Composite Materials Courses in Colombia

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Fulbright Specialist Experience for the Development of Aerospace Composite Materials Courses in Colombia

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Abstract

This work presents a description of activities and results achieved from the implementation of a "hands-on" training program in the field of manufacturing of fiber reinforced composite materials for aerospace applications within the framework of the Fulbright Specialist program. The host institution for the program was the Universidad del Valle in Cali, Colombia and the Specialist was Dr. Ronald Sterkenburg from Purdue University. The implemented process to fulfill the defined objectives is shown as well as some of the work developed after the specialist visit, which is related to what was called project AVE. Finally, some general conclusions were drawn along with the lessons learned and necessities to continue working in the area.

Introduction

The Fulbright Specialist Program, part of the larger Fulbright Program, was established in 2001 by the U.S. Department of State, Bureau of Educational and Cultural Affairs (ECA). It pairs highly qualified U.S. academics and professionals with host institutions abroad to share their expertise, strengthen institutional linkages, hone their skills, gain international experience, and learn about other cultures while building capacity at their overseas host institutions. The program also aims to provide a short-term, on-demand resource to international host institutions, giving them greater flexibility in how they participate with Fulbright. For the case related to this work the host institution in Colombia (Universidad del Valle) wanted to receive specialized academic advice and support in the field of composite materials manufacturing for aerospace applications.

The Fulbright Specialist Program is a unique opportunity for U.S. academics and established professionals to engage in two- to six-week, project-based exchanges at host institutions across the globe [1]. Steven McNeil wrote: “being a Fulbright Specialist was a fantastic experience for me, not just for the increase in cultural awareness and exposure to different learning environments, but also the interactions with the wonderful Italian students and faculty that forged life-long friendships” [2]. Doris MacDonald found during her specialist program in Indonesia that working was intense some days, frustrating sometimes and rewarding every day. She said: “I met so many people whose names I will not remember but wish I could. Everyone

took me in hand and took me places that were just marvelous to see."[3]. David Thompson found that it was empowering to teach in Nepal and was encouraged by the enthusiasm of Nepalese students for mathematics [4]. .

Even though structural components such as beams of carbon fibre reinforced composites have been successfully produced to work on the development of external fixators for bone reconstruction in previous investigations at Universidad del Valle (Univalle) [5-8], faculty members, felt that there was insufficient knowledge of composite manufacturing expertise available in Colombian industry, particularly in the area of mechanical engineering, to produce high quality composite parts. One of the reasons for this situation can be attributed to the lack of practical manufacturing knowledge (hands on) in Colombian engineering students, who are the ones called upon to develop a manufacturing industry once they graduate. Universities, which are the main institutions to train qualified personnel for the development of new and existing industries in Colombia, must take actions to improve this situation. Therefore, a review related to the inclusion of practical skills in the education of engineers is of great importance to directly address the educational problem mentioned. Some challenges and methods to add the composite material manufacturing into an engineering curriculum were shown by Zhang et. al. in 2011 [9] and Sengupta et. al. in 2016 [10]. Hence, the engineering faculty of Univalle requested the aid of the Fulbright commission through its Specialist program as an initial approximation to a hands-on approach for the improvement of the manufacturing techniques in fiber reinforced composite materials.

The main objectives of the composite materials training at Universidad del Valle were: to improve the education of Colombian mechanical/aeronautical engineers based upon the principle of applying theoretical knowledge into practice. The focus of the training was on composite aerospace structures. Secondly, establishing a lasting relationship with the Fulbright specialist to establish a partnership to improve the quality of the master's program of engineering with an emphasis in aerospace engineering at Universidad de Valle. Finally, to establish a methodology for composite materials in aircraft manufacturing that complies with FAA airworthiness certification and standards in the long term. A four week course agenda was developed to meet the proposed objectives. The visit was divided in three main phases. The first phase was accomplished during the first week visiting the University facilities. The second phase was a two week training program for a selected group of future trainers in composites manufacturing and the third phase in the four sequence was focused on teaching what was learned by the "trainers" to an open audience through a workshop. The implemented agenda is shown in detail in the next section of this paper.

The present paper details the knowledge transfer process, the lessons learned and the results from the experience gained with the help of the Fulbright Specialist. The implemented agenda is shown in detail in the next section of this paper. Finally, the conclusions are presented along with the recommended future work aiming to strengthen the capabilities acquired, and certainly conducive to guide relevant technological development in the area of composite material manufacturing in Colombia.

Methodology
The developed program was established in three phases which are detailed below.

