HYPERION: A FOLLOW-THE-SUN DESIGN EXPERIENCE

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ABSTRACT

A delocalized international team of Graduate and Undergraduate students conceive, design, implement, and operate a 3 meter wingspan aircraft with the intent to investigate numerous new 'green' aircraft technologies. The project, known as Hyperion, teaches essential systems engineering skills through long-distance design collaborations with multidisciplinary teams of engineering students located around the world. First year project partners were the University of Colorado at Boulder, USA, the University of Sydney, Australia, and the University of Stuttgart, Germany. The teams on three continents are distributed 8 hours apart; students can relay select work daily so that progress can "Follow-The-Sun (FTS)." As a result three workdays are packaged in one 24 hour period. The student teams operate as a single, independent entity; structuring themselves as a simulated industry operation. Thus, project management and systems engineering principles are learned through a real-world design and deliver experience. The project also teaches delocalized manufacturing: select components are manufactured by each team and integrated both in Stuttgart and Colorado, giving the students an opportunity to learn multifaceted design for manufacturing. The project incubated many problems which lead to mitigation techniques for global collaboration as well as generating a better educated workforce to enter modern industry. In the second year the international collaboration was limited to students at the University of Stuttgart. The team analyzed technical deficiencies of the first generation Hyperion 1.0 aircraft, a flying wing, and redesigned the wings to criteria that make it a blended wing body aircraft. The team also implemented an autonomous flight control system.

INTRODUCTION

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].

With this global trend 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 instill 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 typical 1 or 2-semester academic projects. Efforts to train students in global design have been reported before; however, they were mainly limited to virtual computer design studies and did not include delocalized manufacturing [2].

At the University of Colorado Boulder (CU) during the summer months of 2010, a small team of concurrent 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 engineering industry. This undertaking became known as the Hyperion project. The Hyperion project was to span 2 academic semesters during AY2010-2011, 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 Boulder, 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.

Our first efforts were presented at CDIO-Copenhagen [3]. Further reports are available from AIAA [4] and ASME [5] conference reports.

PROJECT DESCRIPTION

The Hyperion project began in June of 2010, when all three international universities gave the project a green light. 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.

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).

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. This process was in place for the students of the first year effort and repeated for the second year project. The second year project improved the design based on lessons learned in the first year.

The project deliverables are set to ensure both systems engineering principles and project management are projected throughout an exciting education experience. Students are able to gain real world technical experience, not by just 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 budding engineer.

Global Project Team

The first year Hyperion project was divided into 4 student teams:

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

The architecture of the Hyperion 1.0 project team is shown in Figure 1.

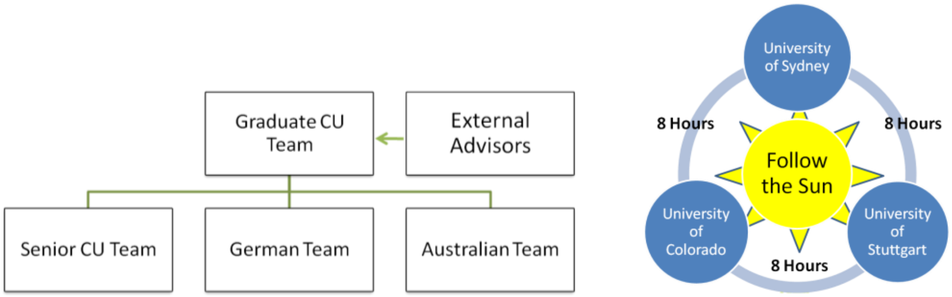

Figure 1. Hyperion 1.0 Team Architecture

The goal of the team design was 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 FTS principle. Robust internet communication is essential. Students are challenged to communicate effectively and efficiently on a daily basis across all sub-teams. The international collaboration requires a more strict time management from each team.

The CU graduate team at the University of Colorado Boulder led the project's development. The team focused on all of the integration, management, and internal designs of the aircraft. The master designs of the aircraft are kept in Colorado, for quality control and logistics (Figure 2). Team members are primarily aerospace engineering masters' degree students with one electrical engineering masters' student and one business masters' student. Multi-disciplinary backgrounds are essential to a successful systems engineering experience.

Each of the team members was given ownership to single subsystem or managerial position of the project, which trains every student in leadership skills. The idea behind assigning team leads is to instill 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.

Figure 2. Hyperion 1.0 Flying Wing and Hyperion 2.0 Blended Wing Body

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 amount of work produced 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 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. Of the three universities, Sydney was the only institution with an adequate wind tunnel for testing the Hyperion aircraft, so it was a natural fit to have Sydney lead the aerodynamic design efforts. This work was primarily performed during their respective summer break. Figure 3 shows the half-scale model installed in the wind tunnel at The University of Sydney.

