Foreword

Ignorance more frequently begets confidence than does knowledge: it is those who know little, and not those who know much, who so positively assert that this or that problem will never be solved by science.

–Charles Darwin

The German physicist Max Plank hypothesized that important scientific innovations become accepted because their opponents gradually die out, not because they gradually win over opponents. Evolutionary algorithms certainly had no shortage of opponents in the optimization community when they were first introduced in the early 1990s. We now see that Evolutionary algorithms are a maturing technology well beyond the bleeding edge and in the realm of the practitioner.Evolutionary algorithms for multi-disciplinary design optimization have been successfully applied in a variety of areas that include: industrial design by parameterization, network design by construction, scheduling, routing, database mining, control systems, time series prediction, artificial intelligence, molecular design and artificial life systems. The current wide- spread use of Evolutionary Algorithms is not a consequence of a high rate of mortality in the optimization community as Dr. Planck would suggest but a result of the dramatic increase in computational capacity and Information Technology implementation. This capacity has transformed what formerly was an interesting theoretical construct into a useful (engineering design) tool.

The issue at hand is not theoretical and conceptual development of Evolutionary Algorithms but developing the expertise for their implementation.The present volume by Felipe Gonzalez, Dong Seop Chris Lee, and Jacques Periaux is dedicated to the development of this expertise. It describes the role that evolution based tools play with game theoretic strategy in the solution or set of solutions as well as multi-disciplinary optimization in a variety of applications. Although the applications focus on aerospace, the methods translate to other fields including surface and marine transport, UAV systems, biomedical engineering, financial engineering, communications, and artificial intelligence. This volume is directed towards entry level scientists, engineers, and technologists in industry and governmental agencies as well in the academy. Optimization is a contact, not a spectator, sport. Several aeronautical applications with increasing complexity are presented. These are accompanied by a series of “hands- on” test problems are which are proposed as exercises to the reader.

November, 2013 William Fitzgibbon
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Foreword

The present volume has three authors, the only one I know personally being Jacques Périaux. For me, Jacques Périaux is many persons in one: a former student, a personal friend, the co-author of many articles, and has been for many years the inspiration of many of my own investigations.

Jacques Périaux is a most remarkable individual and scientist: during a long and remarkable career in Aeronautics and Aerospace industry in France at Dassault Aviation, Jacques Périaux has been actively involved in designing airplanes, and in closing the gap between Academia and Industry, firmly believing that engineers can learn from academics, and conversely. A constant attitude of Jacques Périaux has been to look at new methods developed in universities and research centers, in France and abroad, for their potential applicability to problems from Industry, quite often suggesting new problems to look at, and ideas to investigate. To give evidence of J. Périaux's vision related to this book, let us mention the fact that, almost twenty years ago, he anticipated the power of evolution algorithms for the solution of those multi-objective and multi-physics design problems occurring in Aeronautics and Aerospace.

Jacques' initiative in that direction met with some scepticism from a number of well-known members of the Computational Mechanics community, but time has proved that his vision was right. The good news is that Jacques Periaux has decided, with the help of two young collaborators, Felipe Gonzalez and Dong Seop Chris Lee, to publish a book (this one) about evolution algorithms, such as the genetic ones, multi-objective optimization, game theory, and more, about the solution of design problems from Aeronautics. The reader will find herein a wealth of methods, examples, convergence studies, and recipes. One of the main values of this book is that practitioners from areas other than Aeronautics will have no difficulty in adapting and implementing the various methods discussed here to the solutions of their specific problems. This book is not easy to read, deep thought being inherent to the topics it addresses, but its reading is facilitated by its excellent structure and the large number of very interesting real-life examples it considers. Those motivated by sufficient drive will learn a lot about a unique combination of methodologies applied in a growing number of areas of Science and Engineering.

June, 2013 Roland Glowinski

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Preface

Computer programs that "evolve" in ways that resemble natural selection can solve complex problems even their creators do not fully understand...

John Holland, Scientific American, July 1992

John Holland of the University of Michigan is commonly regarded as the father of Genetic Algorithms. The story begins in 1993.

Genetic Algorithms belong to a larger class of algorithms called Evolutionary Algorithms that generate solutions to optimization problems using techniques inspired by natural evolution. John Holland of the University of Michigan is commonly regarded as the father of Genetic Algorithms. Holland perceived a connection between biology and computation. Machines as well as animals could be trained to adapt to their environment over successive generations with the principles of evolution being the engines of the adaption. The genetic algorithm begins with a population having randomly generated characteristics. Population members are evaluated by some method and then merged to produce a child with traits that are a combination of its parent's characteristics.

Our story, which begins in 1993, concerns the translation of Holland's ideas from theoretical computational science to industrial design, in particular aeronautical design. Pierre Bohn, Director of "Division des Etudes Avancées" of Dassault Aviation anticipated that Genetic Algorithms could be used to improve the performance of aero-engines and suggested that I investigate new evolution based optimization techniques called Genetic Algorithms. In the 90's the Dassault Scientific Center became a hotbed of activity for development of Advanced Evolutionary Software, many of which are used in this book. In this stimulating environment a group of visitors, colleagues, post doctoral fellows and PhD students actively contributed to the effort. Included in the group are: Bertrand Mantel, CHEN Hong Quan, Mourad Sefrioui, Eric Whitney, TANG Zhili, ZHOU Chun Hua and Jun Feng WANG. Special recognition is due to the late Bertrand Mantel, for his enthusiastic numerical experimentation in the area of robust Genetic Algorithms.

