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Students from around the World Design, Manufacture, and Fly an Aircraft

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Motivation

Michael Nielsen[1] studied collaborations among mathematicians and his conclusions can be paraphrased for engineering: “Part of the answer is that the best engineers can learn from people with complementary knowledge, and be stimulated to consider ideas in directions they wouldn’t have considered on their own. Online tools create a short-term collective memory where ideas can be rapidly improved by many minds.” Industry has top level program goals that may require multinational team work and the synergistic support structure of extremely large teams where no one person understands all the systems of systems in detail.

There is a growing trend of global, multi-company collaboration within the aerospace community. With the growing maturity of information technology and ever-increasing complexity of modern engineering and education, many parent companies form partnerships with specialty teams in order to facilitate rapid development across all subsystems of a project. For example, the Boeing Company purchases roughly 65% of the newly developed 787 Dreamliner airframe from outside companies.[2] In a field where work is traditionally performed by small, localized teams of engineers, these complex global projects present new challenges for overcoming cultural differences, language barriers, and bureaucracy.

With these industry trends set to define a large focus of the next 20-50 years of the aerospace industry, educating the next generation of engineers who will be responsible for addressing these challenges is of paramount importance. Efforts to train students in the global design effort have been reported before, and they were mainly limited to virtual computer design studies and did not include delocalized manufacturing.[3] In different cultures the educational program itself may provide students with different skill levels in similar fields of study and new challenges to team work.[4]

The Hyperion project, besides being a challenging technical project, was designed to prepare students to become global engineers.

Introduction

At the University of Colorado at Boulder during the summer months of 2010, a small team of continuing education (B.S./M.S.) aerospace engineering seniors were challenged to develop a global academic project that would assess the feasibility of simulating known pains of the modern global industry. Global sub-contractors often have difficulties understanding requirements the same way as the customer due to cultural differences and educational background. The Hyperion project consisted of three delocalized international student teams, who conceive, design, implement, and operate a completely new type of aircraft.

To satisfy the global project management aspect of the project, the *Follow-The-Sun* (FTS) concept was identified as a promising model for improving the productivity of delocalized teams. The FTS concept revolves around three teams, spread eight hours apart, who relay their work every eight hours, realizing 3 working days in a single 24 hour period. The University of Stuttgart, Germany and the University of Sydney, Australia both agreed to participate with the University of Colorado at Boulder (CU), U.S.A in the experimental project.

The NASA/Boeing X-48B aircraft was set as the inspiration for the aircraft design.[5] The blended-wing-body (BWB) architecture was chosen as the initial design focus, as it is one of industry's leading fuel efficient platforms demonstrating the latest developments in green aircraft technology.

Project Description

The Hyperion project began in June of 2010, when all three international universities gave the project a green light. This was made possible by the collaboration of Professors Jean Koster of Colorado, Claus-Dieter Munz and Ewald Krämer of Stuttgart, and Drs. KC Wong and Dries Verstraete of Sydney. Development began with the initial formation of the project goals, scope, and preliminary work breakdown structure (WBS), preliminary schedule, and acquisition of project funding. With each University's academic semesters starting and ending on different dates, careful consideration had to be taken into account when planning the WBS and schedule. A significant difference in educational approach was that the University of Colorado has formal senior and graduate design course offerings in its curriculum with a rigorous systems engineering educational component; whereas the Universities of Stuttgart and Sydney organized their teams in a framework often described as "independent studies."

Compared to conventional academic projects, the Hyperion schedule was orders of magnitude more complicated to develop as special consideration had to be made to accommodate the out of sync university's semesters. The Sydney semester began first, with Colorado's a close second, and Germany starting third in mid-October. Figure 1 shows a simplified schedule as well as each University's semester dates and overlap.

The overall project schedule was based on the University of Colorado's Senior Design Course timeline, which encompasses an entire project experience over the span of 2 semesters. The project is divided into two phases, in sync with the CU semester schedule. The first semester, or phase of the project course, is focused entirely on design, analysis, and prototyping. The second phase of the project encompasses the manufacturing, integration, and testing aspects. Each component must be manufactured, tested at a subsystem level, integrated to the system level, and tested again to both verify and validate all project requirements.

