Abstract:

This essay outlines the design for the V-3, a supersonic aircraft which is expected to be a common mode of flying for civilian use by the year 2020. The V-3 will be able to meet the following set of criteria when put into production:

Cruise speed: Mach 1.6
Range: 4,000 nautical miles (4,600 miles)
Effective payload: 40 passengers
Fuel efficiency: 3 passenger-miles per pound of fuel
Take-off field length: < 10,000 feet

In addition to the above characteristics, the V-3 will also be introduced as the most efficient supersonic aircraft created, meeting all ecological standards and passing noise emission tests, both at airports as well as during flight. The V-3 will address key issues/problems facing present supersonic aircrafts such as sonic boom reduction, propulsion and aerodynamic airframe efficiency. The V-3 is also expected to be able to transport passengers from one place to another faster than any commercial aircraft present in civil aviation today, without causing undue damage to the environment. Furthermore, this project also proposes a civil aviation system to be formed by the year 2020 which will pave the way for the V-3 and other supersonic aircrafts to navigate the skies with as little interference to the communities below them as possible.

1. Methodology:

This section will provide a brief overview of the methodology used in this project.
All references, materials and research used in this essay are obtained from textbooks and websites on basic, advanced and supersonic aerodynamics. The author has cross-referenced all research data for purposes of surety of information used. The project will mainly use existing concepts of supersonic flight, along with self-generated ideas which are yet to be tried or tested. However, these ideas are based on sound aerodynamic and physical principles. The project and the aircraft design described therein has not, to the best of the author's knowledge, used patented ideas and any reference to, or mention of, an intellectual patent has been checked to make sure it is legal to reproduce it. This paper will follow a standard format for topical research essays.

2. Introduction:

October 14, 1947. Airman Chuck Yeager created history and opened up a whole new sky when he throttled the rocket-powered *Bell X-1* beyond the speed of sound. The day would surely come when civilians too could "break the sound barrier". And so it did. The Concorde revolutionized the way people view passenger transport by way of an aircraft that could travel at over two times the speed of sound. However, on 26th November, 2003, the Concorde officially retired from service and no other supersonic passenger aircrafts remain today.
October 14, 2020. Enter the V-3. A hiatus of 17 years ends with the advent of a new supersonic aircraft which can revolutionize civilian air transport. The V-3 will be required not only to have unprecedented flight efficiency, but also to comply with international standards of ecological safety and noise levels in order to provide civilians with a safe, eco-friendly, economically viable mode of supersonic transport. This essay describes, as accurately as possible, the design for the V-3.

3. THE V-3: Structure.

3.1 Aircraft Design and structure:

The V-3 has a unique fuselage-and-wing configuration. The main structure follows from NASA's N-plus-2[1] idea for a silent, non-carbon-emitting aircraft. The wings of the aircraft are extremely large in comparison to normal 'tube-and-wing' designs seen in most passenger aircrafts today. The fuselage, however, is made much smaller because of lower payload requirements and this makes the wings the most significant component of the aircraft which is in contrast to most present day fuselage-centered models. This leads to an aircraft shape as shown in Fig. 1. The V-3 incorporates forward-swept wings in its design. The basic shape of the V-3 is an isosceles triangle with the nose of the aircraft flush in line with the tips of the wings. The reason for such a design is the increased stability at speeds at and beyond critical Mach. This will be explained further in Section 3.2.

[1] N-plus-2 is the second stage in NASA's project to create a silent carbonless airplane by the year 2020.

