**Manufacturing Producibility Risk Assessments (MPRA)**

The aerospace industry has significantly introduced composite aerostructures replacing metal as the primary structure for such aircraft platforms as: B 787, A350, A400, A380, F-22 (Raptor), and F-35 (Joint Strike Fighter). The decision to introduce composites was based on OEM process trials which have shown to reduce the aircrafts weight while improving fuel efficiency the operating payloads. From the process trials, Original Equipment Manufacturers (OEM’s), such as Boeing and Airbus, relied on automation such as automated fiber placement (AFP) and Automated Tape Laying (ATL) machines to economically manufacture composite structures. The promises of high speed lay down rates were used to establish cost methodology. Failure to fully assess manufacturing producibility using carbon composites design solutions can materially increase financial risks for Tier I and Tier II’s/Tier III’s performance to long-term contracting requirements. The transition into production qualification and first article inspections have demonstrated that the technology remains under development and thus impacting Non-Recurring Cost investments as well as achieving Recurring Price targets.

**What can GMC2 do to provide MPRA’s?**

GMC2 has assembled a team of experienced aerostructure experts with direct working knowledge of manufacturing using automation who can assess the manufacturing producibility risk assessments (MPRA’s) associated with the use and the level of automation necessary to successfully implement the manufacturing approach to produce compliant aerostructure components. The GMC2 experienced engineering team understands that turnkey automation equipment by itself does not assure manufacturing producibility success or the achievement of contracted prices. Designs are often vague and left to the OEM qualification teams to resolve unproven technical challenges, increasing the risk for increased nonrecurring costs. Introduction of high speed machine centers and new non-destructive ultrasonic test equipment are still under engineering manufacturing development. Identification of the manufacturing producibility assessment risks and accounting for them in the cost methodology can significantly contribute to the execution of qualification and track projects against the baseline targets.

When Tier I or Tier II/III companies decide to compete and win long term contracting awards or modifications thereof, the proposal or change proposal
phase is critical. The assessment of company expertise and core competencies must be identified clearly: the project is a derivative from known processes or, it is a significant change in manufacturing producibility requirements which necessitates significant company NRE prior to entering production deliveries. Evaluation of the design to establish base line definitions and compiling the ground rules and assumptions reduces risk for the Tier I and II Company. When evaluating the design, what attributes must be included to facilitate automation and the control of the acceptance criteria can further reduce risk for project performance. The tooling approach can further impact competitiveness for contract award, the GMC2 team can help establish the least manufacturing producibility risk approach and thus assist clients in their cost methodology to establish a composite manufacturing producibility baseline to address necessary solutions for unknown technological challenges due to tooling for automation applications including non-destruct item (NDI) testing standards. GMC2 can help identify key risk areas within cost methodology considerations and potential areas that lead to changes in the baseline statement of work that prolonged period of performance impacts and thus financial considerations of cash flow and operating profit.

**Where the industry is and what do we provide?**

In terms of time, the chart below shows that the Carbon Fiber Reinforced Plastics (CFRP), also known as composites, relative to time is in its infancy stage compared to other known materials and their known manufacturing producibility models. Major new program start-ups have accelerated the development and usage of aerostructure produced parts by means of CFRP solutions supporting programs identified above. International and national program management models using ever increasing CFRP aerostructures are evolving with increased complexities. Transaction costs and new production processes for mass production of CFRP aerostructures have impacted program execution and operating profitability during the start-up phases leading to aircraft certifications and production ramp-ups. Tier II/III suppliers are incurring increasing demands on design authority arrangements in lieu of their expertise as build-to-print and thus further compounded their manufacturing producibility risk assessments. The CFRP is moving from infancy and slowly moving to an engineering manufacturing development state with significant risks to deliver complaint CFRP parts: AFT/ATL or Hand Lay-up produced.

Chart below represents Evolution of Materials and Applications over time.
Commercial Aircraft increasing the use of CFRP aerostructures produced parts while still remaining in an engineering manufacturing development phase.

Usage of Materials in Civil Aircraft Structures, by Major Aircraft Type, 2008

Source: The Carbon Fiber Industry: Worldwide 2010-2014 by Tony Roberts
Accounting of MPRA’s within the Cost Methodology Model

OEMs try to design structure for automation. But given the infancy of the technology all parts do not necessarily exhibit the same producibility and risk. Even if they are manufactured with the same materials using the same equipment, results vary. The original belief was the manufacturing approach is repeatable for multiple parts, but we do not have any history to substantiate this belief. Discussed below are the major factors that impact risk. One fact is clear, proper application of automation will result in cost saving and profitability. The advantages are clear.

