HYPERION: An International Collaboration

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ABSTRACT

The Hyperion aircraft project was an international collaboration to develop an aerial vehicle to investigate new technologies with a focus on performance efficiencies. A delocalized international team of graduate and undergraduate students conceived, designed, implemented, and operated the aircraft. The project taught essential systems engineering skills through long-distance design and manufacturing collaborations with multidisciplinary teams of students located around the world. Project partners are the University of Colorado at Boulder, USA, The University of Sydney, Australia, and the University of Stuttgart, Germany. The three teams are distributed eight hours apart; students can relay select work daily so that developments can "Follow-The-Sun". Select components are manufactured and integrated both in Stuttgart and Colorado, giving the students an opportunity to learn multifaceted design tactics for manufacturing and interface control. Final flight testing was conducted by the global team in Colorado during the month of April 2011.

KEYWORDS

Global design, international teamwork, aircraft design, green aviation.

MOTIVATION

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 [1]. 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. As a result, project management is more significant than ever before. Figure 1 shows an example of Boeing's global distribution and breakdown of work performed on the 787 Dreamliner.

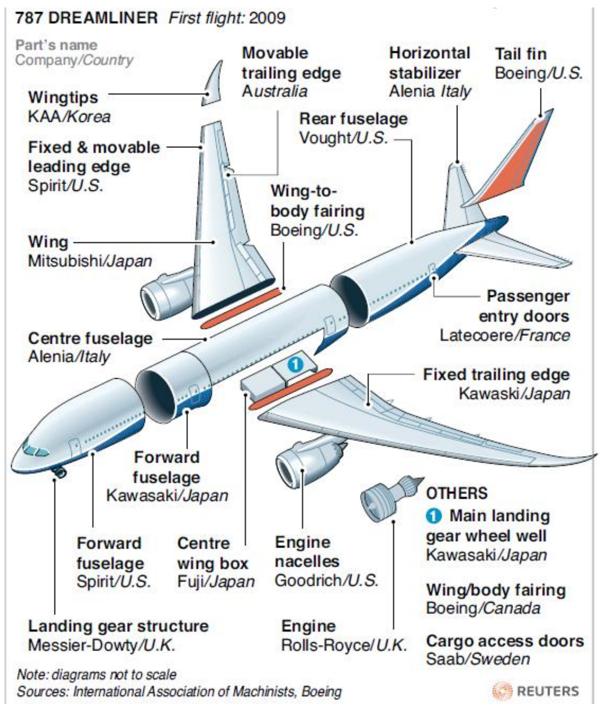

Figure 1. Boeing 787 Global Work Breakdown Structure [1].

Aside from project planning and logistics, there is also a movement towards green aviation and improving the sustainability of the products produced in the aeronautics field. Green aviation is of global significance, with the Asian commercial airline industry flying more passengers than the U.S. in 2009 [2]. According to a 2010 NASA report, the U.S. commercial airline industry is projected to fly 1.21 billion passengers each year by 2030 [2]. The increase in fuel consumption, associated air pollutants, and noise from this growing industry is a mounting concern. Therefore, NASA has issued a new set of industry challenges including reducing fuel burn and nitrogen oxide emissions by 50% by 2020 and restricting the nuisance noise footprint produced by aircraft to the airport boundary [2]. These challenges are being directed to the aerospace industry as a whole, with intended performance improvements in all aircraft subsystems and successful implementation of green aviation technologies.

With both of 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. While aerospace engineering studies typically focus on engineering fundamentals, courses lack opportunities for students to gain experience in extensive systems engineering principles, manufacturing, and project management. While many universities have capstone senior design courses set to instil these values, modernizing the learning experience to better represent the global workings and pains in industry has habitually been omitted due to the perceived level of scope attainable in 2-semester academic projects. 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].

Design engineering is based on customer requirements. These requirements have to be communicated to and continuously discussed by all the team members. To communicate well, both verbally and in writing, is essential for project success. Team members share information, exchange ideas and influence attitudes and actions as well as understanding of the issues at task. Communication is also required to develop interpersonal relationships, inspire team members, and handle conflicts and different opinions. Most students are trained in communication on a local level where face-to-face meetings are common. In a global team, members may not know each other personally or have the possibility to pick up the phone at any point of time to clarify an encountered concern. This requires at the onset a very clear description of the requirements and the development of interface documents. The English language used can no longer be casual and the underlying innuendos of individual words have to be evaluated carefully from a linguistic point of view. This is most important when there is different cultural interpretation at work. The same word may have different meaning for people from different cultures and schooling in the language, especially when English is not their first language. Although the technical terms may be understood, the more descriptive wording may lead to an incomplete or filtered communication. In different cultures the educational program itself may provide students with different skill levels in similar fields of study [4].

Because of their academic nature, student projects are particularly prone to communication difficulties. Utilizing a managerial structure of the teams with defined responsibilities, decentralized decision making, and complex interfaces allows for multiple communication modes of failure. The person issuing a message with a purpose normally encodes that communication based on a personal bias. The bias is rooted in encoding the message based on the environment, culture, and knowledge of the sender. A recipient is biased by one’s own hearing, listening, reading, language skills, ethical values, mood and motivation. Sender and receiver both have preconceived ideas, references, and interests in the project contributing to a certain noise level in the communication. The choice communication medium is known to have an impact on the communication success. One element that is absent in virtual communication is body language which has an impact on the decoding of a message by the recipient.

In an engineering design project, engineers work iteratively at the beginning of the project in order to come up with the best design solutions for the top level project requirements leading to system requirements that get “frozen” allowing a transition to manufacturing. That design phase is extremely dynamic and prone to misinterpretation which may not be caught on time and which could lead to failure of some kind of the project. Design choices have to be negotiated by the delocalized team members. All the technical analyses have to be done with the same software, comprising even the same version of the software.

The Hyperion project, besides being a challenging technical project, is designed to train students in reducing the communication noise inherent in all communications and prepare them 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. This undertaking became known as the Hyperion project. The Hyperion project was to span 2 academic semesters during 2010-2011, consist of a minimum of 3 delocalized international student teams, and conceive, design, implement, and operate a completely new type of aircraft. In essence, the proposed academic project was to incorporate two major elements:

1. A global project management element with three participating teams located on three different continents, and
2. A technical design, implementation, and operation element to teach systems engineering principles required in aeronautics.

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. In addition to the stated goals, the Hyperion project is intended to foster global relationships among aerospace engineers and expose members to different philosophies and techniques. Integral to achieving this is the exploration and adoption of technologies that facilitate the sharing of ideas, real-time collaboration and interaction.

