
TABLE OF CONTENTS

ABSTRACT	iii
TABLE OF CONTENTS	vi
TABLE OF FIGURES.....	xiv
TABLE OF GRAPHS.....	xv
ACKNOWLEDGMENTS	xvi
CHAPTER I: INTRODUCTION	1
1. A Cultural History of Catastrophes and Chaos.....	4
2. Cultural Connectors	8
3. Modeling Practices.....	11
a) Modeling Practices: A Definition	13
b) Practice, Practices, and Conceptual Practice	15
c) Theoretical Technologies	17
d) The Modeling Practice of 'Applied Topologists'	20
4. Patterns of Mathematization'.....	22
5. Sources and Contents	27
CHAPTER II: STRUCTURES.....	36
1. Introduction.....	36
2. Origins.....	41
a) Structuralisms: Lévi-Strauss and Bourbaki.....	41
b) Bourbaki: The Emergence of a Myth.....	44
c) The Architecture of Mathematics	48
d) Structures of Kinship	55
3. Hegemony	62
a) Bourbaki's Reign.....	62

b)	The Rise of Structuralism: The First Interdisciplinary Conferences (1956-1959).....	66
c)	Jean Piaget and Genetic Structuralism.....	72
d)	The Oulipo: Bourbakist Literature?	78
4.	Decline	85
a)	Michel Serres: From Structuralism to Post-Bourbakism	86
b)	The Trouble with Bourbaki's Structures	92
c)	'Nice Visible Novelties' in Mathematical Research	96
d)	Catastrophes and Fractals as Cultural Connectors.....	102
5.	Conclusion	105
	CHAPTER III: CATASTROPHES	108
1.	Introduction.....	108
a)	What Ever Happened to Catastrophe Theory?.....	109
b)	Catastrophe Theory: A Theory of Modeling Practices	112
2.	What Was Catastrophe Theory?	115
3.	Sociologically Speaking, a Mathematician.....	118
a)	Mathematical Styles: Bourbaki Against Intuition.....	119
	(i) Mathematical Interlude I: Thom's Cobordism Theory.....	123
b)	The Mathematical Background of Catastrophe Theory.....	126
	(i) Mathematical Interlude II: Singularity Theory	129
c)	'A Beautiful, Intriguing Field of Pure Mathematics'.....	132
4.	Towards a Theoretical Biology ?	136
a)	From Pure Mathematics to Theoretical Biology, 1960-1968	136
b)	'Wad' and the Synthesis of Biology	140
c)	Dynamical Theories of Morphogenesis	145
5.	Topology and Meaning	151
a)	Man and Catastrophes.....	152
b)	Language and Catastrophe	153
c)	Structuralism and Biology.....	157
6.	Shapes, <i>Logoi</i> , and Catastrophes: Thom's Theory of Modeling Practice .	159
	(i) Nonreductionism.....	160
	(ii) Forms	161
	(iii) The Mundane	162
	(iv) The Logos	163
	(v) The Qualitative.....	165
	(vi) Intelligibility.....	166
	(vii) Hermeneutics	167
7.	Conclusion	169

CHAPTER IV: FUNDAMENTAL RESEARCH	172
1. Introduction: The Puzzle Place	172
2. A Brief History of the Institut des Hautes Études Scientifiques (Bures-sur-Yvette)	175
a) Léon Motchane and the Mobilization for Fundamental Research	177
b) What is Fundamental Research and Why Should Industry Sponsor It?	183
(i) Looking for Patrons	185
(ii) The Nationalized Sector	188
(iii) Big Industry.....	190
(iv) What Thus is Fundamental Research?	195
c) Searching for Financial Stability.....	198
(i) Legal Matters and Threat from Industrialists.....	198
(ii) Finances and Activities	201
3. 'Osmosis' Between Physicists and Mathematicians?	204
a) Statistics for Visiting Professors, 1960-1971.....	204
(i) Comparing Paid vs. Unpaid Professors and Visitors	205
(ii) Comparing Physicists with Mathematicians	207
b) Organizing the Work at the IHÉS	208
c) Setting up Theoretical Physics in France.....	213
d) Theoretical Physics or Mathematical Physics?	221
4. 'Physico-Mathematical' Methodology of the Sciences of Man?	225
5. Thom's 'Dreams'.....	231
6. Conclusion	233
7. Complement To Chapter IV: Documents	235
a) Lettre de Léon Motchane à Pierre Ailleret, Électricité de France (7 mai 1958), accompagnée d'une "Note."	235
b) Note pour les industriels (mai 1958), par Léon Motchane, 3pp. ..	238
CHAPTER V: STABILITY	242
1. Introduction: a History of Structural Stability	242
2. Mathematical Lag Explains Sputnik, or the Cold War Roots of Chaos Theory ?	245
3. Facets of Stability in the Interwar: Radio Engineering, Coarse Systems, Celestial Mechanics	250
a) Dissipative Systems and the van der Pol Equation	251
(i) Mathematics and Radio Problems.....	251
(ii) French Reception and Rocard's Insensitivity	254
(iii) A Model of Mathematical Models?	257