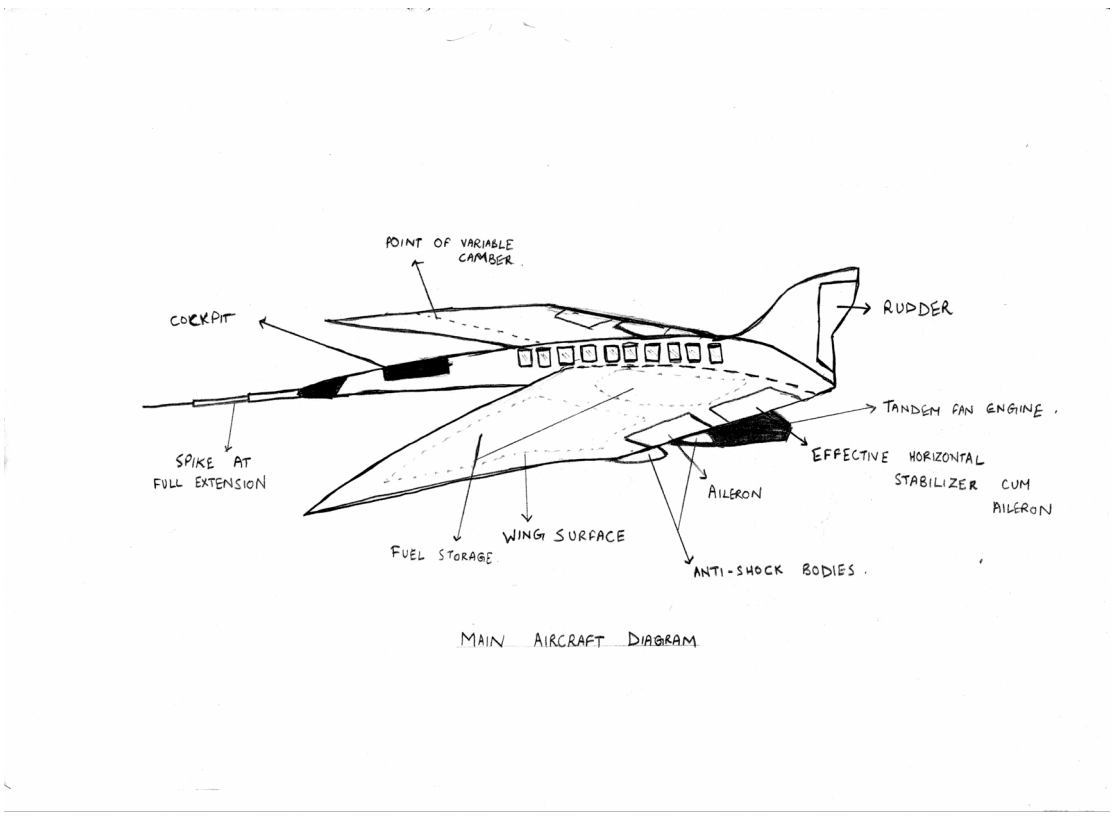


Fig. 1

One of the main requirements for a supersonic transport (SST) is that it must have as little rate of change in CSA as possible. According to the Whitcomb Area Rule, any discontinuities in the *total* cross-sectional area (CSA) of a body (and not necessarily the CSA of the fuselage) will increase the body's wave drag during transonic flight because shock waves are formed at these points. Therefore the perfect shape for any aircraft traveling at a transonic speed must follow an aerodynamically shaped cross-sectional frame called the Sears-Haack shape (The Sears-Haack body has the least rate of change of CSA in comparison to other shapes). However, the V-3's shape will follow a rear-skewed Sears-Haack shape because for supersonic aircrafts, the CSA must be the same along the line of the Mach wave lines[2] and not along the line perpendicular to airflow (parallel to wingspan). The V-3 is designed such that it's CSA exactly conforms to the Sears-Haack body for a supersonic aircraft of its cruise speed (Mach 1.6). This is done so that there is minimal wave drag experienced during flight.

The skin of the fuselage and wings of the V-3 are made not solely with an alloy of metals, but with CFRP[3]-reinforced duralumin. CFRP is light, highly tensile, has a very high modulus of elasticity and low thermal expansion capacity. It is also chemically inert. This makes it ideal as a material for fuselage since it can be used to build a light body and does not expand easily at supersonic speeds when skin friction leads to temperatures of about 100 degrees centigrade. However, CFRP has a major disadvantage. It is extremely brittle. In order to overcome this, it is mixed with duralumin. The duralumin forms a matrix for the CFRP chains and these chains are

[2] Mach Wave lines are the representative lines of the shock waves formed at supersonic speeds.

[3] Carbon Fiber-Reinforced Polymer is a material commonly used in airplane and helicopter bodies.

effectively embedded in the metal alloy. Duralumin is very sturdy and has a high melting point. It is not brittle and when reinforced with CFRP, can form a material that can safely be used for the aircraft wings, fuselage, and control surfaces. Because of its high tensile strength, the CFRP-reinforced Duralumin makes the final airplane skin material difficult to break, stretch or tear. During normal flight, the aircraft encounters several stray shards of particulate matter in the air which are potentially dangerous at such high speeds as Mach 1.6. The CFRP-Duralumin body is expected to be resistant to such impacts allowing for a safe flight.
The spike at the nose of the aircraft is extended only at supersonic speeds and remains extended until final descent and landing[4]. At super-cruise, the maximum extension of the spike is almost two-fifths of the total fuselage length. One of the most important aspects of the V-3's mainframe is it's wing surfaces. The wings provide optimum lift conditions both during subsonic and during supersonic flight (Section 3.2). The aircraft has no independent horizontal stabilizer but the operative horizontal stabilizers are placed at the base of the wings. Horizontal stabilizers are not used because if they are placed at the rear, the wings will have to be shifted forward to accommodate them which will change the isosceles triangle shape of the aircraft. At supersonic speeds, a canard wing system is difficult to use because smooth laminar flow is disrupted at the first wing surface which causes disturbances at the main wing. The vertical stabilizer, however, is placed at the rear end of the aircraft.