Phase 1: Evaluation of facilities
During the first phase of the program, faculty members of Universidad del Valle met with the Fulbright specialist to evaluate a proposed curriculum for the new aerospace master's degree and to tour the facilities to determine the best laboratories to conduct the hands-on training. Due to the warm and humid weather in Cali and the lack of air-conditioning in the machining laboratory it was decided to change the original agenda and to start the hands-on training in the mornings when the weather was cooler and to conduct the lecture and software training in the afternoons in a classroom/laboratory. The first impression was that there was no infrastructure for advanced composite training available. Through the innovation of the Colombian faculty and students an improvised laboratory was developed and existing pieces of equipment were adopted for composite manufacturing processes. Of particular interest was the required curing oven which was substituted by a furnace for heat treatment of metallic parts as shown in figure 1. This equipment had a volumetric capacity of 89 liters, with an internal shape of octagonal prism with dimensions of 22,5 in height and 7 in of edge. The oven's heating elements consisted of exposed kanthal wire spiral with maximum operating temperature of 2200 ^{O}F. The temperature controller was DELTA brand , using J type thermocouples.

Figure 1. Heat treatment furnace adapted for composite curing (with composite part inside).

For future manufacturing projects, Universidad del Valle needs to invest in a dedicated laboratory that is air conditioned, has a programmable oven for curing of composite materials, and has other specialized laboratory equipment necessary for the manufacturing of composite structures.

Phase 2: Training of the trainers

The second phase of the program consisted of lectures, laboratory and software training for a dedicated group of faculty and graduate students who are part of the IDEXA research team. The idea was to train a small group of people to a high level of competency in fiber reinforced composite materials manufacturing so that they could train future students when the Fulbright Specialist returned home. This would ensure a continuation of the knowledge learned as it was seen in a later project called AVE shown in this document in the future work section. The "trainers" would also conduct a workshop during the last week of the program. The daily intensive training would start in the morning with the fabrication and repair of composite aircraft parts made using wet layup and prepreg manufacturing techniques to introduce the trainers to common manufacturing processes. The parts shown in figure 1 were made during the two week course. The trainers made a wing rib section, stringer section and honeycomb panel using prepreg material. They also made a clipboard using wet layup techniques. The honeycomb panel was damaged and repaired to demonstrate typical repair techniques. The last part of the course was dedicated to mold making. An aluminum mold was designed in CATIA software and the advanced machining workbench was used to program the toolpaths. A CNC machine was used to mill the mold as shown in figure 2.

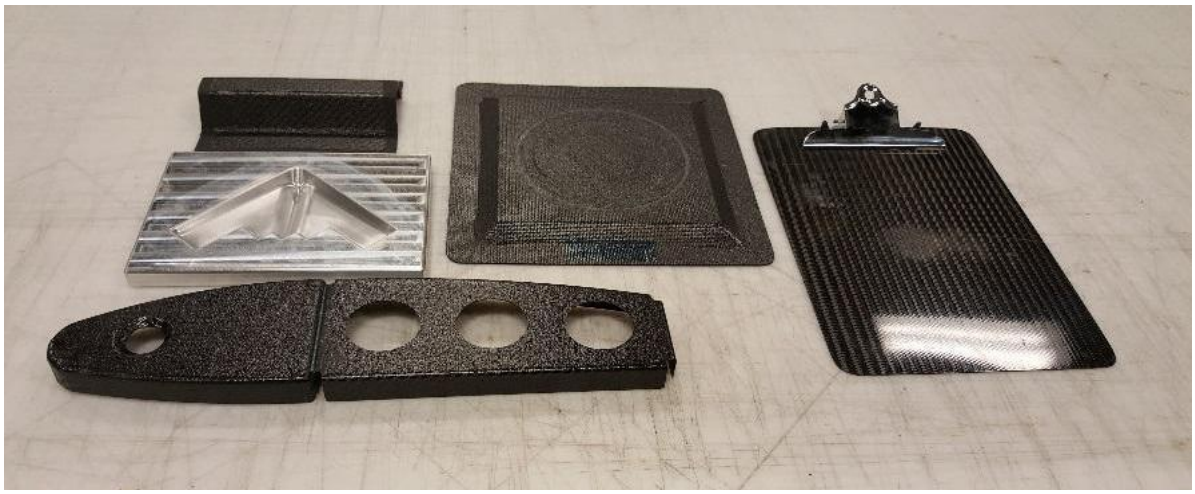


Figure 2. Developed carbon fiber course projects and CNC machined aluminum tool.

