

# Contents

<b>Introduction</b> .....	1
Stefan Hiermaier	
<b>Part I Simulation of Automotive Crash Processes</b>	
<b>1 Simulation of Recoverable Foams under Impact Loading</b> .....	9
Stefan Kolling, Andre Werner, Tobias Erhart and Paul A. Du Bois	
1.1 Introduction .....	10
1.2 Current Implementation According to Fu Chang .....	11
1.2.1 Theoretical Framework .....	11
1.2.2 Validation Tests .....	13
1.2.3 Application: Leg Impact .....	17
1.3 Addition of a Damage Model .....	19
1.3.1 Theoretical Framework .....	19
1.3.2 Examples .....	22
References .....	24
<b>2 The Numerical Simulation of Foam – An Example of Inter-Industrial Synergy</b> .....	27
Paul A. Du Bois	
2.1 Introduction .....	27
2.2 Foams – Physical Nature and Numerical Modeling .....	28
2.3 Numerical Modeling of Foams in Automotive Crash .....	30
2.4 Impacted Foam – The Columbia Accident .....	35
2.5 Summary and Conclusion .....	41
References .....	42
<b>3 Influence of Hardening Relations on Forming Limit Curves Predicted by the Theory of Marciniak, Kuczyński, and Pokora</b> .....	43
Heinrich Werner	
3.1 Introduction .....	43
3.2 Theoretical Model .....	45

3.2.1	Constitutive Equations .....	47
3.2.2	Derivation of Evolution Equations for the Onset of Instability .....	48
3.3	Numerical Solution Method .....	51
3.4	Initial Conditions .....	53
3.5	Validation .....	55
3.6	Convergence Properties .....	57
3.7	Influence of Different Hardening Relations on the FLCs .....	58
3.7.1	Effect of Various Quasi-Static Hardening Relations on Forming Limit Curves .....	59
3.7.2	Effect of Various Strain Rate Formulations on the Forming Limit Curves .....	61
3.8	Summary .....	63
	References .....	64
<b>4</b>	<b>The Challenge to Predict Material Failure in Crashworthiness</b>	
	<b>Applications: Simulation of Producibility to Serviceability</b> .....	67
	André Haufe, Markus Feucht and Frieder Neukamm	
4.1	Introduction .....	68
4.2	The Process Chain of Sheet Metal Part Manufacturing .....	68
4.3	Some Ideas for Failure Modelling in Forming and Crashworthiness Simulations .....	70
4.3.1	The Barlat Constitutive Model for Forming Simulations .	71
4.3.2	Constitutive Models for Crashworthiness Applications ..	72
4.3.3	A Hybrid Approach to Estimate the Void Volume Fraction in Forming Simulations .....	73
4.3.4	A Generalized Scalar Damage Model for Forming and Crashworthiness Simulations .....	75
4.4	Path-Dependent Localization .....	77
4.4.1	Stress and Strain Measures .....	77
4.4.2	Linear Accumulation of the Instability Criterion .....	79
4.4.3	Nonlinear Accumulation of the Instability Criterion .....	80
4.5	Post Critical Behaviour .....	81
4.5.1	Damage-Dependent Yield Stress .....	82
4.5.2	Energy Dissipation and Fadeout .....	83
4.6	Application of a Demonstrator Part .....	84
4.7	Conclusions .....	85
	References .....	87
<b>5</b>	<b>Cohesive Zone Modeling for Adhesives</b> .....	89
	Matthias Nossek and Stephan Marzi	
5.1	Introduction .....	90
5.2	Characterization Procedure .....	90
5.2.1	Bulk Tensile Tests .....	91
5.2.2	Coupon Tests .....	92
5.2.3	Fracture Mechanical Tests .....	93