3.2 Wings:

A supersonic aircraft produces lift by shock waves produced at the ventral side and the expansion fan produced at the dorsal side of the wing. Fig. 2[5] shows this. However, these shock waves tend to lead to tremendous drag for the aircraft. One of the challenges of supersonic flight is to reduce this drag.
The wing system of the V-3 is optimized for supersonic flight. For super cruising, the most efficient airfoil is a roughly diamond shaped one. Most supercritical airfoils use this shape of airfoil. However, the V-3 will use a moderately thick, symmetrical airfoil. Symmetrical airfoils are superior to conventional airfoils because the overpressures created at the leading edges of the wings are comparatively much lower for the former (The NACA 4-digit description for the V-3's airfoil is 0007). Too thick an airfoil will cause extremely high wave drag in the transonic regime of flight because the local airflow above and below the wing will be highly supersonic. A very thin wing cannot be used either because there will be little space for storage of fuel. Therefore the V-3 will use an airfoil which has a maximum thickness equal to 7% of its chord length. The V-3's wing's have a relatively large area, meaning that the lift required can be produced at a much lower angle of attack[6]. Reducing the angle of attack reduces the horizontal component of force (drag) against the wing. In this manner, the V-3 is able to eliminate redundant drag during super cruise.

[4] The spike is explained later on in Section 4.2.1

[5] Fig. 2(b) is taken from the website mentioned in Reference no. 8

[6] Angle of attack is the angle between the airfoil and the direction of airflow as shown in Fig. 2 (b)

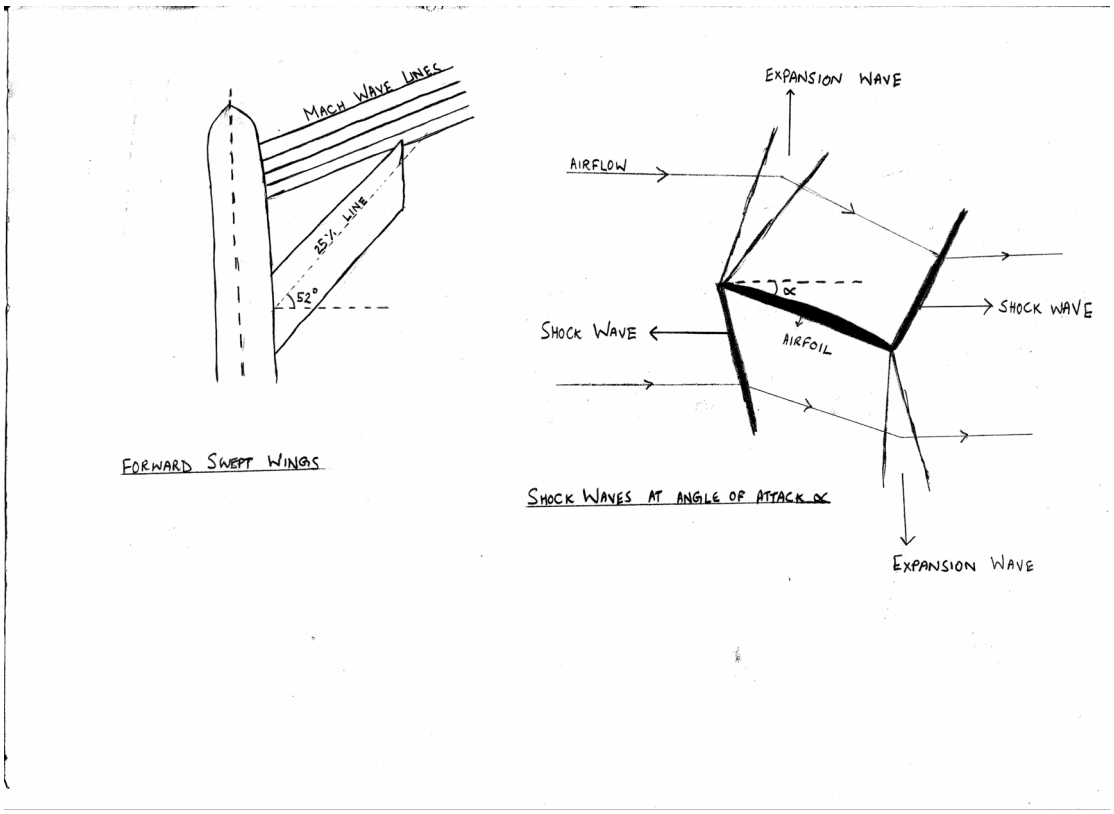


Fig. 2

A slight forward sweep is incorporated in order to reduce the effects of wave drag. The optimum angle of sweep is dependant on the aircraft's cruise speed, and for an average airspeed of Mach 1.6, this angle is about 52 degrees[7]. At this angle, there is minimal drag caused by shock waves produced at the leading edge because the Mach waves meet the wings at a critical angle as shown in Fig. 2(a). Forward swept wings also have a lower chance of stalling during flight and greater maneuverability especially at transonic and supersonic speeds because the air travels from the wing tips *towards* the fuselage and not away from it.

The wings will have variable camber to improve lift during take-off and landing, since symmetrical swept wings are unsuitable for subsonic travel due to their low lift coefficient (C_l). During take-off and landing, the leading edge and trailing edge of the wings will depress, while the plate A will form as the ventral side of the subsonic wing. This can effectively act as a subsonic airfoil in order to provide the required lift for low-speed flight.