The blended-wing-body (BWB) NASA/Boeing X-48B aircraft was set as the inspiration for the aircraft design. The 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. The X-48 BWB concept, shown in Figure 2, was originally designed by Liebeck, Page, and Rawdon in 1998 [5]. The airframe is a merger of efficient high-lift wings and a wide airfoil-shaped body, causing the aircraft to generate lift in its entirety and minimize drag, thereby increasing fuel economy. It is expected that the aerodynamically efficient BWB design will reduce fuel consumption up to an estimated 20% [6]. Unlike conventional tube and wing architectures, the optimal design of a BWB vehicle requires a much more tightly coupled systems engineering analysis, including aerodynamic and structural analysis of the vehicle, flight mechanical design, management of mass properties, and the development of modern control systems. The use of composite materials throughout the construction of the vehicle was also to be maximized in order to increase the experience and exposure of the students to the challenges and techniques used in modern aerospace manufacturing.

Figure 2. Boeing/NASA X-48B [3].

PROJECT DESCRIPTION

The following Hyperion project description pertains primarily to the global engineering and project management experience of the project. Further details on the technical aspects will become available in future publications.

Incubation

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 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. Although the leadership of the project was in the hands of the CU graduate students, The University of Sydney was first to form their student team and begin design work for the aircraft. The project commenced the first week of August, 2010, before the University of Colorado and the University of Stuttgart academic school years began and all the student teams were assembled. In that effort, the first subtask handled by Sydney was the aerodynamic configuration design and analysis of a blended-wing-body flying wing geometry aircraft.

Project Requirements

The top-level project requirements, shown in Table 1, were derived and driven primarily from the two project elements, incorporation of the hybrid engine, and the Boeing/NASA X-48B architecture.

Table 1
Top-Level Project Requirements

Req. #	Top Project Requirement Description
0.PRJ.1	The Hyperion Project shall conceive, design, implement, and operate a blended fuselage and wing aircraft.
0.PRJ.2	The aircraft shall have a wingspan between 1.8 and 3 meters.

0.PRJ.3	The Hyperion project shall consist of a global team network of 4 teams: Undergraduate and graduate teams at University of Colorado at Boulder, a combined graduate/undergraduate team at The University of Sydney, AU, and a graduate team at the University of Stuttgart, GER.
0.PRJ.4	The Hyperion aircraft shall have a lift to drag ratio no less than 20.
0.PRJ.5	The Hyperion aircraft structure shall have a composite material outer skin and internal structure.
0.PRJ.6	The Hyperion aircraft shall have a modular design, allowing for shipping of the vehicle internationally without necessitating a freight shipping classification.
0.PRJ.7	The Hyperion aircraft shall be powered by a hybrid propulsion system, consisting of an internal combustion engine and an electric motor.
0.PRJ.8	The Hyperion aircraft shall be remotely controlled by a ground operator using an onboard vision system.
0.PRJ.9	The Hyperion aircraft shall have a maximum of 8 actuated control surfaces.
0.PRJ.10	The Hyperion aircraft shall be propeller driven.
0.PRJ.11	The Hyperion aircraft shall be capable of takeoff and landing on a 750ft runway.
0.PRJ.12	The Hyperion teams shall communicate regularly using video conferencing, online document sharing, and teleconferencing.
0.PRJ.13	All measurements of systems shall be in SI units.

Schedule

Compared to a conventional academic project, 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 3 shows a simplified schedule as well as each University's semester dates and overlap.

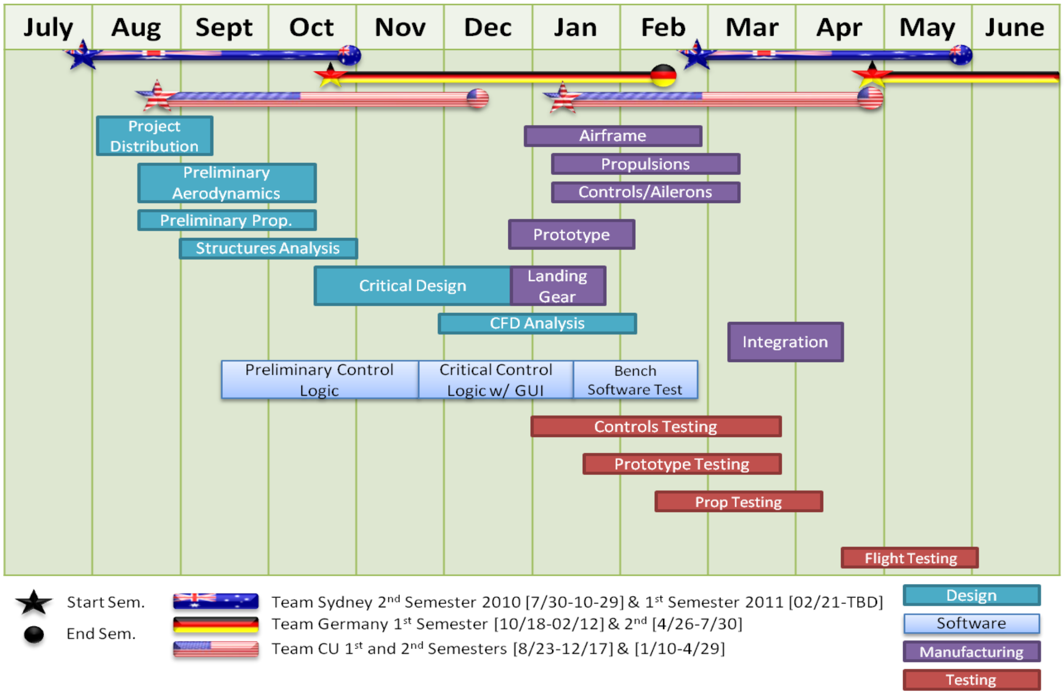

Figure 3. Simplified Project Schedule.

The 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 primary 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. Starting with a statement of work and the top-level-requirements, students begin the semester organizing themselves, defining system and sub-system requirements, developing team and work break down structures, and conducting preliminary design. During the first design phase of the project, there are two major decision gates based off of industry practices, a Preliminary Design Review (PDR) and a Critical Design Review (CDR). These reviews hold several purposes, including:

1. Standing as milestones for the project development
2. Allowing students to gain experience with professional public speaking
3. Forcing students to defend their design work using critical thinking and technical analysis
4. As an internal 'checks and balances' for the team members and subsystems to ensure consistency and compatibility, and
5. Mitigate project risks by providing outside feedback on design decisions

At CDR, the entire design development of each subsystem of the project is to be complete and frozen in terms of future development. This serves as a critical milestone for the teams to work towards.

