

A FACTORY-CENTRIC WORKFORCE DEVELOPMENT APPROACH FOR AEROSPACE INDUSTRY

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ABSTRACT

Given the rapid transformation of the aerospace sector in the last decade, teaching practices should prepare engineers to face fast-paced industries that are dealing with exceedingly complex problems. Now more than ever we need engineers who are capable of working and communicating effectively within large and multi-disciplinary groups, considering the introduction of new material systems such as advanced composites in primary structural elements, development of automated processing methods such as Automated Fiber Placement (AFP), and the transition to interconnectivity among production systems, workers, products and customers. Exceedingly we need to train well-rounded and practical-minded engineers and scientists. At the University of Washington, we are dedicated to support the aerospace industry by training the next generation of engineers. A new 16,000 sq. ft. facility, Advanced Composites Center (ACC), will be dedicated for manufacturing of aerospace composite parts. Taking advantage of automation and AFP processing, sensor technologies, autoclaves and other manufacturing equipment, we aim to replicate a small factory within the university environment at the ACC. Partnering with industry, this facility will enable students to gain practical experience working on industry relevant problems within a factory setting. In addition, while working on industrial projects, students will gain experience on business, intellectual property (IP) and project management aspects.

Keywords: Workforce development, Aerospace, Composites Manufacturing, Industry 4.0

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1. INTRODUCTION

Training of aerospace engineers currently relies on established teaching practices at universities to deliver fundamental concepts of materials science, data science, manufacturing, mechanics and structural engineering in classrooms followed by limited hands-on experience in laboratories. In recent years, more emphasis is placed on project-based teaching approaches and flipped classroom ideas where students first learn fundamentals on their own using pre-recorded online materials, and then gain practical experience while working on group projects in classrooms/laboratories.

For composites, typical courses at universities cover topics such as introduction to raw materials (resin, fiber, fabric architecture, prepreg, sandwich core...), processing methods (prepreg hand lay-up, Resin Transfer Molding...), and heavy emphasis on mechanics (Laminated Plate Theory, failure theories, sandwich theory...). Hands-on experience may include introduction to fabrication methods such as prepreg hand lay-up, bagging and autoclave curing [1]. In some cases, emphasis may be placed on more advanced topics such as thermal management during manufacturing, Non-Destructive Inspection (NDI), repair, and safety considerations in design, manufacturing and maintenance. Toward completion of the degree, capstone projects defined in collaboration with industry, give students a rare opportunity to gain practical experience while working on industry-relevant topics.

However, considering specific needs of the aerospace industry, topics such as building-block approach, certification and substantiation of composite aircraft, maintenance, and size and production scaling considerations in manufacturing are largely neglected in typical university course syllabi. Our teaching practices must evolve to train well-rounded and practical-minded engineers equipped with necessary skill sets to address industry needs. The needs of the aerospace industry have changed in the past two decades, with the implementation of automated and semi-automated fabrication methods such as Automated Fiber Placement (AFP), the formulation and application of science-based process simulation tools [2], and more recently, the embracement of industry 4.0 concepts to use factory data for machine learning and data-driven modeling [3].

The Federal Aviation Administration (FAA) has focused on creating industry curriculum standards for composite materials on three main functional disciplines: Manufacturing, Maintenance and Structural engineering [4-6]. Participation is mostly online by practicing engineers and non-degree seeking students through Continuing Education Programs. Here are some of the offered courses by FAA:

- *Composites Manufacturing Technology Safety Awareness (CMgT)* [7], which covers topics such as introduction to raw materials, processing, machining, inspection and bonding.
- *Composite Structural Engineering Technology (CSET)* [8], which focuses on certification of composite civil aircraft structure and cover topics such as engineering, manufacturing, maintenance, certification and structural substantiation. Additional topics such as flutter, crashworthiness, fire safety and lightning protection are also covered. An optional hands-on lab [9] introduces students to basic prepreg cutting, hand layup, bagging, NDI and scarf repair techniques.

By comparison of the above courses with typical course syllabus at universities, the lack of focus at the university level on relevant topics required for practicing aerospace engineers is highlighted. Moreover, it shows that there is room to enhance the learning experience in current workforce development programs by introducing factory-centric hands-on experience, relevant case studies, and by putting more emphasis on project-based teaching. Critical to this learning experience is the question of how to define an effective workforce development program within the university environment which accelerates the acquisition of necessary skills by students to be successful in the aerospace industry.