The leading edge of the wings have flaps called C-flaps. These flaps are activated at speeds near the critical Mach of the V-3. At critical Mach, the centre of pressure of an aircraft shifts rearwards whereas the centre of mass does not experience any shift. Therefore, the nose of the aircraft tends to tip forwards. The C-flaps are used in order to provide an anti torque to keep the aircraft steady at that speed. The unique structure of the aircraft, the isosceles triangle, also leads to higher stability because the mass of the aircraft is more equally distributed along the line joining the midpoints of the wings than in structures of bygone SSTs like the Concorde. However, one of the main

[7] See reference No. 7

problems associated with using the C-flaps is that it leads to tremendous drag for an aircraft during transonic flight in the form of wave drag. Therefore, a secondary measure is necessary to ensure that the tendency for tipping of the nose is brought to a bare minimum. The fuel in the wings moves towards the base of the wings so that the centre of mass also shifts rearwards. This makes the required angle of incidence of the C-flaps much lower, leading to lesser wave drag.

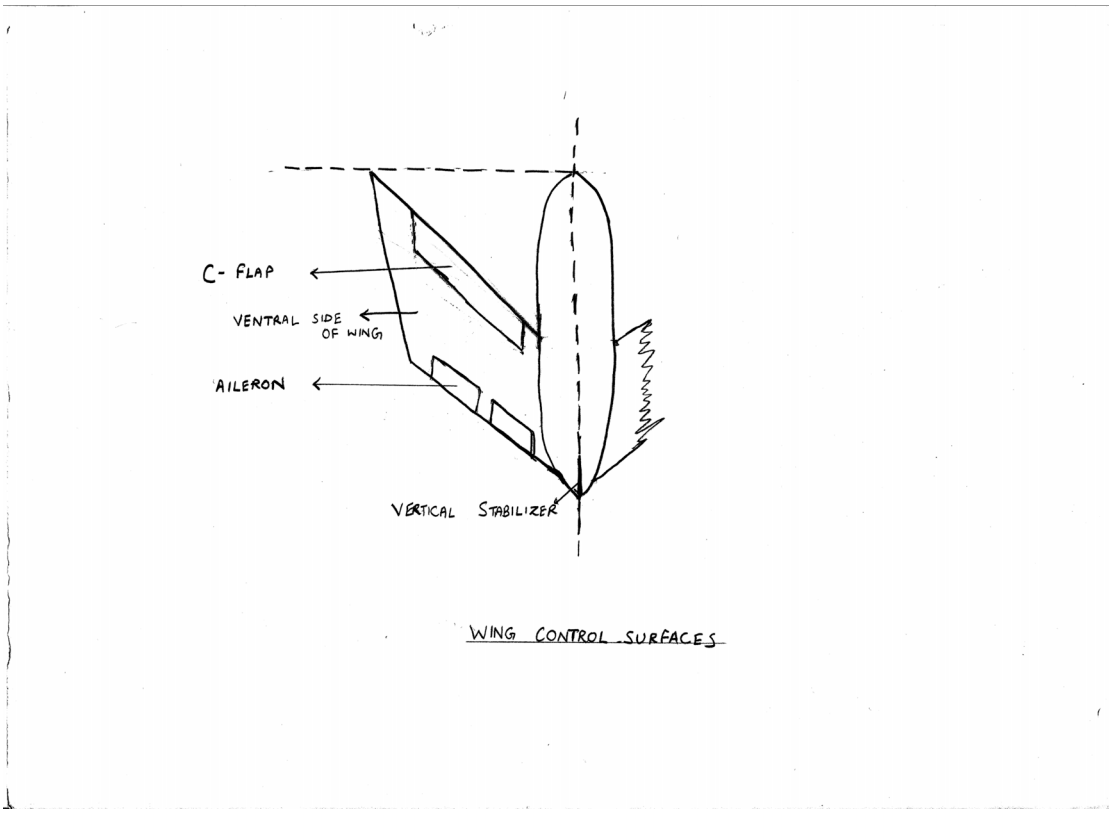


Fig. 3

3.3 Engines:

The V-3 will not use engines previously used for supersonic aircrafts like the Concorde and the Tupolev series. The use of Variable Cycle Engines (VCEs) will be relevant by the year 2020 and they have been proved to be the most efficient engines for mixed range flights. The V-3 will employ the use of a type of VCE known as the Tandem Fan Engine (Fig. 4). The tandem fan engine can work at a much lesser noise level than turbojets and even some high-bypass turbofans. They are efficient during all speed ranges of the V-3. During supersonic flight, the air flows through the primary fan and straight through to the second fan. However, at subsonic speeds, most of the jet flow from the first fan is allowed to bypass the rear fan and is released through a separate outlet. An auxiliary inlet T is used to allow air to flow in to the rear fan and exhaust gases are let out directly through the main nozzle N. This reduces the jet velocity, keeping the specific thrust constant, and therefore its noise emission at airports is greatly diminished.

