

TruPLAN Advanced Simulation for Material Kinematics Behavior during Manufacturing Layup Processes

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ABSTRACT

The objective of an engineering analysis - a numerical model and simulation designed to represent a specific manufacturing process - is not simply to determine the behavior and impact of that process on a specific product. If that were the case, extensive product testing would be a simpler and cheaper solution. The real objective of an engineering analysis is to use its associated numerical models and simulations to predict the impact of important design and manufacturing parameters on the behavior of the final product in terms of performance and cost. When dealing with advanced composite materials, such parameters include: material, surface topology, layup strategy, ply stacking, among many possibilities. Designers today are faced with the challenge of optimizing composite parts and, should redesign be required, having enough reliable data at hand to justify the redesign's necessity.

A multidisciplinary manufacturing analysis tool for designers, TruPLAN's Advanced Material Kinematics Kernel models how a given composite material behaves during the computation of manufacturing process strategies for automated layup technologies, like: fiber placement, tape laying, and robotics. TruPLAN's Advanced Kinematics Kernel models composite material behavior in terms of design criteria - surface topology, fiber direction, angle deviation, gap/overlap - and manufacturing constraints such as: material compaction, layup temperature, material tension, feed rates, material feeding, machine kinematics configuration. TruPLAN's Advanced Material Kinematics Kernel empowers designers to test advanced composite materials against new or existing design strategies for automated layup technologies (Fiber Placement, Tape Layer, Robotics layup), to discover optimum combinations of materials and manufacturing equipments to ensure desired production rates and costs.

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1. INTRODUCTION

1.1. The Composite Market Place

Composite materials continue to penetrate industries like Aerospace, Wind, Automotive, and Marine. Therefore, the need for accurate and economic manufacturing processes is paramount. Parts made from composite materials require significant investment in raw materials and manufacturing tools. No single method has been set as a standard for composite manufacturing; however, multiple variables affect which practices are selected by manufacturers. Such variables include, but are not limited to the size of the part, production rate and the material to be used. Each method has its benefits as well as its drawbacks. The difficulty for manufacturers is choosing which method - or combination of methods - will

optimize production. Compounding that difficulty even further is that once a method is selected, it is often difficult and cost-prohibitive to change courses should the method of choice prove to be ineffective. This report will address the need for a software application designed to provide manufacturing analyses at the conceptual design stage that will make it possible to consider the manufacturability of a part at its earliest stages of development.

To perform detailed analyses of multiple manufacturing processes and composite materials early on at the conceptual design stage, and throughout the entire production cycle, engineers can use TruPLAN's Advance Material Kinematics Kernel to study the implications of initial material and design choices and/or how changes to the design, material or layup strategy, it will impact manufacturing costs and layup quality.

TruPLAN provides the data to help understanding these conditions and it enables engineers to arrive at an optimum combination of materials, design criteria and manufacturing strategies to be used in final production. Traditionally, engineers import design data and resource information from CAD/CAM and FEA applications. The materials is most often selected only because of its mechanical properties, not necessarily on how its forming behavior will impact manufacturing technologies like Tape Layer and Fiber Placement. Commercial projects like the 787, JSF F-35 and A350 have all been negatively impacted at one time or another, because of a failure to analyze the impact of carbon fiber materials on the chosen manufacturing layup strategies and manufacturing equipments such as Fiber Placement, Tape Layer or Robotics layup.

The concept of a Materials Manufacturing Parameters Database, or MMP, would have been extremely useful in the aforementioned examples. TruPLAN provides this link between materials and manufacturing technologies such as Fiber Placement, Tape Layer and Robotics layup, a bridge that has not been available until today. The MMP Database containing material manufacturing allowable, in conjunction with the comparative analyses engine built in TruPLAN, it allows engineers to use real material manufacturing data during the crucial phase of selecting the best material and optimum manufacturing process. Using real data to drive materials selection and manufacturing process decisions should not only ensure higher production quality, but also boost manufacturing production rate by minimizing the potential risk for layup defects such as: material wrinkling, material bridging, material buckling, material steering, compaction and angle deviation - variables among many others present during production.

1.2. Overview of Contents

This paper will discuss an Advanced Material Kinematics Kernel and a case study underlining the major benefits of the Advanced Material Kinematics Kernel.

TruPLAN is a multidisciplinary manufacturing analysis tool that allows designers to test multiple materials and manufacturing scenarios, to fully modeling and analyzing materials behavior during the fiber paths computation for an automated manufacturing layup process (Fiber Placement, Tape Layer), ensuring in this way a complete manufacturability.

