BRIEF HISTORY OF COMPOSITE APPLICATION IN AEROSPACE

CHAPTER 1
The Road to Large Scale Composite Application on Wide Body Commercial Transports

Introduction 2
General Aviation Certified Composite Aircraft Programs 2
Lear Fan 2
Beech Starship 3
Raytheon Premier I 5
Adam Aircraft A500 & A700 7
Cirrus SR20 & SR22 8
Large Commercial Transport, a Big 2 Perspective 8
Composite Manufacturing Processes 11
Hand Lay-Up 12
Pultrusion 13
Filament Winding 14
Tape Laying 15
Advanced Fiber Placement 16
Resin Transfer Molding (RTM) 17
Challenges of Scale 18
Conclusion 18
Acknowledgments 19
Contact Information 19
References 19
CHAPTER 2

Advanced Materials for Aerospace and Space Applications

Introduction 22
Metal Graphite Composites 24
Copper Graphite Composites 24
Silver Graphite Composite Compounds 24
Aluminum Graphite Composites 25
Light Metal Graphite Composites 25
Fiber Reinforced Composites 25
CFRP - Plastic with Special Properties 26
CFC/Carbon Fiber Reinforced Carbon 26
GRP—Glass Fiber Reinforced Plastics 27
Ceramic Matrix Composites (CMC) 27
Coatings for Composites 28
Silicon Carbide Coatings 28
SiC/B4C Coatings 28
Pyro-Carbon Layers 30
Silicon Carbide—SiC 30
Silicon Carbide Sintered without Pressure (SSiC) 31
Hot-Pressed Silicon Carbide (HPSiC)/Hot Isostatically Pressed SiC (HIPSiC) 31
Recrystallized Silicon Carbide (RSiC) 31
Liquid-Phase Sintered Silicon Carbide (LPSiC) 31
Mixed Ceramics 32
Tribology 32
Special Tribological Applications 33
Thermal Management 33
Devices for Passive Heat Dissipation 34
Graphene/AU Composites 34
Summary/Conclusions 35
References 35
CHAPTER 3

Virtual Allowable Computation to Speed-Up CFRP Material Development and Certification

Introduction 40
Technical Background 41
  Mean-Field Homogenization 41
  Progressive Failure 41
  Insertion of Variability 45
Virtual Coupon Simulation Using FEA 45
Applications 47
  Definition of the Test Matrix 47
    Material Calibration 47
    Insertion of Variability 47
    Lay-up Definition 47
    Coupon Test Definition 47
    Environmental Condition 47
Simulations 47
  DIGIMAT Model Calibration 47
  FEA Model 49
Allowables 49
Conclusions 51
References 51

