CONCLUSIONS:

Present work deals with the estimation of stability derivatives for oscillating planar and Non-planar wedges, Delta wings with straight and curved leading edges in supersonic/hypersonic flow, for wide range of Mach numbers, angles of attack, and sweep angles. Later for these shapes the stability derivatives were also evaluated in the Newtonian limit where specific heat ratio $\gamma$ tends to unity and the free stream Mach number tends to infinity. In the present study we have used Ghosh hypersonic similitude, where second order shock expansion theory is used to find the pressure distribution on the surface of the wedge/wing to evaluate the stability derivatives for an oscillating wedge/wing. Initially we started with the estimation of stability derivatives for planar wedge in both hypersonic and supersonic flow which did demonstrate its wide application for a wide range in angle of incidence, semi vertex angle of the wedge, and the Mach number. The theory is valid only when the shock wave is attached with the wedge and the effect of Lee surface has been neglected while discussing the hypersonic flow. The present theory could be handy at the initial design stage of the Aerospace Vehicles. The present theory is simple and yet gives good results with remarkable computational ease. Further, it is found that the expressions derived for stability derivatives in pitch for wedges become exact in the Newtonian limit. From the results it is found that the stability derivatives are independent of Mach number since, they are estimated in the Newtonian limit. It is found that stiffness derivative linearly varies with the pivot position as the same was found for the cases in our previous results at low supersonic, supersonic, and hypersonic Mach numbers. Further, it is seen that due to the increase in angle of attack the stiffness derivative increases linearly for the entire range of the present study. It is also observed that the centre of pressure moves towards the trailing edge and this shift is quite high at high angles of attack. Hence, this behavior could be utilized to stabilize the aerospace vehicle from the stability and flight dynamics point of view. In the case of damping derivative since the expression for the damping derivative is non-linear and hence the non-linearity has been reflected in all the results of the present study. However, the behavior remains linear till angle of attack around fifteen degrees, later the trend is non-linear. The reasons for this behavior may be due to the flow separation at high angle of attack the stability derivatives which were
linearly increasing with the angle of attack will no longer will increase with angle of attack rather in view of the flow separation which will finally result in the stalling. Later we have extended the same similitude to evaluate the Stability derivatives for an oscillating non-planar wedge. The stability derivatives for the Non-Planar wedges in hypersonic flow demonstrate its application for a wide range of the Mach number, angle of attack and the semi vertex angle of the wedge. For semi vertex angle five to ten degrees the variation in the stiffness and damping derivatives is substantial, however; for large values of semi vertex angle the variation stiffness and damping derivative is only marginal. The variation in the center of pressure for stiffness and damping derivatives is from 20 % to 55 % for all the Mach numbers and semi vertex angle of the present study. The theory is valid only when the shock wave is attached with the nose of the wedge. The present theory is simple and yet gives good results with remarkable computational ease with the error in the band of ten percent.

Further, the hypersonic similitude were extended for Non-Planar wedges in Supersonic flow, and from the results it is found that the theory has wide application for large range of angle of incidence and Mach number for Non Planar Surfaces in the supersonic Mach number also. It is free from the restrictions of Lighthill’s theory and Miles theory. The present theory shows that the effect of convexity in non-planar wedges is to decrease stiffness as well as the damping derivatives, and shift damping minima towards the leading edge. This shift in the center of pressure for stiffness as well as the damping derivatives is due the change in the geometry of the wedge, and it is on the expected line that if the non-planar wedge becomes concave instead of convex the trend will get reversed; the center of pressure will shift towards the trailing edge instead of leading edge. In this situation the damping derivative will be attain the maximum value at the leading edge instead of trailing edge. In the present theory the effect of Lee surface is neglected.

The expressions derived for stability derivatives become exact in the Newtonian limit. From the results it is found that the stability derivatives are independent of Mach number as they are estimated in the Newtonian limit. The stiffness derivative and damping derivative in pitch they reflect only the effect of the geometric parameter of the wing in the Newtonian limit too. It is found that stiffness derivative linearly varies with the pivot position as the same was found for the cases in our previous results at
low supersonic, supersonic, and hypersonic Mach numbers, however, the location of center of pressure has shifted towards the trailing edge by nearly twenty percent which will result in increased value of the static margin and hence increase value of stiffness derivative resulting in better performance in the dynamic conditions. In the case of damping derivative since the expression for the damping derivative is non-linear and the same has been reflected in the results. For damping derivative also, the initial value also has increased followed by shifting of center of pressure towards the trailing edge resulting in better performance during the flight. It is also seen that that roll damping derivatives, too vary linearly with angle of attack for a given value of sweep angle; however, for a given angle attack when roll damping derivatives were plotted with sweep angle the behavior is non-linear. From the above results it can be stated that if angle of attack range is between ten degrees to fifteen degrees then the optimum sweep angle will be in the range five to twenty degrees, however, if the angle of attack is in the range of twenty to thirty degrees then the optimum range of the sweep angle will be between fifteen to fifty degrees.

Further, the similitude and piston theory of Ghosh have been extended to a flat wing with Straight and curved leading edges. The concepts of the present theory have been extended to axi-symmetric case, for which analytical or experimental data are quite limited. The stiffness derivative and damping derivative in pitch and roll are dependent on the geometric parameter of the wing in the Newtonian limit for both straight and curved leading edge. It is found that stiffness derivative linearly varies with the amplitude. Whenever, the plan form area is increased the stiffness derivative is also increased and vice versa. There is a shift of the center of pressure towards the trailing edge whenever wing plan form is changed from concave to convex plan form. In the case of damping derivative since expressions for these derivatives are non-linear and the same is reflected in all the results.

The linear dependence of the stiffness derivative is seen for all parameters of the present study with curved leading edges, however for higher angle of attack the non-linearity in the stiffness derivative is observed. When the stiffness and damping derivatives are considered for h = 0.6 which is also happens to be the center of pressure and for some of the cases, it may be the aerodynamic center and hence; the independency with angle of attack has been observed. The present theory is valid for large angle of incidence as well as for the wide range of the Mach number.
Results of present theory are better when compared to Ghosh as it uses straight leading edges where as in the present case wing has curved leading edges. The present theory invokes Ghosh strip theory arguments which was also used by Hui et al, wherein he has considered the flow at span wise station similar to an oscillating flat plate flow; which is obtained and calculated by perturbing the known steady plate flow (oblique shock solution) which forms the basic flow for the theory. Hui et al have obtained closed form expressions for stiffness and damping in pitch but have not calculated the rolling moment derivative. The present theory calculates rolling moment derivative also, since it makes use of Ghosh quasi steady theory which is simpler than both Liu and Hui et al and indicates the explicit dependence of derivatives on the similarity parameter $S_1$.

Stiffness and damping derivatives in pitch calculated by the present theory have been compared with Liu and Hui (Lui et al 1977:804-812). In case of stiffness derivative there is a good agreement. The difference in the Damping derivative is due to the present theory being quasi-steady theory.

For Higher Mach Number the present theory exhibits the Mach Number Independence Principle, however, these variations in the roll damping derivatives are because of change in the wing plan form area due to the variation in the amplitude of full and half sine waves. The present theory is valid for large angle of incidence and the Mach number. The present theory is simpler than both Lui and Hui and Hui et al and shows the explicit dependence of the stability derivatives on the similarity parameter. The present theory is not valid for a detached shock case. Future research can be done by taking into account the effects of shock motion, viscosity, wave reflections, leading edge bluntness, and the real gas effects.