Engineers can analyze the implications of their choices in term of material/manufacturing strategy and/or how any changes in material data impact manufacturing costs while the part is still being designed.

A case study illustrating an aircraft "Wing Spar" is presented, in order to better illustrate the "shortcomings" of current commercial available solutions for modeling automated material layup deposition technologies and the major benefits of implementing an Advanced Material kinematics kernel to improve composite part quality and production rate.

2. KINEMATIC KERNEL PROCESS FLOW

In the fiercely competitive composite manufacturing industry, minimizing time to market is important in order to edge out competitors and begin generating revenue for products that often carry long and expensive research and development cycles. Monitoring products through the development lifecycle is essential for decision-makers. Taking advantage of new composite materials more compatible with advanced automated processes such as Tape Layer, Fiber Placement and robotics layup is an absolute must. TruPLAN provides a set of tools to perform multiple comparative analyses simultaneously, and it uses the values and drawbacks of any possible design, manufacturing or material constraints to replicate real-world scenarios in a virtual environment. The software enables manufacturers to foresee ways to reduce risks and costs associated to the manufacturing of composite parts, to study production rate and optimum manufacturability during the crucial phases of any composite parts such as material selection and manufacturing strategy assessment. Performing such analyses will ideally ensure the feasibility and minimize the costs associated to manufacturing composite parts, while also guaranteeing an optimum combination of material and manufacturing process. In [Fig.01](#) is shown a flow chart for the entire material kinematics kernel infrastructure, from the material definition up to the optimum material layup strategy for the parts.

3. THE MATERIAL MAPPING GRID

In order to verify the reliability and consistency of the computational results together with the accuracy of the material kinematics kernel developed within TruPLAN, a certification procedure has been designed by Magestic Systems Inc and Cytec engineered materials, to ensure the validity of the Advanced Material Kinematics Kernel prior to be applied for simulating real-world production cases. To test different potential production scenarios, Cytec has engineered a simulation work cell that consists of a material layup unit designed to properly simulate automatic material deposition methods. This layup unit is equipped with a fiber delivery module, composed of a fiber placement head and a material storage unit (creel) containing raw material in the form of spools. Using this layup unit, a series of material layup tests have been performed, in order to simulate a variety of different material layup conditions commonly encountered during the production lifecycle of a composite parts.

Different surface topologies - both concave and convex - have been simulated incorporating geometrical singularities, such as: ramps, radii, and ply build-ups. For each surface topology under examination, a set of layup process parameters has been identified to properly simulate material kinematics behaviors as a function of surface topology and layup process conditions. Such process parameters include,