The main engines are shown in figure 4 below. Most jet engines cannot take in air flow greater than Mach 0.6. This is because shock waves are produced at and around the walls of the engines. For the V-3, however, at subsonic speeds, the air flows into the engines directly, but at supersonic speeds, adjustable engine caps are moved into place. These caps allow the little air flowing in through the aperture to expand isentropically until the entry point of the first fan, and the air intake velocity is effectively reduced from the cruise speed of Mach 1.6 to the required Mach 0.5. The ratio of the diameter of the aperture to the point of inlet into the engine can be calculated[8] by using a simplified form of Bernoulli's equation for fluid dynamics and Pascal's Law for fluids:

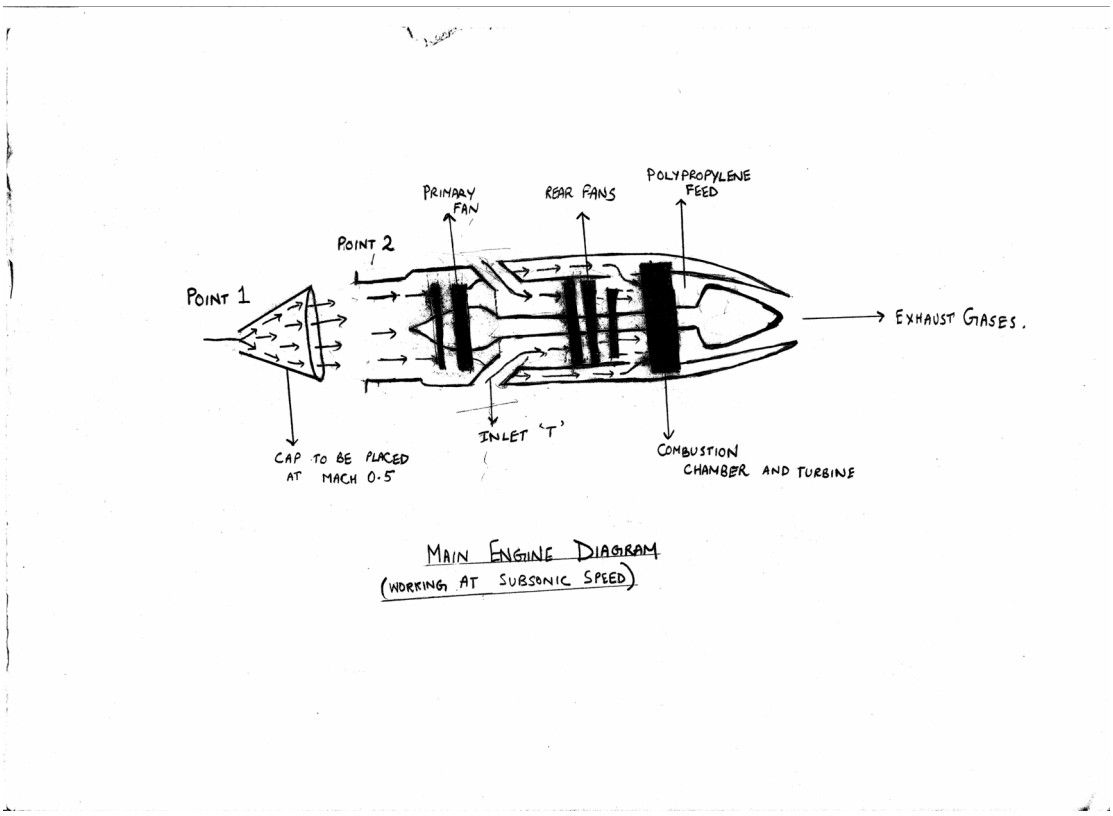


Fig. 4

Bernoulli's equation:

$$P_2 + \frac{1}{2}(dV_2^2) = P_1 + \frac{1}{2}(dV_1^2)$$

Pascal's Law for fluids:

$$P_1 \times A_2 = P_2 \times A_1$$

Where P_1 and P_2 are pressures of the gas at point 1 and 2,
d is the density of the inflow air,
A_1 and A_2 are the CSAs at the points 1 and 2.
And V_1 and V_2 are the velocities at points 1 and 2.

[8] The calculation involves solving for two ratios, given two equations. For sake of brevity, the actual calculation is not shown here.

V_1 and V_2 are Mach 1.6 and Mach .5 (in m/s) respectively
Exact values for P_1 and P_2 can be extracted from actual experiments in wind tunnels during the Research & Development stage of the aircraft.

