Index

Advanced Composite Cargo Aircraft (ACCA), 9, 12
Advanced technology transport bus (ATTB), 108
Air France Flight 358, 99
Air Transport Association Part Marking Initiative, 54
Air vehicles, 181–184
  case study, 25–36
Airbus, 37, 38–39, 53–55
  A320, 113
  A350, 5
  A350-XWB, 22
  A380, 111, 182
Aircraft wings, 112
Aldrete, Gregory S., 178
Aluminum, 2–3
  aluminum graphite composites, 128
  vs. composites, 111–113
  ZTA (zirconia toughened alumina), 136
Analytical engineering, 139, 141–142
Anodes, X-ray rotating, 141
Antimony, 126n
Aramid fibers, 92
ARES I, 109, 111
Arthroscopic pins, 139–140
Asiana Airlines Flight 214, 98
Assemblies
  air vehicle case study, 25–36
  Airbus A350-XWB, 22
  assembly gap, 16f
  automation, 159–160
  bagside accuracy, 155
  balanced layups, 150
  Boeing 787, 20–21
  bondline preparation, 151
  calculating an economic value/cost in hours, 31
  co-cure vs. co-bond, 151–152
  corrosion prevention, 153–154
  defects, 160
  design for manufacturing and assembly (DFMA), 7–8, 12, 13–20, 22
  design of, 30, 150–152
  distortion reduction, 150
  drill dry or wet, 158
  drill selection, 158–159
  drill types, 159
  drilling and drill bits, 34–36
  dust collection, 159
  fabrication, 154
Index

fixtures, 33–34
hole generation, 157–158, 159
hole quality, 153, 160
impact of global supply chain, 38–40
interlaminar tension, 152
lightning strike protection, 154
metallic vs. composite, 14–16
Mitsubishi MRJ, 22
MRO in service, 31–33
offset and countertrade, 37–38
one up assembly, 158
part count reduction, 7–8, 10–13
peel ply, 151
performance optimization vs. assembly considerations, 150
plasma clean, 151
process development, 158–159
pullup and out-of-plane concerns, 152
quality control, 160
radius thinning, 156
shrinkage and bow waves, 157
solvent clean, 151
stopping the electrolyte (water), 153–154
symmetrical layups, 151
thickness control, 154
tool material selection, 157
tooling, 33–34
uncollected in-process costs, 29–30
unitized structure, 151
weight savings, 7, 8–10, 13

Atomic absorption spectroscopy (AAS), 141–142
Auto-drill technology, 37
Automated fabrication processes, 3, 4–5
Automatic vision inspection system, 168
Automation, 3, 4–5, 26
RFID, 54–55, 59–60
assembly, 159–160
Automobile industry, 5, 88, 102, 120
Autonomic nervous system (ANS), 42
Avco Manufacturing, 38

B-2 bomber, 97, 180
Bag side accuracy, 155
Balanced layups, 150
Bartell, Scott, 178
Bayesian updating, 69
Beer–Lambert law, 141n
Bespoke products, 118–119
Bio-carbon-based composites, 101
Body armor, 73–75, 177–178
Boeing, 37, 53
747, 38, 111
777, 98, 109, 110, 111
787, 2, 5, 20–21, 111–112, 182, 189
Bolted repair, 31–33, 184–185
Bondline preparation, 151
Bow waves, 157
Bridges, 66–70, 119, 120, 121
Buy-to-fly ratio, 4, 9–10