5.3	Cohesive Zone Model .....	94
5.4	Validation .....	99
5.5	Application .....	101
5.6	Summary .....	104
	References .....	104
<b>6</b>	<b>Modeling the Plasticity of Various Material Classes with a Single Quadratic Yield Function .....</b>	<b>107</b>
	Markus Wicklein	
6.1	Introduction .....	107
6.2	A Quadratic Yield Function .....	109
6.3	Parameter Identification for Foams .....	112
6.4	Application to Honeycombs .....	114
6.5	Application to Carbon Fiber-Reinforced Plastics .....	117
6.6	Outlook .....	118
	References .....	119
<b>7</b>	<b>On the Computation of a Generalised Dynamic J-Integral and its Application to the Durability of Steel Structures .....</b>	<b>121</b>
	Ingbert Mangerig and Stefan Kolling	
7.1	Introduction .....	121
7.2	Basic Equations .....	123
7.3	Theory of Configurational Forces .....	124
7.4	Finite Element Formulation .....	126
7.5	Fatigue, Stress Intensity Factor and Crack Growth Rate .....	127
7.6	Application to Durability Analysis .....	128
7.7	Summary .....	130
	References .....	131
<b>Part II Numerical Modeling of Blast and Impact Phenomena</b>		
<b>8</b>	<b>The MAX-Analysis: New Computational and Post-Processing Procedures for Vehicle Safety Analysis .....</b>	<b>135</b>
	David Vinckier	
8.1	Introduction .....	135
8.2	Prediction Capabilities for Vehicle Mine and IED Blast Simulations .....	136
8.3	The MAX-Analysis: Unification of the Computational Results ...	138
8.4	Summary .....	140
<b>9</b>	<b>10 Years RHT: A Review of Concrete Modelling and Hydrocode Applications .....</b>	<b>143</b>
	Werner Riedel	
9.1	Introduction: Dynamic Measurements and Model Development ..	143
9.1.1	The Starting Point of the Developments .....	143
9.1.2	Equation of State for a Large-Scale Heterogeneous Composite .....	146

9.1.3	Combining Civil Engineering Knowledge and Shock Physics .....	148
9.2	Applications in Impact Analysis .....	150
9.2.1	Extended Validation and Sensitivity Analysis .....	150
9.2.2	Deformable Projectiles and Coupling with Explosions ...	154
9.3	Protecting Critical Infrastructure against Explosion Effects .....	155
9.3.1	Comparison to Engineering Models and Empirical Formula .....	158
9.3.2	From Power Plant Security to Future High-Rise-Buildings	159
9.4	Summary and Outlook .....	163
	References .....	163
<b>10</b>	<b>Numerical Simulations of the Penetration of Glass Using Two Pressure-Dependent Constitutive Models .....</b>	<b>167</b>
	Sidney Chocron and Charles E. Anderson Jr.	
10.1	Introduction .....	167
10.2	Materials .....	168
10.3	Experimental Techniques for Material Characterization .....	168
10.3.1	'Bomb' Technique .....	168
10.3.2	'Sleeve' Technique .....	170
10.4	Constitutive Model Interpretations .....	171
10.4.1	Drucker-Prager Model .....	171
10.4.2	Mohr-Coulomb Model .....	173
10.5	Numerical Simulation of Penetration .....	175
10.5.1	Drucker-Prager Model .....	176
10.5.2	Mohr-Coulomb Model .....	180
10.6	Summary and Conclusions .....	182
	Appendix .....	184
	References .....	186
<b>11</b>	<b>On the main mechanisms in ballistic perforation of steel plates at sub-ordnance impact velocities .....</b>	<b>189</b>
	Tore Børvik, Sumita Dey, Odd Sture Hopperstad and Magnus Langseth	
11.1	Introduction .....	190
11.2	Experimental Studies .....	191
11.2.1	Experimental Set-Up .....	191
11.2.2	Projectiles and Targets .....	192
11.2.3	Experimental Programs .....	193
11.3	Experimental Results .....	194
11.3.1	Effect of Projectile Impact Velocity .....	194
11.3.2	Effect of Target Thickness .....	195
11.3.3	Effect of Projectile Nose-Shape .....	196
11.3.4	Effect of Target Strength .....	199
11.3.5	Effect of Target Layering .....	201
11.3.6	Summary of Experimental Data .....	203

