EXPERIENCE WITH INTERNATIONAL COLLABORATIVE AIRCRAFT DESIGN EDUCATION: AREND UAV

L Smith*, JN Koster, J Scheinder*****
***University of Pretoria, **University of Colorado, ***University of Stuttgart**

Abstract

Team AREND has over the last 3 years developed an innovative technological solution to rhino poaching. The project posed multiple opportunities to solve international collaboration design education effectively. Leading to valuable knowledge in terms of developing and structuring projects for the purpose of collaborative design education within different University structures.

1 Introduction

The AREND project focuses on design, build, and test of an unmanned sensor aircraft solution to detect and distinguish humans and large animals such as rhinoceros and elephants in harsh environments [1]. The AREND project was started under the leadership of Prof. J.N. Koster (who has good experience with these projects [2]) after an invitation by the Wildlife Conservation Unmanned Aerial Vehicle (UAV) Challenge (www.wcUAVc.com) established in 2013, but never took place due to UAV regulations in South Africa. Despite this, team AREND, over the last 3 years has set out to develop an innovative technological solution to rhino poaching. Team AREND consists of 4 Universities, on 3 continents. The universities are: University of Colorado Boulder, United States; Helsinki Metropolia University of Applied Sciences, Finland; University of Pretoria, South Africa; and University of Stuttgart, Germany. Undergraduates, post graduates, staff and industry partners worked together towards a workable solution for the Kruger National Park in South Africa.

Although not entirely the initial intention, the project posed multiple opportunities and challenges to implement international collaboration design education effectively, at all the Universities involved. One caveat in the organization of a global project with independent local teams is that the project's systems engineer has a more difficult job to understand the system engineering process developed by the individual teams. After forming the concept of operations for the AREND UAV and deriving the design requirements from these, the 4 teams were each given part of the design of the UAV to work on individually. Although each team had a certain level of freedom in terms of the design process, each University had to have a system engineer and manager in place to work collaboratively to ensure successful communication internationally between local and global sub-groups, utilizing different strengths of each team member while managing overall risks of the project.

In this regard there were various key challenges that emerged which had to be considered and also some key findings needed to be worked out in terms of enhancing the international collaboration as a design education project. Each University had a set of unique challenges and opportunities. These will be the core focus of this paper and each University's experience and lessons will be shared.

2 Team Structures

The aerospace industry is one of many multinational organizations heavily effected by globalization. The next generation of aerospace engineers will only succeed in this environment, if we provide our students a platform and more opportunities to learn a great deal about the associated challenges during their undergraduate and graduate studies. The AREND team is not only a multinational, multidisciplinary, vertically integrated student team, but also relies on industries for mentorship and support. The projects allows for various engineering and interpersonal challenges which would prepare the students involved for challenges later in their career.

Some of the main challenges at some of the Universities were that initially the project did not fall within an assessable curriculum structure and relied on students' interest in the cause or educational components the project could provide. The global team was structured according to specific fields of expertise as shown in Fig. 1.

Colorado University (United States)	University of Pretoria (South Africa)	University of Stuttgart (Germany)	Metropolia University (Finland)
Embedded systems	Concept of Operations	Wings	Ground Network
Propulsion	Fuselage, camera gimbal, landing and launch systems	Empennage	
Communications			

Fig. 1. Global team structure with assigned work sections.

Support and participation are key to a project in creating an efficient and functional team. It is important to create a support system in a team. This allows people to lean on each other and ask each other for advice, this make the collaborative process much easier and allows the team to work as a group rather than just as individuals.

2.1 University of Colorado

The University of Colorado AREND team was started as part of a graduate design course program that the Department offers to graduate students at the Masters and PhD level as part of their degree fulfillment requirements. The starting team included 10 students with skills in embedded systems, propulsion, and command and control. The team was organized similar to a small business with specific functions (Fig. 2). The program manager was selected by the team and other students assumed functions like Systems Engineer, Chief Financial Officer, Safety Engineer and technical leads for the different major tasks. Like in start-up companies, each student in a lead position was required to assume other subordinate tasks according to skills needed for a successful outcome. For example the Project Manager may also contribute to a technical task under the leadership of another student. Funding was received through a crowdfunding campaign organized by a supporting organization and through a small company.