Carbon fiber, 1–2, 91–92, 161
    prepreg materials, 3–4
    recycling, 101–102
Carbon fiber reinforced carbon (CFC), 130–131
Carbon fiber reinforced plastics (CFRP), 34, 36, 129–130, 187–188
Carbon-graphite/epoxy advanced composite material (cgeACM), 97–98
Case studies
    air vehicle, 25–36
    commercial aviation, 108–111
    macro economics calculations, 117–120
    return on investment, 172
    RFID, 53–56
    wind turbine blades, 70–73
CATIA V, 37
Caul plate, 18f
Ceramic coatings, 132–134
Ceramic matrix composites (CMC), 131
Certification, 13, 113, 165
Ceteris paribus, 116–117
Change, economics of, 106
Chemical vapor deposition (CVD), 159
China, 39
Chlorinated compounds, 96
Coatings
    ceramic, 132–134
    pyro-carbon layers, 133–134
    silicon carbide (SiC), 132–133
    SiC/B4C, 133
Co-bond, vs. co-cure, 151–152
Co-bonded part, example of, 11f
Coefficient of thermal expansion (CTE), 128, 138–139, 157
Commercial aviation, 8–9, 121
    case study, 108–111
Commercial Remote Sensing and Spatial Information (CRS&SI) Technologies Program, 66–67
Complexity, 11–12
Composites
    vs. aluminum, 111–113
    aluminum graphite, 128
    assembly of, 149–161
    automated fabrication processes, 3, 4–5
    bio-carbon-based, 101
    ceramic matrix composites (CMC), 131
    coatings for, 132–134
    copper graphite, 126–127
    cost of, 113–117
    definition of, 1
    drill bits for, 186–187
Index

drilling in, 187–188
economic issues, 3
emerging challenges, 181–183
fiber reinforced, 128–131
and fire fighting, 97–99
graphene/Au, 142–144
health concerns, 86–100
    potential hazards, 93t
impact damage to, 44–45, 56–59
impact on assemblies, 7–22, 25–40
industrial change to, 2–3
light metal graphite, 128
low-cost, 2
macro economics calculations, 117–120
market potential for, 85f
metal graphite, 126–128
monitoring raw materials, 45–53
qualification of, 113–114
recycling of, 99–100, 101–102
safety concerns, 86–100
silver graphite compounds, 127
and standardization, 4
tooling management, 59–60
total life cycle cost, 105–122
uncollected in-process costs, 29–30, 183
Condoms, 144
Conductivity measuring cells, 142
Convert time to money, 170–171
Copper graphite composites, 126–127
Corrosion prevention, 153–154
Cost Affordability Initiative (CAI), 9, 12
Cost avoidance, 149
Costs, 2–5, 8
    capture, 171
    emerging challenges, 181–183
    estimating, 9
    fuel, 109
    hidden, 106
    labor, calculating, 31
    maintenance, 2
    micro economics, 113–117
    total life cycle, 105–122
    uncollected in-process, 29–30, 183
Countersink    see Holes/countersinks
Crenulations, 155
Curing agents, 90–91

D4&P (dimension, depth, damage, debris, and perpendicularity), 27, 181–182
Damage, 28, 44–45, 56–59, 64, 65
    Paris damage evolution law, 69
Data, baseline, 169
Data analysis, 170–171
Data collection
   after installation, 170
during installation, 169
Data normalization, 80
DC10, 38, 111
Defects, 160
Defense Contract Audit Agency (DCAA), 59
Defense Contract Management Agency (DCMA), 59
Delamination, 16, 159, 160
Dental root pins, 140–141
Design, 183–184
   of assemblies, 150–152
Design for manufacturing and assembly (DFMA), 7–8, 12, 13–20, 22
De-stack process, 27, 182
Development of a Self-sustained Wireless Integrated Structural Health Monitoring (ISHM) System for Highway Bridges, 67–70
Dialysis measuring cells, 140
Dimpling, 15
Dirac equation, 142–143
Distortion reduction, 150
Douglas Airplane Company, 38
Drilling, 26, 32, 34–36, 37, 94, 153, 160, 187–188
dry or wet, 158
   hand drilling, 26, 33–34
Drills
   selection of, 157–159
   types of, 159
Dust, 94–95, 159

Earthquake resistant composite wraps, 67
Economics of composites, 8, 86, 125
   introduction to, 1–5
Embedded sensors, 44–45, 64–76
   on bridges, 66–70
   design/manufacturing considerations, 60–61
   innovative airplane applications, 75–76
   innovative human application, 73–75
   wind turbine blades, 70–73
Engine pistons, 138
Epichlorohydrin (ECH), 92
Epoxies, 86, 90
Erosion, 160

