

However, for takeoff, taxi and approach, the engine operated in a 'tandem' or 'parallel' mode. In this mode of operation, an exhaust valve opens between the two fans, allowing the air from the first fan to be expelled 'prematurely' i.e. without combustion'. Auxiliary air intakes will open up on the side of the engine, and this air passes through the rest of the engine (goes through the combustion chamber). This increases the total engine airflow, mimicking a high-bypass ratio turbofan, without the increased cross-sectional area. Also, the velocity of the exhaust gas is reduced, significantly reducing noise emissions from the engines.

This system allows for high efficiency at both high and low speeds, and although the system of valves and ducts appears complex, it is easier to maintain compared to other Variable Cycle and Variable-Bypass engine types.

The four engines will be mounted in pairs, in pods on the wings near the fuselage. The pods will be mounted towards the rear of the wing (relative to the front of the wing), as this helps minimize sonic boom.

The engine fan blades will be made of lightweight titanium alloy. Even though they are more expensive to construct than standard fan blades, they are more durable and have reduced maintenance costs. These blades can withstand the high temperatures created by the friction of the incoming air at supersonic speed. Since titanium has high strength, the air can flow directly into the engines, without being slowed down. This eliminates the need for 'ramps' to slow down incoming air, as in Concorde. Since the air already has a high velocity, it does not require as

much compression, reducing the number of the compressor blades, reducing weight. The natural shape and position of the engines and the wings also slightly reduces the speed of incoming air.

The engines will have multiple fuel pipes, so the plane can continue flying if one ruptures. These pipes will be self sealing, to prevent a fuel leak that could lead to a catastrophic explosion or a fire.

Aerodynamic Efficiency

The aircraft will be extremely streamlined, and will have a very high lift-to-drag ratio due to the overall large lift area.

In addition to this, the fuselage will be optimized to reduce drag by aerodynamic shaping, using, in part, Whitcomb Area Ruling. In accordance to this, the cross-sectional area of each point along the airframe will have to be shaped accordingly – i.e. having a slight ‘pinch’ along the wings.

The use of a delta wing has allowed for high-cruise efficiency, due to its shape and large lift surface. In addition to this, delta wings can carry much more fuel than conventional wing types, allowing for more fuel to be carried. Delta wings are also a much better option for supersonic aircraft, as they are only sparsely affected by transonic disturbances.

To reduce drag, any objects jutting out of the fuselage, or compromising the streamlining will be moved elsewhere, or will be replaced with a more aerodynamic alternative. For example, the forward-facing part of the Pitot tube can be embedded in the wing (so that it does not cause as much drag), and the part that is perpendicular to the direction of airflow can also be embedded early in the wing, in one of the ogives. This allows only small sections of the Pitot tubes to be protruding out of the airframe. To prevent any aerodynamic unbalance, there will be two sets of Pitot tubes, one embedded in each wing.

The aircraft fuselage will be narrower than other aircraft, reducing air resistance (around 2.8 meters at its widest point). However, the vertical diameter will be slightly less, around 2.6m. To prevent the reduced volume from adversely affecting passenger comfort, the main fuselage will have a tubular shape, but with a slight bulge in the middle (similar to the bulge around the earth’s equator, but not a spherical bulge). This means that the aircraft will be slightly wider at eye level (while the passengers are seated). The aircraft has been streamlined for low drag on the fuselage, and this, combined with high specific thrust from the Variable Cycle engines gives the aircraft a high thrust-to-weight ratio.

The high thrust-to-weight ratio means that the aircraft can travel at greater speed with less fuel consumption, which is essential, as the prices of fuel will skyrocket once the world’s oil deposits start to run out.

Although the aircraft is optimized for high altitude, supersonic flight, the aircraft is not inefficient at low altitude, despite its delta wings. This is because the lift surfaces are more spread out, and as the aircraft’s wing camber can be varied, to create a higher angle of attack, which is essential for delta wings at low speed.

Efficiency will be increased further by reducing the size and weight of the Auxiliary Power Unit in the rear of the plane.

Lightweight, Durable Airframes and Engines for Supersonic Cruise Temperatures

The main structure of the plane will be of mixed titanium and duralumin in different areas, depending on the structural strength required - the wing roots will have a titanium cross-beam structure, and the flying surfaces will have titanium leading edges, and titanium alloys will also be used for the engine intakes, fan blades, and compressors.