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.

End of project deliverables include:

1. An oral presentation
2. A flight demonstration showcasing the advances in technology
3. The Hyperion Aircraft, itself, with operations manual
4. A comprehensive Project Final Report (PFR) covering all engineering, documentation, and contacts tied directly to the project,
5. (In the event of system failure) A technical report documenting test findings for the root of the system failure.

The project deliverables were set to ensure both systems engineering principles and project management are projected throughout an exciting educating experience. Students are able to gain real world technical experience, not by designing, but by building their creation in a hands-on environment. Seeing manufacturing processes and learning to understand the technical limitations of production are an extremely valuable experience for every engineer.

The student team in Sydney comprised of 3rd and 4th year (of a 4-year BE (Aeronautical) program) undergraduate students as well as 1st year volunteers who helped out in the construction of the wind tunnel model. As the senior students enrolled in the project as an elective unit of study, the local deliverables in Sydney included reports or hardware for aerodynamic testing.

The activities of the students in Stuttgart were organized within the framework of diploma theses. Here, the usual deliverables are

1. An oral midterm presentation,
2. An oral presentation at the end,
3. A written diploma thesis at the end.

For the Hyperion project the listed deliverables were accompanied with short meetings on a weekly basis with the advisers to keep them updated on the project. The diploma theses which shall be written on the Hyperion contributions will not only contain a description of the performed scientific and technical work, but also include comprehensive information about the global project objectives and the contributions and validations performed by the individual student.

Global Project Team

The Hyperion project was divided into 4 student teams:

1. A Graduate team from The University of Colorado
2. A Graduate 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 more difficult 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 is shown in Figure 4.

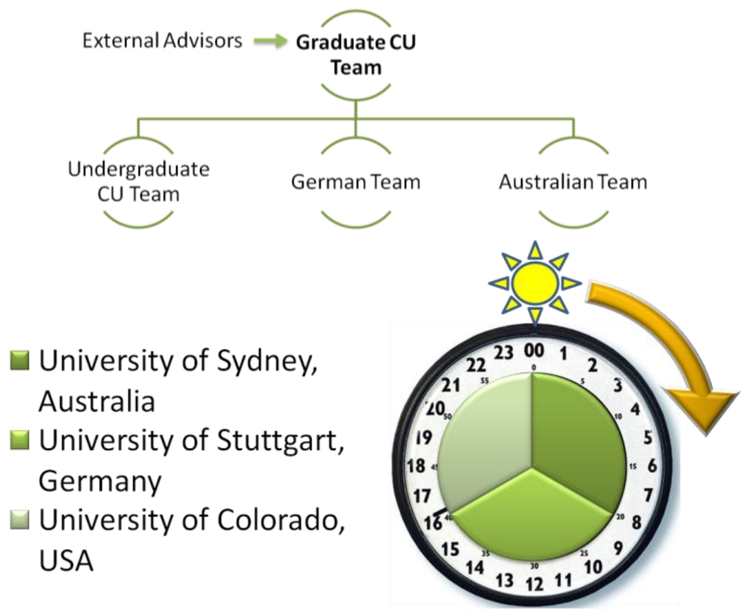

Figure 4. Hyperion Team Architecture

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. The English words may have subtle underlying meanings that may be interpreted differently by different cultures, work procedures in different cultures may be different, and teams must agree on using the same software packages as well as the same versions of software. 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 subteams.

The Graduate University of Colorado Team

The graduate team focused on all of the integration, management, and internal designs of the aircraft. The master designs of the aircraft are archived in Colorado, for quality control and logistics. The team was selected based on an individual's contribution to the skill sets identified as being critical to the project.

Each of the 13 CU team members was given ownership to single subsystem or managerial position of the project, which trains every student in leadership skills. Table 2 shows the breakdown of ownership amongst the CU graduate team. Students work toward a degree in Aerospace Engineering Sciences (AES), Electrical Engineering (EE), and Master in Business Administration (MBA).

Table 2
Graduate CU Team Members & Leadership Roles

Name (Background)	**Primary Responsibility**	**Secondary Subteam(s)**
Alec Velazco (AES)	Project Manager	Business, Manufacturing
Eric Serani (AES)	Configuration & Systems Manager	Controls, Propulsion
Derek Hillery (AES)	Systems Engineer	Controls
Cody Humbargar (AES)	Propulsions Lead Engineer	Aerodynamics, I&T
Scott Balaban (AES)	Structures Lead Engineer	Aerodynamics, I&T
Chelsea Goodman (AES)	Controls Lead Engineer	CAD, I&T
Richard Zhao (EE)	Electrical Lead Engineer	Controls, I&T
Julie Price (AES)	Mass Properties Manager	CAD, Controls
Andrew Brewer (AES)	Integration & Testing Lead Engineer	Electrical, Structures
Derek Nasso (AES)	Aerodynamics Lead Engineer	Mass Properties, Structures
Mikhail Kosyan (AES)	Manufacturing Lead Engineer	CAD, Structures
Mark Johnson (AES)	CAD Lead Engineer	I&T, Structures
Thomas Wiley (MBA)	Business Operations Manager	I&T, Accounting, International

The idea behind assigning team leads is to instil a sense of ownership over that particular item or subsystem of the project. That allows for each team member to be involved directly, and allows the team as a whole to divide and conquer. Each sub-team lead is responsible for organizing their own respective meetings with secondary members to delegate and micro-manage the work effectively. This allows the Project Manager to efficiently delegate work and easily identify the performance of the team.

The graduate CU team holds a formal 1-hour weekly Configurations & Systems meeting where all sub-teams report on the progress, problems, and plans of their system development. The meeting also serves as an opportunity for external advisors, sponsors, and the customer to provide input and guidance for problem solving strategies and risk mitigation. In addition, weekly meetings are held between CU/Stuttgart, CU/Sydney, and Stuttgart/Sydney. The agenda is similar with updates on progress, problems, and plans.

During the second phase, the project effort must shift from design to manufacturing, integration, and testing.

The University of Sydney Team

Of the three international Universities, The University of Sydney's semester scheduling was the most significantly different from the other two universities. Not only did Sydney's semester begin before both Colorado's and Stuttgart's, it was also the second semester with regards to their academic year. This early beginning drove the early decisions with regards to the work breakdown of the project.

In order to maximize the contributions by the Sydney team, they were given the task to perform the preliminary aerodynamic trade studies regarding the geometric shape of the aircraft. In this manner, the work could begin immediately, without waiting for the Colorado and Stuttgart teams to be formed. By the time the Colorado team was fully structured, Sydney had several preliminary models complete for designs to be evaluated and discussed between all the teams.