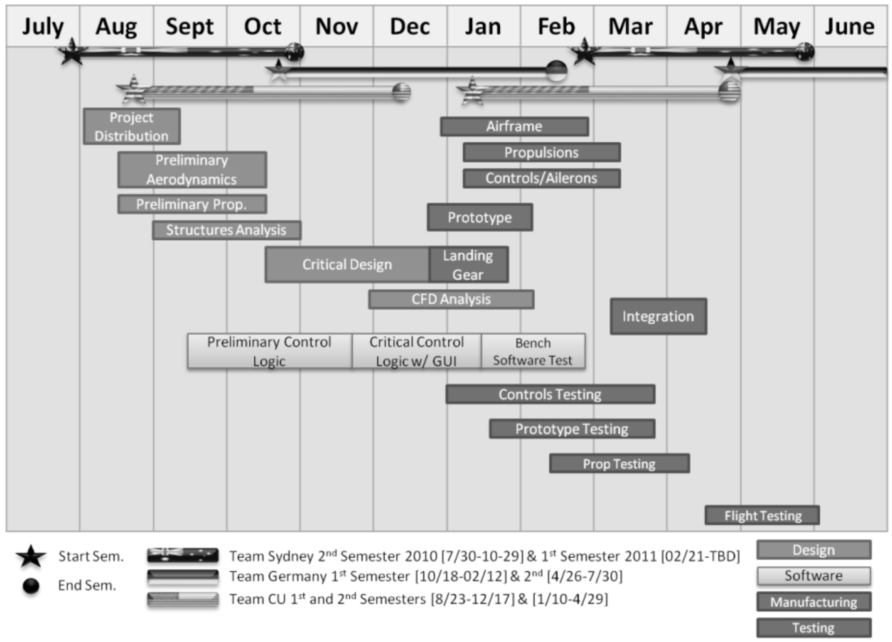

Figure 1. Simplified Project Schedule.

Global Project Team

The Hyperion project was divided into 4 student teams:

1. A Graduate team from The University of Colorado
2. A Graduate/undergraduate team from University of Stuttgart
3. A graduate/undergraduate team from The University of Sydney
4. An undergraduate team from The University of Colorado

Projects at the academic level are notably different from industry due to two primary factors. Collegiate students have varying class schedules with respect to one another, compared to industry teams' steady work hours. This makes scheduling the necessary daily meetings of a college team very difficult for the students to internally manage. A second notable difference is that students who work on an academic project are motivated by a grade, not salary. Their work is largely voluntary rather than mandatory. This requires a different approach to project management, as the monetary motivational leverage is not available to the manager. Fortunately students have another strong motivational driver—passion.

The architecture of the Hyperion project team with leadership by the Colorado graduate team is shown in Figure 2. The goal of the team design is to expose senior and graduate students to the need for collaborating in a global industry with design offices and manufacturing facilities around the world. Colorado's graduate team leads the development of the project and distributes and incorporates work from the CU undergraduate team, the German and Australian teams through the use of Configuration Control Documents. These living documents are essential to maintaining consistency and direction of the designs. The requirements on quality of these documents are very high due to several factors. Tasks, revised at the end of workday for the next team, must be defined with great precision and extreme clarity. Each team works eight hours and updates the configuration control document, then passes it to the next team to work eight hours, and so on. The model allows packing three regular working days by three teams on different continents into 24 continuous hours, accelerating project development by the "Following-The-Sun" principle. Robust internet communication is essential. Students are challenged to communicate effectively and efficiently on a daily basis across all sub-teams.

Figure 2. Hyperion Team Architecture

Work Breakdown Structure

The work breakdown structure (WBS) of the Hyperion project served as a challenging logistics problem for students inexperienced in project planning. The question, "who can do what, why, and when?" is easier to identify in an industry environment, where employees are hired for specific jobs and titles. For a student team comprised of varying degrees of skill-sets and schedules around the world, there is little time to waste in determining who is responsible for each subsystem and deliverable. There were two primary drivers for the WBS distribution, *skills* and *schedules*. In determining which teams were assigned tasks and ownership in the project, the skill-sets of each university were weighed with respect to one another to identify strengths. The schedules were then evaluated to determine what work correlated with the development stage of the project. Since Australia began their semester first they were given the responsibility of the aerodynamic shape of the aircraft, the preliminary configuration design, the sizing of the control surfaces and contributing to weight and balance analysis for stable flight. Germany were given the lead in developing the wingtip and vertical stabilizer designs, CFD analysis, and manufacturing of the center body skin. The broader Colorado graduate team lead the structures, electronics, controls, software, mass properties management, financial operations, and overall project management. The Colorado undergraduate team was listed as individual team because of their charter to develop the hybrid propulsion system.