The alloy of titanium used in this case will be a Grade 5 alloy, commonly used in the construction of airframes of many air craft due to its relatively high corrosion resistance, light weight, and high strength. Grade 5 Titanium alloy consists of 6% Aluminum, 4% Vanadium, and 90% Titanium. This alloy will be used in areas such as the engine casing, wing panels, etc.

At supersonic speeds, to prevent any deforming of metal on the fuselage, the leading edges of the plane will be made of temperature-resistant titanium. Although titanium is more expensive than most other aircraft-making materials, it is highly resistant to temperature fluctuation.

On the Leading edges of the aircraft (on both flying surfaces and engine intakes and exhausts), an alloy of Titanium containing 5% Aluminum, 2.5% Tin, and 92.5% Titanium will be used. This alloy has a high resistance to temperature fluctuation, and is easier to shape. This is useful as some of the curves on the wings are somewhat complex.

On a high-altitude supersonic airliner, there is a large temperature difference between the leading edges of the plane and other areas, and titanium can withstand such extremes (even on the same metal sheet). To ensure that the metal does not deform at high speed, the wing will be embedded with temperature sensors (similar to those on the Space Shuttle, though not as many). This temperature difference will be harnessed using thermocouples that can produce electric current to charge the onboard battery bank. Titanium casting has a high initial cost, as specialized equipment has to be made. For my proposed airliner, new machine-tools will have to be made, but the high usage of the airliner will offset this cost. Machine tools similar to those used on the proposed XF-108 Rapier prototypes (a cancelled U.S. Air Force supersonic interceptor) and on the Mikoyan-Guerevich MiG-25 can be used to construct the airframe of my airliner, as the basic airframe uses similar materials.

The titanium alloys, and all other metals will not be solid, except in areas where high strength is required. Instead, a honeycomb structure will be used (except for the wing spars and beams themselves). For engine cooling, the inlets will have a simple air-cooling system, in which the engines are cooled by small bypass tubes, which are small enough that they will not affect engine weight and performance. To save weight, the main airport noise-reducing features will be incorporated into the engine exhaust ducts, preventing any excess protrusions from the aircraft. These features include plasma actuator technology, which was pioneered by researchers at Ohio

State University, which uses electrical arcs to create an ionization stream, which creates turbulence in the exhaust from the engines, without significantly affecting aircraft thrust or weight.

To reduce airport noise, a Variable Cycle Engine type has been used, with the ability to create both a high and low specific thrust, without any significant gains in weight, or losses in thrust.

Airport Noise Reduction

The airport noise from the engines will be reduced by the use of a tandem fan engine. During takeoff, taxi, and approach, the engines operate in a 'tandem' or 'parallel' mode. In this mode of operation, an exhaust valve opens between the two fans, allowing the air from the first fan to be expelled 'prematurely – without combustion'. Auxiliary air intakes open up on the side of the engine, and this air passes through the rest of the engine.

This increases the total engine airflow, mimicking a high-bypass ratio turbofan, without the increased size. Also, the velocity of the exhaust gas is reduced, significantly reducing noise emissions from the engines. Airport noise is also reduced as the engines are no longer needed to give electrical power on the ground, since a battery bank is used instead. This means that the aircraft engines do not need to be started until the aircraft reaches the taxiway, a significant distance away from the terminal and passenger areas. Another method of noise reduction is the introduction of plasma actuator technology, embedded near the engine exhaust. This technology uses electrical arcs to create an ionization stream, which causes turbulence in the exhaust airflow from the engines.

This turbulence significantly reduces engine noise on the ground, which can be proven if the airflow from the engines is analyzed. This technology was pioneered by Mohamed Samimy and his research team at Ohio State University, which was sponsored by NASA's Glenn Research Center.¹

The technology mimics the effects of chevrons, which are zigzag-shaped cutouts at the nozzle exit that introduced longitudinal turbulence structures into the exhaust flow and so affected the mixing and noise characteristics of the engine. Many newly designed aircraft engines incorporate chevrons. Dr. Samimy also worked on chevrons at NASA in the 1990s.

Although Chevrons reduce takeoff engine noise, they increase weight, and reduce fuel efficiency at cruise speed and altitude. However, they are fixed, and cannot be removed or disengaged, unlike plasma actuator technology.

Sonic boom modeling

The sonic boom levels of the aircraft will be significantly lower than other civilian and military supersonic aircraft. This is because the lift surfaces of the aircraft will be evenly distributed, due to the delta wing and the relatively large canards near the front of the airplane.