3.4 Control Systems:

The V-3 is a Control Configured Vehicle which uses optical fibers to transmit signals from the cockpit to the control surfaces. Fly-by-Optics systems are used mainly because extremely precise measurements of aerodynamic forces and torques are necessary at supersonic speeds. Human reaction time is too high when compared to reaction times required for control during transonic and flight where airflow and shock wave formation is unpredictable. Fly-by-Optics is a new system of aircraft control in which optical fibers are used to transmit signals from the cockpit to the control surfaces. The negative aspect of a Fly-by-Optics system is the added weight of a computer to manage and network between the control surfaces. This will lead to fuel inefficiency, but the advantage of using a computerized control system supersedes the disadvantage of the increased weight in terms of superior flight performance and safety. Fly-by-Optics systems are advantageous over conventional Fly-by-Wire systems because electromagnetic waves from external sources do not affect the flight control signals.
The wing control surfaces of the V-3 are placed at the positions shown in Fig. 3. The ailerons are placed at one-third and two-thirds distance of the total wingspan and the C-flaps are shown on the underside of the wings. The vertical stabilizer has a full length rudder for better yawing ability.
During the transition from the subsonic regime to supersonic, the C-flaps will activate, allowing for a lift of the leading side of the aircraft. At transonic speeds, the powerful wave drag must also be overcome. In order to do this, the engines of the V-3 use afterburners during transonic speeds of about Mach .9 to .95 to push through the wave drag and into supersonic flight.

4. Airport Noise Control and Sonic Boom Reduction.

4.1 Airport Noise Control:

The main reason for a jet engine producing high levels of noise is that the flow of exhaust gases is turbulent. If the jet flow can be made laminar, it would considerably reduce noise emissions. Reynolds' number determines the characteristics of the fluid flow and it is given by:

$$Re = 2dVR/k$$

where d is density of fluid, V is fluid velocity, R is radius of nozzle, and k is dynamic viscosity of fluid.

In order to promote laminar flow, Reynolds' number must be low, and therefore, assuming ceteris paribus, k or dynamic viscosity must be increased. One method to increase viscosity of the exhaust fumes (mainly composed of CO_2) is by dissolving long chain carbon polymers in it. Therefore, at the exhaust nozzle, a continuous flow of liquid emulsions will be dissolved with the exhaust fumes and will exit the VCE. One example of a viable emulsion is polypropylene. It is an

ecologically harmless polymer and can be dissolved[9], along with a co-solvent, in gaseous CO_2. However, polypropylene is a solid at room temperature and therefore, it must be liquefied in order to be useful as a solvent. The excess heat from the engine can be removed using a coolant and this heat can be controlled and used to liquefy the polypropylene. This can be done without breaking the chain since the melting point of polypropylene is about 160 degrees centigrade whereas the decomposition temperature is 300 degrees centigrade.

4.2 Sonic Boom Reduction:

Sonic Boom reduction measures must be treated in an integrated manner. The two parameters of boom reduction are the aircraft and the community it affects. Hence, there are two ways of reducing the effect of sonic booms.

4.2.1 Boom reduction measures in aircraft:

Sonic Boom intensity is directly proportional to the acceleration of the air particles due to supersonic airflow around an aircraft. The fuselage and the wings of the V-3 are designed specially to decrease boom intensity. When the aircraft breaks the sound barrier, a spike extends from the nose of the aircraft. The spike will extend in front of the base of the isosceles triangle shape of the aircraft and therefore, this is the point at which the sonic boom forms. The spike initiates the sonic boom more gradually than the nose of the aircraft and also helps to "spread out" the sonic boom over a greater length of aircraft which together help reduce boom intensity considerably. The wings have a very thin leading edge; this means that, like the spike, it can initiate the sonic boom in a much more gradual manner, leading to lower boom intensity.

4.2.2 Boom reduction measures in community:

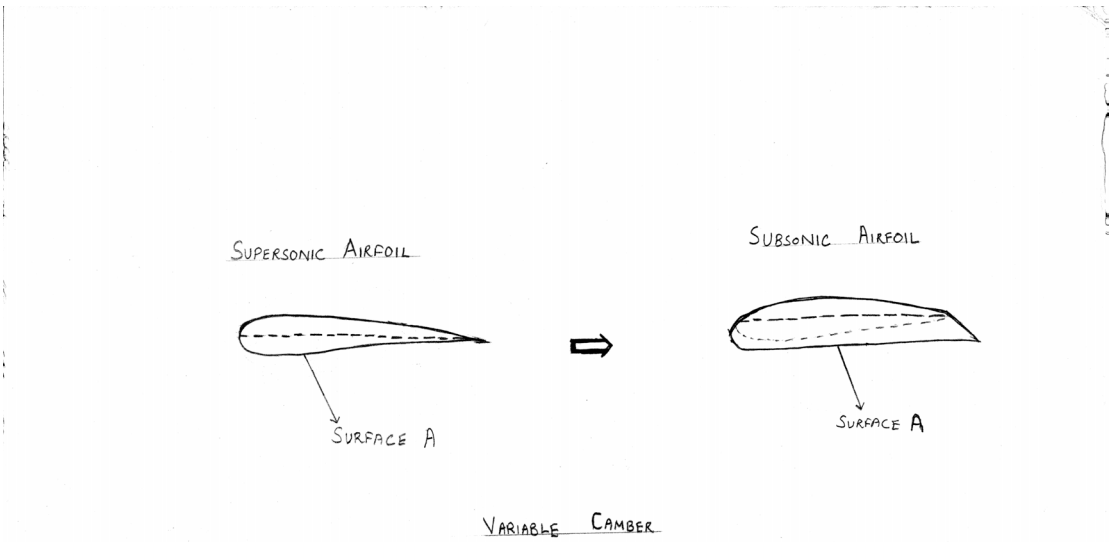
The success of the project to introduce supersonic travel as a viable mode of travel in the future is as dependent on aircraft manufacturing companies as the countries wishing to see it happen. Therefore, it is proposed that by the year 2020, a system be effected that consists of receivers-cum-transmitters placed on the surface of the Earth which can detect the characteristics of the sonic boom, and transmit sound waves which will cancel out the noise from the boom by using destructive interference of the shock wave. Even though the sonic boom does not have normal physical characteristics of a mechanical wave, it still has a frequency and amplitude. The boom reduction system can exploit these characteristics of the sonic boom, thereby reducing or completely eliminating its effect. This system works much like the modern day noise cancelling earphones which use Active Noise Control (ANC). Such a system, however, is not limited to sonic booms. It will be capable of eliminating or (lowering the volume of) *all* noises above a certain PLdB[10] which can be an added advantage to communities in the future.