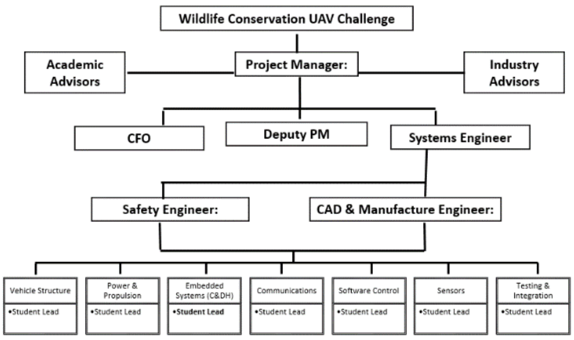

Fig. 2. University of Colorado local team structure.

This structure was similar to what was in place for senior level undergraduate capstone design courses. At the graduate level the student team had to develop a professional discussion with industries that provide technical sub-systems or who engaged in the mission of the project. This led to an industrial team of engineering advisors, scientists and conservationists from different countries.

Initially, the CU team organized regular web-meetings between all four member teams. Fortunately three teams were in the same time zone and only 8 hours ahead of Colorado Mountain time. As individual teams had distinct tasks, these conferences were essential to share new developments and assure that each team is well informed about the progress at each university. This exchange is essential as the systems engineers had to determine that all sub-systems are verified and that the final integration validates the requirements of the project. It is important to ensure that everyone contributes and that time is being used efficiently to discuss issues and communicate ideas. Along these same lines a clearly defined hierarchy needs to be developed to ensure that the project continuously moves forward and that important decisions are never made without consulting the project manager and the systems engineer. Selection of the personnel is important to ensure the project goals are met in a timely fashion.

2.2 University of Pretoria

The team at the University originally consisted of two part-time PhD students which were full-time staff members at the University and 6 volunteer final year mechanical engineering students. However, due to the workload of the final year curriculum, the students had limited availability and the times they were available did not align with the goals and timeline of the original project driven by the wcUAVw competition.

It was critical to ensure continuity of the project that the UP project manager and design advisor remain constant in the project and therefore the two staff members (part-time PhD students) took on these roles. At the University of Pretoria, all staff members are assigned a group (10 to 20) of final year design and research students each year. The two staff members involved in team AREND could then assign some of their design and research related topics on AREND to these students as their focus for the year and by default they would become the main designer and project manager of that project. These projects consisted of for example, design and testing of the landing device, implementation of an emergency recovery system, and modification and testing of a launch device.

As part of the outcomes for the Mechanical Engineering degree at the UP, students must gain 240 hours of industrial experience at the end of their 2nd and 3rd years of study. The aim is to develop an insight in the practical application of engineering science in industry and the related human relationships and safety aspects. The Engineering Council of South Africa requires this type of experience in the training of engineering students. We recruit between 6-10 students here and have them trained at the Council of Scientific and Industrial Research (CSIR) and Epsilon Engineering in composite design and manufacturing. The final airframe integration and testing phases were overseen by another local partner Aerial Monitor Solutions. After this training each of these students are assigned to smaller design and manufacturing portions of the greater project.

Graduate students volunteered and acted as interim project managers and advisors, but within this structure the main staff members were still involved at each level and with each design decision, to ensure success of the project. In order to interface with the electronic team in the US, UP also had a staff member in the electronic department and 2-4 electronic engineering undergraduates to learn the system and prepare for integration phases of the UAV. Fig. 3 shows the specific structure of the University of Pretoria team.