F/A-18, 37, 38
Fabrication, 88–96, 154
Fasteners, 11, 15, 26, 31–32, 181, 184–185
Fiber reinforced composites, 91, 128–131
Fiber reinforced plastic (FRP), 117–119
Fiber tearout, 160
Flame atom absorption spectroscopy (F-AAS), 141–142
Fuel costs, 109
Index

Gauges, 33, 36
Geim, Andre, 143
Glass fiber reinforced plastics (GRP), 131
Global supply chain, 38–40
Goodyear Aerospace, 38
Graphene/Au composites, 142–144
Graphite tube atom absorption spectroscopy (GF-AAS), 142
Green, 33n
Grip length measurement, 29, 30–31, 183

Hand-drilling, 26, 33–34
Health concerns, 86–100, 159
Heat-sinks, 138–139
Helicopter blades, 76
High-frequency (HF)-based RFID, 47, 50
High-speed rapid transit, 138
Holes, 11, 15, 32, 185
  generation of, 157–158, 159
  quality of, 153, 160
Holes/countersinks, 26, 32, 36, 181–182
Homologue, 25
Hot isostatically pressed SiC (HIPSiC), 135
Hot-pressed silicon carbide (HPSiC), 135
Human body, 41–42
Hydride atom absorption spectroscopy (CV-AAS), 142

Impact damage, 44–45
  assessment of, 56–59
India, 39
Inner mold line (IML), 14
  IML controlled tooling, 16–17, 21
Inspection of parts, 5
Intangible benefits, 171
Integrated product teams (IPT), 166–167, 172–173
Integrated structural health monitoring (ISHM), 43–44, 63–65, 68–70, 73
  summary, 77–80
Integrated structure savings, 10, 12
Interlaminar tension, 152
Internal rate of return (IRR), 172–174
ISO 15686 on Service Life Planning, 117

Japan, 39

Key terms and definitions, 193–204
Keytone, 95

L1011, 38, 111
Lambert-Beer law, 141n
Landsburg, Steven, 106
Layups
    balanced, 150
    symmetrical, 151
Leprosy, 42
Light metal graphite composites, 128
Lightning strike protection, 154
Linothorax, 178–180
Liquid shim, 19, 20
Liquid-phase sintered silicon carbide (LPSiC), 136
Local data processing, 79
Local excitation, 65, 78–79
Lockheed, 37
“Lotus leaf” micro texturing, 76

Maintenance, 2, 56, 69, 75, 114, 119
    MRO, in service, 31–33, 184–185
Malaysia, 37
Manufacturing, 44–60, 188
    composite tooling management, 59–60
    design for manufacturing and assembly (DFMA), 7–8, 12, 13–20, 22
    embedded sensors, 44–45, 60–61
    environmental concerns, 86
    impact damage to composite parts, 44–45, 56–59
    monitoring raw materials, 45–53
    RFID, 46–56
Marshall, Alfred, 116
Materials Innovation Technologies, 102
McDonnell Douglas, 37
Medical engineering, 139–141, 143–144
Metal graphite composites, 126–128
Micro-sensors (MEMS) accelerometers, 64, 65, 78
Military aircraft, 8, 37, 38–39,168
Mitsubishi MRJ, 22
Mixed ceramics, 136
Mullite, 131n
Multifunctional ISHM coatings, 75–76
Multivariate random variable, 25

North Carolina State University (NCSU), 67
Northrop Grumman, 37, 83, 108
Novoselov, Konstantin, 143

Obsolescence, 118–119
Offset and countertrade, 37–38
One up assembly, 158
Original equipment manufacturers (OEMs), 9
Outer mold line (OML), 14
    OML controlled tooling, 16–18, 21
Out-of-plane concerns, 152
Out-time, 45, 54
Index

Paris damage evolution law, 69
Part count reduction, 7–8, 10–13
Passenger comfort, 111
Passive heat dissipation, 138–139
Peck drilling, 160
Peel ply, 151
Performance, 8
Performance optimization, 150
Phillips ROI Methodology, 167
Pi joint, 12–13
Plasma clean, 151
Plastics
  CFRP, 34, 36, 129–130, 187–188
  GRP, 131
Poland, 38
Polycrystalline diamond (PCD) drills, 34–36, 157, 158–159, 186–187
Polyurethanes, 91, 94
Post-optimality analysis, 43n
Power generation, 72, 73
Power source, 79
Prepreg materials, 3–4, 90
Price elasticity of demand, 116
Price elasticity of supply (PES), 115–116
Probe approach, 172
Process sensitivity, 188–189
Prognosis, 69
Pullup concerns, 152
Pyro-carbon layers, 133–134