The development of the logistics of collaboration was a major undertaking. The skills of all the participating international students had to be incorporated in the work distribution management. The WBS was first split in 5 categories which followed the systematic order of the project's development, with the exception of management which was constant across the 9 months. From this WBS and the items identified as the top level systems of the project, further more specialty

WBS were developed, which were then decomposed further. The systematic approach to the WBS resulted in an effective use of team skills, maximizing production and minimizing risk.

Strict oversight of the budget is crucial to realize the ambitious goals of the Hyperion project. Much like the opportunity to learn global collaboration skills, learning how to manage financial resources helps prepare the students for real-world project management.

Best Practices

Information management was perhaps the most critical aspect of the Hyperion project. With multiple teams operating in separate locations, perpetual contact is necessary to make sure efforts are in sync and misunderstandings are corrected early on.

An example of this successful communication and work flow can be found in the aerodynamic design experience. Engineers in Australia would work with model dimensions and upload their CAD files to the cloud and verbalize ideas over Skype™. This allowed for seamless continuation in Germany, where the Stuttgart team refinement work could take place. Towards the end of the Stuttgart work day, updated files and ideas would be shared with the Colorado team who would add their expertise to the aircraft's design and check progress with the requirements. After a day's work, they in turn would post their contributions on Huddle™, discuss changes over Skype™, and the Australia team would pick up where Colorado left off. This constant work allowed for normally three days CAD work to be completed virtually in 24 hours.

The CAD design work was accelerated significantly by using Follow-The-Sun techniques. The entire structure, skin, landing gear, and propulsion system was designed in roughly 6 weeks. This included structural analysis and sizing of the ribs, spars, skin, landing gear attachment points and elements of the propulsion system, either by analytic calculations or through CATIA with contributions from each university. The Hyperion 1.0 design and model is shown in Figure 3.

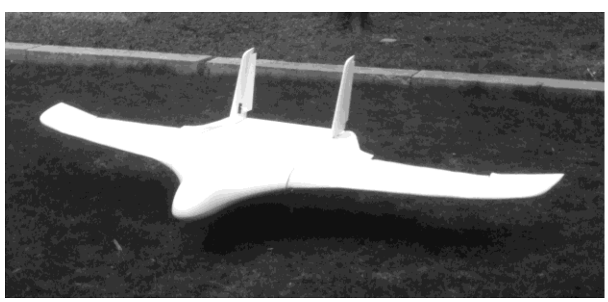

Figure 3. The Hyperion 1.0 Aircraft

The problems faced by Boeing's Dreamliner team highlight the complexity of international manufacturing.[6] Boeing outsourced components to manufacturers around the world. The CU-Hyperion team has benefited from access to different points of view as well as facilities of the global team partners, items that would be unavailable to a lone local team.

The logistical constraints imposed by time and distance are another significant problem caused by international manufacturing. It is important to design for manufacturing! The central internal body frame structure was manufactured at Colorado and shipped to Germany where the covering fiberglass skin was manufactured. The fiberglass body was created at the University of Stuttgart, with very little margin to allow for time over-runs. If the production schedule is not met, it would be very difficult for the Hyperion team to meet their objectives of flight before school ends in Colorado for summer break. This constraint mimics problems faced by global industries that face delivery to customer deadlines.

Lessons Learned

Early into the design phase, several weeks' worth of progress were lost when weight and balance and elevator sizing problems forced the relocation of the propulsion system from a pusher to tractor configuration. This forced multiple sub-teams to adjust their work to compensate for the new design. Communicating the redesign across to all of the teams was ultimately not a problem. However, problems did arise with a general lack of understanding and communication amongst the international team deliverables and involvement in presentations. Including the international team members in presentations and design reviews was difficult and sometimes not possible due to the time differences and technological constraints of low budget video conferencing systems.