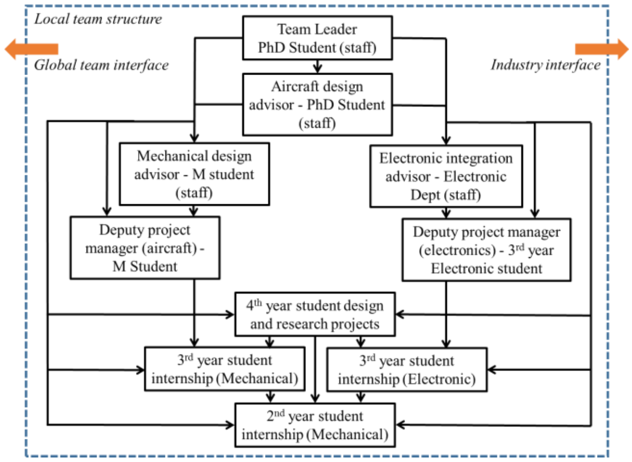

Fig. 3. University of Pretoria local team structure.

2.2.1 Challenges within the UP Structure

The major challenge within the UP structure was the timeline and interface of student deliverables. The second and third year students working as interns on the projects only has time during the semester breaks to complete their hours on the project, during which the final year students usually take a break from their busy project schedules. The final year research project students are the driving force behind the deliverables. If semester breaks and their interns were not properly managed it lead to interns feeling that there is not enough work in the break period and the final years that they have to do too many small design components which distract them from their main focus. Even though this never lead to any project delays it did compromise the overall experience for some students. However, many say this not as a disadvantage but rather as a personal lesson in time and resource management.

2.2.2 Benefits of the UP curriculum

Consistency in leadership of the UP team was a major benefit to the project. The two PhD/staff members involved in the management and design supervision have been team members and drivers since the beginning of the project and remain intimately involved with all the levels of the project to ensure long-term success. It is also a major benefit to have the vertically integrated teams, where students from 2nd year up to graduate level worked together on various systems of the UAV.

Structured task memos derived from the main objectives by the lead designer served as good focus points for students at UP, so all members of the group at all times understood their responsibility and knew the overall objectives and role in the global team. This also led to more motivated individuals and greater success in small manufacturing and integration challenges during the visits from the international Universities to UP.

2.3 University of Stuttgart

A PhD Student of the Institute of Aerodynamics and Gas dynamics at University of Stuttgart (www.IAG.uni-stuttgart.de) who was part of a former project collaboration between CU an the IAG, introduced the project to the Bachelor and Master students of the Aerospace Engineering program. Since the general program offers little chance for practical work and this project promised to actually build an aircraft, 5 students (4 of the Master - and 1 of the Bachelor program) were willing to work on the project as volunteers. One of the Master students was assigned as the team coordinator and the PhD student became the project technical advisor. The team of the remaining 5 students was easy to manage, even for the inexperienced team coordinator.

Considering the team size as well as the level of individual knowledge and experience of aircraft design the students had, a sub-team structure was not feasible. In addition, to ensure a reasonable allocation of time to this volunteer project, all tasks were completed as a team. This gave all students a great opportunity to understand and learn the process from designing to manufacturing a wing and an empennage. The team morale was sustained within the team by allowing each student to gain experience with every design task and synthesize their theoretical engineering knowledge to produce a workable product. The size of the team and the ability to share the feeling of individual and team successes was an incredibly motivating factor, which would have been lost had individuals worked independently. The student of the Bachelor program managed to create a topic for his final thesis out of one specific design steps. This fact also kept motivation high amongst the other team members since he was dependent on results from the team.

When it came to manufacturing of the wing and empennage within a quite tight timeframe, workload increased dramatically to several hours per day. The options to credit the students for their effort are very limited within the university system but there is a possibility to give students a salary and an employer's reference. Institutes can apply for money from the University to buy materials and pay students if the job/project supports educational goals. For the manufacturing period the students got payed for 20 hours per month. The actual workload was higher but it helped during the critical time. The team delivered the prototype wings and empennage for the first prototype at the end of 2014 and one of the team members spent 2 months in South Africa to complete the integration and test phases. After delivering the prototype wings and empennage to South Africa the team was dissolved and the student that visited South Africa became the project manager for any further collaborations.