Quality control (QC), 33, 160

Radius thinning, 156
Ragupathy, Lakshminarayanan, 144
Raw materials
  monitoring, 45–53
  storage, 45–46
  transporting, 46
Recrystallized silicon carbide (RSiC), 135
Recycling composites, 99–100, 101–102
Remaining useful life (RUL), 69
Resins, 92, 94
Return on investment, 163–164
  baseline data, 169
  calculating, 171
  current trends and challenges, 165–167
  convert time to money, 170–171
  data analysis, 170–171
  data collection, 169–170
  evaluation planning, 168
  intangible benefits, 171
  probe approach, 172
  process of, 167–171
  proposal, 169, 173–174
Index

reports, 171
sample calculation, 172
vision system approach, 172
RFID, 46–53
   aerospace case study, 53–56
   wind turbine, 70
Risk mitigation, 11–12
Rohr Industries, 38
ROI Institute
   certification, 165
   Phillips ROI Methodology, 167

Safety, 30, 86–100, 113–114
Scrap, 4, 9
Sensitivity analysis, 43n
Shimming, 14
Shrinkage, 157
Silicon carbide (SiC), 132–136
   SiC/B4C, 133
   sintered without pressure, 135
Silver graphite composite compounds, 127
“Smart skin” coatings, 75–76
Solar cells, 144
Solid waste generation, 108
Solvents, 89, 92, 95–96, 151
Space shuttle nose cap, 133
Spectroscopy, atomic absorption (AAS), 141–142
Structural health monitoring (SHM), 63–65, 70, 73, 77
Symmetrical layups, 151

TATA Advanced Materials Center for Aerospace, 39
Temperature, 45, 46, 49, 50–52
Thermal management, 138–139
Thermosets, 89
Thickness control, 154
Time value of money, 118
Tolerances, 30
Tooled-to-machine surface assembly, 19
Tooled-to-tooled surface assembly, 19
Tooled-to-untooled surface assembly, 20
Tooling, 33–34, 188–189
   automating tracking, 59–60
Tools, materials selection, 157
Total life cycle cost (TLCC), 105–122
   commercial aviation case study, 108–111
   composites vs. aluminum, 111–113
   elements of, 106–108
   macro economics calculations and case study, 117–120
   and micro economics, 113–117
Trek Bicycles, 101
Tribology, 136–138
   special applications, 138
Index

Uncollected in-process costs, 29–30, 183
Union Carbide Corporation, 1–2
Unit of labor, calculating, 31
Unitized structure, 20, 151
University of Maryland (UMD), 67
University of Tennessee Center for Clean Products and Clean Technologies, 107
Untooled-to-untooled surface assembly, 20
URS Corporation, 67
US Air Force, 97
USDOT Research and Innovative Technology Administration (RITA), 67

Vijayaraghavan, Aravind, 144
Vision system approach, 172

Wall Street, 164
Water, 153–154
Weight savings, 2, 7, 8–10, 13
Whole life costing (WLC), 117–118, 119, 120
Wind turbines, 99, 114–115, 121–122
case study, 70–73
Wings, 112, 189
Wireless data transmission, 70, 74, 79

X-ray rotating anodes, 141

Zirconium oxide, 140
ZTA (zirconia toughened alumina), 136
About The Authors

George N. Bullen

George N. Bullen is an internationally recognized expert and consultant to industry for the manufacture of fixed and rotary wing air vehicles, rockets, missiles, and space vehicles. His expertise includes inhabited and uninhabited aerial vehicles, space vehicle design and manufacture, laser weapon system design and manufacture, and lean processes and applications. He has been awarded 16 US and international patents for technology innovations related to manufacturing, mechanization, robotics, robotics control software, and nuclear testing/quality devices, which are the basis for all current automated systems for the assembly of airframes in the United States and Europe.