11.4	Material Modelling, Material Tests and Identification of Material Constants .....	206
11.4.1	Constitutive Relation and Fracture Criteria .....	206
11.4.2	Material Data and Model Calibration .....	209
11.5	Numerical Studies .....	211
11.5.1	Numerical Models .....	212
11.5.2	Some Numerical Results .....	213
11.6	Concluding Remarks .....	216
	References .....	217
<b>12</b>	<b>Dimensioning of concrete walls against small calibre impact including models for deformable penetrators and the scattering of experimental results .....</b>	<b>221</b>
	Norbert Gebbeken, Tobias Linse, Thomas Hartmann, Martien Teich and Achim Pietzsch	
12.1	Introduction .....	221
12.2	Penetration and perforation of concrete walls with non-deformable penetrators .....	223
12.3	Deformable projectiles .....	226
12.3.1	Jacketed projectiles .....	226
12.3.2	Homogenous deformable projectiles .....	229
12.4	Scattering of experimental data .....	232
12.5	The new software-tool PenSim .....	235
	References .....	236
<b>13</b>	<b>Numerical Analysis of Fluidynamic Instabilities and Pressure Fluctuations in the Near Field of a Detonation .....</b>	<b>239</b>
	Arno Klomfass	
13.1	Introduction .....	239
13.2	Physical Models .....	243
13.3	Numerical Methods .....	245
13.4	Computational Methodology .....	247
13.5	Results 1D, 2D and 3D Free Field .....	248
13.6	Results 2D Above-Ground Detonation .....	250
13.7	Conclusions .....	251
	References .....	251
<b>14</b>	<b>Numerical Simulation of Muzzle Exit and Separation Process for Sabot-Guided Projectiles at <math>M &gt; 1</math> .....</b>	<b>261</b>
	Jörn van Keuk and Arno Klomfass	
14.1	Introduction .....	261
14.2	Technical Specifications / Experimental Setup .....	262
14.3	Numerical Solution Method .....	263
14.4	Simulation Results / Comparison with Experiments .....	264
14.5	Conclusions / Future Work .....	268
	References .....	269

<b>15</b>	<b>Numerical Analysis of the Supercavitating Flow about blunt Bodies .</b>	<b>271</b>
	Arno Klomfass and Manfred Salk	
15.1	Introduction . . . . .	271
15.2	Physical Models . . . . .	273
15.2.1	Conservation Equations . . . . .	273
15.2.2	Equation of State . . . . .	273
15.3	Numerical Method . . . . .	275
15.4	Steady State Flow Fields . . . . .	276
15.5	Summary . . . . .	277
	References . . . . .	278
<b>16</b>	<b>Numerical Analysis Method for the RC Structures Subjected to Aircraft Impact and HE Detonation . . . . .</b>	<b>281</b>
	Masahide Katayama and Masaharu Itoh	
16.1	Introduction . . . . .	281
16.2	Analytical Method . . . . .	282
16.2.1	Analysis Code . . . . .	282
16.2.2	Material Models . . . . .	283
16.3	Numerical Analyses . . . . .	287
16.3.1	Missile Impact on RC Structure (2D) . . . . .	287
16.3.2	HE Detonations On and Near the RC Slab (2D & 3D) . . . . .	290
16.3.3	F-4 Phantom Crashing on a RC Wall (3D) . . . . .	296
16.3.4	Boeing 747 Jet Impacting on Thick Concrete Walls (3D) . . . . .	302
16.3.5	HE Detonation in Tunnel Structure with Inner Steel Liner (3D) . . . . .	307
16.4	Conclusions . . . . .	311
	References . . . . .	311
<b>17</b>	<b>Groundshock Displacements – Experiment and Simulation . . . . .</b>	<b>315</b>
	Eliahu Racah	
17.1	Introduction . . . . .	316
17.2	Experiment . . . . .	316
17.2.1	Experimental Setup . . . . .	316
17.2.2	Experimental results . . . . .	317
17.3	MSC.DYTRAN DYMMAT14 Material Model . . . . .	319
17.3.1	Deviatoric Behavior . . . . .	319
17.3.2	Hydrostatic Behavior . . . . .	321
17.4	Soil Data . . . . .	321
17.4.1	Density . . . . .	322
17.4.2	Refraction Survey and Elastic Moduli . . . . .	323
17.4.3	Pressiometer Tests and Volumetric Crush . . . . .	324
17.4.4	Direct Shear Tests and Yield Surface . . . . .	325
17.5	Simulation . . . . .	326
17.5.1	Simulation Setup . . . . .	326
17.5.2	Simulation Results and Discussion . . . . .	327
17.6	Conclusion . . . . .	330