[9] A good solvent for polypropylene is yet to be discovered, owing to its insolubility in most organic solvent. However, Tetrachloromethane can dissolve polypropylene to a sufficient degree.

[10] PLdB is a measure of *perceived* loudness as compared to decibels which measures noise intensity. PLdB takes into account loudness perceived indoors, outdoors and under varying climatic conditions. This makes it a better metric of sonic boom intensity than the decibel.

5. Flight characteristics:

The V-3 is designed for subsonic, transonic and supersonic flight. During subsonic flight, (mainly take-off, climbout and landing) the V-3 sports a subsonic wing. Consequently, at these speeds, the V-3 uses equations for lift according to subsonic airfoils. The subsonic wing is shifted to a supersonic one during the transonic flight with the help of the variable camber wing (shown in the figure below).



A regular wide body passenger jet has a take off field length requirement of 8,000 to 13,000 feet. The V-3 requires much less runway length because the large wing area in relation to the size of the fuselage produces much higher overall lift than those of conventional aircrafts. The V-3 is also lighter in terms of mainframe weight, and therefore, can also take off with much less lifting force. This lifting force, therefore, can be produced with less runway length. The V-3 has high aerodynamic efficiency, leading to lower form drag and parasitic drag.

The V-3 is expected to carry about 40 passengers for a distance of roughly 4600 miles. At 3 passenger-miles per pound of fuel, that equates to about 61,350 pounds of fuel. This fuel can be stored in the wings of the aircraft and at rear end of the base of the fuselage.

The V-3, being a supersonic aircraft, must encounter as little form drag as possible during flight. Assuming that the wetted surface area is kept constant, the only other parameter that can be changed is the altitude at which the aircraft flies. The higher the aircraft flies, the lower is the drag associated with it's motion through that particular airframe. Another advantage of flying at a higher altitude is that the intensity of sonic booms decreases with increasing altitude. However, the V-3 cannot fly at too high an altitude because of passenger safety concerns like cosmic ray radiation and prolonged exposure to high levels of ultra-violet ray radiation. Also, the oxygen levels start

decreasing with increasing altitude. In the absence of oxygen, the CFRP chains can be decomposed thermally. In order to maintain safety standards, the optimum altitude for the V-3 is about 50,000 feet above sea level. Most supersonic aircrafts travel at a higher altitude but the V-3's low parasitic drag allows it to work efficiently even at as low an altitude as 50,000 feet.

6. Flying the V-3 in 2020:

If the V-3 is to be used a viable mode of supersonic transport by the year 2020, changes must be effected in the aviation infrastructure of all countries involved in the project. The primary reason for this is that sonic booms created by supersonic aircrafts may cause noise pollution in all geographical lands which are swept under the boom carpet. The use of ANC systems to cancel oncoming sonic booms will be a necessary measure for all these landforms because of the need to comply with international regulations on noise emissions.

Another modification in infrastructure required to integrate the V-3 into civil aviation is that airports must be able to house and manage the aircraft. This will mean that airports must widen their runways, have ground support crew to help the V-3 taxi off the runway (the engine of the V-3 is highly inefficient on the runway during positioning and taxiing, much like the Concorde) and locate runways further away from main terminals for minimum disturbance at the airports.

The V-3, with its expensive in-flight equipment, sophisticated technology and seemingly redundant environment-friendly measures will prove much more expensive to the common man than regular jet air travel. This may raise concerns about the economic viability of such supersonic air travel. However, the primary aims of the V-3 are to provide a safe, comfortable, ecologically stable method of flying at supersonic speeds in the near future. Undoubtedly, traveling supersonic will be more expensive, but the V-3 aims to reduce passenger expense without compromising on primary aspects such as flight safety, and environment-friendliness. The high fuel efficiency of the V-3 will mean that the per capita cost for this sector is much lower. Another segment where the V-3 will be able to cut costs is in travel comfort. Most present-day airliners have high overhead charges because of luxury interior designs and extra comfort features for passengers. The V-3 will reduce costs here as it is designed to provide a balance between passenger comfort and cost. The maximum time of flight for the V-3 is about 4 hours and therefore, passengers will be able to reach their destination in a manageable period of time.