A Fellow of the Society of Manufacturing Engineers (FSME) and certified in production and inventory control management (CPIM), George Bullen has an MBA from Loyola Marymount University and a BSMG degree from Pepperdine University. He maintains membership on the academic boards of major universities and is a member of the steering committees of professional societies. George is founder of the International Aerospace Automation Consortium and cofounder of the international Economics of Composites Symposium. He is widely published in magazines, conference proceedings, and peer-review journals. In 2014, he received SAE International’s Forest McFarland Award, and in 2000 the American Institute of Aeronautics and Astronautics (AIAA) Design Engineering Award for significant advances in aerospace engineering.

Mr. Bullen retired as principal engineer and Technical Fellow from Northrop Grumman Corporation at the end of 2010.
Carroll Grant

Carroll Grant has 41 years experience in the aerospace/aircraft industry. His aerospace experience includes 31 years in composites and 10 years in metal aircraft structure. In the 1990s, he was heavily involved in the largest composites R&D programs funded by the US government (NASA Langley Research Center programs and DARPA programs).

For the past 15 years, he has operated successfully as an independent contractor/consultant in the aerospace composites industry. While working as an independent contractor, his primary activities have been marketing of automated composites processing equipment (ATL and AFP machines) and aircraft parts fabrication services. His marketing pursuits have been primarily in North America and Europe. He has extensive knowledge of the aircraft industry in both regions.

Mr. Grant’s area of composites expertise is in the field of automated processes for aircraft composite structure. He is especially knowledgeable on the automated fiber placement (AFP) and automated tape layer (ATL) processes.

Mr. Grant is extensively involved in aerospace composites conferences. He is the current chairman of SAE’s Manufacturing, Materials, and Structures (MM&S) Committee and chairs automated composites manufacturing sessions at SAE events. Other activities include writing occasional articles for a composites magazine; he is an advisory board member for two technical colleges, and conducts occasional “Composites 101” seminars for non-composites companies that want to learn about composites. He also does “automated lamination” tutorials at a community college for students who are studying composites.

Dan Day

Dan Day graduated with a BS in mechanical engineering from Montana State University in 1990. He has since been employed with the Boeing Commercial Airplane Division in Seattle, Washington. Dan’s experiences range from fabrication to assembly of aluminum and composites structures. He became an Associate Technical Fellow in 2005 while developing lean wing assembly systems. Dan has worked across numerous airplane programs from development through the early production implementation, including the graphite composite intensive 787. Dan has also led composite fabrication projects for primary structural wing components requiring extensive cross-functional integration. Dan is currently leading research and development in composite wing assembly and automation technology.
Alan Hiken

Alan Hiken is a subject matter expert in composites manufacturing with more than 30 years of experience in the aerospace and defense industries. His expertise includes hands-on experience in the design and manufacture of advanced composite structures and elastomer-based products for high-performance applications. He served as VP of Operations and VP of engineering and technology at Rubbercraft Corporation, where his responsibilities included overseeing the development and deployment of the company’s elastomeric tooling for composites manufacturing. Alan previously worked for Northrop Grumman in El Segundo, California, and held composite intensive leadership positions such as:

- Manufacturing Team Leader—Fuselage Structure YF-23 Program
- Team Leader for Composites Manufacturing F/A-18 E/F Program
- Composites Center Manufacturing Manager
- IPT Lead—JSF Center Fuselage

Alan received his bachelor’s degree in chemical engineering from the University of Missouri-Columbia.

David Champa

David Champa is currently a consultant for AIP Aerospace. His history of supply chain management, business development and operations has been focused on the automation of manufacturing processes such as automated drilling, composite lamination, friction stir welding, and automated fastening.

Having worked for Ford Aerospace, McDonnell Douglas, Boeing, and M Torres allowed him to participate in most major A&D programs of the last two decades.

He is a resident of Southern California and is married with two children. His formal studies were through University of Phoenix and University of California, Irvine. He continues to learn through industry conferences and meetings.

He enjoys outdoor activities, especially the beach, and has a passion for his fictional writing.