

Contents

List of Symbols	v
1 Introduction	1
2 Literature review	7
2.1 Total Pressure Loss in Compressor Bleed Air Systems	7
2.1.1 1D-Flow Solver: Assumptions and Correlations	7
2.1.1.1 Off-take	10
2.1.1.2 Manifold	15
2.1.1.3 Exit tube	18
2.1.2 Complete System, Component Interaction, and Three-dimensional Effects	19
2.2 Interaction with the Compressor Main Gas Path	23
2.2.1 Uniform Bleed	23
2.2.2 Non-uniform Bleed	27
2.3 Objectives and Structure of the Present Investigation	29
3 Experimental methods	33
3.1 Test Rig Infrastructure	33
3.2 Test Section Conception	34
3.2.1 Guide Vanes	36
3.2.2 Off-take Design	37
3.2.3 Manifold and Exit Tubes	38
3.3 Test Section Instrumentation	40
3.3.1 Manifold measurements	42
3.3.2 Vane passage measurements	43
4 Numerical Method	49
4.1 Domain Modelling	49
4.1.1 Grid Generation	52
4.1.2 Turbulence Model	54
4.1.3 Boundary Conditions	54
4.1.4 Sensitivity Study	55

4.1.5	Solver and Simulation	57
4.2	Data Post-processing	57
4.3	Validation of the Simulations	59
4.3.1	20° Vane No Bleed Slot	61
4.3.2	20° Vane with 45° Slot and Four Exit Tubes at $br = 9\%$	63
5	Results and Discussion	71
5.1	Influence of the Exit Tube Configuration and Slot Geometry on Total Pressure Losses	72
5.1.1	Total Pressure Loss in the System Components	73
5.1.2	Slot Flow Specificities	77
5.1.3	Manifold Flow Specificities	81
5.1.3.1	Manifold Static Pressure Distribution	82
5.1.3.2	Manifold Velocity Field	89
5.1.3.3	Mass Flow Distribution in the Manifold	91
5.1.4	Total Pressure Loss Generation in the Manifold	96
5.1.4.1	Flow Topology and Swirl Tube Analogy	96
5.1.4.2	Total Pressure Loss on the Positive Stream	100
5.1.4.3	Total Pressure Loss on the Backflow Stream	103
5.1.5	Exit Tube Flow	111
5.1.5.1	Total Pressure Loss Generation in the Exit Tube	112
5.1.5.2	Comparison with 1D network Correlations	115
5.2	Influence of the Vane Aerodynamic Loading on Total Pressure Losses	119
5.2.1	Total Pressure Loss in the System Components	119
5.2.2	Slot Flow Specificities	121
5.2.3	Manifold Flow Specificities	122
5.2.3.1	Manifold Static Pressure Distribution	123
5.2.3.2	Manifold Velocity Field	125
5.2.3.3	Mass Flow Distribution in the Manifold	126
5.3	Bleeding Non-uniformity	129
5.3.1	Influence of the Exit Tube Configuration and Slot Geometry on the Main Gas Path Interaction	130
5.3.2	Influence of the Vane Aerodynamic Loading on the Main Gas Path Interaction	134

5.4	Onset and Development of Backflow	137
5.4.1	Modelling of Backflow Onset and Development	137
5.4.2	Influence of the Vane and Slot Configuration on the Backflow Onset . . .	143
6	Conclusion	149
	Bibliography	153
	Appendix	165
A.1	Wedge Probe Calibration	165
A.2	Manifold Flow Field Description	171
A.3	Swirl Tube Analogy	172
A.4	Turbulence Kinetic Energy with the 90° Slot Configuration	174
A.5	Exit Tube Recirculation with the 20° Vane Configuration	175
A.6	Exit Tube Recirculation with the 10° Vane Configuration	177
A.7	Turbulence Kinetic Energy with the 45° Slot and both Exit Tube Configurations	180
A.8	Bleeding Non-uniformity for the 90° Slot with the 10° Vane	183
A.9	Slot Flow Interaction with a Single Exit Tube for the 90° Slot with the 20° Vane	184