7. Future Avenues:

The V-3 has been conceptualized and designed in the year 2009. Technological advancements, however, take place every year and the advent of these new technologies can certainly be incorporated into the design of the V-3 insofar as it does not clash with its performance and ecological goals. The concept of variable cycle engine is still new and there is great potential for expansion in this field of propulsion. NASA's Supersonics Project continually aims to improve practical designs for supersonic flight models through various avenues of research such as Sonic Boom Modeling and Multidisciplinary Design, Analysis and Optimization. This and other projects will undoubtedly contribute to the design of the V-3 in years to come. The V-3 project team will be required to conduct many further hours of testing, research and experiments in order to make this idea a reality.

8. Conclusion:

Keeping the primary concerns of safety, environment friendliness and flight efficiency in mind, the V-3 is designed in order to be a viable mode of transport by the year 2020. It's ability to provide supersonic air travel open to passengers without damaging the environment will make it a good example of sustainable development, one of the thrust areas of world progress today. It is hoped that by the year 2020, all countries concerned with the project to make sustainable supersonic flight a reality can agree to a universal standard in terms of flight parameters like noise and emission levels. If the official retirement of the Concorde was a step backward in aviation history, then the arrival of the V-3 will be a bigger step forward; a step that man can look back upon as the beginning of a new era in aviation history.

9. References:

1) Ilan Kroo. "Applied Aerodynamics: A Digital Textbook". Desktop Aeronautics, Inc. January 2007. <http://www.desktopaero.com/appliedaero/preface/welcome.html>

2) Peter Coen, Mary Jo Long-Davis, and Dr. Louis Povinelli. "Fundamental Aeronautics Program, Supersonics Project, Reference Document". National Aeronautics and Space Administration. 26 May, 2006. <http://www.aeronautics.nasa.gov/nra_pdf/sup_proposal_c1.pdf>

3) Carlo Kopp. "Artificial Stability and Fly-by-Wire Control". Australian Aviation and Defence Review. 2005. <http://www.ausairpower.net/AADR-FBW-CCV.html>

4) Deborah Bazar. "The work of wings". Virtual Skies interactive tutorial. <http://virtualskies.arc.nasa.gov/vsmenu/vsmenu.html>

5) Don Baals, Warner Robins and Roy Harris, "Aerodynamic Design Integration of Supersonic Aircraft", Journal of Aircraft, Vol. 7, No. 5, pp. 385-394

6) (Anonymous) "Chemical Fact Sheet: Polypropylene". Orica Limited. October 1992. <http://www.pacia.org.au/_uploaditems/docs/3.polypropylene.pdf>

7) Carl Knowlen. "High Speed Flight". Department of Aeronautics and Astronautics, <http://www.aa.washington.edu/courses/aa101/Lectures/aa101_19-highspeed.pdf>

8) (Anonymous) "How do Lift and Drag Work at Supersonic Speeds?" Website of the Smithsonian National Air and Space Museum. February, 1999. <http://www.nasm.si.edu/exhibitions/GAL109/NEWHTF/HTF525.HTM>

9) Ilan Kroo. "Propulsion Systems: Basic Concepts". Aircraft Aerodynamics and Design Group, Stanford University. January, 1999. <http://www.nasm.si.edu/exhibitions/GAL109/NEWHTF/HTF525.HTM>

10) Dr. Robert M. Enick. "A Literature Review of Attempts to Increase the Viscosity of Dense Carbon Dioxide". Website of the National Energy Technology Laboratory. October, 1998. <http://www.netl.doe.gov/publications/others/techrpts/co2thick.pdf>

11) Dmitri Kopeliovich. "Carbon Fiber Reinforced Polymer Composites". Substech. September, 2008. <http://www.substech.com/dokuwiki/doku.php?id=carbon_fiber_reinforced_polymer_composites>

12) "Theories of Flight (Aerodynamics)". U.S. Centennial of Flight Commission. <http://www.centennialofflight.gov/essay_cat/9.htm>

13) Jeff Scott. "Area Rule and Transonic Flight". Aerospaceweb.org. November, 2002. <http://www.aerospaceweb.org/question/aerodynamics/q0104.shtml>

14) Jennings Heilig. "What's the angle?". March, 2003.

15) (Anonymous) “Concorde-Jet”. TREBOSC. 2006. <http://www.concorde-jet.com/e_vols.htm>*

16) (Anonymous) “The Problem”. Undated. <http://www.cebuanderson.com/problem.htm>

17) Jim Hodges. “The Quest: A Silent, Carbonless Airplane”. NASA Langley Research Centre. February, 2009. <http://www.nasa.gov/centers/langley/news/researchernews/rn_colliergreenbag.html>

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