After lunch the Fulbright specialist would present lectures explaining types of composite materials, manufacturing techniques, mold making, curing, testing, and repair of composite structures. The last two hours of the day, students would learn several workbenches in CATIA V5 software. The students used eBooks written by the Fulbright specialist and classroom demonstrations in order to virtually create tools and analyze possible manufacturing defects using hand layup techniques in complex geometries. At the end of phase 2 the trainers were proficient in the generative shape design, composite design, and advanced machining workbenches and were ready to teach the workshop.

Phase 3: Composite Materials Workshop

A three day composite materials workshop was scheduled and taught by the Fulbright specialist and IDEXA trainees after the intensive phase 2 was completed. This workshop was not only focused on spreading knowledge of manufacturing techniques to a wider audience but also to verify what was learned by the trainees in phase 2. The attendees were a mixture of Univalle students, faculty members and industry professionals. The attendees learned about composites through lecture/discussions, Catia software demonstrations, and practical exercises. The attendees were strongly encouraged to participate in the hands-on projects and they really enjoyed making parts. Figure 3a shows a CATIA software demonstration taught by one of the Univalle graduate students who completed phase 2. Figure 3b and 3c show the attendees working in the laboratory making composite parts. The IDEXA trainees performed excellent and we were all convinced that the intense training of phase 2 had created knowledgeable instructors for future courses and research at Universidad del Valle.

Figure 3a CATIA demonstration.

Figure 3b Laboratory training.

Figure 3c Laboratory training.

Cultural experiences

The traditional 6 to 9 month Fulbright scholar program places a large emphasis on the cultural experience of the participant. The Fulbright specialist program is a shorter program which is focused on the needs of the host institution. Therefore, we decided to use our limited time to learn as much as possible about the hands-on application of composite materials. The time for exploring Colombia and interacting with the local population was limited due to the intense course schedule. The Fulbright specialist primarily communicated with faculty, staff, and students at the host university. We believe that a short intense Fulbright specialist program is really beneficial for the host institution and the Fulbright specialist. The ability to communicate with someone who lives in a different part of the world and trying to understand their needs and desires is very satisfying. We realized that although we were in different geographical locations and speak different languages our dreams of establishing the best educational program for our young talented people was real and similar. One of the most important things that we learned, besides teaching a course, was the development of a friendship between faculty members, which has the potential for the development of a long term partnership. The host institution benefited from the expertise of the Fulbright specialist and on the other hand the specialist learned valuable lessons during his stay in Colombia and will be able to apply the things that he experienced in Colombia back in the United States.