This means that instead of only two large pressure waves being produced (a normal N-wave); several smaller booms will be produced. The engines will be mounted towards the rear of the wing, close to the fuselage. This reduces boom as it creates a lot of distance between the two distinctive pressure spikes created by the plane.

The length of the plane will further separate the boom created by the nose and the boom created by the enginesⁱⁱ.

Also, the boom of the plane is reduced by reducing the amount of pressure produced by the aircraft while it travels at supersonic speeds. Incidentally, the main reason that the FAA banned commercial supersonic overflights of the United States was not because of the large amount of sound produced by the 'sonic boom', but because of the adverse effects of the pressure wave on vital sensory organs in the human body.

Emissions Research

As the aircraft cruises in the upper reaches of the ozone layer, any large amounts of emissions from the aircraft can damage the upper atmosphere. As a result of the combustion of aviation fuel, emissions including nitrogen oxides, carbon dioxide, water vapor, and suspended particulate matter (SPM) will be released into the ozone layer. The use of fuels low in nitrogen and sulphur will be essential for this aircraft to operate efficiently and without damaging the environment. Also, the shape of the engine inlets will allow more air to enter the engine at high speed, acting similarly to the intake of a ramjet engine, without the shape and size.

This ensures that adequate amounts of air reach the engine's combustion chamber, ensure complete combustion of the fuel, reducing the likelihood of emissions like carbon monoxide and nitrogen oxides from forming. In addition to these methods, emissions will be reduced by controlling the amount of fuel the engine receives, so that the engine does not receive excess amounts of fuel, and only combust it partially. This can be brought about by varying the number of the fuel pipes being used to supply the engine, depending on its needs.

Descent and Landing Challenges

Since having a long, tapered nose is essential for both aerodynamic efficiency and low-sonic boom design, landing becomes especially difficult on any large supersonic aircraft. Another problem is that delta wings, which are the most viable and efficient option for large supersonic aircraft require a high angle of attack to generate adequate lift while at low speed. This means

that a high nose gear is required, so that during takeoff, the nose is higher up than the aft section of the aircraft.

In large aircraft such as the Anglo-French (BAC/Aerospatiale) Concorde, and the Tupolev Tu-144, the nose is at such a height that the pilots can no longer see the runway, due to the elongated nose section. To counteract this, both aircraft had a 'droop nose', which required large amounts of complicated machinery to raise and lower. This also increased the weight of the aircraft, making it less efficient and less economical. In my aircraft, the nose is at the normal level. In order to create the high angle of attack necessary for delta wings at low speed, powerful, lightweight hydraulic actuators will be embedded in the wing, allowing the rear section to change its angle of attack to some degree, allowing adequate amounts of lift to be created.

In case of an accident, there will be two sets of these actuators. One set will be linked to the rest of the plane's hydraulics, and the other set will be a redundant independent system. This eliminates the need for complicated hydraulic systems in the nose. As supersonic aircraft need to slow down from very high speed to land, large speed brakes have been incorporated into the wing design. These will be lifted and lowered by hydraulic actuators, and will be able to slow the aircraft quickly. There will also be normal flaps and control devices incorporated into the wings. Landing will also be made easier by the existence of canards near the front of the aircraft, which will help improve aircraft control in the absence of horizontal rear control surfaces.

The aircraft will have one pair of wheels in the nose gear, allowing the nose gear to be moved further towards the nose (as there is no 'droop nose' in the front). The rear wheels will be in pairs of six, with two wheels to an axle in each pair. The wheels will retract into the fuselage, as the wing root is higher up in the fuselage. However, this means that some amount of cargo space will be lost (also due to the rear exit system). This will not hamper baggage capacity, since the amount of baggage carried by around 65 people is not a very significant amount. Also, the aircraft will not be used to carry any cargo, eliminating any needs for a large cargo area. The wheels will have disk brakes, which will augment normal deceleration methods like thrust reversal. The aircraft will be able to land on paved runways greater than 7,000 feet in length.

This means that my proposed airliner can land and takeoff from most of the airports in the world, unlike aircraft like the Concorde. This allows for a higher usage rate, which will offset the high production cost of the airliner due to the usage of titanium alloys and carbon-fiber composites. The cockpit of the aircraft will be an all-glass cockpit, with one large windscreen facing forward, and several smaller ones facing towards the side, allowing all-round visibility. High resolution cameras will be built into the floor of the cockpit and the rear of the plane. Pilots will be provided with goggles with HUD displays that show airspeed, engine statistics, etc.