At the University of Washington, we are setting up a unique facility focusing on advanced composites which incorporates engineering, manufacturing and maintenance disciplines in an integrated product team environment. This new 16,000 sq. ft. facility, the Advanced Composites Center (ACC), will replicate a small-scale factory equipped with necessary equipment, including an AFP machine, autoclaves/ovens, hot press, automatic ply cutter, NDI and mechanical testing equipment. This new facility will provide a unique platform to create a factory-centric workforce development program to train next generation aerospace engineers by linking academic knowledge of composites with the needs of industry and practicing engineers, mechanics and factory workers. The ACC provides opportunities for students and engineers in training to gain practical experience on manufacturing, maintenance and engineering practices, and can be used to educate university students and serve as a platform for the continuing education of practicing engineers. We will build upon current FAA established courses by offering fundamental courses in a variety of teaching venues, including classroom and asynchronous/synchronous remote and online methodologies to provide accessibility to a wide audience. Relevant case studies which apply learning content to real-world situations will be delivered in advanced classrooms for online participation and discussions by remote subject matter experts to enhance the learning experience. Future research projects at ACC will be used to further develop case studies to enhance the learning experience of students [10]. The educational content and venue for the proposed workforce development program are discussed next along with an introduction to the new ACC center at the University of Washington.

2. EDUCATION CONTENT AND VENUE

Building upon current FAA courses [7-9], we propose a new workforce development program with the following four main components:

- **Fundamental courses** to introduce students to topics such as raw materials, processing methods, building block approach, certification and substantiation, maintenance and repair, and design. These courses will be given in advanced classrooms equipped for online participation.
- **Case studies** to enhance the learning experience of participants and to introduce important lessons learned in the aerospace industry. These will be combined with the fundamentals in advanced classrooms.
- **Hands-on labs** at ACC to gain experience in manufacturing, machining, NDI, maintenance and repair. ACC will be equipped for online participation and virtual tours.

- **Industrial/research projects** for students and engineers-in-training to gain practical experience while working on industry-relevant topics in multi-disciplinary groups.

The university must involve industry to define research projects and case studies for the workforce program, while soliciting industry feedback for continuous improvement to make this a sustainable program. Fundamental courses will be an overview of the practice and challenges of certifying commercial composite aircraft using composite materials, and would include the subjects of maintenance, manufacturing and structural engineering. Following established FAA course content curriculum standards, we propose the following two courses for fundamentals:

- Course I: Composite Materials Maintenance and Manufacturing
 - o Essential properties and characteristics of composite materials
 - o Manufacturing processes (raw materials, transport and storage, curing and solidification, machining, NDI, bonding and assembly)
 - o Maintenance (teamwork, safety, maintenance and repair, source documentation, damage detection, characterization and repair substantiation, repair processes, regulations overview)
 - o Engineering design for manufacturing and maintenance (design considerations, thermal management, manufacturing implementation, maintenance implementation)
- Course II: Composite Materials Structural Engineering
 - o Composite applications (challenges, integrated product teams)
 - o Material, processing, and fabrication development (material and process control, defects and damage, protection of structure)
 - o Design development (requirements, criteria and objectives, lamination theory and analysis methods, material allowables, design values and knockdown factors, structural bonding, structural bolted joints)
 - o Structural substantiation (regulations and guidance, certification approaches, damage and defects, building block testing and analysis, large scale testing and modeling)
 - o Flutter, crashworthiness, fire safety and lightning protection
 - o Engineering special topics (maintenance: structural repair development and substantiation, manufacturing: certification conformity process)

The main components of the proposed workforce development program and venues are schematically shown in Figure 1 below.

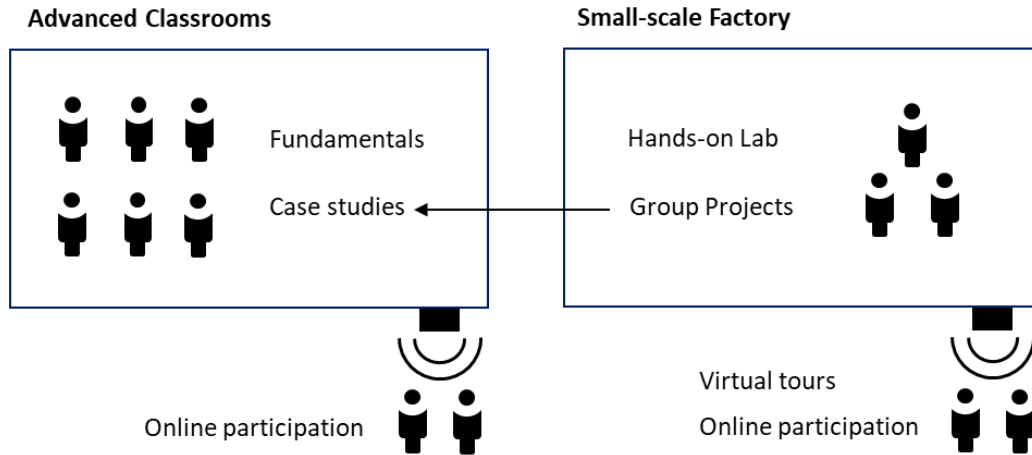


Figure 1: Schematic of the main components of the proposed workforce development program.