In terms of overall progress in the team at Stuttgart, if the students were merely volunteers, there were various difficulties in management of this structure. A group of 5 volunteers could easily be demotivated by a single member in the team that is unreliable and lazy. This was especially true when the inefficient member received the same appreciation as a useful part of the team. Team members easily move from a perception of hard work is rewarded to doing the sub-minimum if this happened. Volunteer workers need a strong supervisor who could inspire students to achieve their goals without these goals necessarily contributing to credits for their studies. At first Prof JN Koster and the team leader of the Colorado team were the primary drivers and achieved this goal.

The two Institutes of the faculty of Aerospace Engineering which had the most contact with the team were very pleased with the order of events and surprised about the motivation of the University students to do something practical. As a result an infrastructure of work-space, finance, advisors and a way to credit students was established to run a permanent team of students (name: UAStudents Uni Stuttgart) working on (international) UAV projects. In this Team students can either work voluntarily or doing final theses and project works which also counts to their program.

2.4 Metropolia University

Since the ground sensor system was part of the long term plan the group responsible for this at Metropolia only had a single advisor and two graduate volunteers to work on the project. However this part of the project remained a paper study for the duration of the project with some basic testing in terms of proof of concept. It was challenging to integrate into the team at these initial stages since the project depends on the final results from the UAV flights and sensor payloads.

3 General/ Challenges within the Project Structure and Management

The local teams create a clear motivation to foster collaboration and greater awareness of each other's responsibilities. This is something that needs continued reviews and improvements. Motivation is what drives a project forward and a project manager should be able to inspire this motivation. Without the motivation tasks take longer to complete and the team moral plummets. Motivation creates excitement and makes people take pride in their work, rather than dreading working on a task. The creation of a multi-university team was an architect of motivation; and challenges incurred frequently.

In both the University of Pretoria and University of Stuttgart teams one of the primary means to motivate and inspire students occurred through general awareness of the project within the Faculties. Both frequently published progress or success stories on their individual University websites which lead to awareness amongst staff members and fellow students. This lead to the local teams becoming proud of their work and made it easier for them to receive help from other staff members not formally involved with the project.

3.1 Local and International Communication

International communication was primarily via email or via video teleconferencing using Zoom. Weekly meetings were scheduled and all team members could join, but specific members were requested to always be present. Effective communication always forms the cornerstone of project success. Although engineering students at their respective universities and in their respective fields are taught to communicate effectively, verbally and in writing, the challenge of a vertically integrated, multinational and multidisciplinary team cements these skills for undergraduate and graduate students. Any misunderstanding will lead to delays and contribute to individual or team frustration. The team leaders of each University carried the responsibility for effective communication. Any misunderstanding or confusion between teams were discussed with the team leader, who then contacted the appropriate team leader of the other University.

Awareness and sharing of potential issues can eliminate technical problems that could hinder the team's effort. If the team is not effectively communicating design challenges and progress, awareness cannot exist. This is an issue that happened to team AREND a few times due to different approaches and perceived design challenges that were not clearly communicated across teams. This was a difficult challenge to anticipate, but great lessons learnt to remember that some points that are obvious to UP students, for example since they live in the country where the UAV would operates, and therefore not thought to communicate.

3.2 Challenges in Curriculum Integration

Beside the effectiveness of inter-personal communication of individuals and the obvious challenges of cultural and language differences, difference in engineering design approach was the most challenging in AREND. Initial phases of the project relied strongly on the UP teams' ability to formulate the problem posed by the rhino poaching in the Kruger National Park and a lot of time went into truly considering what the exact needs are of the rangers. Multiple other UAVs have been tested in the KNP so it became imperative to provide a system that truly addresses the needs of the rangers. International meetings driven and dictated to follow a specific routine design procedure did not align with this intention and so a lot of time was wasted and members on all sides frustrated with delays that seemed unnecessary.