These goggles will improve visibility, as they will show live video feeds from the various cameras, depending on where the pilot is looking. This feature will use the powerful aircraft computers to merge feeds from various cameras to produce a 'seamless' 360-degree view. This feature is useful in landing and takeoff, as the pilot can control the airplane, and the co-pilot can look rearwards and ensure that the aircraft has taken off properly, without 'tail-dragging'. A similar system has been developed for Lockheed Martin's F-35 Joint Strike Fighter. There will also be a system similar to the XVS (External Vision System) being tested at NASA's Dryden Flight Research Center.ⁱⁱⁱ

The HUD can be turned on and off when needed. The standard avionics will be represented on a large number of liquid crystal display (LCD) panels. There will also be standard avionics for redundancy purposes.

Safety

Safety is one of the most important aspects in a supersonic airliner, and extra precautions (compared to those taken on current commercial airliners) must be taken to maintain it, as supersonic transports fly at higher altitudes and speeds. As the aircraft's cruising altitude is much higher than most commercial aircraft (55,000 feet), the windows and doors must be reduced in size, to reduce the risk of an explosive decompression. At high altitudes, the cold temperature sometimes causes hydraulics failure. In case of an explosive decompression, the plane will begin a computer-controlled descent to around 8,000 feet, which is the minimum altitude needed for proper human functioning.

As the cruising altitude is over twice as high as on other planes, the oxygen masks will be supplied by oxygen canisters with a bigger capacity, to prevent hypoxia during the elongated descent, which will be lengthier than that of a current subsonic commercial airliner. In case of this, there will be a double redundancy for each system on the aircraft. For the main control surfaces, there will be two, and in some cases, three fly-by-wire links to the multiple sets of actuators. There is also redundancy in the engines, as if one engine fails, the corresponding engine on the opposite wing can be shut down, and the aircraft can perform an emergency landing at subsonic speed. The engines will also have an auto-shutdown if a fire starts, allowing the engine to cool and then restart, to allow for a safe emergency landing.

Many air crashes have been caused by the leakage of fuel pipes, which subsequently caused the fuel to ignite. To prevent any such mishaps, all the fuel pipes will be self-sealing, and in the case of damage, the pilot can simply switch to another fuel pipe (there are four for each engine) and continue normal flight. There will also be a more advanced form of terrain-avoidance radar, since the approach speed of any supersonic aircraft will be slightly higher than that of a normal airliner. This radar will be a system independent from the normal radar present on the airplane. Other systems present on all airliners today will also be present on the aircraft.

The main doors of the aircraft will have inflatable rubber slides, powered by pneumatic pumps, which will open in case of an emergency. The rear doors will be in the bottom half of the aircraft, as the delta wing necessitates the usage of specialized staircases or gantries to allow passenger exit from above-wing exits.

However, in emergencies, small emergency exits over the wings can be opened, and passengers can walk over the wing, and slide to safety, as slides will be embedded in front of the wing root.

Conclusions

The conclusion that I have come to upon evaluating all of the technologies and design innovations needed for the construction of a functional, efficient supersonic aircraft, that the construction of such an aircraft is certainly possible, even within the timespan of the next ten, or even five, years.

It can also be concluded that any airliner that is to be successful, (and thus both economically and ecologically viable), needs to be low-cost, and has to have the highest fuel efficiency possible.

Ideally, an aircraft should be so efficient that it can run the similar distances of normal airliners, and on half the amount of fuel. This would be an extremely useful technological innovation both due to the emissions of fossil fuels, and due to rising fuel costs.

A very promising alternative to the usage of conventional fuels, and one that demands further study ,(especially in supersonic or transonic airliners) is the use of ‘biofuels’, either as a ‘pure’ fuel, or as a fossil fuel additive. Last year, both Virgin Atlantic Airlines, and Japan Airlines flew large, modern (albeit modified) passenger jets on ethanol, obtained from corn, which not only burns ‘cleaner’ and with less emissions, but is also much cheaper to produce. Thus, the use of such fuels is a promising vista for further study.

The use of lightweight, temperature-resistant, and inherently strong materials like titanium alloys and carbon-fiber composites needs to be investigated further as well. The manufacturing and molding techniques of the same need to be investigated further also... The supersonic airliner whose design I propose uses large amounts of these materials, in every aspect of construction. While the usage of such materials in the ways that I have proposed is both technically and economically feasible with today’s technology, it will be much easier for the use of supersonic airliners for use as mass transport to spread.