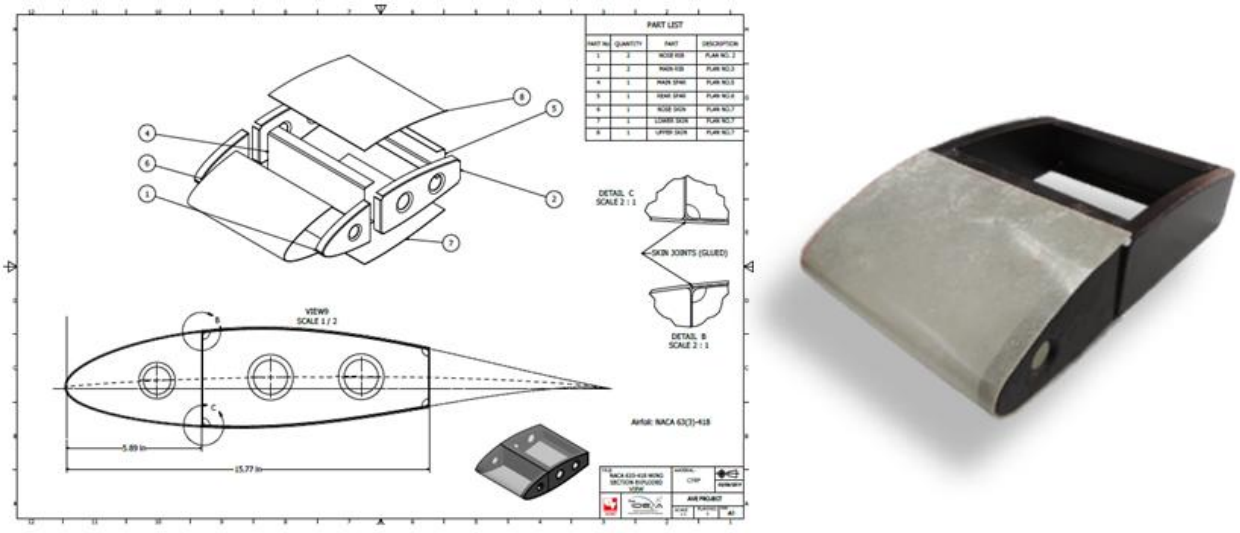
Future plans

Future collaboration is one of the objectives of the Fulbright specialist program and faculty members have discussed many potential areas of research. The first project would be a joint design and build project where students of Universidad del Valle and Purdue University will design an airfoil section together. The airfoil will be used as a student project at Purdue University in the AT272 introduction to composite materials course. Also the airfoil design and manufacturing processes would also be used to research new innovative ways to design and construct a wing for a glider aircraft. Students, guided by faculty, will meet each week on Google Hangouts to discuss the progress of the project. Estimated completion time is set for August 20, 2019. If this project is a success, a larger full scale wing for a glider will be designed, built, and tested. Ultimately, resulting in the manufacture of a fully operational glider aircraft.

Development of a carbon fiber wing section

Once the visit of the Purdue professor ended, Purdue and IDEXA (Univalle) will team up to work on a Purdue "hands-on experience" class project. The idea is that a group of students from each university starts to communicate with each other to manufacture a wing section of a simple aircraft. This aircraft will be designed by the IDEXA team within a higher-term project called AVE which stands for educational flight aircraft ("Aeronave de Vuelo Educativo" in Spanish).

The first phase for this long term project started three weeks after Dr. Sterkenburg departure from Universidad del Valle. Afterwards, there was a call out in the School of Mechanical Engineering at Univalle and 13 undergraduate students assembled a team to work in this short term project (project AVE - phase I, see Arango et al in 2019 [11]), which consisted on generating blueprints to make a composite material wing section as it is shown in fig. 4 for an undergraduate class taught by Dr. Sterkenburg at Purdue.



a) b)

Figure 4. Project AVE - phase I results. a) Exploded view of an assembled wing section with a NACA airfoil 63_3418. b) A manufactured wing section with a modified CLARK YH airfoil.

Also, Univalle faculty members will open a new "hands-on experience" class focused on composite materials manufacturing, by the first semester of 2020. The plan is continuing this

type of learning procedure [11] and to integrate academic undergraduate or graduate student groups to force them solving problems under appropriate guidance but also involving them in collaborative multicultural environment to achieve a simple goal. Thomas and McGregor in 2005 [12] emphasized the relevance of this type of interaction.

Development of a two crew lightweight sailplane (project AVE)

The IDEXA team is currently designing a sailplane for educational purposes which will serve as a keypart in the collaborative work between Purdue and Univalle giving several “project-based learning” projects to student groups in each university with their respective classes.

The sailplane is a two-crew lightweight aircraft most of it manufactured with composite materials and currently there are several undergraduate projects in IDEXA / Univalle, addressing different challenges AVE to accomplish the goal of designing and manufacturing an AVE. Students working in these tasks come from the project AVE - phase I, who finished it on August 26th 2019. This project is proposed by faculty at IDEXA/Univalle, guided and oriented by faculty at Purdue and completely developed by students.

Lessons learned

The four weeks course was an academic success. The Colombian Univalle faculty members and students were very sharp and self-motivated to achieve the maximum result during the course. For instance a simple 30 minutes lecture could easily turn into an hour long discussion in which everyone in the class would participate. In words of Dr Sterkenburg: *"This is not common when I teach my courses at Purdue University in the United States. The Univalle faculty who hosted my visit were taking care of me all the time and they made sure that I had everything I needed. Our strategy of training a small group of people first and use them to teach a larger audience was a strategy that worked out great. It instilled pride and ownership in these trainers. It was amazing to observe them during the final workshop, they acted like they had been teaching this material for years."* Secondly, there was no language barrier during the workshop because the trainers provided the training. It is never enough to emphasize how important it is to establish a good working relationship with the host faculty before you go to make sure what to expect when you arrive and to inventory what materials, laboratories and classrooms are available. Dr. Sterkenburg decided to ship enough materials to Univalle before he went on the trip so that he could teach the course as soon as he arrived. Also, be specific about your needs with the host. For instance, if you need a specialized curing oven of a certain size make sure you communicate this clearly. That was not done in this experience and Dr Sterkenburg had to improvise because the equipment he needed was not available.

It is important to start the project with an open mind and be flexible. Expect the unexpected and enjoy it. Many things are not going to work as planned, for instance in our case the host university was closed during the first week due to student demonstrations and facilities and materials might not be available but relax and find alternatives. It is not a sprint to the finish but a slow journey with many challenges, choices and opportunities. During the four weeks we had to make many adjustments to the agenda, facilities and projects but innovation and adaptation to the local situation prevailed. Dr. Sterkenburd said: ***"****One of the main obstacles for me was my*

lack of Spanish language skills, which made it hard to communicate with the local population. I wish that I had more time to prepare myself for this trip and learned some basic Spanish. I would advise anyone to learn the local language and not rely on English." Most faculty and students were proficient in English but there were occasions that Dr. Sterkenburg met people he could not communicate with.

