CHAPTER 6

CONCLUSION AND FUTURE WORK

The performance of the Busemann biplane is very favorable at designed Mach number with a negligible wave drag at $M_\infty = 1.7$, but has undesirable aerodynamic performance at off design conditions due to flow chocking and subsequent increase in wave drag. Extensive literature reviews show that the chocking occurs over the wide range of freestream Mach numbers from 0.5 to 1.6. In this regard, the effect of stagger on the aerodynamic characteristic characteristics of a Busemann biplane is investigated numerically using coupled Navier-Stokes Solver for Mach numbers ranging from 0.5 to 2.5. The pseudo-steady state shock structure and resulting lift and drag coefficients are studied for various staggered configurations wherein the lower element of the Busemann biplane is shifted backwards by a distance of 0.1c, 0.2c, 0.3c, 0.4c and 0.5c from its original position. It has been observed that the subsonic and low supersonic aerodynamic characteristics of the Busemann biplane can be greatly improved by the staggering of biplanes. The Busemann biplane which shows extremely reduced drag at the design Mach number of 1.7, exhibits undesired aerodynamic characteristics at off design Mach numbers, especially below 1.7. The chocking phenomena seen in Busemann biplane for a Mach number of 1.6, is alleviated by a stagger of 02.c or more. At lower supersonic Mach numbers, although the choking is not completely eliminated by staggering, the shock wave attached to the leading element is weaker than a bow shock and thus a reduced drag is observed at all Mach numbers. The advantage of using stagger is highly justifiable in the subsonic range where not only the drag is reduced significantly, but a substantial increase in lift is observed. The staggered configuration have shown a consistent list due to lower element suction even at 0^{o} angle of attack giving L/D ratios of up to 12. The reduction in drag increases with increase in stagger, however the increase in lift diminishes with increasing stagger. The L/D ratio or the aerodynamic efficiency however, in subsonic and transonic range is significantly higher than those for Busemann biplane at all angles of attack. For staggered configurations at Mach numbers between 0.5 And 1.6, an increment of 175% to 67% in L/D ratios is observed at $\alpha = 3^{o}$. At Mach 1.7 and higher, the Busemann outperforms all staggered configurations because of small wave drag of the Busemann biplane and negative lift shown by staggered configurations, especially at $\alpha = 0^{o}$.

In supersonic flow, the shock waves are generated at the sharp edge, hence the pressure at the sharp edge becomes very large and generate large amount of force at the sharp edge. The edge of the element must be strong enough to resist the pressure increment by the shock waves; therefore it is necessary to use the rounded leading edge. The numerical simulations are done for different leading edge and trailing edge radius (1mm, 2mm, 3mm and 5mm) for the Busemann biplane as well as for the different staggered configurations. It is found that the drag coefficient is decreased with the increasing leading edge radius for the subsonic range, and remains constant for $1.0 \leq M_{\infty} \leq 1.6$, as flow remains subsonic in front of the elements due to bow shock waves in front of the elements. But in case of supersonic condition the wave drag is increased as the strong bow shock is induced in front of the elements. For different leading edge and trailing edge radii at Mach numbers between 0.5 to 1.0, an decrement of 11.45% to 27% and for supersonic Mach number of 1.7 to 2.5, an increment of 67% to 200% in drag values are observed at $\alpha = 0°$.

In summary the staggering of biplanes dramatically improves the aerodynamic efficiency of the biplanes at subsonic Mach numbers and at supersonic Mach numbers below design Mach numbers. Adding rounded leading and trailing edges to enforce structural strength does not seems to diminish the advantages of staggered biplanes at Mach numbers below the design Mach number of 1.7. The aerodynamic efficiency of the biplanes is slightly improved at sub-design Mach numbers with the use of rounded leading and trailing edges. This improvement comes primarily due to reduction in drag and a mild increase in lift at positive angles of attack. At supersonic Mach numbers above design Mach number, the roundedness of the leading and trailing edges causes a large increase in wave drag which deteriorates the performance of the staggered biplanes. Nevertheless, the staggered biplane configurations with rounded leading and trailing edges are suitable candidates for supersonic transport aircrafts to alleviate the sub-design Mach number performance as the airplane has to spend a lot of its mission time at subsonic Mach numbers.

The final integration of the staggered biplane concept for the right amount of stagger can be based on the drag calculation for full aircraft with three dimensional practical wings with various combinations of other geometric parameters. Nevertheless, the stagger provides a mechanism of reducing the starting Mach number for supersonic biplane and provides favorably low drag for wide range of Mach number. Thus for a future supersonic aircraft designated to fly with a biplane, the staggered configuration should certainly be given a chance because of its consistent better aerodynamic characteristics at Mach numbers encountered from take-off to cruise. If structurally sustainable, the supersonic biplane can use variable stagger from take-off to cruise and finally reconfigure back to the original Busemann biplane configuration while flying at design Mach number of 1.7. By using a variable stagger the biplane can be accelerated to the design Mach number without suffering the disadvantage of high wave drag and thus the staggered biplanes are a strong candidate in the development of the nearly boomless supersonic transport aircraft.

This investigation focuses only on two aspects of supersonic biplanes and further comprehensive investigation is required before integrating the concept into practical application. The concept of must be investigated from the multidisciplinary point of view including but not limited to structural integrity and stability and control point of view. As far as the aerodynamics of supersonic biplanes, the future work can be carried out in following directions.

(a) As the current investigation focuses on two dimensional results, the effects of three dimensionality of the flow on shock wave interactions between the staggered biplanes and thus aerodynamic characteristics must be studied.

(b) For the variable stagger biplane configurations, wherein the stagger can be changed during flight, a dynamic time accurate simulations along with supporting experiments must be conducted to establish the transient forces and moment acting on the biplane configurations during configuration morphing.

(c) The integration of biplanes into the fuselage create additional interference drag and thus the effect of the size, orientation and position of the biplanes with respect to fuselage should be studied along other aspects such as the effect of the aspect ratio and sweepback of the biplanes on its performance.

(d) Researches have shown that multi-element biplanes can perform better than conventional biplanes. In this regard, the combined effect of stagger and elements likes slats and flaps on the flow chocking and performance of biplane must be studied.

Besides the above mentioned points, there is a need to do exhaustive research in the field of supersonic biplanes to suggest innovations that can lead to the design of a completely boomless supersonic transport aircraft. The propulsive requirements along with economic considerations must be given a thought as well. Finally, the observations made through these investigations must be supported by an extensive wind tunnel experiments so as to leave no doubts for a better and prosperous future of the super civil transport.