b)	Stability in Mathematics and in Modeling Practice for Radio Engineering	259
(i)	Coarse Systems	259
(ii)	Stability in Cartwright's Work	262
(iii)	Stability as Program and Philosophy	263
c)	Birkhoff: Conventionalism for Stability	267
4.	As it Goes West, Coarseness Becomes Structural Stability.....	274
a)	Filling Wholes.....	274
b)	A Density Theorem by Peixoto.....	277
5.	Smale's 'Bad' Conjecture and the Horseshoe: 'An Admirable Battle'	281
a)	The Topologists' Hand	282
b)	'My Best-Known Work Was Done on the Beaches of Rio'	286
(i)	Ancestors of the Horseshoe.....	287
(ii)	Smale's Geometric Translation of Levinson: The Horseshoe.....	291
c)	'An Unfinished Painting with Several Superposed Sketches'	294
(i)	Poincaré Again: The Homoclinic Tangle.....	294
(ii)	A Russian Encounter.....	298
(iii)	What That Allowed in Mathematics?	300
d)	Steve Smale's Research School of Dynamical Systems	302
(i)	'The Heady Wonderful Years of the Mid-Sixties'.....	302
(ii)	Structurally Stable Systems Are Not Dense, So What Is Next?	306
6.	Historiography of Chaos: A Question of Timing.....	310
(i)	Traditions, Synthesis, and Topology.....	311
(ii)	The Impact of the Computer: Lorenz's Butterfly and Similar Cases	315
7.	Conclusion	325
	CHAPTER VI: QUALITATIVE DYNAMICS	327
1.	Introduction: The Modeling Practice, or Practices, of 'Applied Topologists'	327
2.	Thom's Program: The Early Years, 1964-1966	331
a)	Settling in at the IHÉS	332
(i)	Singularities Versus Dynamics	333
(ii)	Malgrange's Preparation Theorem	336
(iii)	Dynamics and Structural Stability	338
b)	Zeeman: Topology for Mathematical Modeling.....	341
(i)	'The Perfect Environment Both to Think and to Write'	343
(ii)	Topology of the Brain.....	344
c)	Convergence: The Spring of 1966	349

3.	The Emergence of a Modeling Practice, 1966-1970.....	351
a)	The Stability of C^∞ -Mappings.....	352
b)	Consequences of Smale's Counterexample.....	353
c)	May 68 at Bures: 'Le Bois-Marie Never Looses Her Magic'	355
(i)	Zeeman Dives In	356
(ii)	The Road to Ruelle's Turbulence	357
(iii)	Motchane: Formal Structures of Real World.....	359
d)	Mathematics versus Rhetoric: The Case against Deligne.....	362
e)	The Network in Full Swing.....	364
4.	External Success and Internal Crises, 1969-1972.....	366
a)	First Skirmish.....	367
b)	Grothendieck, the IHÉS, and The Military	370
(i)	Grothendieck's Politics and Biology	371
(ii)	Military Credits at the IHÉS	377
(iii)	Jalousie? Better a Good Divorce than a Bad Union.....	381
c)	The Birth of Catastrophe Theory	388
d)	A Research School for Thom in the Methodology of the Sciences of Man?	393
5.	Applied Topology? The Modeling Practice of Qualitative Dynamics, 1971-1972	398
a)	Dynamical Systems at Bahia, 1971.....	399
(i)	Thom and Linguistics.....	400
(ii)	Zeeman and Physiology	404
(iii)	Smale and Economics	409
(iv)	Seeds of Discord?	411
b)	Abraham: Student of Morphogenesis	414
(i)	Morphosophy	414
(ii)	Chaos.....	417
(iii)	Is Mathematics Worth Doing?	419
6.	Divergences and Controversies, 1974-1977	421
a)	Media Success: The Vancouver Congress in 1974.....	422
b)	The Thom-Zeeman Debate	424
c)	The Twofold Way: The Heart of Modeling Practices.....	428
d)	Critiques and Attacks: A Social Phenomenon?	431
e)	The Smale-Zeeman Debate.....	435
7.	Conclusion	440
CHAPTER VII: STRANGE ATTRACTORS.....		444
1.	Introduction: A New Alternative for the Modeling practice of Physics ...	444
2.	The Nature of Turbulence: Three Alternatives	450
a)	The Argument of Ruelle and Takens's Paper.....	452