Conclusions

From all the learning process during the specialist visit and the ongoing projects that emerged from it, especially taking into account all the difficulties found, several important conclusions were addressed:

- The trip was an academic success since relevant theoretical and practical knowledge in fiber reinforced composites were imparted to different faculty members and students at Universidad del Valle.
- Redundants plans must be set in order to deal with possible adverse situations. To satisfy a specific necessity plan A, B and C should be prepared taking into account to always expect the unexpected and get ready for it.
- A good practice to multiply the knowledge through a greater number of students is to start the training with a small committed group of trainees with enough language skills to successfully communicate with the specialist. Then, the training can be replicated to a greater audience.
- Hands-on sessions are the top priority mechanism for knowledge transfer.
- An unexpected not frequent wrong result from a project is a good learning plan. This means that making not frequent mistakes during the manufacturing process is also an opportunity to teach the whole team about what to do and do not to satisfy with goals and requirements of product.
- If serious manufacturing processes courses and trainings for aerospace composites parts are going to be imparted at Universidad del Valle, investments regarding at least basic equipment must be made. Of importance from the experience a programmable curing oven for composites and a particular freezer for prepreg storage were identified.

Finally, like many other Fulbright Specialists before, Dr. Sterkenburg said: "*I also experienced very motivated faculty and students who were ready and willing to learn, it was frustrating at times due to the lack of equipment and other resources, but it was a lifetime experience that I would like to recommend to other faculty members*". He also mentioned: "*before I participated in the Fulbright Specialist program, I was not really aware of Colombia or South American, but now I have a better understanding and more interest in this part of the globe. I would definitely want to do this again*.

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References

[1] The Fulbright Specialist Program, “What is the Fulbright Specialist Program?”, 2018. [Online]: https://fulbrightspecialist.worldlearning.org/the-fulbright-specialist-program [Accessed 24 - May - 2019].

[2] Best Practices: A Fulbright Specialist Experience in Perugia, Italy 2015 … file:///U:/Personal/Downloads/Stephen%20Mcneil_Best%20Practices%20A%20Fulbright%20Specialist%20Experience%20in%20Perugia%20Italy.pdf

[3] Experiences, Northern Star https://northernstar.info/news/fulbright-specialist-back-from-indonesia-shares-experiences/article_a141ee08-66de-11e9-a6a0-5b654463377e.html

[4] Thomas, D. Six Weeks in Kathmandu: Reflections of a Fulbright Specialist. https://amte.net/connections/2017/09/six-weeks-kathmandu-reflections-fulbright-specialist

[5] F. Ortega, A. Leyton, F. Casanova. Design And Evaluation Of A Rail Made Of Carbon Fiber Reinforced Material For An External Fixation System, Dyna rev.fac.nac.minas vol.79 no.174. Medellín July/Aug. 2012.

[6] A. F. Carrera. Desarrollo de un dispositivo de fijación externa para transporte y alargamiento óseo. School of Mechanical Engineering - College of Engineering. Universidad del Valle, Cali - Colombia 2016.

[7] J. F. García. Desarrollo de un sistema de fijación externa en materiales compuestos para transporte y distracción de hueso., School of Mechanical Engineering - College of Engineering. Universidad del Valle, Cali - Colombia 2017.

[8] W. A. Carabalí. Diseño de un sistema de fijación externa monolateral, de fibra de Carbono, para tratar fracturas abiertas. School of Mechanical Engineering - College of Engineering. Universidad del Valle, Cali - Colombia 2018

[9] L. Zhang, , M. Bárcena, Z. Chen. New frontiers in Materials Processing Training and Learning II. Series Materials Science Forum. Trans Tech Publications, Limited Ed. Vol. 62. Santander, Spain. 2011.

[10] Sengupta et al. Using module-based learning methods to introduce sustainable manufacturing in engineering curriculum. International Journal of Sustainability in Higher Education. 2016.

[11] C. E. Arango et al. User guide to assemble a composite wing section. IDEXA, Universidad del Valle - Purdue University. Cali - Colombia. Aug. 26th 2019.

[12] W.R. Thomas, S.M. McGregor, Online Project based learning: How collaborative strategies and problem solving processes impact performance. Journal of Interactive Learning Research. 16(1). 83-107. 2005.