The SonicLiner

A commercial supersonic aircraft

NASA High School Competition

Hwa Chong Institution (College)
661, Bukit Timah Road
Singapore

Sainyam Gautam

Grade 12

Adult Mentor - Dr. Nidhi Gautam

[Personal Information Redacted]

Faculty Advisor – Mr. Lee Lih Juinn, (Physics Department)

CONTENTS

ABSTRACT

Supersonic travel has been highly sought after because it promises swifter travel and saving on time. As is said time is money and so swifter means of transportation have been always coveted. After the Concorde was banned and taken out of service, there is a void to be filled by a better supersonic aircraft. This project aims to propose a new supersonic jetliner called the SonicLiner which promises to replace the Concorde and take us into a new era of aviation.

Inspired by nature, in the ways that the peregrine falcon and the spine-tailed swift take to the skies, and based on creative and novel ideas like hybrid engines, developments from nanotechnology and ensured to be one of the most environmentally friendly and efficient aircrafts, the SonicLiner offers a promising prospect of supersonic aviation in the 21st century.

The SonicLiner with its swept back wings and unique plan form and rather unusually shaped nose, may look like something right out of a sci-fi movie but all its features have been incorporated to give it the extra edge over its competitors and thwart some of the challenges faced by supersonics in the past century. The SonicLiner will undoubtedly revolutionise commercial aviation in the coming future. Flight times will be slashed by up to half and passengers will get what they most desire – less travel time. The SonicLiner is a very promising contender for the next generation of supersonics.

1 Introduction

On the 21st of January in 1976, there was a revolution in commercial aviation waiting to strike everyone by surprise and awe. One very promising aircraft called the Concorde, a pioneer of its kind, started operating on the London-Bahrain and Paris-Rio. The Concorde was developed jointly by Aerospatiale of France and the British Aircraft Corporation. It signalled the arrival of a new era in transportation, aviation to be precise; it was the beginning of supersonic travel. Since the ancient times, man has always wanted to make his travel swifter and save on time. From horses and chariots to cars and trains, the ultimate pursuit for travel has been to lower travelling time. After the demise of the Concorde, it is time for a newer, better and more efficient supersonic aircraft to take its place and let man closer to his fantasy of quicker travel.

1.1 Challenges of Supersonic Aircrafts

The rather embarrassing regression from supersonic to subsonic commercial aviation was imperative due to the multitude of challenges and problems that hampered the success of commercial supersonic aviation and in particular, its most famous symbol, the Concorde. The following is a brief summation of the plurality of difficulties faced:

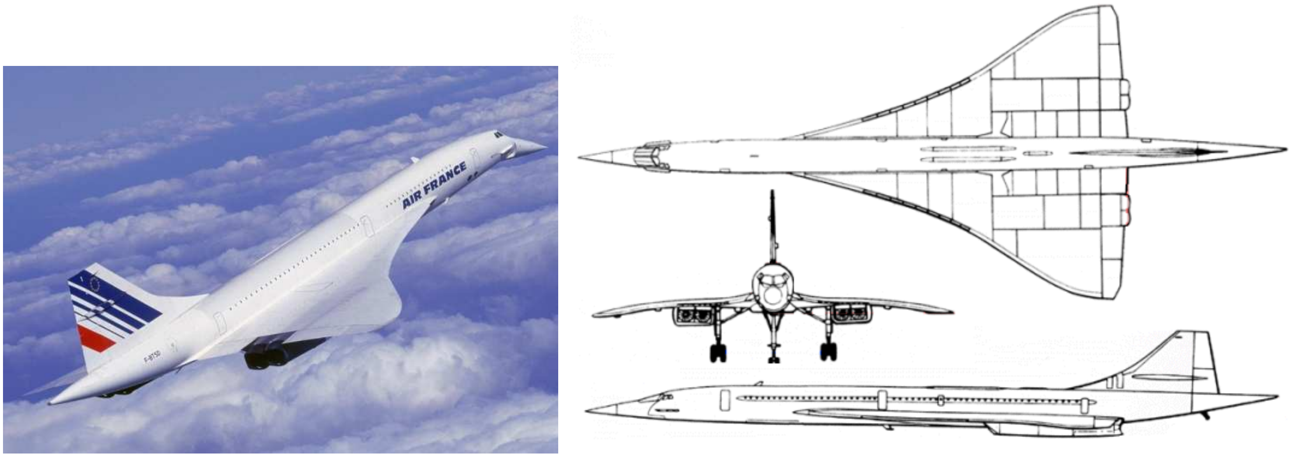
- Efficiency issues mainly including engine, range and low-speed efficiency. It is said that the Concorde burnt two tonnes of fuel while taxiing at the airport.

- Heating concerns that arose when the aircraft would hit supersonic speed. Though the outside temperature would be around -60 °C, the temperature of the exterior of the aircraft would rise to 120 °C. This limited the aircraft's speed and in turn, its cruise efficiency.