After the design work was complete, the efforts in Sydney shifted to produce a ½ scale static wind tunnel model of the Hyperion aircraft to be tested at the University of Sydney's 7 x 5ft wind tunnel. This work was primarily performed during their respective summer break. Students ranging from first year engineering students to 4th year students participated in building multiple models and performing aerodynamic testing on the aircraft. This led to preliminary sub-scale flying model to verify stability and control characteristics of the design concept, followed by the wind tunnel testing of a half-scale model, which verified the confidence of the earlier CFD analyses, and provided guidance to set up the full-size flight test prototype. Figure 5 shows the half-scale model installed in the wind tunnel.

Figure 5. Half-scale wind tunnel model installed in the 7 by 5 ft wind tunnel in Sydney.

Table 3 denotes the members and responsibilities of the University of Sydney team.

Table 3
The University of Sydney Team Members & Leadership Roles

Name	**Responsibilities**
Kai Lehmkuehler	International Aerodynamic Lead / Team Manager / Wind tunnel testing Lead
Matthew Anderson	Performance Engineer / Wind tunnel model construction and testing
Joshua Barnes	Structures Engineer for wind tunnel model / CAD
Byron Wilson	Structures Engineer for wind tunnel model / CAD
Andrew McCloskey	Sensors and Autopilot Engineer

The University of Stuttgart Team

Last to form and begin their semester, the University of Stuttgart team was brought on board the project after the preliminary trade studies had been performed on the shape of the aircraft.

Similar to Sydney being well suited for aerodynamics studies, the German team brought a unique set of skills in computational fluid dynamics (CFD) and composite manufacturing which were absent on the Colorado and Sydney teams. One student took the responsibility to serve as the local project manager and primary contact between the international teams.

The CFD computations performed at Stuttgart served mainly three purposes: first of all was the computation of a half-scale model with symmetric flow conditions. These results were used as a cross check for the results obtained at Sydney during the preliminary design process. The second purpose was the assessment of the engine integration and its impact on the aerodynamic characteristics of the aircraft. The third task was the investigation of the manoeuvrability of the aircraft. Several configurations with control surface deflections were investigated for symmetric and asymmetric flight conditions to evaluate the effectiveness of the flight control system. The aerodynamic derivatives obtained in this part are needed by the team responsible for the flight control software.

Table 4 denotes the Stuttgart team members and responsibilities.

Table 4
Graduate Stuttgart Team Members & Leadership Roles

Name (Background)	**Primary Responsibility**	**Secondary Subteam(s)**
Holger Kurz (AES)	Stuttgart Project Manager	Structures, Manufacturing
David Pfeifer (AES)	Aerodynamics Engineer	CATIA Contact, CFD
Matthias Seitz (AES)	Aerodynamics Engineer	CFD Engineer
Martin Arenz (AES)	Propulsions Lead Engineer	Aerodynamics, I&T
Baris Tunali (undergrad)	Manufacturing	
Jonas Schwengler (undergrad)	Manufacturing	

The Undergraduate University of Colorado Team

With no previous project experience, the undergraduate team in Colorado was formed per the requirements of the capstone aerospace senior design course (ASEN4018/4028). Eight students were assigned to the team, all seniors in aerospace engineering. In order to maximize the undergraduate teams learning experience the undergraduate team operated largely independently, with their primary project goal to design, build, and operate the hybrid propulsion system for the Hyperion aircraft. The hybrid propulsion system was considered a stretch goal for Hyperion. Taking ownership of the propulsion subsystem allowed for minimal overlap and dependency with the rest of the aircraft's design development. One graduate team member assumed the liaison position with the undergraduates. The undergraduate team was given a set of requirements recognized in an interface document for their propulsion system to meet, which included dimensions and performance criteria. This allowed for the Stuttgart, Sydney, and Graduate Colorado team to move forward with the designs without constant involvement with the senior CU team. In the event the undergraduate team fails to produce a working engine, a basic electric motor propulsion system was designed to be used as an off-ramp for the airframe.

This allowed for the senior team to have an adequately scoped project, while minimizing the risk to the international Hyperion project failing being able to fly due to lack of engine delivery. In the same sense the success of the undergraduate team needed to be independent of success or failure of the graduate team designing the Hyperion airframe.

The undergraduate CU team is structured under the same principles as the graduate team, with team leads and specific subsystem ownership assigned to individuals, shown in Table 5.

Table 5
Undergraduate CU Team Members & Leadership Roles.

Name (Background)	Primary Responsibility	Secondary Subteam(s)
Gavin Kutil (AES)	Project Manager	Aerodynamics
Gauravdev Soin (AES)	Electrical Systems Engineer	Controls
Corey Packard (AES)	Mechanical Systems Engineer	Aerodynamics, Mechanical
Michaela Cui (AES)	Chief Communications Liaison	Software, CAD
Brett Miller (AES)	Chief Financial Officer	Controls, CAD
Tyler Drake (AES)	Chief Safety Officer	Mechanical, Electrical
Marcus Rahimpour (AES)	Chief Test Officer	Controls, Structures
Arthur Kreuter (AES)	Chief Equipment Specialist	CAD, Software

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 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 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. The top level WBS is shown in Figure 6. From this WBS and the items identified as the top level systems of the project, further more in-depth WBS were developed, which were then decomposed further.

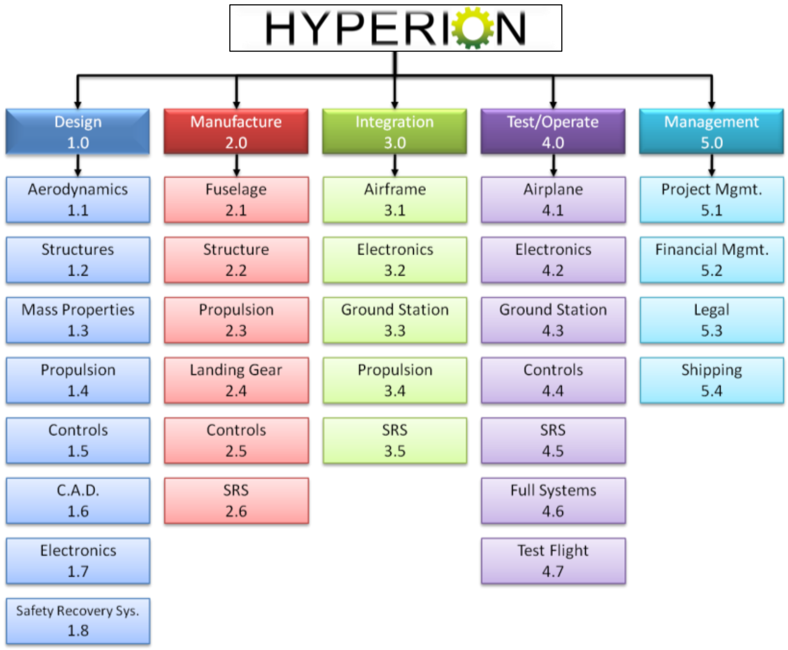

Figure 6. Top-Level Work Breakdown Structure

The systematic approach to the WBS resulted in an effective use of team skills, maximizing production and minimizing risk.