References .....	330
<b>Part III Numerical Simulation of Hypervelocity Impact Effects</b>	
<b>18 Hypervelocity Impact Induced Shock Waves and Related Equations of State .....</b>	<b>333</b>
Stefan Hiermaier	
18.1 Introduction .....	333
18.2 Shock Wave Formation and the Necessity of Adequate Equations of State .....	334
18.2.1 Wave Dispersion due to Nonlinear Compressive Material Characteristics .....	334
18.2.2 Requirements to an EoS with Respect to Shock Formation	336
18.3 Equations of State for the Simulations of Shock Processes .....	337
18.3.1 Complete versus Incomplete Equations of State .....	337
18.3.2 Mie-Grüneisen Shock EoS .....	339
18.3.3 Equations of State for Porous Materials .....	340
References .....	347
<b>19 Artificial Viscosity Methods for Modelling Shock Wave Propagation .</b>	<b>349</b>
James Campbell and Rade Vignjevic	
19.1 Introduction .....	349
19.2 The Von Neumann - Richtmyer viscosity .....	350
19.2.1 Demonstration .....	352
19.2.2 Wall Heating .....	356
19.3 Test problems for shock viscosity formulations .....	356
19.3.1 Sod shock tube .....	356
19.3.2 Noh generic constant velocity shock .....	358
19.3.3 Saltzman piston .....	359
19.4 Alternative forms of artificial viscosity .....	361
19.4.1 Edge centred viscosity .....	362
19.4.2 Tensor viscosity .....	363
19.5 Summary .....	364
References .....	364
<b>20 Review of Development of the Smooth Particle Hydrodynamics (SPH) Method .....</b>	<b>367</b>
Rade Vignjevic and James Campbell	
20.1 Introduction .....	367
20.2 Basic Formulation .....	372
20.3 Conservation Equations .....	373
20.4 Kernel Function .....	377
20.5 Variable Smoothing Length .....	378
20.6 Neighbour Search .....	379
20.7 SPH Shortcomings .....	380
20.7.1 Consistency .....	380

20.7.2	Tensile Instability .....	384
20.7.3	Zero-Energy Modes .....	389
20.8	Summary .....	391
	References .....	392
<b>21</b>	<b>Assessing the Resiliency of Composite Structural Systems and Materials Used in Earth-Orbiting Spacecraft to Hypervelocity Projectiles</b> .....	<b>397</b>
	<b>Projectile Impact</b> .....	<b>397</b>
	William P. Schonberg	
21.1	Introduction .....	397
21.2	Historical Overview .....	400
21.3	Composite Material Panels .....	401
21.3.1	HVI Response Characterization .....	401
21.3.2	Use in MOD Protection Systems .....	403
21.4	Honeycomb Sandwich Panels .....	406
21.4.1	Early Work – The 1960s and 70s .....	406
21.4.2	The 1980s and 90s .....	407
21.4.3	Recent Work .....	409
21.5	Conclusions .....	410
	References .....	411
<b>22</b>	<b>Numerical Simulation in Micrometeoroid and Orbital Debris Risk Assessment</b> .....	<b>417</b>
	Shannon Ryan	
22.1	Introduction .....	417
22.2	Ballistic Limit Simulation of a Representative Satellite Structure Wall .....	423
22.2.1	Target Definition .....	424
22.2.2	Experimental Validation of the Numerical Simulation .....	424
22.2.3	Simulation Results .....	426
22.3	Simulation of Hypervelocity Impact on a Representative Satellite Structure Wall Causing Penetration and Fragment Ejection .....	428
22.3.1	Target Definition .....	430
22.3.2	Experimental Validation of the Numerical Simulation .....	430
22.3.3	Simulation Results .....	434
22.4	Numerical Simulation of Impact Induced Disturbances in Satellite Structures .....	435
22.4.1	Target Definition .....	436
22.4.2	Experimental Validation of the Numerical Simulation .....	436
22.4.3	Simulation Results .....	439
22.5	Discussion and Summary .....	444
	References .....	445



**23 Numerical Modeling of Crater Formation by Meteorite Impact and Nuclear Explosion . . . . . 447**  
Charles L. Mader  
23.1 The NOBEL Code . . . . . 447  
23.2 Modeling the Arizona Meteor Crater . . . . . 449  
23.3 Modeling the SEDAN Crater Created by a Nuclear Explosion . . . . 452  
23.4 Conclusions . . . . . 455  
References . . . . . 457

**Index . . . . . 459**

<http://www.springer.com/978-1-4419-0726-4>

Predictive Modeling of Dynamic Processes

A Tribute to Professor Klaus Thoma

Hiermaier, S. (Ed.)

2009, XX, 460 p., Hardcover

ISBN: 978-1-4419-0726-4