- The excessive overhead noise was protested against by many people.

- The exhausts contained nitrogen oxides and other pollutants that were believed to have catastrophic impact on the environment.

1.2 The Concorde



(*Source: http://www.airfarewatchdog.com/Portals/0/concorde.jpg*

http://www.aerospaceweb.org/aircraft/jetliner/concorde/concorde_schem_01.gif)

Figure 1. The Concorde

The Aérospatiale-BAC Concorde aircraft is a supersonic passenger airliner or supersonic transport. It was a product of an Anglo-French government treaty, combining the manufacturing efforts of Aérospatiale and British Aircraft Corporation. First flown in 1969, Concorde service commenced in 1976 and continued for 27 years. Concorde flew regular transatlantic flights from London Heathrow (British Airways) and Paris Charles de Gaulle (Air France) to New York JFK and Washington Dulles, profitably flying these routes at record speeds, in less than half the time of other airliners.

1.3 The SonicLiner

The SonicLiner is an average-sized commercial supersonic aircraft. The following are the rough specifics of the SonicLiner:

- Dimensions: 76 m in length, Wingspan of 55m, Height of 4-6m (excluding landing gear)
- Capacity: approximately 125 passengers plus crew (with a double deck in the front)
- Range: around 10,000 km
- Weight: 125,000 kg
- Cruise Speed ~ Mach 2.5

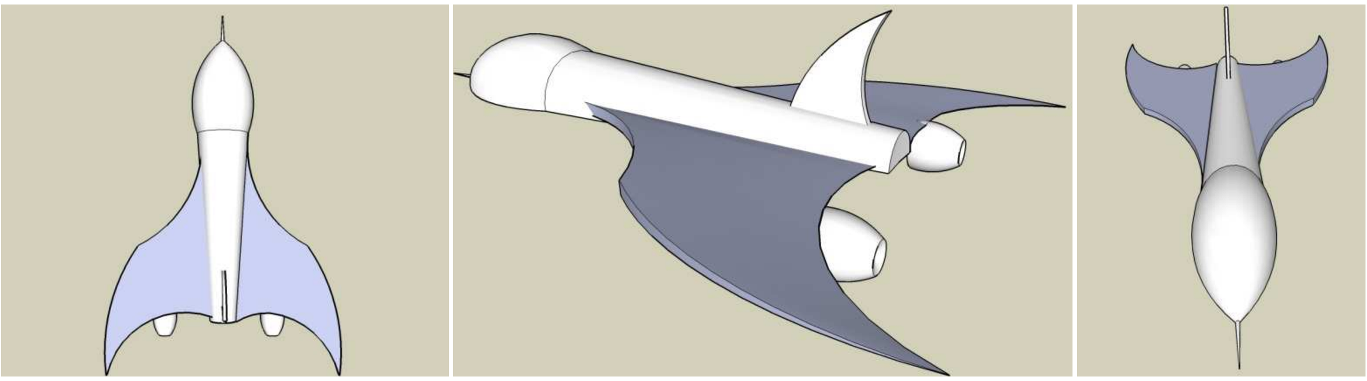


Figure 2. Basic computer generated models of the SonicLiner

The SonicLiner is a supersonic aircraft designed for efficiency as well as performance. Its unique features are as follows:

- It has been designed for supersonic speeds of around Mach 2.5.
- It is economically more viable with lower maintenance costs as well as higher fuel efficiency.
- Its engines provide it with remarkable power yet they are cost effective and use less fuel as compared to other designs.
- Design and structural measures have taken care of the severe heating problems that its predecessor, the Concorde faced.
- Its fuselage has been designed so that it provides additional lift to the aircraft.
- The wings are designed to reduce sonic boom and increase efficiency as well as lift.
- The aircraft is aerodynamically stable and efficient.
- The aircraft can roughly accommodate around 125 passengers.
- The aircraft has been so designed that it does not require any special arrangements at operating airports. So all existing infrastructure can be used with the SonicLiner as well.

2 Propulsion

The main concern for any supersonic aircraft is to how to get the aircraft to be supersonic in the first place. Not only do we need immensely powerful propulsion to cross the sound barrier was it also has to be done in the most efficient manner.

2.1 Engine – The TurboRam

For the SonicLiner, the scramjet and the rather conventional turbojet designs have been incorporated into one engine. Moreover, as demonstrated by the following air patterns designs, for supersonic aircrafts, a lot of incoming air actually passes over the engine and never enters the compressor through the air inlet. To solve this problem, the SonicLiner will have a shape that acts pretty much like a funnel to streamline the incoming air and reduce its volume so that not only does it enter the engine and consequently produces greater thrust but also the efficiency of the engine is greatly improved.