Budget

As students, the labour cost to design and manufacture the systems necessary to fly Hyperion is negligible. Further, the student teams have unparalleled access to resources, both intellectual and physical. In traditional industry groups, considerable money is spent to leveraging these resources. These include contact with professors and industry engineers as well as university owned hardware like computers and manufacturing equipment.

Despite the economic advantages of working with university engineering teams, there are costs that must be absorbed in order to produce the aircraft. These include materials and components, communication, travel, and access to testing facilities. Large contributions were made by different industry leaders to help defray many of these costs.

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

A budget was carefully developed to allocate financial resources appropriately and each team's purchases are closely tracked. This careful budgeting has afforded additional opportunities to test design alternatives and material characteristics. Figure 7 shows how funds have been allocated across subsystems based on a percentage of each university's total allotted funds.. The Sydney team was not able to secure any industry funding due to a depressed local industry situation. Sydney's funding stems from support through the School of Aerospace, Mechanical and Mechanical Engineering (lab, workshop, and wind tunnel resources), the school's R.W.

McKenzie Resource Centre for Teaching and Research in Aeronautical Science and Technology (sensors), CU (wind tunnel model), and the academic advisors' maintenance funds.

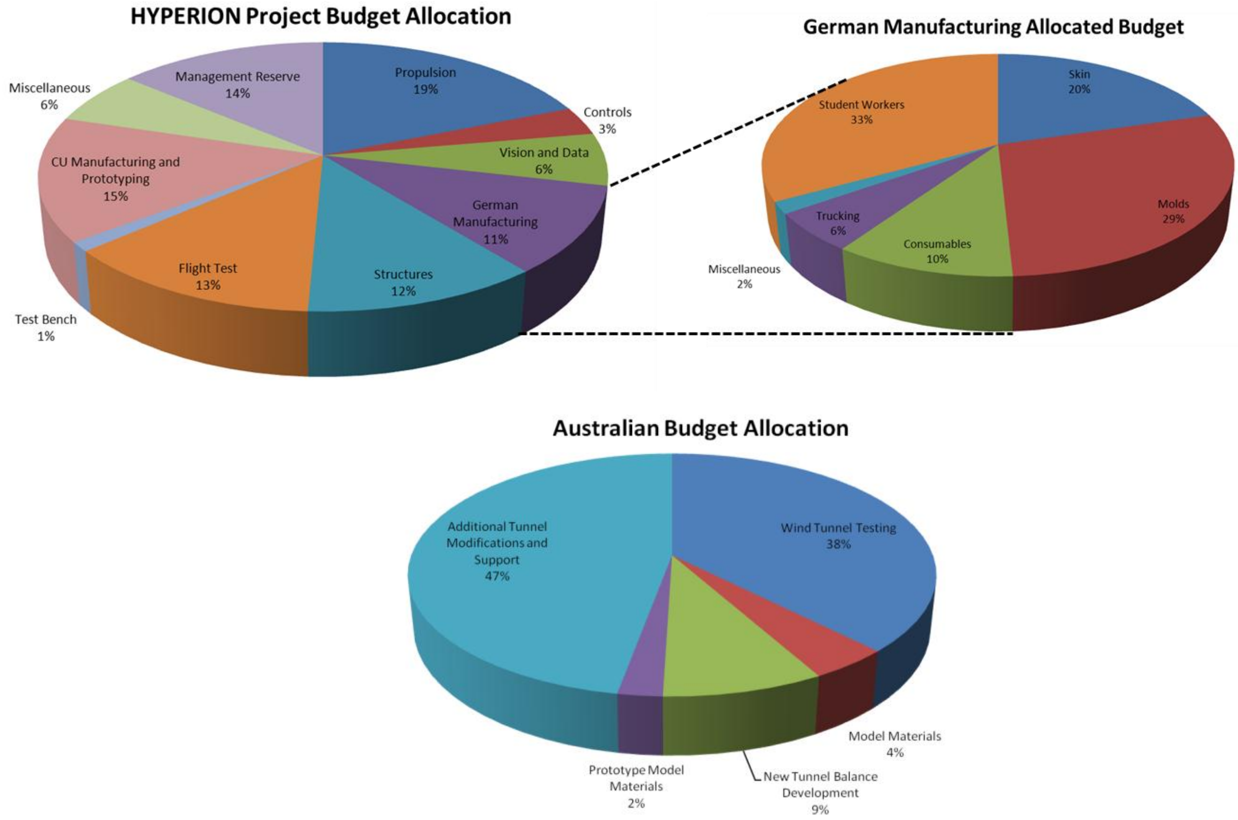

Figure 7. Budget Allocation

The procurement process was closely monitored to ensure that parts were ordered on time and from the appropriate vendors. Care was also taken so that parts did not arrive too early and risk loss, accidental damage or obsoleteness due to changes in design. Figure 8 shows procurement activity over time in both a daily and accumulative way. This graph closely resembles manufacturing activity.