- Lay down rates for machines outperform hand labor
- Quality is improved by machine function
- Process is repeatable: processes can be engineered around machines for increased cost reduction in the out years.
- More product can be processed in smaller facilities and the machines can be designed to manufacture multiple part configurations allowing for flexibility in the production line.

Factors That Influence AFP Performance: Machine, Methods, Tooling & Material

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<th>AFP Machine</th>
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<td><strong>Temperature</strong></td>
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<td>CCR</td>
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<td>Room</td>
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<td>Lower Chute</td>
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<td>Compaction Roller</td>
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<td>Creel</td>
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<th>Methods</th>
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<td>Training</td>
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<tr>
<td>Part Design</td>
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<tr>
<td>Heat</td>
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<tr>
<td>✔ IR/Hot Air</td>
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<td>Cleaning</td>
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<th>Tooling</th>
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<tbody>
<tr>
<td>Tackified</td>
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<td>Insulated</td>
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<td>Vacuum Bag</td>
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<th>Material</th>
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<tbody>
<tr>
<td>Type</td>
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<tr>
<td>✔ Eutectic</td>
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<tr>
<td>✔ Standard</td>
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<td>Out Time</td>
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<td>Fuzz</td>
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<td>Splices</td>
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Risk models involve materials and part geometry tailored for automation and the need to control cycle time. Automation equipment producers can estimate the lay down rate for a given project but these models do not account for other factors such as material performance, tool set-up, inspection and the need to apply non-automated plies in the lay-up such as corrosion prohibiting fiberglass fabric. Some structures require lightning strike fabric. Automation has some limits for the size of the pad ups it can perform. If a pad up is small, the company might consider hand operations. Geometry also impacts the access of the machine to apply material. When pricing these impacts, the machines ultimate lay down rate is reduced, knowing how to account for these factors will provide the necessary approach to achieve the desired target cost.

Part configuration may not be designed for automation, what are the technical challenges to seek producibility changes to the original design for automation? Laminate structures must meet product acceptance for geometry for features such as part thickness, flatness, profile, porosity, bridging and wrinkles/buckles as an example. Unidirectional tapes are used on machines such as ATLs and AFPs. These processes are shown below and represent the need to carefully assess the design against the company’s automation to assure the design is capable of being automated.

AFP 6000 and ATL models are below:
Summary of the types of composite methodologies and automation equipment used in the manufacturing of CFRP structures are identified below.

Below is a basic process flow for automated tape lay-up and hot drape forming.

To further account for part configuration for automation the original cost model must assess the following factors:
• Acceptance criteria.
• Process capability for part configuration. Product tolerance and machine capability.
• Buy-to-fly ratio of the process to include ATL/AFP factors and overstock to account for machining.
• CAD modeling and derivative models for production to control:
  ✓ Flat patterns
  ✓ Laser project files
  ✓ AFP/ATL programs
  ✓ CNC machine files
  ✓ 5 axis ultrasonic inspect programs
  ✓ CMM inspection program
• What aftermarket software needed to support laser projection for manufacture and inspection?
• Ultrasonic (NDI) inspections and the need for manufacturing defect standards.

Tools function and procurement costs account for a significant risk to any project. When considering tooling for automation, GMC2’s connections to premier composite tooling houses can help control tooling costs. Large invar tools are difficult to handle and often present special handling solutions, not to mention the expensive of metal tooling. Using composite tools for automation reduce tool costs and improve performance due to tools mass and other factors that heavy tools impact machine function. During the NRE phase for tool development, process engineering must endeavor to establish tool design. Engineers establish the design and often must order these tools because of long lead times for procurement before the process trials are concluded. Factors considered in the tool design include:

• Rate tooling
• Schedule for tool procurement
• Tooling storage and transportation
• Tool function
• Design parameters
  ✓ Twist, warp and spring back
  ✓ Integration in automation equipment
  ✓ Autoclave cure, the design for vacuum ports and thermal couple
  ✓ Tooling material, invar or composite material
  ✓ Use of intensifiers for compaction
Closed tooling or bag surface finishes
✓ Design account of co-cured structure
✓ Resin bleeding, how to dam and the vacuum bagging Scheme.
✓ How much over stock to facilitate machining and automation capabilities
✓ Inspection of parts on tooling to maintain part reference for profile and GD&T of tightly tolerance part design.