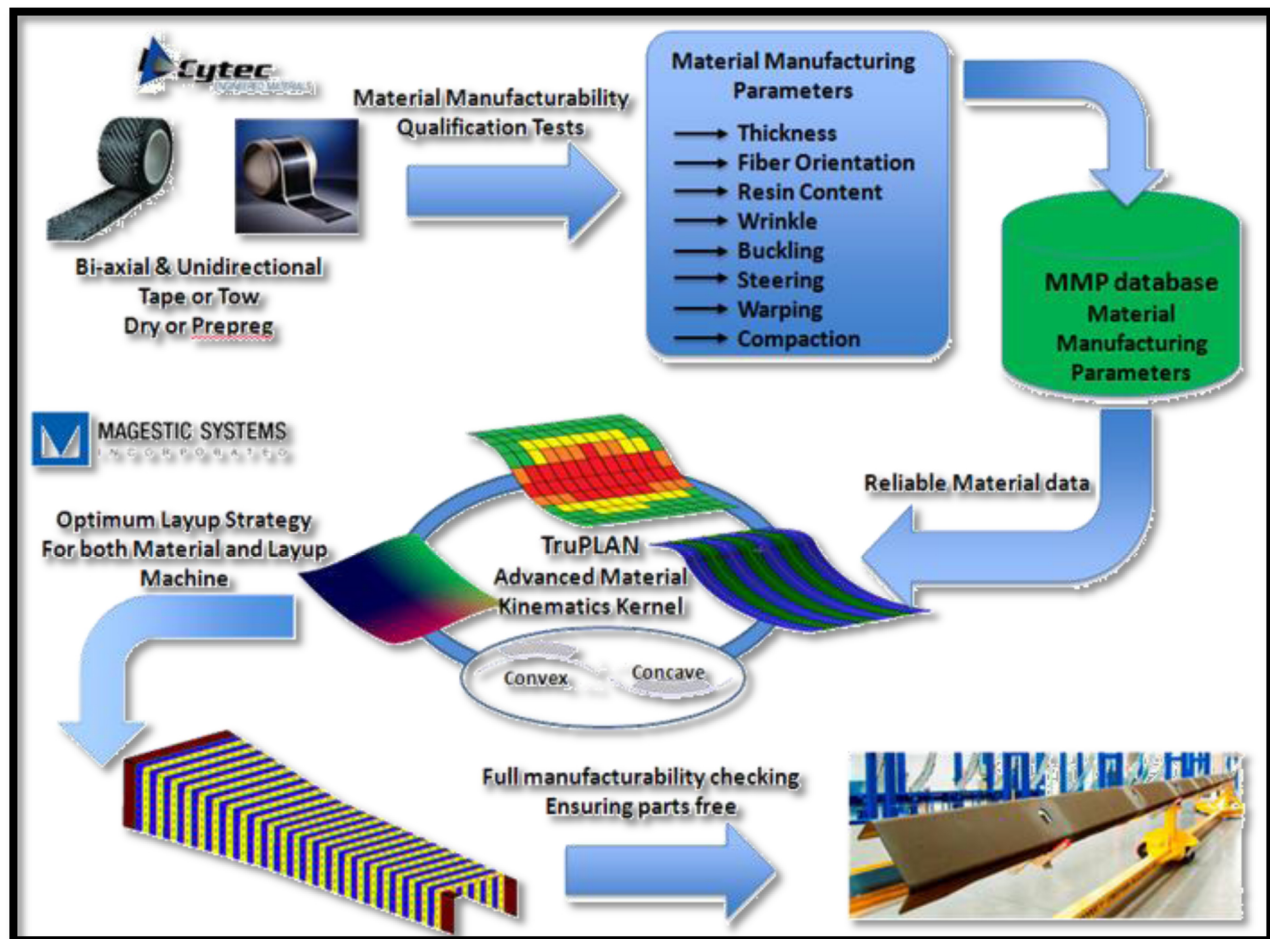


Fig. 01. Kinematics Kernel Process Flow

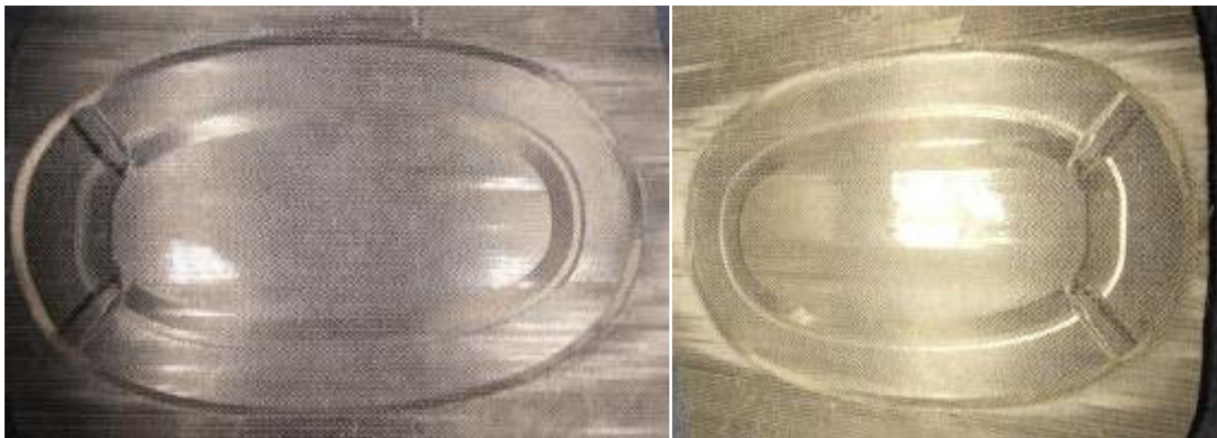


Fig. 02. Layup Tests

but are not limited to: layup speed, layup temperature, layup compaction, material tension, material feed rates, etc. Similarly, specific manufacturing parameters have been tested including, but are not limited to: material thickness, material tackiness, impregnation method (dry, thermoset,

thermoplastic, out-of-autoclave, etc.), and material type (carbon fiber, fiberglass, etc.).

In [Fig.02](#) it is possible to observe the result from layup tests performed at Cytec Lab: