
Contents

1. Introduction	1
1.1 Transition Process	2
1.2 Prediction of Transition	5
1.2.1 Empirical Correlations	5
1.2.2 Michel's Method	5
1.2.3 Granville's Method	5
1.2.4 $H-R_x$ Method	6
1.3 Factors that Influence Transition	7
1.3.1 Effects of Freestream Turbulence and Noise	7
1.3.2 Effects of Pressure Gradient	8
1.3.3 Effects of Heat Transfer	9
1.3.4 Effects of Surface Roughness	10
1.3.5 Effects of Suction	11
1.3.6 Effects of Surface Curvature	12
References	13
2. Stability-Transition Theory	17
2.1 Introduction	17
2.2 Underlying Mathematical Arguments for e^n -Method	17
2.3 Linear Stability Equations	19
2.3.1 Orr-Sommerfeld Equation	27
2.3.2 Properties of the Orr-Sommerfeld Equation for Two-Dimensional Flows	29
2.4 e^n -Method for Two-Dimensional Flows	32
2.5 e^n -Method for Three-Dimensional Flows	34
2.5.1 Eigenvalue Formulations	34
2.5.2 The Zarf	37
References	40

3. Numerical Method	43
3.1 Introduction	43
3.2 Numerical Solution of the Orr-Sommerfeld Equation for Two-Dimensional Flows	44
3.2.1 Eigenvalue Procedure for Stability Diagrams	46
3.2.2 Eigenvalue Procedure for Transition	51
3.3 Numerical Solution of the Orr-Sommerfeld Equation for Three-Dimensional Flows: Mack/Arnal Eigenvalue Formulation	51
3.4 Numerical Solution of the Orr-Sommerfeld Equation for Three-Dimensional Flows: Cebeci-Stewartson Eigenvalue Formulation	53
3.4.1 Eigenvalue Procedure for Zarf	54
3.4.2 Eigenvalue Procedure for Transition	56
3.4.3 Estimation of Eigenvalues	57
Appendix 3A	58
References	58
4. Stability Transition Program for Two-Dimensional Incompressible Flows	61
4.1 Introduction	61
4.2 Description of the Computer Program STP	61
4.2.1 MAIN	62
4.2.2 Subroutine VELPRO	63
4.2.3 Subroutine CSAVE	63
4.2.4 Subroutine NEWTON	64
4.2.5 Subroutine NEWTONI	64
4.3 Stability Diagrams for Falkner-Skan Flows	64
4.3.1 Falkner-Skan Flows	64
4.3.2 Sample Calculations for Constructing Stability Diagrams for Blasius Flow	66
4.3.3 Stability Diagrams for Falkner-Skan Flows	67
4.3.4 Sample Calculations for Constructing Stability Diagrams for Lower-Branch Solutions of the Falkner-Skan Equation	70
4.4 Sample Calculations for Predicting Transition	71
4.4.1 Flat-Plate Flow	71
4.4.2 Airfoil Flow	72
4.5 Description of the Computer Program STPW	73
4.5.1 Input to STPW	75
4.5.2 Sample Calculations	77
Appendix 4A Shooting Method	78
4A.1 Description of the Method for $f_w'' \geq 0$	78

4A.2	Description of the Method for $f''_w < 0$	80
4A.3	Computer Program	81
References	84
5.	An Interactive Boundary-Layer and Stability-Transition Program for Two-Dimensional Flows	85
5.1	Introduction	85
5.2	Interactive Boundary-Layer Method	86
5.2.1	Turbulence Model	87
5.2.2	Numerical Method	89
5.2.3	Inviscid Method	94
5.2.4	Computer Program	95
5.3	Extension of the Interactive Boundary-Layer and Stability-Transition Approach to Multielement Airfoils	98
5.4	Airfoils at High Reynolds Numbers	99
5.5	Accuracy of the e^n -Method for Flows with Separation	100
5.6	Airfoils at Low Reynolds Numbers	105
5.7	Multielement Airfoils	107
References	110
6.	Stability-Transition Program for Three-Dimensional Incompressible Flows	113
6.1	Introduction	113
6.2	Description of the Computer Program 3DSTP and Sample Calculations	113
6.2.1	Description of the Computer Program	113
6.2.2	Sample Calculations	114
6.3	Applications of 3DSTP	119
6.3.1	ONERA-D Infinite Swept Wing	119
6.3.2	Prolate Spheroid	125
6.4	Prediction of Transition with Curvature Effect	135
6.4.1	Stability Equations with Curvature Terms	136
6.4.2	Calculation of the Curvature Terms	139
6.4.3	Effects of Sweep Angle and Reynolds Number on Transition with Curvature Effect Included in the Stability Equations	140
6.5	Computer Program 3DSTPWC and Sample Calculations	145
6.5.1	Description of Input	145
6.5.2	Sample Calculations	146
References	147