- Tolerance stack-up and geometry coordination thru the manufacturing process, Example index tool holes.

Material performance impacts overall costs. Modern materials attempt to control part thickness and facilitate the combining of structure into co-cured/co-bonded assemblies. OEMs are attempting to achieve reduced shimming and hole-to-hole indexing at the assembly level which reduces the overall assembly touch labor. When these requirements are driven down to the part definition, suppliers are exposed to more risk. Successful suppliers must be capable of reducing costs for co-cured/co-bonded assemblies by eliminating repetitive operations such as autoclave cures and machining. The cost model must also account for when to order material to support NRE efforts and production needs. Most materials exhibit better handling characteristics as a function of the freshness of the material. The fresher the materials, the better the machine function. Handling life and working life of the material could also be impacted if the structure is large or takes a long cycle time to build up before the structure is cured in an autoclave.

Ultimately the part must be inspected ultrasonically. Special teams are often employed to develop the equipment and processes to NDI accept composite
structure. Often a special qualification process is needed to design defect standards, and to certify ultrasonic equipment. Supplier engineers generate defect designs that represent part design. Technique sheets that control part, equipment set up must be developed. Ultimately all of these documents are submitted to the customer for approval before any real work can begin. After each of these documents is approved, final reports are submitted for final acceptance of the standards, equipment and personnel. Once concluded, the part qualification effort can continue. GMC2 can assess these requirements and include them into the cost model. Below is a basic summary of the NDI process with an assessment of the risks for project completion.

Overall qualification process is identified below with most likely initial project risk projections.

Often, companies must invest in new non-destructive ultrasonic equipment that is designed for high speed inspection of composite parts. Given the higher rate production in the out years, equipment must be capable of high speed scanning with multiple array, cover more part surface in a single pass; evaluate results while reducing the need for more machines in the out years. Below is an example of a 5-axis submersible system for inspection.

Examples of NDI Equipment used in CFRP manufacturing production acceptance of production hardware.
Overall NDI Qualification Process and key areas of risk are below.

**Defect Standard Design Phase**
- Identify total number of defect standards needed. Represents a full range of part geometry.
- Obtain porosity standard from customer:
  - No discontinuities
  - High risk if supplier is required to manufacture standard
- Design defect standards and submit to customer for approval. Artificial discontinuities included.
- Manufacture defect standards. Develop tools and work instruction.
- Obtain final customer approval to inspect production parts.

**System Qualification Phase**
- Qualify inspection system. Supplier must qualify process prior to inspecting parts.
- Customer Level III could impose system activities in support of project specific requirements.
- Qualification is for specific configuration:
  - Equipment
  - Software
  - Procedures
  - Supplier Level III
- Submit plan and report for customer approval of Supplier facilities, equipment and Level III.
- Submit NDI qualification plan for each part configuration.
- Scan production part per qualification plan and submit to customer for approval.
- Scan defect standards and submit report for customer approval.
Key risk factors for NDI qualification is identified below.

<table>
<thead>
<tr>
<th>System</th>
<th>Technical Risk</th>
<th>Execution Risk</th>
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<tbody>
<tr>
<td><strong>Equipment</strong></td>
<td>New equipment is needed to inspect parts</td>
<td>Equipment set up for repeatable results. Often transducers must be positioned 90 degrees from part surface</td>
</tr>
<tr>
<td></td>
<td>Software evaluation: software is not proven</td>
<td>Access of equipment based on part geometry.</td>
</tr>
<tr>
<td></td>
<td>Fidelity of results require company evaluation and explanation of results</td>
<td>Complexity of part geometry</td>
</tr>
<tr>
<td></td>
<td>New facilities and personnel</td>
<td>Re-qualification if company level III has changed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Requalification for software revisions, new equipment or equipment failure</td>
</tr>
<tr>
<td><strong>Defect Standards</strong></td>
<td>Each part geometry could include defect representative for product range at minimum, maximum and mean tolerances.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Defect design must include full range of part geometry for angles, thickness and radius.</td>
<td></td>
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<tr>
<td></td>
<td>Artificial discontinuities are manufactured into standard and could be missed during the design phase</td>
<td></td>
</tr>
<tr>
<td></td>
<td>a. Brass – represents void and delaminations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>b. Pressure sensitive tape – represents detectable inclusions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>c. Peel Ply – represents pulse echo inclusions</td>
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<tr>
<td></td>
<td>Each defect stand is micrographed and lab porosity tested, could be in conflict with ultrasonic inspection results.</td>
<td></td>
</tr>
<tr>
<td><strong>Porosity Standard</strong></td>
<td>Standard is not customer furnished</td>
<td>Has no discontinuity with naturally occurring laminate structure. Part must be optimally produced with very low porosity</td>
</tr>
</tbody>
</table>
Realistic schedules are required for project performance. Customers are often involved with qualifying a supplier during the NRE phase. The pricing model must account for the following:

- What is approved by the qualification team?
- Where is the manufactured part in its manufacturing maturity, is it repeatable?
- Are you the first to manufacture or are you a second source?
- Lessons learned from incumbent.
- Might have to modify manufacturing approach to match your investments and infrastructure.
- Breaking down the project into smaller tasks that can be managed and demonstrated.
- Within each task, what are the long lead SCM items?
- Work with supplier to control risks.
- How many trials are needed to demonstrate maturity?
- Capital investments - new equipment and facilities
- How to train personnel for first unit and sustained production.
- Supplier must have sufficient time to get up to speed and develop equipment expertise if the equipment is new to the supplier.
- Demonstrate company capability for execution on the equipment.

**Transition into Production**

In the cost model, the project must transition into steady state production. The original cost model should account for this transition. Most projects start at a low rate production, ramping up to high rate in later years. Recurring cost models show costs decrease over time. Major impacts to these improvements include:

- Training of operations personnel
- How to accept products in production, the in-process buy-offs to reduce QA involvement
- How to deal with non-discrepant hardware and the impact to the schedule and corrective actions
- Technical support during low rate production
- If a single part representative was manufactured and the remaining part family was not, what preliminary operations should be conducted to reduce risk on the first part manufacture for the entire family of parts?
• How to control the process into a coordinated steady state process. Is the factory lay-out optimized for material handling?
• Configuration management models to address all the changes and the break in effectivity for these changes

**Understand Risk Model**

GMC2 has developed a process to condense the risks described above into a comprehensive model that can be used to ultimately understand and control risks. Given all the factors discussed above, the diagram below shows all the elements of this evaluation and methods to present the data to the bids and proposal team along with supporting the contractual baseline assumptions.

The first step in the process is to define a metric for the project that breaks down the elements of the proposal. The GMC2 engineering team reviews the statement of work, part definition (design), and terms and conditions for project
performance with expected deliverables for each task. The purpose of the exercise is to establish the risk elements from the customer data and develop the risk model.

**Need analysis model**

The process of condensing the risk elements involves the definition of the risk model with mitigation planning. The GMC2 team will provide an executive summary of the project to help company leaders with understanding the elements of the contract and what tasks must be investigated for planning consideration. The ultimate deliverable for this phase is a plan that helps companies determine non-recurring costs, capital investments, unit price and establishment of the baseline definition for the project.

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**Comprehensive Risk Plan: Manufacturing & Qualification**
After the executive summary of the project, a comprehensive risk plan should be defined. Below are examples of this model. The project investigates the project from defining the engineering manufacturing approach, tool plan, and facilities layout to name a few. Each functional organization will be required to perform on the given model after project award so the elements below are further broken down into task by organization, the definition of completing each task, the risks/ground rules and assumptions, and the scope of the work for each assignment. Often times, the model has to include customer witnessed production activities for the first part manufactured of the supplier. This activity specifically qualifies the supplier to manufacture production parts and cannot be modified unless the supplier wishes to re-qualify the process. Because of the specific nature of this qualification, the following is fixed after qualification.