Murphy's first law says that nothing is as easy as it first looks. The fact that Genetic Algorithms are simple to implement and frequently succeed at generating solutions of high fitness when applied to practical problems first led me to believe that further investigation would lead to a rapid completion of several existing optimization methods proposed to those working in the area of Aerodynamic Design. Despite the remarkable potential of Genetic Algorithms their application to design in industrial environments, for several reasons, proved more complicated than I had anticipated:

- Many aeronautical applications involve nonlinear Partial Differential Equations (PDEs) for the mathematical modeling of fluids, structures or waves. This makes the evaluation of a candidate solution in a detailed design expensive.
- The needs of aeronautical industries were moving very rapidly to automated multi-disciplinary design optimization (MDO) in the field of (green) digital aircraft design and manufacturing;
- In order to account for uncertainties in flight conditions or geometrical parameters for maintaining reliable performance, robust stochastic optimization of real life problems was becoming a first priority that designers had to take into consideration.

In the time period between 1996 and 2006 Dassault Aviation launched several research projects in collaboration with the Laboratoire Informatique Paris 6 (LIP6) and the Aerospace Engineering Department of the University of Sydney (USYD) from 1996 to 2005. The outcomes of these projects showed significant progress in both efficiency and quality and led to a new class of advanced evolutionary algorithms for multi-objective optimization problems in aeronautics. Several new methodologies were introduced including successively hierarchical topology, asynchronous parallelism, game strategies and more recently hybridized game coalitions.

Over the course of the last ten years, Felipe Gonzalez, Dong Seop Chris Lee and I have given many seminars, workshop presentations and conference lectures on Genetic Algorithms within the context of aerodynamical design. On the basis of this activity we decided to create the present volume, whose raison d'être is to provide physicists, engineers and computer scientists with advanced evolutionary methods and tools useful to the numerical solution of multi-objective optimization problems in Aeronautical applications. In particular we wished to introduce entry level, neophyte, scientists and engineers to Genetic Algorithms, thus providing them with not only computing guidelines but examples or test problems of increasing complexity and difficulty.

We hope to make the scientific and industrial community aware of the potential of both Evolutionary Algorithms and Game Theory. Evolutionary Algorithms form the basis for robust decision making software that searches solutions in hilly spaces. Game Theory offers mathematically well-defined strategies for solving multi-objective optimization problems. In an effort to optimize efficiency within the context of industrial applications, we provide a detailed description of methodologies that combine game theoretical strategy with Evolutionary Algorithms. We conclude with an Appendix which offers the reader several practical, "hands-on" test problems together with descriptions of software and guidelines for capturing, presenting and discussing solutions. It is our expectation that these test problems will provide readers a pathway for solving their own optimization problems.

The applications of innovative advanced evolutionary tools are not limited strictly to aeronautics. Applications may be found in complex multi-physics optimization problems drawn from a wide variety of areas such as biomedical engineering, surface transport, energy, and green technologies, among others.

After an introductory chapter which outlines the requisite background we sequentially address the following topics:

- Requisite Background
- Evolutionary Methods
- Multi-objective Evolutionary Algorithms and Game Theory
- Advanced Evolutionary Algorithms
- Multi-disciplinary Design/Robust Design
- Introduction to Algorithms for Numerical Design and Optimization
- Single Objective Model Test Problems
- Multi-Objective Model Test Problems
- Multi -Disciplinary Design Optimization
- Robust Multi-Disciplinary Design Optimization
- Morphing Design Optimization

We provide a summarizing conclusion and then end with the aforementioned appendix that contains the hands on optimization test problems with guidelines on how to apply the methods and tools that have been described in the text.

Most of the numerical experiments have been conducted in collaboration with my co-authors Dr. Felipe Gonzalez and Dr. Dong Seop Chris Lee, both of whom I met during their course of PhD study at the University of Sydney. Computations performed by two of my PhD students J. Leskinen and Ms. Wang Hong, at the University of Jyvaskyla have been useful in the presentation of some test problems of the Appendix which can be found in the Finnish Database http://www.jucri.jyu.fi. Several numerical experiments have been performed by accessing and using software from many well-known scientists. We express our thanks to Frederic Hecht and Olivier Pironneau (FreeFem++), A. Jameson (Flow22), Mark Drela (XFOIL and MSES), Bijan Mohammadi (NSC2KE), and the Navy (POFACET).