3. WORKFORCE TRAINING

Manufacturing and rework processes through factory Material Review Boards (MRB) will be replicated in the Advanced Composites Center as shown schematically in Figure 2. The center will be used as a testbed for the workforce development program described in the previous section. Given the recent transformations in manufacturing industry and also rise of machine learning approaches, it is essential for such a center to be equipped with sensors (e.g. infrared and digital cameras, thermocouples, pressure sensors...) for data mining. We propose that the manufacturing data to be used in the workforce program to support case studies while introducing students and engineers to data science and machine learning techniques.

Students and engineers in training can gain practical experience by participating in hands-on lab or industrial/research projects in such a center. Aside from research projects defined by industrial members, capstone projects for students can also be defined within the factory setting at such a center. Results may be used to develop case studies for fundamental courses where appropriate, depending on the intellectual property agreements of a project. We also propose that such a center to be equipped for virtual tours and online participation, either asynchronously through a Learning Management System (LMS) such as Canvas or Blackboard, or synchronously utilizing advanced classroom technologies.

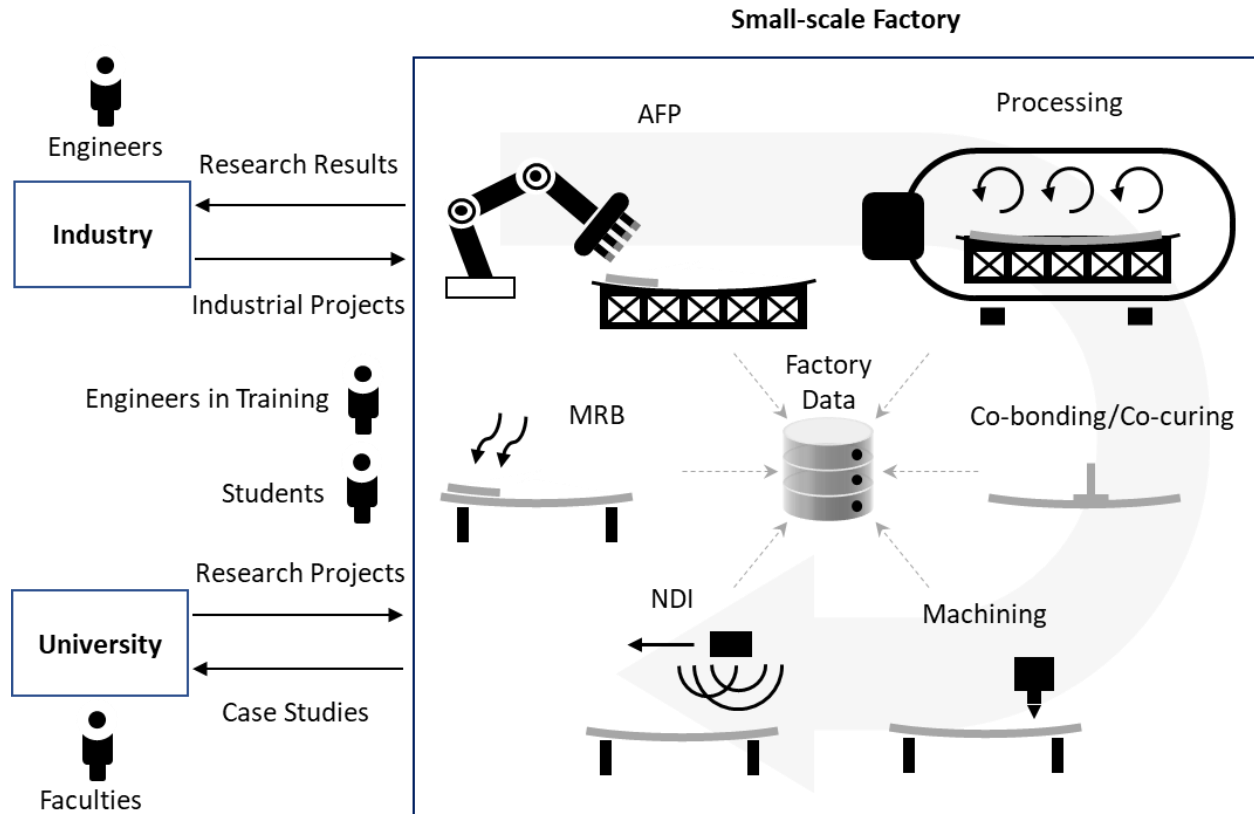


Figure 2: Workforce development program at the ACC.