- List of production parts
- Facility
- Tooling
- Equipment
- Manufacturing process up through cure, example hand layup versus automation.
- Acceptance criteria
- NDI process plan which controls equipment, defect standards, level III, and technique sheets.
- Company manufacturing work instructions

The Composites Manufacturing Cost and Production Qualification Models are identified below.
Composites Manufacturing Cost Model

- Intellectual Property
- Plant & Equipment
- Training: Human Capital
- Non Recurring & Tooling Design
- Production Qualification
- Non Destructive Inspection: NDI
- Packaging And Shipping

Pre-Award Action:
- Materials Qualification Programs performed by OEMs
- Manufacturing Composite Qualifications must be completed prior to Awards

Production Qualification Model

- Materials Acceptance Testing
- Manufacturing Work Order Instructions
- Tooling Assembly
  - Part Family Qual
  - Prc. Final, FAI
- Assembly
- Inspection Criteria
- Trim and Drilling
- Edge Scaling

- Gerber Cutting Programs
- Hand Lay-up
  - ATL
  - AFF
  - RTM
  - Filament Winding
  - Pultrusion
- Defect Standards Development
- Bagging/Curing/De-tooling
- Water Jct Cutting

- Software Programming of ATL, AFF
- Software Programming of Trim & Drill Machines
- Bertsehe Machine
- Non Destruct
- Dimensional
  - CMM
  - Laser Tracking
  - Faro Arm
- Model Based Definition
- MRB/Material Defects
  - Dispositions
  - Acceptance
  - Documents
- 5 Axis SNK
Integrating Manufacturing Risk Assessments with Change Management that protects contractual baselines in order to seek recovery of costs while maintaining Build-to-Print or Design & Transition to Build-to-Print contract provisions

In addition to the important steps involved in creating the Manufacturing Producibility Risk Assessment model and incorporating such MPRA factors into the cost methodology, improving the financial results for the company when dealing with their customers is ensuring that they do not waive any of their contractual rights or assume responsibilities not expressly required by the long term contract. Every world class company wants to maintain a high level of customer satisfaction with the company products, it is imperative for any company to take every reasonable step to ensure that their contractual baselines are reviewed to ensure that the contract over time:

- Accurately describe the obligations of both contracting parties
- Are modified to reflect any changes to those obligations
- Enable the company to receive full payment for its work

A disciplined system with experienced personnel must be in place to assess and evaluate changing requirements in order to promptly identify, assess, give notice, and request contract coverage for customer-caused impacts to the company’s contract performance and thus the financial health of the company.

Changes in contract specifications, drawings, or performance requirements will always have some impact on the company’s contract obligations, as will customer requests to re-sequence work or to maintain the same completion schedule even though customer-furnished property or data is late or deficient. Preserving contractual rights that affect price and schedule are major tools in the proper allocation of the company resources.

Types of contracts from Firm Fixed Price to Cost Reimbursement and their relationship to cost and profit are provided below:
It is important to remember that the company has a right to their interpretation of the contract / specification if it meets minimum requirements and is reasonable. If a company disagrees with the customer’s interpretation, then:

- Keep working under your interpretation
- Notify the customer in writing of the company’s position
- Proceed until directed in writing to change
- Document and process a change or claim for an equitable adjustment to price and schedule
- State the undefinitized change on invoices following notifications

The long-term contract is the basis for payment, changes and claims, and final protection of a customer proceeding to terminate for default, i.e., the customer cannot terminate for default without showing that the company is not performing to the “baseline.”

Constructive Changes come from a multitude of areas that require documentation and knowledge of contractual change remedies involving customer actions or inactions that have the effect of changing the terms of the contract. These might include:
In addition, constructive changes are also resulting from a series of communications involving the following:

- Correspondence
- Technical Interchange Meetings
- Program Formal Plans
- Corrective Action Plans
- Data Approval Rights
- Delivery & Acceptance
- Customers directing the company suppliers

In many cases, experienced GMC2 personnel in the field of changes/claim history can provide the business remedies through hard work and research of the facts to mitigate the financial impact of what becomes an unpaid account receivable.
The staff at GMC2 has the proven experience in supporting the needs of growing companies from Pre-Award and Post Award transactions including Manufacturing Producibility Risk Assessments. Our mission is to provide our clients with the most viable growth scenarios and transactional options to assist them in achieving their business pursuits. We offer extensive managerial and global negotiating experience that enables us to ensure the protection of our client’s investments through prudent Mergers & Acquisition support, Proposal Management and pre-award phases, and Change Management and post award phases, so that the client’s financial targets and overall health of their growing companies are sustained.

As Patrick Henry stated: “...I have but one lamp by which my feet are guided; and that is the lamp of experience. I know no way of judging the future, but by the past....” There is no substitute for proven experience.