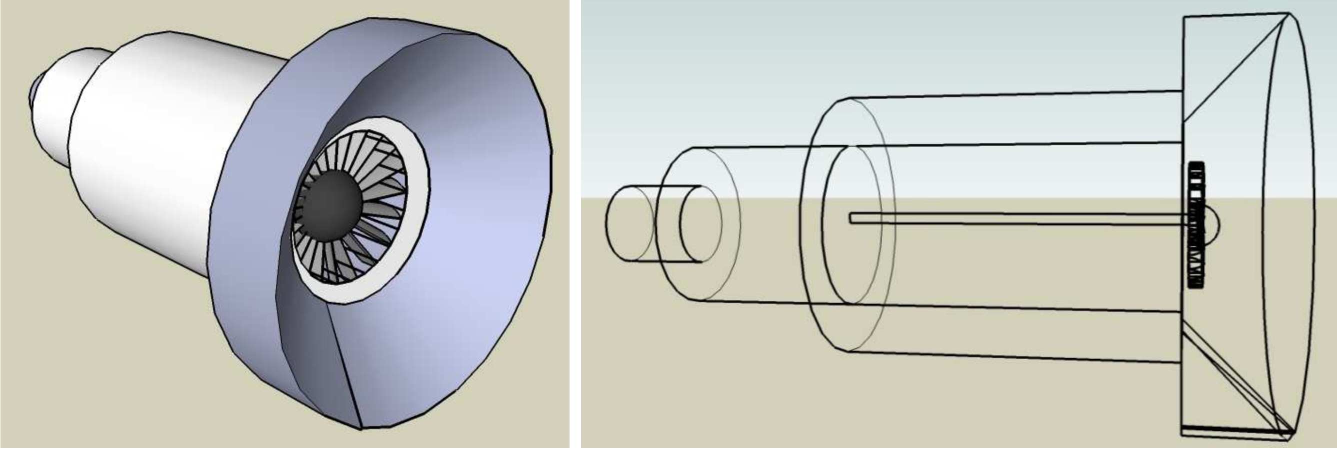


Figure 3. Simplified computer models of the engine used in SonicLiner named TurboRam in the Turbofan mode.

The engines used in the SonicLiner are based on a novel way of combining a very promising supersonic engine with a conventional jet engine. The following is a table to illustrate the properties of the Ramjet and the Turbofan:

Engine	*Features*	*Advantages*	*Limitations*
High Bypass Turbo Fan	First stage compressor engine, works on the principle that it is better to move more gas at a slower speed than to move a little amount of air at extremely fast speeds Most commonly used in civilian aircrafts today.	Quieter and has cooler exhaust, more efficient than its low-bypass cousin. Most efficient for subsonic speeds	Limited top speed due to potential shockwaves Inefficient for use in supersonic aircrafts
Ramjet	Incoming air is compressed by speed of oncoming air and the duct shape No fans or compressors are involved	Few moving parts so easy to maintain Very efficient for supersonic speeds of > Mach 2.0 Lightest of air breathing jet engines Easy to cool as there are no turbine blades to cool	Needs a high initial speed to function efficiently At low speeds, compression is not sufficient for efficiency

The ramjet is a supersonic engine but main Achilles' heel is that it needs a very high speed to start functioning efficiently. So, in the SonicLiner, the high-bypass turbofan will be used to reach high subsonic speeds of about 800km/h after which the blades of the fans will collapse in on the shaft thereby providing little resistance to the incoming air. The design of the engine is such that once the blades collapse, it functions like a ramjet and can work efficiently at supersonic speeds.

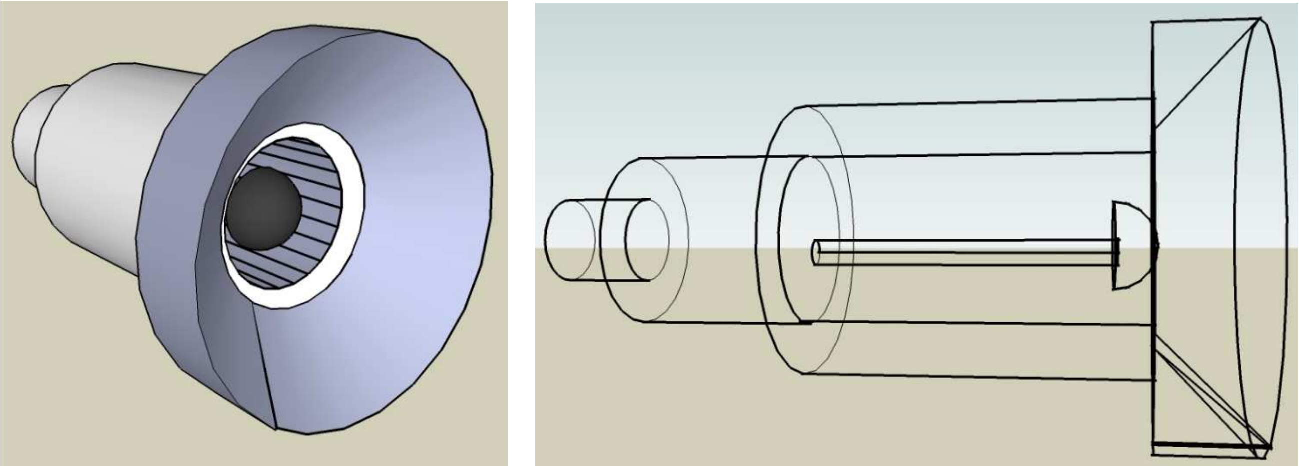


Figure 4. Computer models showing the Ramjet mode (with the turbine blades collapsed onto the shaft) of the TurboRam engine used in the SonicLiner.

