Fluid flow modeling of resin transfer molding for composite material wind turbine blade structures
by Scott Montgomery Rossell

A thesis submitted in partial fulfillment of the requirements for the degree Of Master of Science in Chemical Engineering
Montana State University

Abstract:
Resin transfer molding (RTM) is a closed mold process for making composite materials. It has the potential to produce parts more cost effectively than hand lay-up or other methods. However, fluid flow tends to be unpredictable and parts the size of a wind turbine blade are difficult to engineer RTM without some predictive method for resin flow.

There were five goals of this study. The first was to determine permeabilities for three fabrics commonly used for RTM over a useful range of fiber volume fractions. Next, relations to estimate permeabilities in mixed fabric lay-ups were evaluated. Flow in blade substructures was to be analyzed and compared to predictions. Flow in a full-scale blade was to be predicted and substructure results were to be used to validate the accuracy of a full-scale blade prediction.

Permeabilities were calculated for three fabrics (A130, DB120 and D155) in the fiber volume fraction range of 0.27 to 0.47. In addition, relations were determined for each fabric over the given range of fiber volume fractions.

Two estimation methods were used to predict flow. One method was based on the relative thickness of glass in the fabrics and the other was based on the thickness of fabric layers at a given clamping pressure.. The clamping pressure method was able to accurately predict the flow front shapes of a lay-up, but tended to under predict permeabilities. The relative thickness method did not capture the proper flow front shapes and under predicted permeabilities as well.

Liquid Injection Modeling Simulation LIMS was used to predict flow in the substructural models. Substructures in which flow was analyzed include a thick flanged T-section and a steel root insert. Filling times were well predicted in the T-section, but flow front shapes were not exact due to preferential flow in the mold. The steel root insert section was not well predicted due to the complex lay-up and a significant amount of interlaminar flow.

Two full blade simulations were created. One was an end injection and the other consisted of 6 injection ports in three stations. Ports were located at the flange on the low and high pressure sides of the blade at each station. Filling times were reduced by a factor of 10 using the 3 stage injection instead of injection from an end.

Based on results from the substructure experiments, the blade filling times are over predicted. Due to the large scale of the blade, interlaminar flow problems should be negligible so flow front shapes should be accurately predicted.

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APPROVAL

of a thesis submitted by

Scott Montgomery Rossell

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

Dr. John F. Mandell — Chairman, Graduate Committee — Date 8/8/00

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Dr. John T. Sears — Department Head — Date 8/11/00

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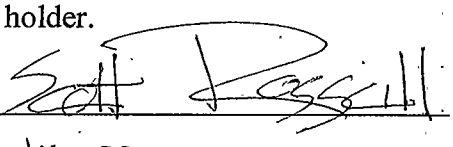
Signature 

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ABSTRACT

Resin transfer molding (RTM) is a closed mold process for making composite materials. It has the potential to produce parts more cost effectively than hand lay-up or other methods. However, fluid flow tends to be unpredictable and parts the size of a wind turbine blade are difficult to engineer RTM without some predictive method for resin flow.

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CHAPTER 1

INTRODUCTION

Advanced composite materials offer an exciting and diverse alternative to traditional materials. Their high strength and stiffness-to-weight ratios combined with a wide range of design options have allowed them to be a popular material in performance driven areas such as aerospace and sporting goods industries. In addition, they can provide a competitive, low-cost solution in piping, storage tank, and marine applications[1,2]. Another application where advanced composites are gaining popularity is the wind industry. E-glass reinforced polyester, vinyl-ester or epoxy composites are becoming the material of choice for producing wind turbine blades. These composites allow designers to make lighter more efficient blades at an affordable price.

Wind energy is a clean, renewable source of energy. Despite the potential benefits of wind energy, its cost per kilowatt-hour remains high enough to limit its growth in the United States. One area where wind energy can see a cost reduction is in the manufacturing of wind turbine blades. Currently most composite wind turbine blades are manufactured by the hand lay-up process. The AOC 15/50 is one example[3]. Resin transfer molding (RTM) offers the potential of making lighter, more efficient blades while at the same time lowering production costs of the blades[4 5]. A typical blade geometry and structure are illustrated in Figure 1[3].

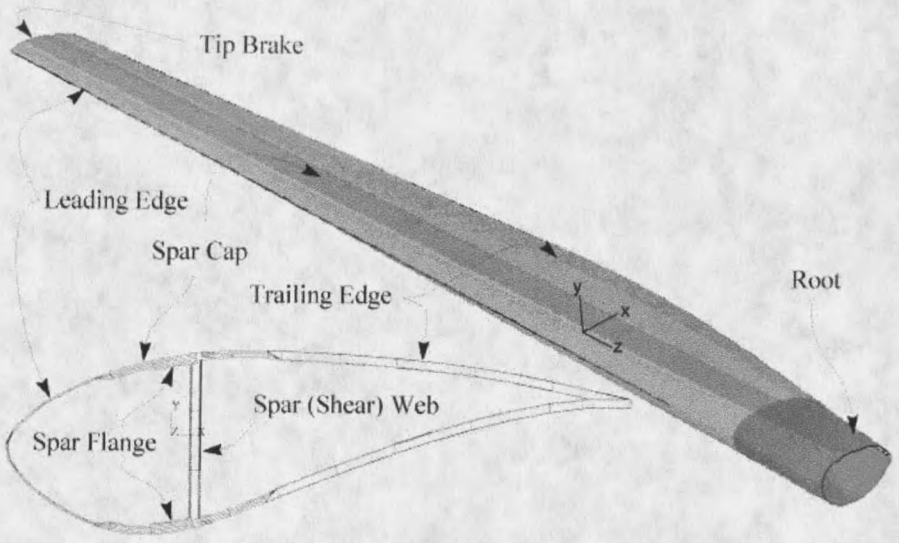

Figure 1. AOC 15/50 blade and cross section (length is approximately 8 m)[3].

Motivation

Hand lay-up involves manufacturing by the sequential addition of layers of reinforcement and resin matrix in an open mold. It allows for the manufacture of a wide range of geometries and requires low initial investment. Despite these advantages, hand lay-up is not well suited to large-scale production due to the fact that it is very labor intensive and requires high cycle times. In addition, it is not possible to make hollow structures with the hand lay-up process. Therefore, a blade must be manufactured in pieces and secondary bonded together, Figure 2. The hand lay-up process uses a one-sided mold, and this adds some complications to the manufacturing process. Since there is only one mold half defining the part shape, parts tend to vary significantly in thickness and only have only one finished surface. The unfinished surface requires additional time to condition for bonding, Figure 3, and poor manufacturing tolerances may result in thick bond lines, Figure 4. Another limitation of hand lay-up, is that fiber volume fractions are