In 2014, at both the University of Stuttgart and the University of Pretoria, there were no infrastructure to support the project. This made the initial exchange visit from Stuttgart quite challenging since there was no explicit lab space, equipment or material available to do the work before the first flight test and integration. However, due to the context of the project being to contribute to a technological solution of the rhino poaching problem, there were various ways to gather local support from industry in South Africa in terms of mentorship and sponsorships. This might not have been the case if the project had no specific purpose. Without such infrastructure and support, there is a possibility that volunteers will lose interest in the work. However the experience of the exchange from Stuttgart was very beneficial and the practical knowledge and experience gained was meaningful.

In the second year of the project, 2015, the project was not driven by a design course curriculum from CU but rather individuals that were working on the project as part of their design course. This included a single Masters level electronic engineering student at CU and multiple final year research project students at UP. Without unnecessary administrative distraction there was a clear directive of the work required.

Although all the Universities had different semesters and individual timelines, the integration phases were planned and aligned to all parties. Remaining focused on both the students individual deadlines for the university reports as well as the integration phases between universities is more intensive than a project without the collaborative design component, but did not seem to deter students from selecting the project as their focus.

3.3 Management of Expectation and Abilities

Leadership requires effective skills in communication, conflict resolution and persuasion. In terms of project AREND there were two aspects of leadership which presented challenges. The first and most challenging was to align personal goals with those of the project as a whole for the staff members responsible for the project at each University. At first the project would have been a simple UAV design to take part in the wcUAVw competition. However after the competition was cancelled and the team decided to provide a feasible solution to the KNP, the vision and parameters of the project was not well defined. It was unclear what the purpose of the project was and who would take responsibility for ensuring the design leads to a product the KNP could use and complicated intellectual property (IP) issues delayed progress at critical integration phases of the project and frustrated some of the Universities involved.

The second level of leadership challenges are that of the students involved in the project. At CU all the students were part of a graduate design course and each student was allocated to a specific role (project manager, systems engineer, lead aircraft designer etc). At UP the students ranged from 2nd year to graduate level. Assigning leadership roles to students can be risky since most students do not have the soft skills anticipate conflict and motivate team members, while remaining focused on the project objectives. The structure at UP allowed the student to assume leadership roles on components of the design but was still managed by the staff members acting as lead designer and project manager. This ensured that deadlines were met but also that the students had the opportunity to practice their ability to lead and manage small task within their design project.

Although not all of the students have a natural ability to lead and organize others towards a common project goal, the staff members were very mindful of such inabilities and spent time guiding the students to develop these skills.

Change can be very difficult to manage (especially at the international level). This has been a big lesson in the project as a lot of change has occurred throughout. These changes include personnel changes over the semesters/quarters that cause overlap or gaps in the design process and local design changes that were made and not communicated clearly. Change can cause a lot of time wasting in a project and if change is not documented and communicated properly it can lead to significant delays and even failure in a project.

Building and preserving a sense of responsibility is very important for getting tasks done. This is something that is important in a team, but also very difficult to accomplish at an international level. Responsibility drives a team to take pride in their work and produce better results. Without this responsibility a team can fail and a project will not come together in the originally planned time frame. Once that responsibility is established it needs to be supported, fostered, and encouraged.

3.4 Intellectual Property

IP was a surprising issue not anticipated by those involved in the project and had quite a detrimental effect on various individual motivation to take part on the project. Although not all projects would require the effort of setting up an IP agreement upfront it is the opinion of some of the team members that the experience in handling this crisis late in the project as well as the experience of working with lawyers to establish such an agreement was extremely informative and educational. Therefore adding this process even if an IP agreement is not explicitly required, would be beneficial to students and also ensure that there are no detrimental surprises later in the project.

With the transfer of hardware and software the teams have to consider legal issues and government regulations on export control. Funding was also transferred to the University of Pretoria to purchase components based on government regulations implemented in South Africa.