John Lennon and Paul McCarthy penned the phrase "I get by with a little help from my friends" in 1967. Continuing in this vein I would like to acknowledge and extend my warmest thanks to my friends and colleagues. First and foremost, J.L. Lions has continuously shown me at the University Paris 6 and later at Dassault Aviation along my career the critical role of Applied Mathematics in complex problems in Aeronautics Industry; Roland Glowinski provided a foreword to this book and over the course of forty years has provided mentorship, continuous encouragement, and inspiration. William Fitzgibbon has also provided a foreword and personal encouragement and guidance for proper word usage and syntax. Olivier Pironneau has been always present when needed in difficult moments of my life with high spirit and at important decisions of my scientific and industrial career.

This book would not have existed without the support and encouragement at Dassault Aviation received from CEOs of the company and many colleagues and friends of the Theoretical Aerodynamics Department . I am particularly indebted

to my colleagues and friends, Pierre Perrier who taught me with talent and vision aerodynamics applied to the design of civil, military and space aircraft and also to Patrick Pinganeau and Bruno Stoufflet, Division of the Scientific Strategy Directors for their encouragement in the creation and animation of a Pole Scientifique at Dassault Aviation co-chaired with Olivier Pironneau, UPMC .

Different chapters of this book have been written at the following institutions: the University of Pierre et Marie Curie (UPMC), INRIA Rocquencourt and INRIA Sophia Antipolis, the University of Sydney, the University of Queensland, the University of Milano, the University of Jyvaskyla, the International Centre of Numerical Methods in Engineering (CIMNE), the University of Las Palmas de Gran Canaria (CEANI and IUSIANI), the Von Karman Institute (VKI), the National Technical University of Athens (NTUA), The Kyoto Institute of Technology (KIT), Chiba University, the University of Houston and the Nanjing University of Aeronautics & Astronautics (NUAA). The authors express special thanks to V. Capasso, B. Chetverushkin, G. Ganascia, H. Deconink, J.-A. Desideri, W. Fitzgibbon, B. Galvan, K. Giannakoglou, R. Glowinski, GUO Xiaoping, JIN Quanyuan, H. Kawarada, Y. Kuznetsov, Y. Maday, K. Morinishi, E. Onate, K. Papailiou, K. Srinivas, R. Walker, G. Winter, N. Satofuka, T. Verstraete, and ZHA Rong, ZHAO Ning for their hospitality and the facilities provided during many stays or educational courses. A special thanks to P. Neittaanmaki for his long and enjoyable hospitality at the Univ. of Jyvaskyla and for his continuous encouragement to complete the material of the book.

We would also to thank Eric J. Whitney, A. Abbas, J. Alonso, G. Auchmuty, W. Annicchiarico, R. Bank, T. Burczynski, G. Bugeda, M. Cerrolaza, C.A. Coello Coello, P. Cuesta, Damp, K.Deb, A. Dervieux, M. Galan+, N. Gauger, D. Goldberg, D. Greiner, M. Hafez, F. Hecht, C. Hirsch, H. Kawarada, H. Suito, W. Haase, M. Holst, R. Hoppe, A. Jameson, I. Kroo, Y. Kuznetsov, R. Makinen, G. Meurant, Z. Michalevich, K. Miettinen, T. Nguyen, S. Obayashi, P. Perrier, V. Pediroda, O. Pironneau, C. Poloni, Ning Qin, D. Quagliarella, M. Schoenauer, K. Srinivas, J. Toivanen whose collaboration through fruitful discussions were essential for many of the results presented in the book.

My motivation in Computational Multi- physics Design Optimization in Aeronautics has been stimulated for almost two decades by European Commission projects of DG Research Aeronautics coordinated by CIMNE. The recent series of EU-China projects with Aerochina, Aerochina2 and more recently GRAIN and GRAIN2 are examples of collaborative teams focused on new methods and tools for advanced design in Aeronautics. I am particularly grateful to Dr. D. Knoerzer, a colleague and friend, for his continuous interest shown in Computational Fluid Dynamics and Multi-disciplinary Design Optimization and also to Dr. L. Breslin, Head of Unit Aeronautics for his involvement in EU-China cooperation and his interest in numerical methods, particularly at the ECCOMAS 2004 Congress in Jyvaskyla, Finland.

We are grateful to Ms Kati Valpe, Ms Marja Leina Rantalainen and Ms Anu Penttila, from the University of Jyvaskyla, for providing us with the beautiful picture of the front page of the book— Swans in a “high lift aerodynamic configuration”

during landing on a Finnish lake—and also for checking many figures and helping in many ways the completion of this book.

Finally, I would like personally to express my gratitude to Ms. Nathalie Jacobs, Springer Publishing Editor and her staff and also to Prof. E. Onate, CIMNE Director and Editor of the Series Lectures Notes in Numerical Methods in Engineering and Sciences for their understanding, patience and encouragement during the difficult 2007–2008 period of personal tragedy and trauma.

Jacques Periaux and his co authors Felipe Gonzalez and Donseop Chris Lee
April 2014

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http://www.springer.com/978-94-017-9519-7

Evolutionary Optimization and Game Strategies for
Advanced Multi-Disciplinary Design
Applications to Aeronautics and UAV Design
Periaux, J.; Gonzalez, F.; Lee, D.S.C.
2015, XXI, 305 p. 246 illus., 48 illus. in color., Hardcover
ISBN: 978-94-017-9519-7