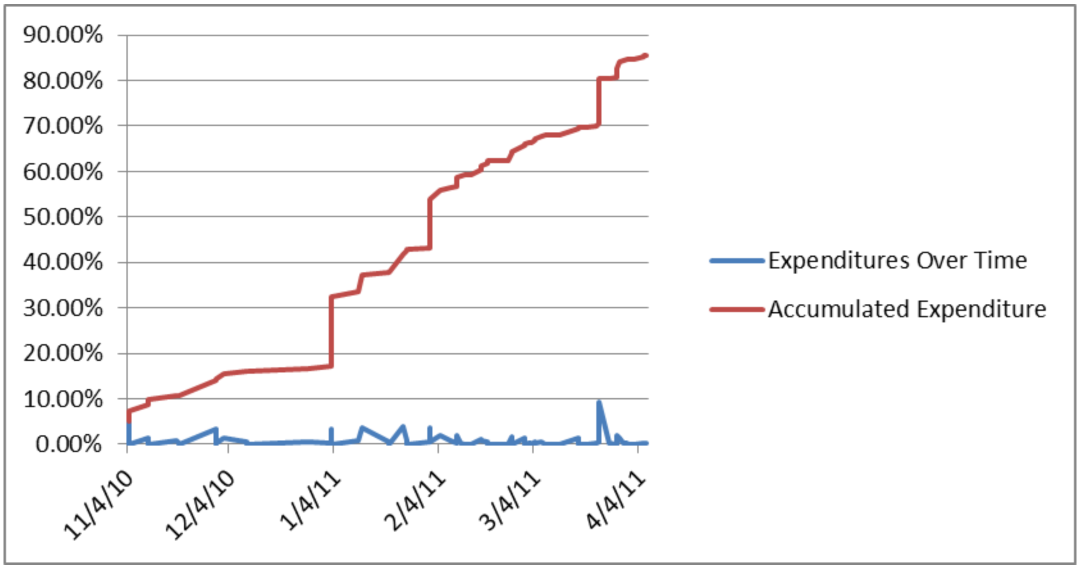

Figure 8. Expenditures across time

Human Resources

The team tracked the total number of hours worked per week which helped monitor those tasks that were running behind and whether or not deadlines were being met. This data also helps show how industry is able to benefit from partnering with academia. The three graduate teams combined worked a total of 6,335 hours over two semesters. Using salary data from the US Bureau of Labor Statistics, this work would have cost $259,489 in wages. Not included in that budget number are the conceivable consulting fees of the many faculty members advising the students. Figure 9, below, shows the hours worked each week over time. The drop midway through corresponds with semester break during the holidays.

The steady climb, drop and resumed climb correspond with the different phases of the project. Week 12 was the end of the semester for Colorado students which include deliverable deadlines before break. Many students departed for the holidays and resumed increasing amounts of work once the spring semester began. Of note is the saw-toothed profile of student work.

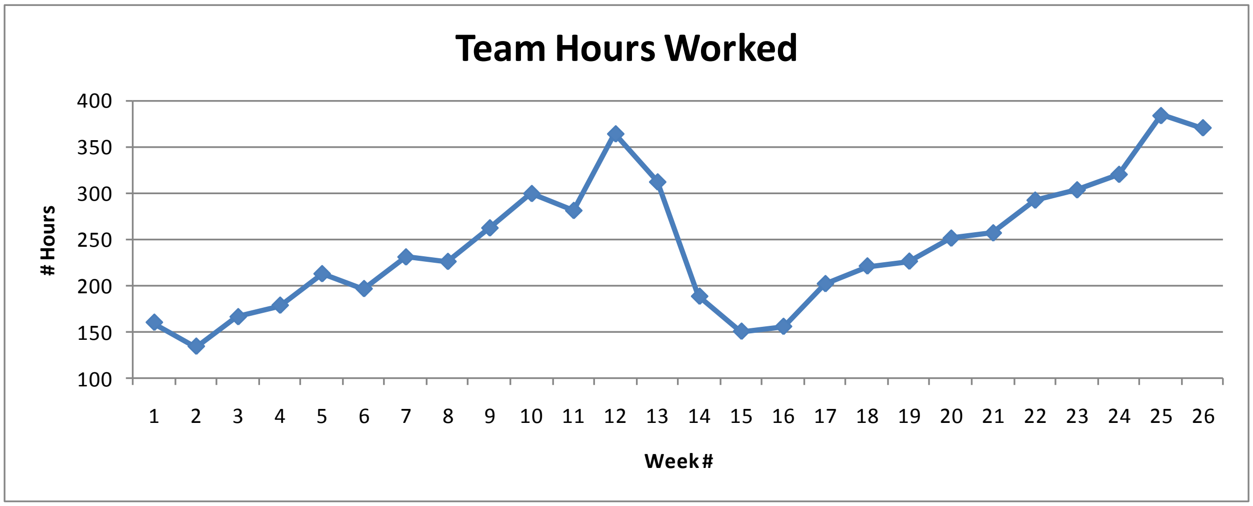

Figure 9. Graduate Hours Worked

BEST PRACTICES

Communication

The Hyperion project is a great lesson in international design collaboration. Coordinating the efforts of multiple international teams, each with their own language and culture, is complicated at best. These soft constraints in turn are amplified by the constraints of different time zones and challenges of international shipping.

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. Fortunately, the options provided by the internet have enabled all three teams to share documents, test aerodynamic models and maintain synchronization. Weekly conference calls were held via Skype™, allowing for both audio and visual communication. Documents were shared through cloud computing using Huddle™.

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 three days virtual CAD work to be completed in 24 hours.

The large number of Hyperion members makes communication intricate. Between the three universities there are 32 students and professors. Adding the 20 industry and academic contributors brings the number to 52 and the possibility for 1,326 one on one communication channels. With so many opportunities for communication, a small percentage of miscommunication is already a large number of miscommunications! To mitigate or reduce the occurrence of miscommunication, interface and configuration control documents were implemented to be able to track and manage critical pieces of information on a daily or weekly basis.

The CAD design work was accelerated effectively by using Follow-The-Sun techniques. With most student projects only comprising 1-2 CAD engineers, the Hyperion project was able to employ roughly 10 students with CATIA design work each week during the design phase. This allowed for far more design work to be completed in a very short amount of time. 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 formulaic calculations or through CATIA with contributions from each university. The Hyperion design and model is shown in Figure 10.