7. A Stability-Transition Program for Three-Dimensional Compressible Flows on Wings	149
7.1 Introduction	149
7.2 Boundary-Layer Equations	150
7.3 Initial Conditions	151
7.3.1 Quasi-Three-Dimensional Boundary-Layer Equations ...	152
7.3.2 Attachment Line Equations.....	153
7.4 Turbulence Model.....	153
7.5 Interface Program.....	154
7.5.1 Choice of the Surface Coordinate System.....	154
7.5.2 Geometric Parameters of the Coordinate System	157
7.5.3 Calculation of Inviscid Velocity Components for Boundary-Layer Grid	159
7.5.4 Computer Program.....	160
7.5.5 Sample Calculations	162
7.6 Solution of the Boundary-Layer Equations	163
7.6.1 Transformed Equations	163
7.6.2 Numerical Method	166
7.7 Solution of the Stability Equations for Compressible Flows	167
7.8 AS409 Infinite Swept Wing.....	167
7.8.1 Experimental Data	168
7.8.2 Calculations with the Mack-Arnal Formulation.....	170
7.8.3 Calculations with the Cebeci-Stewartson Formulation ...	175
7.9 Software for Calculating Transition in Incompressible and Compressible Flows on Wings with and without Suction ...	178
7.9.1 Boundary Layer Program	179
7.9.2 Calculation of Zarf	179
7.9.3 Amplification Calculations	181
7.9.4 Summary of Transition Calculations	182
7.9.5 Calculation of the Lower Branch of the Zarf	182
7.9.6 Amplification Calculations for Disturbances from the Lower Branch	183
7.9.7 Amplification Calculations for Disturbances from the Upper Branch	183
References	184
8. Transition Prediction by Parabolized Stability Equations ...	185
8.1 Introduction	185
8.2 Parabolized Stability Equations.....	186
8.3 Numerical Method	191
8.4 Description of the Computer Program	196
8.4.1 Subroutine START	197

8.4.2	Subroutine COEF	198
8.4.3	Subroutine GETNA	198
8.4.4	Solution Algorithm: Subroutines MATRIX6, GAUSS, USOLV, GAMSU	198
8.5	Sample Calculations with PSE.....	198
	References	205
Appendix A Computer Programs in the CD-ROM		
Accompanying the Book		
A.1	Shooting Method: For $f''(0) \geq 0$	207
A.2	Shooting Method: For $f''(0) < 0$	207
A.3	2D Stability Transition Program (STP2D)	208
A.4	Interactive Boundary-layer (IBL) Program	208
A.5	Panel Method (HSPM), 2D Interface Program (IPRPM2D), Inverse Boundary-Layer Program (INBLP) and STP2D.....	208
A.6	HSPM, IPRPM2D, Boundary-Layer Infinite Swept Wing (BLISW) Program and 3D Stability-Transition Program (3DSTP)	209
A.7	Stability-Transition Program Based on Parabolized Stability Equations (PSE)	210
A.7.1	Cross-Flow Dominated Flows	210
A.7.2	Flows in Which Tollmien-Schlichting (T-S) Waves Dominate	210
Appendix B Computer Programs in the CD-ROM		
Available from the Author		
B.1	Boundary Layer and Stability-Transition Program for Air, Water and Sea (STPW)	211
B.2	Panel Method (HSPM), 2D Interface Program (IPRPM), Infinite Swept Wing Boundary-Layer Program (BLISW) and 3D Stability Transition Program with Curvature Effects (3DSTPWC)	212
B.3	HSPM, IPRPM, BLISW, 3DSTPWC, Parabolized Stability Equations (PSE)	213
B.3.1	Cross-Flow Dominated Flows	213
B.3.2	Flows in Which Tollmien-Schlichting (T-S) Instability Dominates	214

Appendix C Interactive Boundary-Layer Method for Single and Multielement Airfoils (MEIBL)	217
C.1 Application of MEIBL to Three-Dimensional Flows	217
C.1.1 Inviscid Flow	217
C.1.2 Viscous Flow	218
C.1.3 Interaction	218
C.2 Coordinate Systems for Viscous and Inviscid Flow Calculations .	218
C.3 User's Manual	219
C.3.1 Input Data	219
C.3.2 Output Data	225
C.4 Sample Calculations	228
C.4.1 Detailed Flow at $\alpha = 4^\circ$ and $\alpha = 20^\circ$	228
C.4.2 Force and Moment Coefficient Calculations	232
References	232
Appendix D Software for Calculating Transition in Three-Dimensional Compressible Flows	233
D.1 Description of the Boundary Layer Program	234
D.1.1 Input Data Description	234
D.1.2 Output Data Description	236
D.2 Description of the Transition Calculation Procedure	238
D.2.1 Zarf Calculation	239
D.2.2 Amplification Calculation	240
D.2.3 Summary of the Procedure	241
D.3 Sample Calculation: Input and Output Data Description	241
D.3.1 Input File Description	242
D.3.2 Calculation of the Lower Branch of the Zarf	245
D.3.3 Amplification Calculations for Disturbances from the Lower Branch	246
D.3.4 Zarf Upper Branch Calculation	251
D.3.5 Amplification Calculations for Disturbances from the Upper Branch	254
D.4 Quick Reference Manual	257
Subject Index	259