In order to incorporate the ideas and viewpoints of our delocalized team, regular conference calls have been held using Skype™ and Polycom™. By no means perfect, this system has been successful in coordinating the efforts of all teams. The students from all three schools never met personally until the final assembly and test flight at the end of the project.

A key component to the Hyperion project was the international work delegation and distribution. The underlying concept for each team to trade off work daily is conceptually ideal; however it is difficult in an academic environment. Each student team member has a unique schedule, due to variances in class schedules and part/full time employment. Without students working full eight hours on a task it worked reasonably well in the initial phase of the conceptual design of the aerodynamic shape and structure.

Being able to allocate even one single continuous 8-hour block to a Follow-the-Sun activity is unlikely for any student team. Therefore, Follow-the-*Week* (FTW) assignments became soon more manageable and successful to implement during verification and integration work. Rather than each person work 8-hour days as in industry, each person or group of students was given a specific design item to complete each week.

The largest benefit to FTW activities came in the form of the CAD design of the aircraft during integration in which at the beginning of each week a set of part deliverables were assigned and then integrated with the model upon completion of the work week.

Refinements to a global project course shall be made, just as processes are refined in industry. Academic advisors need to have a solid understanding of the different academic systems around the partner universities. The participating education programs may have different focus on technical fields and the desired learning outcomes may be different as well, as dependent on accreditation requirements. Students at the same official academic level at different universities may have different technical abilities and backgrounds and all need to be integrated in the skills profile of the global team. Academic planning needs to be significant.

The internal ribs and spars for the aircraft manufactured at Colorado were shipped to Germany where the external skin was manufactured and the central body assembled. Export documentation forms must be filed correctly by the sender and the recipient must fill out import documentation with correct content to allow adding value in Germany and shipping back to the sender. For the return shipment, the carrier's pre-clearance team must have specific information on the bill of shipment. All these formalities are not in the mindset of most academics. Universities may not be well prepared to support international shipments correctly either.

Financial transactions between universities may also be complicated by the fact that universities seldom or never exchange funds and thus have little experience in commercial transactions.

Conclusion

The Hyperion project was intended as a graduate student design project for an aerodynamically efficient aircraft. All requirements of aerodynamic, structural and mass performances defined for first vehicle were met. The Hyperion was flown successfully with electric motor.

The international collaboration by teams from three international universities became a great learning experience. Students at different universities introduced new and unique skills that benefited the design concepts in all aspects. The totally new design concept was brought from an idea to a finished product in about 9 months. This is a fast development of a novel and complex technology. The Follow-The-Sun collaboration worked well in the initial design phase. After the system decomposition was done, the concept of Follow-The-Week collaboration became more efficient for manufacturing of the aircraft, verification of requirements and validation of the design.

The lessons learned for global engineering collaborations were substantial. With a positive mindset of all international participants the operational procedures during the design phase and during the manufacturing phase were quickly absorbed by most of the team members. Altogether, the first year Hyperion project was a rewarding experience for more than 30 students from around the world.

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References:

1. Michael Nielsen, *Reinventing Discovery: The New Era of Networked Science*, (New York: Princeton Univ. Press: 2011)

2. Kyle, Peterson, *A Wing And A Prayer: Outsourcing At Boeing* [Rep. Everett: Reuters, 2011. http://graphics.thomsonreuters.com/11/01/Boeing.pdf]

3. P. Witte, W. Cann and H. Jiminez, "Capstone Design Project Challenges in Inter-Institutional, Geographically Dispersed Teams", *AIAA 2010-893*, 2010.

4. Xiaohua Lu, Yinghui Fan, S. Banzaert, J. Jacobs, "Multi-disciplinary Design-Build PBL as an Introduction to Engineering", *Proc. 6th International CDIO Conference*, Ecole Polytechnique, Montreal, June 15-18, 2010.

5. Joseph R. Chambers: "Innovation in Flight: Research of the NASA Langley Research Center on Revolutionary Advanced Concepts for Aeronautics", *NASA SP- 2005-4539*.

6. Rob Coppinger, "X-48B Scale Model to Fly Next Year", *Flight International Magazine*, 22 Nov. 2005.

Biographical Information

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