b)	The Quasiperiodic Model for the Onset of Turbulence	455
(i)	Physics à la Landau.....	455
(ii)	The Hopf Bifurcation	460
(iii)	What Hopf Did and What He Did Not Do, Compared with Ruelle and Takens.....	467
c)	Leray: Turbulence as Irregularity	472
(i)	Turbulent Solutions.....	472
(ii)	What Use for the Theory of Equations? Existence and Uniqueness Theorems	476
3.	Dynamical Systems in the Ruelle-Takens Model	481
a)	Thom, Smale, and the Concept of Attractors	482
(i)	Acknowledgments.....	482
(ii)	Attractors.....	483
b)	Modeling Practices at the Institut des Hautes Études Scientifiques.....	487
c)	Strange Attractors and Genericity.....	491
4.	David Ruelle, The 'Monster': the Career of a Mathematical Physicist	495
a)	Still Another Mathematical Physicist?.....	496
b)	Ruelle, Statistical Physics, and the Military	500
c)	The Structure of Physical Theories: The Bourbakization of Physics?.....	501
5.	A Long-Term Disciplinary Survey of the Turbulence Problem	503
a)	Fluids Are Described by the Navier-Stokes Equations.....	506
(i)	Euler's Equations.....	506
(ii)	Navier and the Molecular Hypothesis.....	508
(iii)	Stokes: The Robustness of Partial Differential Equations	511
b)	The Turbulence Problem: From Hydraulics to Physics	513
(i)	Early Studies of Turbulence: Poiseuille, Darcy, Boussinesq, etc.....	514
(ii)	Osborne Reynolds's Experimental Discovery of Turbulence	518
c)	Stability Theory: The Conceptual Unit Challenged by the Ruelle-Takens Model.....	525
(i)	Ancestors and Controversy	527
(ii)	Success with Taylor-Couette Flow: Sequence of Instabilities	531
(iii)	Synthesis, but Insignificance?.....	536
(iv)	Nonlinear Stability Theory.....	539
6.	Reception of the Ruelle-Takens Model by Stability Theorists; Reception of Stability Theory by Ruelle.....	545
a)	Confrontation at Battelle	546
b)	Ruelle and the IHÉS After Ruelle-Takens	548
c)	Stability Theorists in the Age of Chaos	556

7.	Conclusion: Bourbaki and the Computer.....	561
CHAPTER VIII: CHAOS.....		568
1.	Introduction.....	568
a)	Reception of the Ruelle-Takens Model	571
b)	Rayleigh-Bénard: A Boundary System.....	574
c)	Structure of the Chapter	576
2.	Classic Rayleigh-Bénard: Experiments and Theories.....	581
a)	Classic Problems of Convection	583
b)	The Hydrodynamicists' Approach to the Rayleigh-Bénard System.....	587
(i)	Experiments: 'How the Onset of Convection Actually Occurs'.....	587
(ii)	Theory: No 'Real Breakthrough in Understanding'?.....	589
3.	Rayleigh-Bénard: A Boundary System.....	594
a)	Rayleigh-Bénard as Dissipative Structure	595
(i)	Prigogine: From Irreversible Thermodynamics to Rayleigh-Bénard	595
(ii)	Instability and Dissipative Structures in Brussels, 1973...	600
(iii)	Order through Fluctuations: Debate with Thom	602
(iv)	Prigogine and Ruelle: Noiseless Turbulence	604
b)	Rayleigh-Bénard as Phase Transition	606
(i)	Phenomenological Analogy with Phase Transition	606
(ii)	A Visit at Bell Labs: The Computer as Experimental Development	608
(iii)	Physicists Take over Fluid Mechanics, Part I	610
(iv)	The Topological Analogy	612
c)	Rayleigh-Bénard as a Test-Case for Theories of Turbulence	616
4.	Hydrodynamical Instabilities and Turbulence in France, 1971-1975.....	622
a)	Three conferences in France	622
b)	An 'Action thématique programmée' on turbulence.....	626
(i)	The VIth Plan, the CNRS, and the ATPs: Active Management of Scientific Research	626
(ii)	Liquid Crystals: Analogies Get Real	631
(iii)	Les Houches 1973: Physicists and Turbulence.....	633
(iv)	De Gennes's Program: Let Physicists Take Over Fluid Mechanics, Part II	637
(v)	Disputes and Disappointment: Interdisciplinarity is not an Easy Task	643
c)	Geilo 1975: The Emergence of an International Community?	647
5.	Epilogue: Beyond Ruelle-Takens	650
a)	Ruelle and the IHÉS, 1970-1977	652