3.5 The International Traffic in Arms and Regulations (ITAR)

The International Traffic in Arms and Regulations (ITAR) of the USA presented also a serious challenge. During international design reviews with the global team, the UP team had to be made aware of these restrictions and the impact on the final design. Although not all the sub-systems that the individual students were working on were influenced by these restrictions, some of them led to an overall objective assessment of the aircraft and this led to minor adjustments in their designs. This was a unique opportunity to give students a typical non-engineering challenge that regulatory bodies can bring into the design space and to best work with these restriction without compromising the final design objectives.

4 Project Successes

Project AREND as a multi-disciplinary, multi-national, vertically integrated collaborative research and design project has been successfully run as a formative project-based project with close involvement of aware, mature supervisors. In a true research or design scenario there are continual changes and challenges from different sources (client requirements, product viability, engineering method advances, manufacturing advances, etc.). The success of these projects lie as much in the students engineering skill and reasoning abilities as it does in the more soft skills like project, time and risk management and conflict resolution. These soft skills are difficult to formally teach but they are rather skills developed due to difficulties encountered within these project structures. At time this happens automatically, but it is important to remain subjective as the supervisor, to guide the student without doing the personal development work for them but give them reasonable challenges to overcome and feel empowered within their own abilities, which has been a success in project -

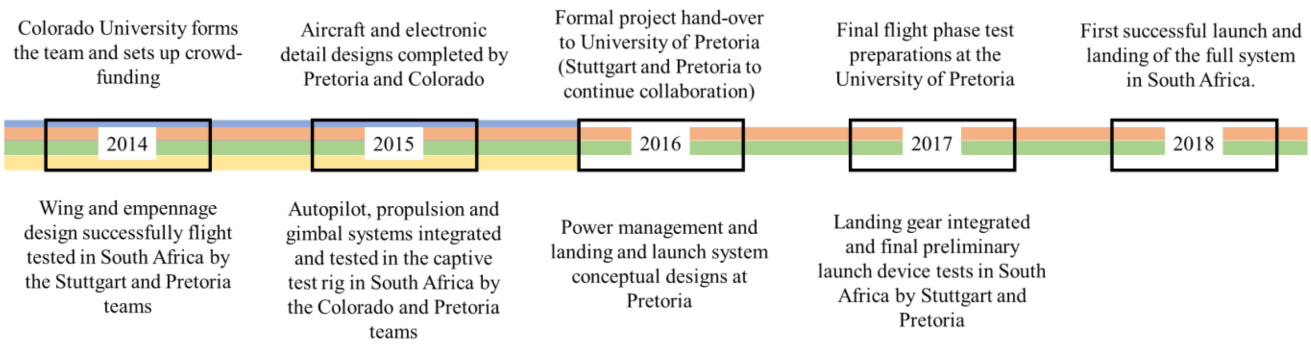

Fig. 4. Timeline of major stages in the AREND project

AREND based on student feedback over the last 3 years.

Communication and transparency were key factors here to the successful management of the team. Weekly meetings were held with the senior students and all students were linked to a WhatsApp group through which updates and information was given. Not only does this allow for more instant communication but it allows the supervisors to be closely involved and give attention to any problems or stresses. It is important for me to remain professional and not give the students the impression that the staff is available to them 24/7 so it is made clear that this is only used during business hours unless other prior arrangements were made or in the case of some emergencies.

5 Current Status

Fig. 4 shows the timeline for the project since 2014 up to July 2018. After the initial gliding flight test of the AREND UAV aircraft configuration in 2014 when Stuttgart came to Pretoria, all consecutive testing were completed in the captive test rig. At the end of 2015, Colorado brought the cameras, propulsion and autopilot systems to Pretoria and these systems were individually tested in the captive test rig. After the hand-over of the project the team rerun some of the captive flight tests in 2017 (primarily for the new student team in Pretoria and exchange student from Stuttgart to gain some experience with the system). Towards the end of 2017 the landing gear was integrated into the UAV and the captive test rig was modified to temporarily act as a launch system to test the landing gear. These tests were successfully completed in July 2018. The next phase of the project will include the primary launch device for the AREND UAV, emergency landing parachute integration and gimbal stabilization.