CHAPTER 4

Efficient Procedure for Robust Optimal Design of Aerospace Laminated Structures

Introduction 54
Explanatory Application 54
Methodology Proposed 55
  Multi-Objective Optimization Algorithm 55
<table>
<thead>
<tr>
<th>Possible Algorithm Improvements</th>
<th>56</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penalty Method</td>
<td>56</td>
</tr>
<tr>
<td>Convergence Test</td>
<td>56</td>
</tr>
<tr>
<td><strong>Structural Knowledge</strong></td>
<td>56</td>
</tr>
<tr>
<td><strong>Micro-Mechanics</strong></td>
<td>56</td>
</tr>
<tr>
<td>Fiber and Matrix Properties</td>
<td>56</td>
</tr>
<tr>
<td>Composite Property as Function of Fiber Volume</td>
<td>57</td>
</tr>
<tr>
<td><strong>Individual Evaluation</strong></td>
<td>57</td>
</tr>
<tr>
<td>Model Validation</td>
<td>57</td>
</tr>
<tr>
<td>Parallelization and State Machine</td>
<td>57</td>
</tr>
<tr>
<td>PCL File Pseudo-Code</td>
<td>59</td>
</tr>
<tr>
<td><strong>Composites Manufacturing Rules</strong></td>
<td>59</td>
</tr>
<tr>
<td><strong>Robust Statistical Property</strong></td>
<td>59</td>
</tr>
<tr>
<td><strong>Monte Carlo Methods</strong></td>
<td>59</td>
</tr>
<tr>
<td>Crude Monte Carlo Method Used</td>
<td>59</td>
</tr>
<tr>
<td>Quasi Monte Carlo Method Used</td>
<td>60</td>
</tr>
<tr>
<td>CMCM with Surrogate</td>
<td>60</td>
</tr>
<tr>
<td>Comparison CMCM, QMCM and CMCM with Surrogate</td>
<td>61</td>
</tr>
<tr>
<td>Estimators Approximation</td>
<td>61</td>
</tr>
<tr>
<td>Convergence Rate</td>
<td>61</td>
</tr>
<tr>
<td>Dealing with Structural Failure</td>
<td>61</td>
</tr>
<tr>
<td><strong>Statistical Inference</strong></td>
<td>61</td>
</tr>
<tr>
<td><strong>Explanatory Example of Robust Multi-Objective Optimization</strong></td>
<td>62</td>
</tr>
<tr>
<td><strong>Plies Direction Constrains</strong></td>
<td>62</td>
</tr>
<tr>
<td>Setting First Population</td>
<td>63</td>
</tr>
<tr>
<td><strong>QMCM</strong></td>
<td>63</td>
</tr>
<tr>
<td>Variables to Represent Manufacturing Uncertainties</td>
<td>63</td>
</tr>
<tr>
<td>Number Samples</td>
<td>67</td>
</tr>
<tr>
<td><strong>Robust Multi-Objective Optimization</strong></td>
<td>67</td>
</tr>
<tr>
<td>Comparison</td>
<td>68</td>
</tr>
<tr>
<td><strong>Summary/Conclusions</strong></td>
<td>68</td>
</tr>
<tr>
<td><strong>Time Reduction</strong></td>
<td>68</td>
</tr>
<tr>
<td><strong>RMOO or MOO Optimization</strong></td>
<td>69</td>
</tr>
<tr>
<td><strong>Contact Information</strong></td>
<td>69</td>
</tr>
<tr>
<td><strong>Definitions/Abbreviations</strong></td>
<td>69</td>
</tr>
<tr>
<td><strong>References</strong></td>
<td>69</td>
</tr>
<tr>
<td><strong>Appendix</strong></td>
<td>71</td>
</tr>
</tbody>
</table>
CHAPTER 5

Software to Enable Composite and Assembly Development Processes for Modern Airframes

Introduction 74
Main Section 74
  Leveraging the Full Potential of Composites 74
  Multi Disciplinary Composites Engineering 75
  Concurrent Composite Structure Development 75
    Common Understanding 76
    Weight Optimization 77
    Redefining the Engineering Model 77
    Shallow Cut Angle 80
    Staggered Origins 80
    Machine Independent Part Definition 80
    IML Tooling 80
  Composite Airframe Assemblies 81
  Design Change Management 82
  Extending Advanced Capabilities to the Supply Chain 84
  Ensuring Data Longevity 84
Conclusion 85
Contact Information 85
References 86

CHAPTER 6

Digital Manufacturing: The Digital Tapestry

Introduction 88
The Digital Tapestry 88
  Advanced Analytics 90
  MDAO 90
    Key Benefits 92
  I-Triple A 92
  Factory C³ 93
  Expert Systems 94
  Game Theory 95
  Best Athlete 95
References 96
## Contents

- Conclusions 130
- Contact Information 130
- Acknowledgments 130
- Definitions/Abbreviations 130
- References 131

### CHAPTER 9

**Exploring the Manual Forming of Complex Geometry Composite Panels for Productivity and Quality Gains in Relation to Automated Forming Capabilities** 133

- Introduction 134
- The Current Approach in Manual Forming 135
- Geometry Description and Initial Forming Trials 137
- Drape Simulation for Manual Forming Quality Improvement 138
- Drape Simulation for Productivity Improvement 140
- AFP Productivity Comparison 144
- Discussion 147
- Conclusions 149
- Contact Information 150
- Acknowledgments 150
- Definitions/Abbreviations 150
- References 151
- Appendix 153
  - AFP Productivity Calculations, General Description 153

### CHAPTER 10

**Composites Design Optimization for Automated Fiber Placement Process** 157

- Introduction 158
- Aerospace Use Case 158
- Multiple Constraints Problem 159
  - Fiber Angle Deviation 159
  - Isotropy 160
  - Fiber Steering Radius 160
  - Fiber Gaps and Overlaps 161
- Manufacturing Process 162
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automatic Ply Boundary Splicing</td>
<td>163</td>
</tr>
<tr>
<td>Summary/Conclusions</td>
<td>165</td>
</tr>
<tr>
<td>Contact Information</td>
<td>166</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>166</td>
</tr>
<tr>
<td>References</td>
<td>166</td>
</tr>
<tr>
<td>About the Author</td>
<td>167</td>
</tr>
</tbody>
</table>