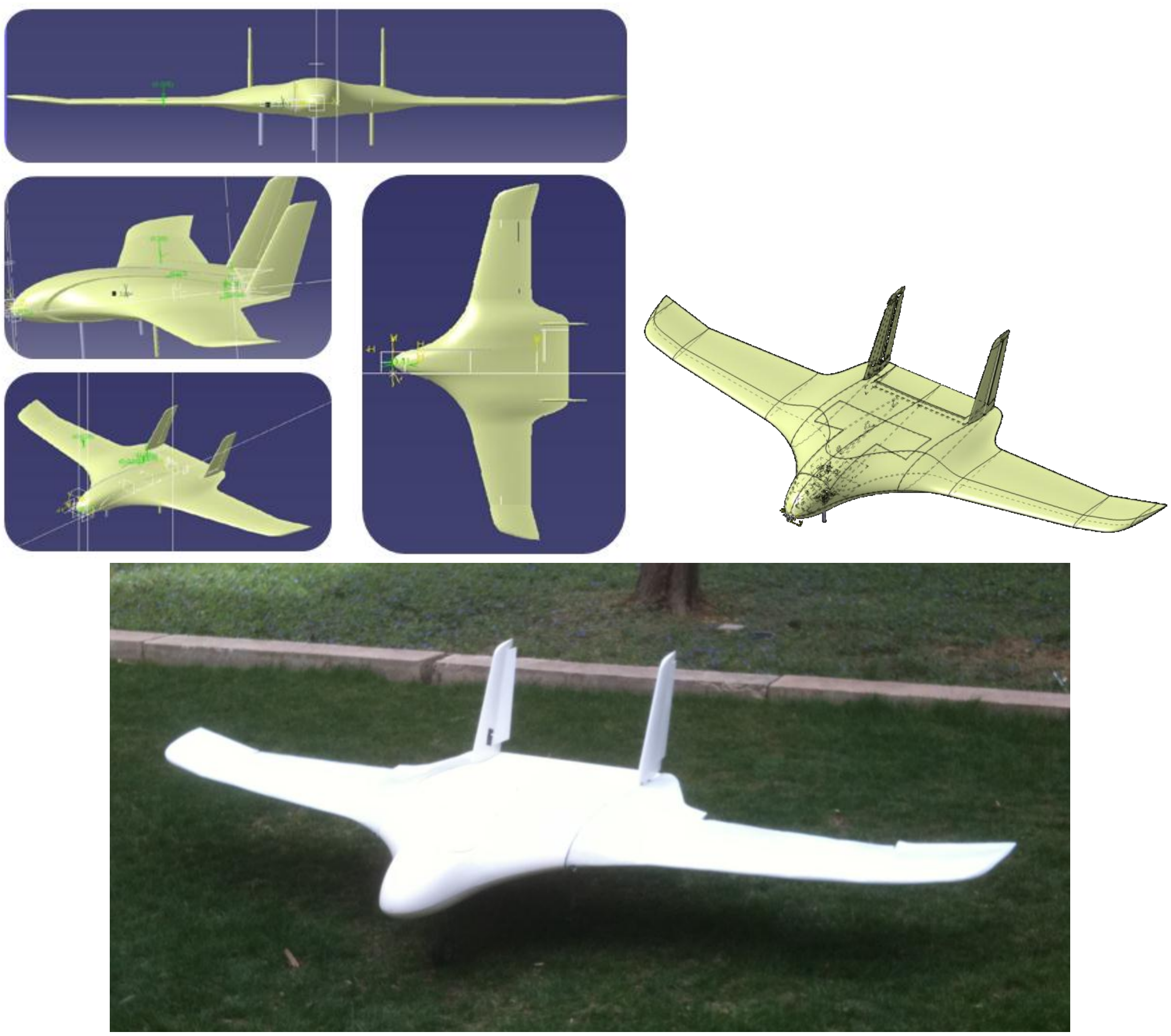

Figure 10. The Hyperion Aircraft

None of the collaborative CAD work could have been possible, had each university not had the same CAD program and version. Determining early on in the project which software to use proved highly valuable.

Manufacturing

The problems faced by Boeing's Dreamliner team highlight the complexity of international manufacturing [7]. The CU-Hyperion team has benefited from access to different points of view as well as facilities otherwise unavailable. These include engineers who have extensive experience with the X-48 design, advice from experienced professionals with international collaboration knowledge, as well as fabrication and testing facilities in the Australia, Germany and the United States.

The logistical constraints imposed by time and distance are another significant problem caused by international manufacturing. As Boeing experienced, millions of dollars' worth of sub-assemblies will sit idle while the appropriate fasteners are still being sourced [1]. The Hyperion supply chain is much less complex, but still at the mercy of late deliveries. The central internal body frame structure was manufactured at Colorado and shipped to Germany where the 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 for summer break. This constraint highlights the problems faced by global industries that face delivery to customer deadlines.

Risk mitigation has been undertaken to ensure that failure to flight test does not come about. The German team began work on the negative molds, while Colorado, manufactured the internal structure of the plane, Figure 11. Due to the size of the molds necessary, the German team contracted an outside firm, Plandienst, to CNC-mill the molds of the centerbody, further requiring extensive planning and quality control, mirroring industry practices. While the molds were being constructed, students were allowed time to build the shipping crate necessary to ship the center body to Colorado for integration with wings and engine for flight testing. One critical requirement was also identified early in the project to ensure expedited shipping would be possible if need be. The largest shippable box dimension had to be kept under international priority freight classification, which is considerably more expensive.

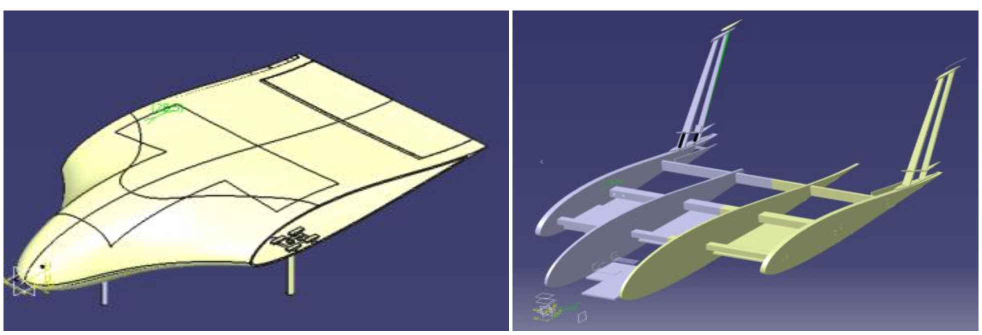

Figure 11. German Manufacturing Skin (Left) & CU Manufacturing Internal Structure (Right)

After the internal structure was shipped to Germany for integration with the outer shell, the Colorado team shifted their manufacturing efforts towards 4 ½ scale, fully functioning prototype planes and the full scale wings. By manufacturing the critical components first, time was managed effectively to maximize production and minimize down time. The ½ scale models were used to test flight control systems of the novel aircraft design.

To ensure that final assembly will be completed once the center body arrives from Stuttgart, a laser cut Interface Dimension Template (IDT) was designed to be used to verify the center-body produced in Germany will line-up with the wings produced in Colorado. One IDT was shipped to the Stuttgart team, while its exact twin remained with Colorado.

LESSONS LEARNED

Language and Cultural Barriers

Like the design and development of the 787, the Hyperion aircraft is a collaboration of multiple international teams. Although all of the German team members speak English fluently, and both the Australian and US teams are mostly made up of native English speakers, information is often lost due to subtle connotations of individual words or not conveyed effectively. This can partially be attributed to the dispersed evolution of the English language around the globe, which has led to unique expressions and different interpretations of the meaning of words in different cultures. It clearly shows how attention needs to be paid to the exact wording used when passing on information between the different geographically distributed teams. This is a good indication of the value of language skills in the current globalization of engineering in general and aerospace engineering in particular.