3 Aerodynamic Concerns

3.1 Fuselage

For the design of the fuselage, the Whitcomb area rule, also called the transonic area rule was adopted. It is a design technique used to reduce an aircraft's drag at transonic and supersonic speeds, so to reduce the number and power of shock waves, an aerodynamic shape should change in cross-sectional area as smoothly as possible. This leads to a "perfect" aerodynamic shape known as the Sears-Haack body, roughly shaped like a cigar but pointed at both ends. The SonicLiner's fuselage is not exactly like the Sears-Haack body because of the blunt nose in the front but the cross-sectional area does change very smoothly. The area rule also holds true at speeds higher than the speed of sound, but in this case the body arrangement is in respect to the Mach line for the design speed. For example, at Mach 1.3 the angle of the Mach cone formed off the body of the aircraft will be at about $\sin \mu = 1/M$ (μ is the sweep angle of the Mach cone). In this case the "perfect shape" is biased rearward, which is why aircraft designed for high speed cruise tend to be arranged with the wings at the rear. The SonicLiner falls exactly in line with the predictions of theory. So the wings are situated at the rear to minimise drag and shockwaves. Another good example of this design is the Concorde as well. The fuselage of the SonicLiner is unique in the way that the cross-sectional area first increases and then decreases. However, the change in the cross-sectional area has been kept very gradual and smooth in accordance with the Sears-Haack body. This is because it has been shown that such designs actually produce the least amount of vibrations and disturbances on the surface of the aircraft.

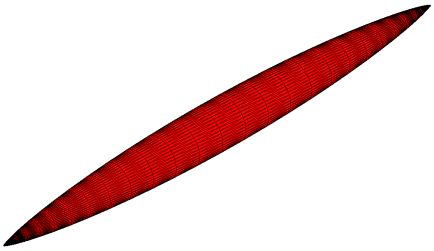


Figure 5. Sears-Haack Body

(Source: http://triaero.sourceforge.net/-Sears-Haack.png)

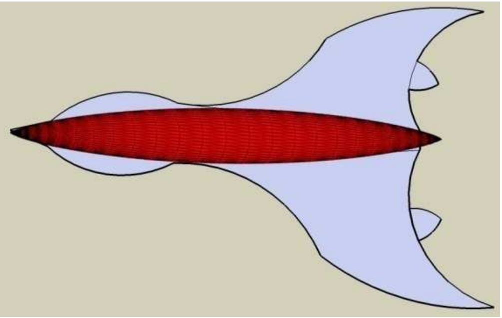


Figure 6. A model showing that although the fuselage of the SonicLiner is not exactly in shape with the Sears-Haack body, the change in cross-sectional area is smooth, identical to the Sears-Haack body.

Owing to the unique design of the SonicLiner, it can generate lift from both the wings as in conventional aircraft as well as the fuselage. A longitudinal section of the fuselage shows that how it has been designed as an aerofoil too. This shape helps the SonicLiner to generate even more lift, making it more efficient, especially when the aircraft is in climb mode. The fuselage also provides least resistance to air flow due to its aerofoil-like shape.