4. RESEARCH DIRECTIONS

The mission of a similar center described in the previous section should be to provide a robust innovation ecosystem for industry and academia to advance the field of digital manufacturing and maintenance of advanced composites. In terms of fabrication processes, the focus should be on AFP processing and autoclave curing, but other fabrication methods such as hot drape forming, hot press processing and out-of-autoclave curing. Research projects should be defined in collaboration with industry partners or through government funding programs. Some of the main current research topics are listed here:

- Optimization of existing manufacturing processes using a combination of material/process characterization, process simulation, failure simulation, building block mechanical testing, and machine learning. Factory data will be used for characterization and optimization using machine learning. This is schematically shown in Figure 3
- Remote repair of composite parts in the service environment
- Research on different aspects of bonding including repair and quality control, and challenges of achieving thermal uniformity

- Investigating effects of defects by establishing process-microstructure-performance correlation using a combination of simulation, testing, and machine learning
- Developing new material systems/processes
- Investigating material aging and recycling methods
- Leveraging the acquired knowledge to develop certification guidelines for advanced composites

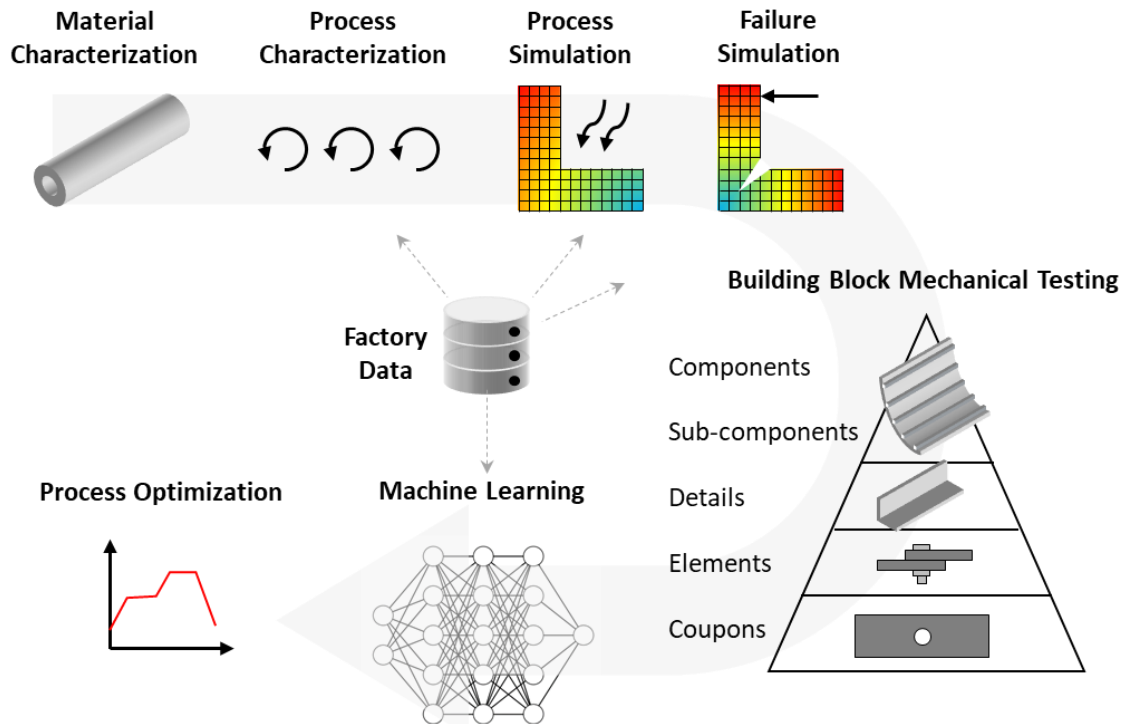


Figure 3: Research on process optimization at the Advanced Composites Center at the University of Washington.

5. SUMMARY

This paper proposes a new factory-centric workforce development program for aerospace engineers. The main components of the program are fundamental courses, case studies, hands-on labs and industrial projects in a variety of learning environments and venues. Fundamental courses will be developed based on established FAA courses and will be enhanced with relevant industrial case studies. While fundamental courses and case studies will be delivered in advanced classrooms and through remote learning management systems for online participation, hands-on labs and research projects will be conducted in Advanced Composites Center (ACC), a new research facility at the University of Washington. This 16,000 sq. ft. center will replicate a small-scale factory equipped with AFP and autoclave processing, and equipment for machining, NDI, and repair.

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