

## LIST OF FIGURES

	Page No.	
Figure 1.1	Monoplane configuration.	2
Figure 1.2	Biplane configuration.	2
Figure 1.3	Supersonic Transport Aircrafts	4
Figure 1.4	North American XB-70 Valkyrie.	5
Figure 1.5	High-speed flows over streamlined bodies	7
Figure 1.6	Flow over Airfoil at high speeds	9
Figure 1.7	$C_D$ Variation with Mach number	10
Figure 1.8	Supersonic flow over double wedge airfoil at $\alpha = 0^\circ$	11
Figure 1.9	Supersonic flow over double wedge airfoil at positive $\alpha$	12
Figure 1.10	Propagation of Disturbances. (a) Subsonic Flow. (b) Supersonic Flow	13
Figure 1.11	Supersonic flow over a corner	14
Figure 1.12	Oblique shock geometry	15
Figure 1.13	Attached and Detached shock	17
Figure 1.14	Expansion Wave	18
Figure 1.15	Supersonic flow over a flat plate at positive $\alpha$	20
Figure 1.16	Diamond airfoil in a supersonic flow at $\alpha = 0^\circ$	21
Figure 1.17	Regular reflection of a shock wave from a solid boundary	22
Figure 1.18	Intersection of shock waves	23
Figure 1.19	Shock-wave Boundary Layer Interaction	25
Figure 1.20	Variation of Critical Mach number with thickness/chord ratio	26
Figure 1.21	Variation of Critical Mach number with Aspect ratio	27
Figure 1.22	Schematic illustration of flow over Supercritical airfoil	28
Figure 1.23	Schematic illustration of effect of wing sweep	28
Figure 1.24	Delta wing in low-speed flow at angle of attack	30
Figure 1.25	An oblique wing	31

Figure 1.26	Wave reduction effect	32
Figure 1.27	Wave Cancellation effect of the Busemann airfoil	33
Figure 1.28	Shock Structure and Pressure Distribution for Busemann biplane	34
Figure 1.29	Starting Mach Number for Supersonic Inlets	35
Figure 1.30	Conceptual Boomless Supersonic Transport Aircraft	36
Figure 2.1	Wave Cancellation Effect in Busemann biplane	39
Figure 2.2	Licher Biplanes with lift and thickness components	40
Figure 2.3	Modified elements of Busemann biplane proposed by Kusunose et al.	42
Figure 2.4	Busemann biplane with Control Devices	43
Figure 2.5	Busemann biplane with leading edge and trailing edge flaps	44
Figure 2.6	Variable biplane Configuration for complete flight regime	44
Figure 4.1	Schematic of two-dimensional control volumes grids	57
Figure 4.2	Reynolds averaging – illustration of turbulent velocity fluctuations $v'$ and statistical mean value $\bar{v}$	64
Figure 4.3	Basic geometries	69
Figure 4.4	Grid points and cell centers	70
Figure 4.5	Unstructured triangular mesh on a unit square	71
Figure 4.6	Different types of block arrangement	73
Figure 4.7	Geometry cut out from a rectangular grid	74
Figure 4.8	Multi-block grid around (a) Diamond Airfoil and (b) Busemann Biplane airfoil	75
Figure 4.9	Multi-bloc structured mesh around (a) Staggered Busemann biplane and (b) Busemann biplane with rounded leading and trailing edges	76
Figure 4.10	Farfield boundary conditions for domain around Busemann biplane	84
Figure 4.11	Variation of Drag coefficient with number of elements for the Busemann airfoil	85
Figure 4.12	$C_p$ and Mach number variation for Diamond airfoil at $M_\infty = 1.7$	87
Figure 4.13	$C_p$ and Mach number variation for Busemann airfoil at $M_\infty = 1.7$	87
Figure 4.14	Contours of $C_p$ for Busemann biplane at $0.5 \leq M_\infty \leq 1.0$	88
Figure 4.15	Contours of $C_p$ for Busemann biplane at $1.2 \leq M_\infty \leq 1.6$	89

Figure 4.16	$C_p$ variation of Busemann biplane for $1.9 \leq M_\infty \leq 2.5$	91
Figure 4.17	$C_D$ variation with freestream Mach number for Diamond and Busemann airfoil at zero-lift condition	92
Figure 5.1	Pressure Variation with Stagger distance at $M_\infty = 0.6$ and $\alpha = 0^\circ$	95
Figure 5.2	Pressure variation with Stagger at $M_\infty = 1.6$ and $\alpha = 0^\circ$	97
Figure 5.3	Pressure Variation with Stagger distance at $M_\infty = 1.4$ and $\alpha = 0^\circ$	98
Figure 5.4	Pressure Variation with Stagger at $M_\infty = 1.7$ and $\alpha = 0^\circ$	100
Figure 5.5	Drag variation (a) for with $M_\infty 0.5 \leq M_\infty \leq 1.7$ and (b) $1.8 \leq M_\infty \leq 3.5$ for different Staggered configurations at $\alpha = 0^\circ$	101
Figure 5.6	$L/D$ ratio for different Stagger at $\alpha = 0^\circ$	102
Figure 5.7	$C_p$ Variation for Stagger 0.1c and 0.2c at $M_\infty = 0.7$ , $\alpha = 1^\circ$	103
Figure 5.8	$C_p$ Variation for different Stagger distance at $M_\infty = 0.7$ , $\alpha = 1^\circ$	104
Figure 5.9	$C_p$ Variation for different Stagger distance at $M_\infty = 0.7$ , $\alpha = 3^\circ$	106
Figure 5.10	$C_p$ Variation for Busemann and Stagger distance 0.1c at $M_\infty = 1.7$ , $\alpha = 1^\circ$	107
Figure 5.11	$C_p$ Variation for different Stagger distances at $M_\infty = 1.7$ and $\alpha = 1^\circ$	108
Figure 5.12	$C_p$ Variation for different Stagger distances at $M_\infty = 1.7$ and $\alpha = 3^\circ$	109
Figure 5.13	$C_D$ Variation at different angle of attack with $M_\infty$	111
Figure 5.14	$L/D$ ratio of different Stagger configuration at $\alpha = 1^\circ$	113
Figure 5.15	$L/D$ ratio of different Stagger configuration at $\alpha = 2^\circ$	113
Figure 5.16	$L/D$ ratio of different Staggered configuration at $\alpha = 3^\circ$	114
Figure 5.17	$L/D$ Variation with angle of attack at $0.5 \leq M_\infty \leq 1.7$	115
Figure 5.18	$L/D$ Variation with angle of attack at $M_\infty = 1.7$ & 1.9	116
Figure 5.19	The Busemann biplane with rounded leading and trailing edges	117
Figure 5.20	Multi-block Grid around biplanes with rounded leading and trailing edges	118
Figure 5.21	$C_p$ variation for Busemann biplane with a) sharp leading edge and b) rounded leading edge of 1 mm radius, at $M_\infty = 0.6$ , $\alpha = 0^\circ$	120
Figure 5.22	$C_p$ variation for different leading edge radius at $M_\infty = 0.6$ , $\alpha = 0^\circ$	120
Figure 5.23	$C_p$ variation with leading edge radius at $M_\infty = 1$ , $\alpha = 0^\circ$	122
Figure 5.24	$C_p$ variation with leading edge radius at $M_\infty = 1.7$ , $\alpha = 0^\circ$	123

Figure 5.25	$C_p$ variation of Busemann biplane at $M_\infty = 1.7$ , $\alpha = 0^\circ$ for (a) sharp leading edge and (b) rounded leading edge with 5 mm radius	124
Figure 5.26	Variation of drag coefficient with leading edge and trailing edge radius for Busemann biplane at $\alpha = 0^\circ$ .	125
Figure 5.27	Grid for Staggered biplane with rounded leading edge and trailing edges	125
Figure 5.28	$C_D$ variation with $M_\infty$ for radii of leading edge and trailing edges for Stagger configuration at $\alpha = 0^\circ$ .	127
Figure 5.29	Comparisons of pressures contours for Staggered configurations with round and sharp leading edges	128
Figure 5.30	$L/D$ variation with $M_\infty$ for different leading and trailing edge radii for Stagger configuration at $\alpha = 0^\circ$	129