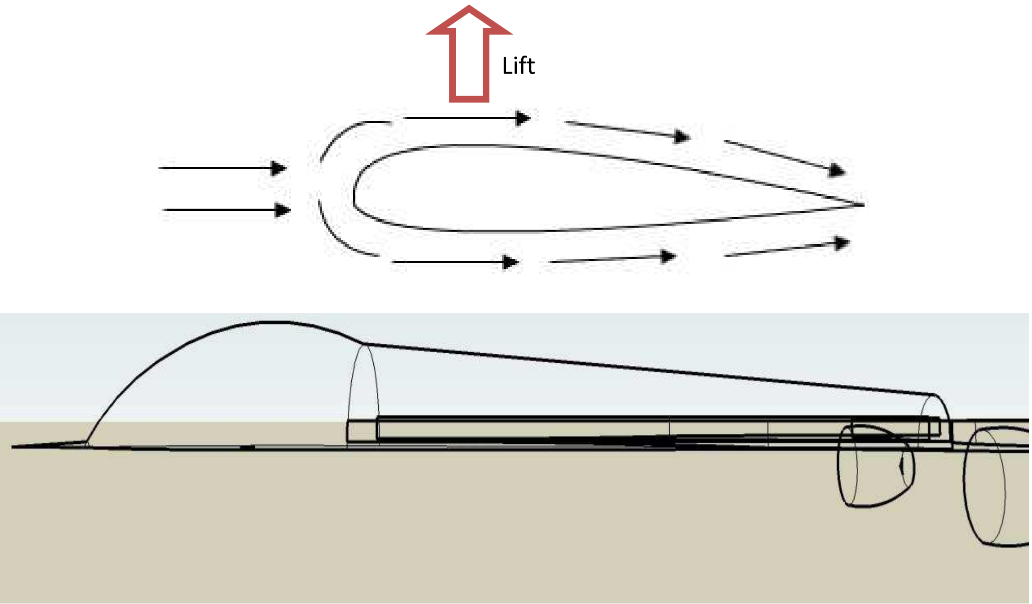


Figure 7. Computer illustrations showing how even the fuselage of the SonicLiner helps in generating lift and providing less resistance to the air flowing past it.

3.2 Wings

3.2.1 Wing Sweep

The fastest bird on the planet in (terms of level flight) is the Spine-tailed swift while the peregrine falcon is the fastest when it is stooping (diving). This was the inspiration for the swept-back wings for the SonicLiner.

Figure 8. Swept back wings of a peregrine falcon

(Source: http://farm4.static.flickr.com/3220/-2592634463_8215a4cba4.jpg)

Figure 9. Swept-back wings in a Spine-tailed swift

(Source:http://www.birdsinbackyards.net/images/factsheets/full/Hirundapus/caudacutus/-2892whitethroatedneedletail_cropped.jpg

Some of the reasons are for using the swept-back wings are:

- Aerodynamically efficient with low disturbances being produced. They also reduce wave drag significantly.

- Produce little sonic boom as compared to others designs. This so because the wing sweep helps reduce the strength of the oblique shock wave produced from the leading edge of the wing.

- Better suited from the point of view of thermal heating.

- Swept-back wings also increase the stability of the aircraft.

3.2.2 Aspect Ratio

Besides this, the wings for the SonicLiner have a rather small aspect ratio. The aspect ratio for a wing is given by $AR = \frac{b^2}{S}$ where AR is the aspect ratio, b is the wing span and S is the wing area. A lower aspect ratio typically means that the aircraft has a lower moment of inertia and thus it is easier for the aircraft to roll over and the aircraft has higher manoeuvrability. However, because the aspect ratio is not too low, the SonicLiner does produce lower lift-induced drag which is low in wings with higher aspect ratios. The aspect ratio of the SonicLiner comes out to be around 8.5 which is a rather moderate value.

3.2.3 Lift

The equation for the lift generated is given by

$$L = \frac{1}{2}\rho v^2 A C_L$$

Where L is the lift force, ρ is the fluid density, v is the true airspeed, A is the area of the plan form and C_L is the lift coefficient for the given angle of attack, Mach number and Reynolds number. For the SonicLiner, the most notable features are that the airspeed is typically higher, the plan form area is comparatively larger as well which directly transfers to a greater lift. Hence, higher altitudes can be efficiently reached and the aircraft can reach cruise speed efficiently as well as cruise efficiently once it has reached the cruise speed.

In other words, since lift is directly proportional to the product of the amount of air bent around wings per time and the vertical velocity of the air behind the wing, an obvious way of improving the wing's efficiency is to increase the amount of air diverted by the wing. If more air is diverted then vertical velocity of the air is reduced for the same lift and so is the induced power. This is done by increasing the size of the wings.

However larger wings could mean higher aspect-ratios but since, the SonicLiner's wings have a moderate to low aspect-ratio and are large, they can generate more lift and yet have high manoeuvrability.

4 Sonic Boom Concerns

There were several measures taken so that the sonic boom produced by the SonicLiner is considerably reduced as compared to the Concorde and other supersonic aircrafts. This lessened sonic boom will enable the SonicLiner to fly over urban areas as well as not violate sound regulations in the aviation industry.

Richard Seebass and his colleague Albert George at Cornell University studied the problem extensively and eventually defined a "figure of merit" (FM) to characterize the sonic boom levels of different aircraft. FM is a function of the aircraft weight and the aircraft length. The lower this value, the less the boom the aircraft generates, with figures of about 1 or lower being considered acceptable.

- The SonicLiner's length which is supplemented by the extendable tip of the nose has been designed such that the FM for the SonicLiner is only a little more than 1. There is an improvement of over the 1.4 of the Concorde.

- Moreover, the swept-back wings design of the SonicLiner helps reduce the N-wave sonic boom that reaches the ground and makes supersonic flying problematic for people on the ground.

- As a final measure, the wingspan of the SonicLiner has been designed bearing in mind that sonic booms are reduced for aircrafts that have not too large wingspans.