In conclusion, I propose that this design be evaluated not only for its technical benefits, but also for the ease of manufacturing, and high fuel efficiency. Along with flight abilities, these two factors are the most important ones in deciding whether a new technological innovation, especially a commercial aircraft will be used, and thus be both economically and ecologically successful.

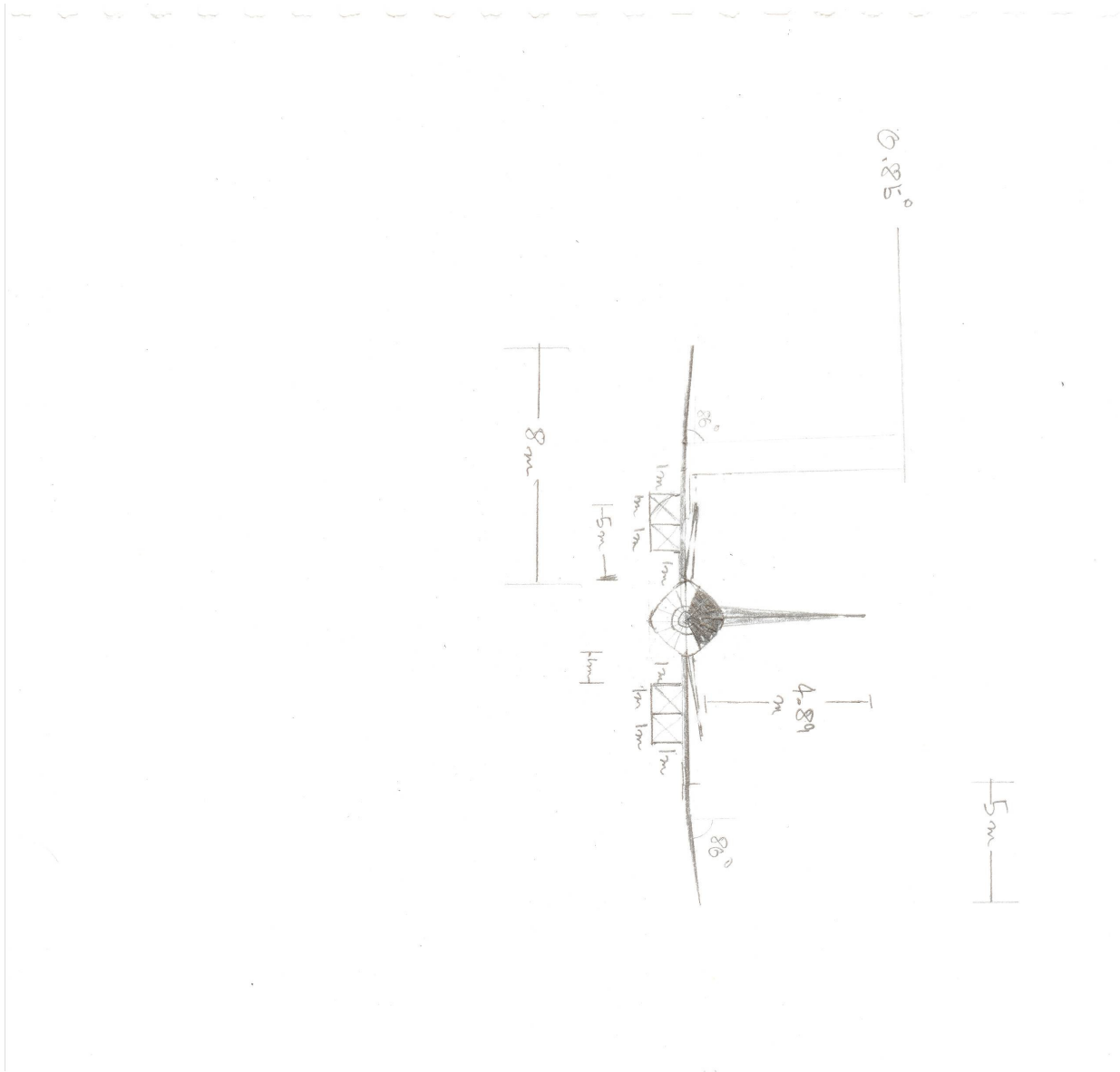
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¹ ‘All Sonic, No Boom – Popular Science Magazine, March 2007

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Aircraft Front View

Scale: 1 cm = 0.5 m



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