	(i) Ruelle's Picks up Lorenz	653
	(ii) IHÉS: 'Foreign in View of Some Frenchmen'.....	656
b)	Bergé-Dubois: Laser Velocimetry	661
	(i) A Simple and Easy to Implement Technique.....	661
	(ii) Mere Confirmation of Theory?	663
c)	Pomeau: Interdisciplinarity in Action.....	666
	(i) A New Scientific Community?	666
	(ii) Intermittency: Translation of Dynamical Systems Modeling Practices.....	669
d)	Libchaber: Helium in a Small Box	674
	(i) Bolometers: A Local Probe.....	675
	(ii) Experiment and Observations	678
	(iii) Feigenbaum: Surprise and Excitement	681
e)	Eckmann's Synthesis: The 'Dynamical Systems Approach'?.....	684
6.	Conclusion	688
a)	The Triumph of 'Light' Physics.....	688
b)	Experiment-Based Topology?.....	691
7.	Complement to Chapter VIII: Document.....	693
	Research Program Presented by Nicolaas Kuiper to the Volkswagen Foundation (1976).....	693
	SOURCES AND BIBLIOGRAPHY.....	696
1.	Archival sources.....	696
2.	Oral Sources: Interviews Conducted by the Author	698
3.	Published Sources	699
a)	Abbreviations Used in Bibliography and Text	699
b)	General Bibliography.....	699
	THE END.....	782

TABLE OF FIGURES

Figure 1: E. Christopher Zeeman's Pictorial Representation of the Relation Between Science and Mathematics.....	27
Figure 2: François Le Lionnais and Robert Oppenheimer at the IHÉS in 1963.....	81
Figure 3: Waddington's Epigenetic Landscape.....	143
Figure 4: Switches in the Epigenetic Landscape.....	144
Figure 5: Waddington's Switching Diagram.....	154
Figure 6: Thom's Analogy Between Graphs of Sentences and Development.	156
Figure 7: Robert Oppenheimer and Léon Motchane at the IHÉS in 1963.....	177
Figure 8: Flow in Phase Space for the van der Pol Equation.....	252
Figure 9: Solutions as Function of Time of the van der Pol Equation.....	254
Figure 10: Smale's Horseshoe.....	292
Figure 11: Citations to Edward Lorenz.....	311
Figure 12: René Thom Lecturing on Catastrophe Theory at the IHÉS in the Early 1970s.	366
Figure 13: The Hopf Bifurcation of a Point Attractor into a Close Trajectory.....	464
Figure 14: Secondary Oscillation Observed by G. I. Taylor in the Couette Flow.	533
Figure 15: Landau's Picture for the Onset of Turbulence, and Three Alternatives.....	569
Figure 16: A Schematic View of the Contents of Chapter VIII.....	577
Figure 17: The Fluid Dynamicist's View of the World.	638
Figure 18: Poincaré Map from the Lorenz Model	672
Figure 19: Libchaber's Experimental Apparatuses for the Study of Superfluid Helium, and for the Study of the Onset of Turbulence.....	677

TABLE OF GRAPHS

Graph 1: Evolution of the actual total income of the Institut des hautes études scientifiques, 1958-1977	202
Graph 2: Relative contributions of the different types of sponsors to the Institut des hautes études scientifiques, 1958-1977	203
Graph 3: Total number of professors and total number of "mois-professeurs" at the Institut des hautes études scientifiques versus years, 1960-1971.....	204
Graph 4: The number of "mois-professeurs" emphasizing the part played by unpaid admitted professors versus years, 1960-1971.	206
Graph 5: The absolute number of professors emphasizing the part played by unpaid admitted professors versus years, 1960-1971.	206
Graph 6: Percentage of mathematicians, as opposed to physicists, among the total number of professors invited at the IHÉS, 1960-1971.....	207
Graph 7: Percentage of "mois-mathématiciens" as opposed to "mois-physiciens" spent at the IHÉS, 1963-1970.....	208
Graph 8: Citations to David Ruelle and Floris Takens, "On the Nature of Turbulence."	461
Graph 9: Citations to Eberhard Hopf, "Abzweigung einer periodischen Lösung", "A Mathematical Example", and the translation: "Bifurcation of a Periodic Solution," according to the <i>Science Citation Index</i> , 1945-1988.....	462