The fuselage of the SonicLiner is very sleek and with enough angle of attack and wing span the plane can fly so high that the boom by the fuselage is not important. The larger the wing span, the greater the downwards impulse which can be applied to the air, the greater the boom felt. A smaller wing span favors the SonicLiner and helps reduce the boom.

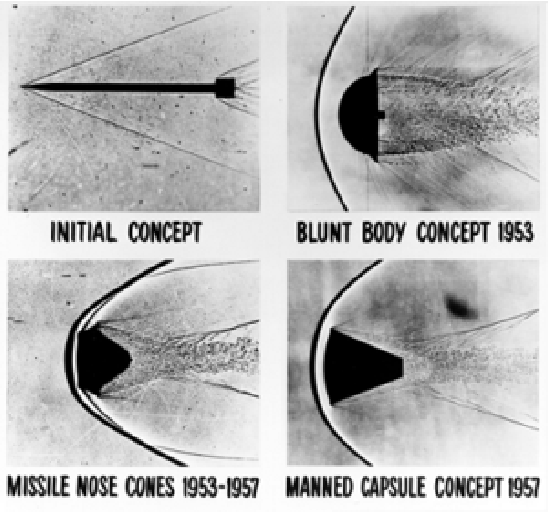
Seebass-George also worked on the problem from another angle, trying to spread out the N-wave laterally and temporally (longitudinally), by producing a strong and downwards-focused shock at a sharp, but wide angle nosecone, which will travel at slightly supersonic speed (bow shock), and using a swept back flying wing or an oblique flying wing to smooth out this shock along the direction of flight (the tail of the shock travels at sonic speed). The swept-back wings of the SonicLiner fall in line with their work.

As a last measure, the SonicLiner uses a very new and creative method for reducing sonic booms which has been dubbed the "*Quiet Spike*". The lance-like spike in front of the nose of the plane which is supposed to reduce sonic booms was developed by Gulfstream Aerospace and NASA's Dryden Flight Research Center [2].

5 Thermal Concerns

5.1 Design

Upon atmospheric re-entry, the greatest concern is that the nose and especially the tip of the aircraft are under tremendous heat and pressure. This may result in extensive damage and maybe even disintegration as in the case of the Columbia disaster. Therefore, the SonicLiner uses a design that is suitable for atmospheric re-entry for a supersonic jetliner. It uses a blunt nose shape that spreads the heat more evenly and research has shown that the blunt nose is the best shape for minimising heat-transfer concerns. From simple engineering principles, Allen and Eggers showed that the heat load experienced by an entry vehicle was inversely proportional to the drag coefficient, i.e. the greater the drag, the less the heat load. Through making the re-entry vehicle blunt, air can't "get out of the way" quickly enough, and acts as an air cushion to push the shock wave and heated shock layer forward (away from the vehicle). Since most of the hot gases are no longer in direct contact with the vehicle, the heat energy would stay in the shocked gas and simply move around the vehicle to later dissipate into the atmosphere. The schematic below compares the various nose shapes as far as heat-transfer is concerned.



(Source: http://upload.wikimedia.org/wikipedia/commons/thumb/2/23/Blunt_body_reentry_shapes.png/300px-Blunt_body_reentry_shapes.png)

Figure 10. Shadowgraph images of different nose shapes in atmospheric re entry simulations

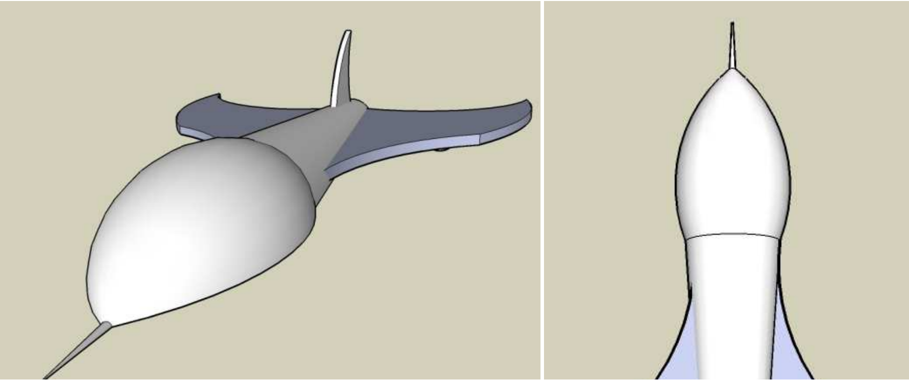


Figure 11. Computer models of the blunt nose of the SonicLiner

5.2 Carbon Nanotubes coating

Usually one expects to have ceramic tiles to protect the aircraft's tip from thermal damage. In space shuttles as well as entry vehicles, ceramic tiles are used. However, the SonicLiner uses carbon nanotubes as the ultimate thermal protection. Carbon nanotubes have been shown to have amazing tolerance to heat with them being able to withstand temperatures in the region of 2800 degrees Celsius in vacuum and about 750 degrees Celsius in air. Thus, carbon nanotube coatings are used at the thermally more vulnerable spots such as the tip of the nose and the tips of the wings. This diagram shows where the carbon nanotubes coating are put to use.