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.

According to Tom McCarty, president of the local union representing Boeing engineers in Puget Sound, plane-making is best performed by a group of engineers and builders working in close proximity without the distraction of language barriers, cultural differences and bureaucracy [8]. Perhaps he is right; it would be easier if all team members were at the same location and there were no language barriers. By drawing on the talents of the world's engineers, international companies gain access to ideas and capabilities they would otherwise forgo. Likewise, Hyperion benefits from the knowledge and experience of its international colleagues. From an educational and experience point of view, nothing compares.

In order to incorporate the ideas and viewpoints of our delocalized team, regular conference calls have been held using Skype™ and Polycom™. This has enabled the three teams to give real-time updates and communicate issues that are difficult to articulate via email. 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 in April 2011.

A related lesson is to understand and subsequently take advantage of the differences, rather than impose a common "comfortable" work knowledge and culture to the rest of the team. Achievements through teamwork are greatly enhanced when leadership understands the team members (groups) to take advantage of, and to complement skill sets. One of the hardest lessons for any leadership to learn is to know when to "let go" and delegate. Having to deal with 3 universities with significantly different structures has certainly been an incredible journey in 2010/11. This paper is a mere introduction to many valuable lessons for this unique and pioneering global engineering design project. The students involved had a learning experience which should be highly valued in the aerospace industry.

Follow-the-Sun

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. Being able to allocate even a single continuous 8-hour block to a Follow-the-Sun activity is unlikely for any student team. Therefore, Follow-the-*Week* (FTW) assignments became much more manageable and successful to implement. Rather than each person work 8-hour days, each person 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 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. As the designs matured and more parts became dependent on each other, fewer team members were needed to manage and continue the CAD designs, as the files become too large and complex for multiple people to manage. It was much more efficient to have 1-2 people leading the CAD designs in the later stages of development, rather than try and have 6-8 people trying to download and edit the master CATIA file simultaneously. Two advantages became apparent from shifting the design work from multiple CAD engineers at PDR to only a select few nearing CDR. First, the schedule risk was reduced, as development was extremely fast. The entire Hyperion aircraft was drawn in CATIA from scratch in little more than 4 weeks. The second advantage was it greatly reduced our integration risk. The primary CAD engineer at CU worked closely with the primary CAD engineer at Stuttgart, constantly in communication regarding the designs and manufacturing of the aircraft. After CDR and during manufacturing, both universities had a primary contact who was 100% up-to-date with the designs. This allowed for the rest of the team to quickly obtain the most current design information at any given time.

Part of the global learning objective is to go through project definition, with the added complexity of international schedules. The Follow-The-Sun concept for CDIO can be potentially taken to another level with a bit of lateral planning. In the beginning phases of the Hyperion project, there was time lost due to the immaturity of the project's definition and a poor understanding of each universities class schedules, student work capabilities, and deliverables for the project. It appears inadequate to have only one student at one university (Colorado) develop a schedule complex enough to take full advantage of each school's capabilities. A top-level project definition and work break down structure needs to be developed first, so that the first team can begin on their schedule. This is not to hinder the other students' learning experience by not having to define requirements, as they have plenty of opportunities throughout the definition of the system architecture and subsystem requirements.

Ultimately, for the Sydney Team, the big challenge was allocating undergraduates to specific jobs over the summer break because the overall work schedules were not defined clearly and realistically enough by the project developers. Hence, Sydney "lost" most of the Year 1 student volunteers very early on and likewise lost many of the Year 3 students over their summer. Another option to consider is a three semester project in North-South hemisphere cooperation with independent projects filling in the larger summer breaks in the North and South. There are "mechanisms" in place where students can choose to undertake a "project" unit of study, or independent study over summer which would help the continuity of the work.

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.

International Shipping

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. The parts were declared as part of a remote control aircraft frame and so did not encounter American ITAR issues. 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. Academic and staff personnel and students who then have to handle the custom formalities do not have the appropriate education to handle import-export and mistakes are prone to be made. These mistakes may end in a quarantine of the shipment which can derail such a global project, especially because of the teaching time schedules. Customs have strict rules that need to be followed with highest precision and getting educated on that topic well ahead of shipment dates is adamant.

Financial Transactions

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. The University of Colorado supported The University of Sydney, who did not received any primary funding for the project. This was feasible by setting The University of Sydney up as a vendor to the University of Colorado. As The University of Sydney is tax exempt, the transaction was not taxed and the deal was smooth. At the University of Stuttgart the accounting office was scared that they get taxed although the university is tax-exempt as well, and refused to be set up as a vendor to the University of Colorado. The University of Colorado is unable to freely distribute funds and must, by law, set up all partners as a vendor. This required creative ways to find a no exchange of funds process to reimburse the University of Stuttgart for the materials purchased for the project. The creativity lies in the payment of the four German students' stay at the University of Colorado during the final assembly and testing of the aircraft.

CONCLUSION

The Hyperion project was intended as a design project for an aerodynamically efficient aircraft also using novel hybrid propulsion technology as a stretch goal. In addition the vehicle was designed to become a new test bed for future design improvements and further development of green aircraft technologies.

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 an extremely fast development of a novel and complex technology.

The lessons learned for engineering collaborations were substantial, but with a positive mindset of all international participants the operational procedures during the design phase and during the manufacturing phase were quickly absorbed by all the team members. A major bottleneck in the international manufacturing world is dealing with constraints by local governments and customs agencies, which remain a wild card in any international cooperation. Another major constraint is financial interaction between universities, which may be new territory for some departments.

Altogether, the Hyperion project was an exciting and rewarding experience for more than 30 students around the world. Hyperion is a first trial course which should be built upon and an improved assignment should be developed with the lessons learned for the next round of students.

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References:

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

[2] *Green Aviation: A Better Way to Treat the Planet. NASA Facts*. Web. 17 OCT. 2010.<http://www.aeronautics.nasa.gov/pdf/green_aviation_fact_sjeet_web.pdf.

[3] P. Witte, W. Cann, 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] R.H. Liebeck, M.A. Page, B.K. Rawdon, “Blended-Wing-Body Subsonic Commercial Transport”, AIAA 98-0438., 1998.

[6] “X-48 Blended Wing Body (BWB).” GlobalSecurity.org – Reliable Security Information. Web. 09 Apr. 2011 http://www.globalsecurity.org/military/systems/aircraft/x-48.htm.

[7] Rob Coppinger: "X-48B scale model to fly next year", Flight International Magazine, 22 November 2005

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

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