Some aspects of the original design [1] were changed after the handover of which the most significant is the launch device which will be a catapult system, and the landing gear was changed from a retractable skid to a fuselage shell reinforcement. This part was statically tested before the first flight and the design was adapted after certain parts failed. The final integrated skid system survived the controlled crash into terrain landing during July 2018. Fig.5 shows the new skid system.

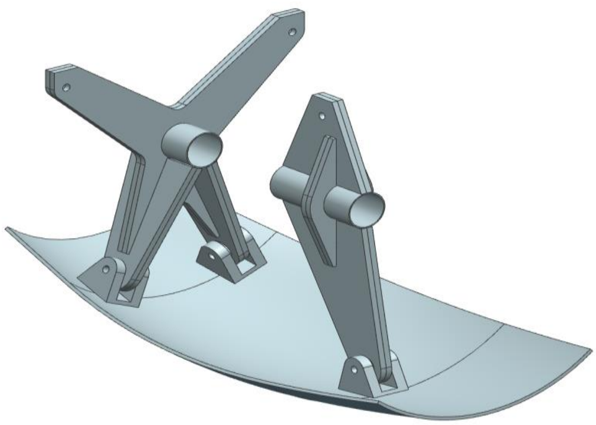

Fig. 5. Landing skid design for the AREND UAV.

6 Conclusions

As an overall reflection of the success of this project and the management thereof, there were some aspects not considered with regard to an

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academic student based project. The most critical and disruptive of these challenges were the alignment of vision between teams and individuals. Since the original intention was to take part in wcUAVc, the change of intention once the competition was cancelled was not well-defined. Challenges in *terms of IP agreements deterred* the project quite late in the development phase and also demotivated some members involved. With each of these challenges the whole project had to be reviewed and adjusted to not strain the students with additional workload, but allow them to be part of discussions and decisions within these complex frameworks that exist in real-world projects but are never formally taught in the curriculum. The AREND project has been a great engineering education project and will continue to evolve and grow at the University of Pretoria.

Acknowledgements

In [1] there is a long list of acknowledgement listed up to then end of 2015 to whom we are still grateful for. During the last two years the South African industry has been incredible supportive and has been a crucial part of the project success, not only in terms of sponsoring materials but also in terms of offering mentorship to the students involved. John Monk and his team at the CSIR continue to support the team as an advisor as well as with composite material manufacturing and design training. Epsilon Engineering has also been a major contributor in this, offering the opportunity for student to train and providing materials and molds to the project. Paramount Group has provided the team with multiple networking opportunities and connections to the UAV industries as well as guiding us through the flight test procedures, safety procedures and understanding interface with regulation bodies in South Africa. The time and effort from Marius Cronje and his team has been very meaningful to the team. Lastly, Adam Rosman and his team at Aerial Monitor solution has allowed the team at UP to do various pre-flight checks on the system under their guidance. This was not only an incredible learning experience for the team but also allowed them to be flight ready much faster than they would have been without.

The students worked incredible hard on the project and specifically the Stuttgart intern, Mr L Fels and Mr A Buysse from the Colorado team that used some of his holiday in South Africa at the end of 2017 to join the team for some tests. Currently Mr A Sharma, a Master student at UP was also essential to the managing the team.

Reference

[1] Koster, J.N., Buysse, A., Smith, L., Huyssen, J.R., Hotchkiss, J., Malangoni, J. and Schneider, J., “AREND: A sensor aircraft to support wildlife rangers,” *57th AIAA/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference*, AIAA SciTech, AAIA 2016-0827, San Diego, CA, 4 – 8 Jan 2016.

[2] Koster, J., Velazco, A., Munz, C. D., Kraemer, E., Wong, KC and Verstraete, D., HYPERION UAV: An International Collaboration. AIAA 2012-1223, 50th AIAA Aerospace Sciences Meeting, 09 - 12 January 2012, Nashville, Tennessee.

8 Contact Author Email Address

Lelanie.Smith@up.ac.za
jean.koster@colorado.edu
schneider@ifb.uni-stuttgart.de

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