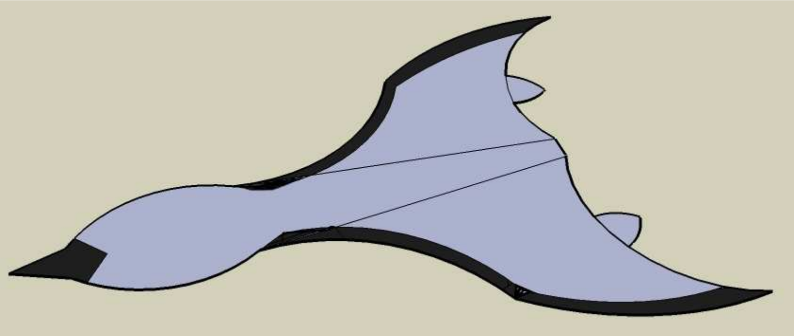


Figure 12. A computer generated model of the areas where the aircraft is coated with carbon nanotubes

6 Structural Features

The SonicLiner has been designed to be both efficient as well as powerful. Thus, it is crucial that the right structural materials be used for the SonicLiner. The material should be chosen such that it is very strong and should also be quite lightweight so that the whole weight of the SonicLiner is not more than 125,000kg.

For these required properties, the use of carbon nanotubes as well as lightweight Aluminium has been proposed. The following are the main reasons of making this choice:

- Aluminium is relatively cheaper and alloys of aluminium are typically light and easy to work with
- Carbon Nanotubes are exceptionally strong. Their tensile strength is twice that of titanium. They are not only great thermal insulators but also lightweight and are quite cheap to produce.

Keeping in mind that the SonicLiner needs to be economical and also commercially feasible, it would be built from aluminium. The main fuselage and wings will be made up of light and strong aluminium or one of its alloys like Duralumin.

However, carbon nanotubes will be used in areas that are particularly susceptible to high amounts of stress as well as thermally vulnerable. These areas typically include the tip of the nose and of the wings. So, there will be a coating of carbon nanotubes in these areas or alternatively, a significant amount of carbon nanotube can be added to the alloy to increase the strength-to-weight ratio.

If in the near future, carbon nanotubes can be manufactured even more cheaply then they can be added to the main alloy of which the fuselage and the wings of the SonicLiner are made so that the whole body can be made stronger and lighter.

7 Environmental Concerns

7.1 Biofuel

There has been a lot of talk about having blended hybrid jet aviation fuels and the SonicLiner has taken it to a new level. The SonicLiner will be using fuel that is composed of partly conventional aviation fuel and biofuel.

As the research done at Baylor University [1] shows, ethanol shows promise as a biofuel to be used in aviation. Another alternative, *jatropha curcas* also exists. Either one can be used in proportion with conventional aviation fuel to make the SonicLiner more carbon neutral and more environmentally friendly.

Benefits of Ethanol are as follows:

- Much cleaner fuel as far as emissions is concerned.
- No lead is involved.
- Ethanol is substantially less expensive than jet fuel.
- Potential for longer time between overhaul.
- Domestically produced fuel in fields.
- A blended fuel might be more efficient as fuel in terms of energy per unit amount.

7.2 High Altitude Atmospheric Emissions

To curb the dangers to the environment due to high altitude emissions, a very effective and efficient method has been used for the SonicLiner. The engines have fitted filters to the end when the exhausts are released. This simply works like a sieve where the pollutants can be simply separated out so that they do not cause harm in the upper reaches of the Earth's atmosphere. However, it was noted that the exhausts would be travelling at a huge speed and under high pressure and high temperature. Moreover, the filters have to be effective so that their main purpose is not defeated. Thus, it was concluded that the most suitable materials for the filters would be carbon nanotubes. This is due to their unique molecular structures as shown in the schematic diagram below:

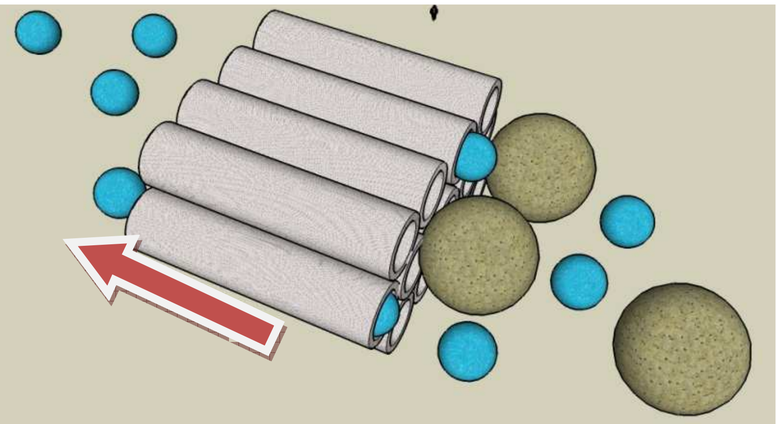


Figure 93. A computer generated model showing how carbon nanotube filters work at the molecular level. In this case, the flow is from right to left. The pollutants being larger (polyatomic) are retained while the smaller and simpler air molecules pass through

Moreover using carbon nanotube filters has the following added benefits:

- They are heat resistant and can withstand temperatures much higher than that of exhausts.
- They are quite cheap to manufacture and more effective as compared to other filters.
- They can be easily cleaned through processes like autoclaving, ultrasonication, using mild oxygen plasmas and laser cleaning.
- They are environmentally friendly and pose no threat to the environment unlike other non-biodegradable filters.

8 Future Research

The following aims should be kept in mind while considering the future developments regarding the SonicLiner:

- The engine should be tested and further improved. Specifically, the engine can be upgraded to one combining the high bypass turbofan with the more powerful, Scramjet engine that NASA has used in the X-43.
- The right fuel combination should be tested for the maximum efficiency.
- A possibility for providing the energy for the plane could be to fit solar panels on the wing areas of the plane so that they can generate eco-friendly energy for the aircraft while it is flying. The high altitudes at which the aircraft flies will be helpful towards the same.
- Aerodynamics can be improved through testing in the wind tunnel. The design should be tested for aerodynamics in extreme conditions of temperature as well like heat and snow.
- The sonic boom should be further reduced so as to ensure comfort to people living near airports.
- The structural properties can be improved either by using more carbon nanotubes or finding other suitable materials like composites or polymers that can not only reduce the cost but also provide more strength while reducing the weight of the aircraft.

9 Conclusion

The SonicLiner has novel and innovative approaches to increasing efficiency and performance of supersonic aircrafts. However, it should be noted that due to limitations of capital and access to cutting-edge research facilities and wind tunnels, no actual testing has been done on the designs of the SonicLiner. In theory, the SonicLiner promises to show amazing results but commercialisation will have to be preceded by extensive testing and experimentation. I hope that in the future, I do get some opportunities to test out my designs and conduct more research into developing an efficient supersonic aircraft.

10 Acknowledgements

I, Sainyam Gautam, would like to heartily thank all of the following people and organisations for their direct or indirect help in the completion of this project on the SonicLiner:

Dr. Nidhi Gautam, Parent and Adult Mentor

Mr. Lee Lih Juinn, Hwa Chong Institution, Faculty Advisor

Jing Xian Library, Hwa Chong Institution

Hwa Chong Institution, Singapore

I would also like to acknowledge that I generated all the computer models featured in this report with the help of the software Google SketchUp developed by Google Inc. and would like to thank Google Inc. for the same.

Reference

- **Biofuel** - http://www.eri.ucr.edu/ISAFXVCD/ISAFXVPP/IBAGAM.pdf
- **Quiet Spike** - http://www.aiaa.org/events/aners/Presentations/ANERS-Henne.pdf
- **Atmospheric Re-entry** - http://en.wikipedia.org/wiki/Atmospheric_reentry
- **The Concorde** - http://en.wikipedia.org/wiki/Concorde
- **Supersonics** - http://www.aeronautics.nasa.gov/nra_pdf/sup_proposal_c1.pdf
- **Carbon Nanotube Filters** - http://npg.nature.com/nmat/journal/v3/n9/pdf/nmat1192.pdf
- **High Speed Propulsion** - http://www.energy.kth.se/courses/4A1346/2ndLecture/KTH%20High%20Speed.pdf
- **Supersonic Area Rule** - http://naca.central.cranfield.ac.uk/reports/1956/naca-report-1284.pdf
- **Atmospheric Re-entry** - http://naca.central.cranfield.ac.uk/reports/1958/naca-report-1381.pdf
- **Sonic Boom Reduction** - http://aero-comlab.stanford.edu/Papers/iutam02.pdf
- Mack R.J, Needleman K. E, “A methodology for designing aircraft to Low Sonic Boom Constraints” (1991) NASA Technical Memorandum 4246
- Kermode A.C. (1999), Mechanics of Flight (10th ed.), Longman
- Anderson, John D. (2004), Introduction to Flight (5th ed.), McGraw-Hill
- McCormick, Barnes W, Aerodynamics, Aeronautics, and Flight Mechanics
- Anderson David F, Eberhardt S, (2001), Understanding Flight, McGraw-Hill

I hereby certify and affirm that all the above work on the project entitled “SonicLiner – A commercial supersonic aircraft” is the original work of the student author, namely, Sainyam Gautam.

Dr. Nidhi Gautam, Adult Mentor