Figure 3. Half-scale model installed in the 7 by 5 ft wind tunnel in Sydney

Last to form and begin their semester later in the calendar year, 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. That level is considered in the USA as equivalent to first year graduate level.

Similar to Sydney being well educated and equipped for aerodynamics studies, the German team brought a unique set of skills in (CFD) and composite manufacturing which were absent on the Colorado and Sydney teams (Figure 4).

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 maneuverability 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.

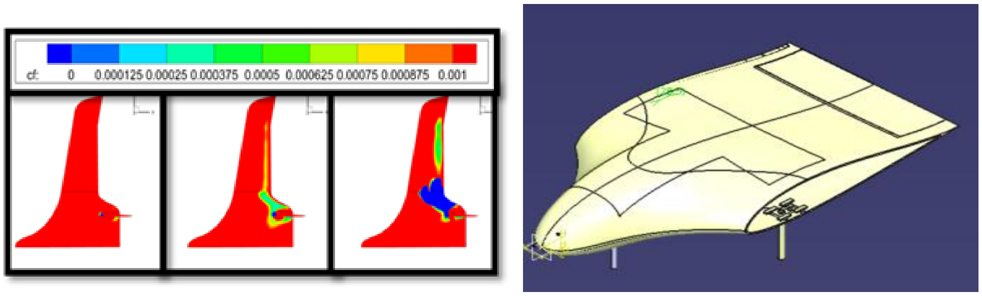

Figure 4. CFD validation and composite skin provided by Stuttgart

The undergraduate team in Colorado was formed per the requirements of the capstone aerospace senior design course. Their focus was on the hybrid propulsion system, an attainment which was considered a stretch goal for implementation in the Hyperion aircraft. 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 optional hybrid propulsion system for the Hyperion aircraft. Taking ownership of the propulsion subsystem allowed for minimal overlap and dependency with the rest of the aircraft's design development.

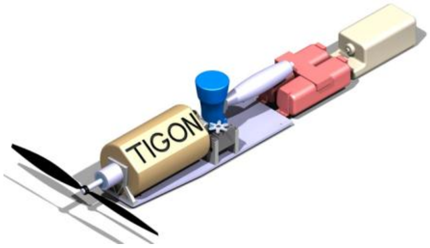

Figure 5. Hybrid engine designed by Colorado undergraduates.

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 Hyperion design, powered by electric motors, 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.

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 and were strong in aerodynamics, 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, with their CATIA strength and fabrication skills, were given the lead in developing the wingtip and vertical stabilizer designs, CFD analysis, and manufacturing of the center body skin. The Colorado graduate team led the structures, electronics, controls, software, mass properties management, financial operations, and overall project management.

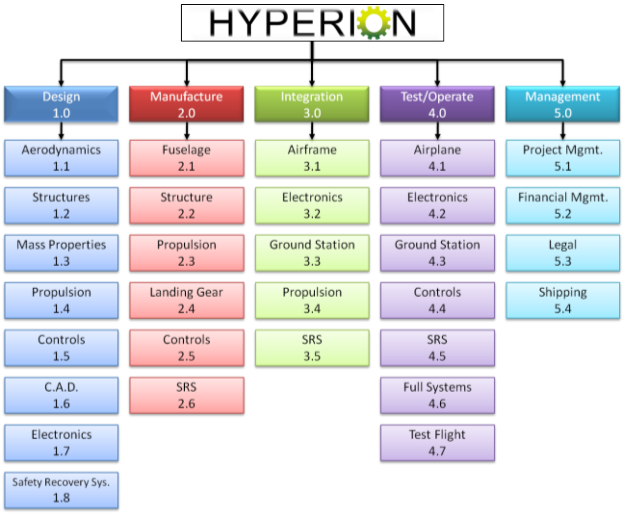

Figure 6. Top-Level Work Breakdown Structure

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. The top level WBS is shown in Fig. 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.

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

During the second year the international collaboration was significantly reduced. A significant element of that change was the requirements to get funding for the project in an adverse economic environment of the aerospace industry. This led to a discontinuation of the University of Sydney collaboration. The University of Stuttgart experienced a problem finding students who are eligible to participate as part of their degree requirements.

BEST PRACTICES

Communication

Coordinating the efforts of multiple international teams, each with their own language and culture, is complicated at best and can lead to misunderstandings and setbacks. These in turn are amplified by the constraints of different time zones and challenges of international shipping. More significantly, team members gained valuable experience working with engineers in different countries.

Communications management is perhaps the most critical aspect of the Hyperion project. With multiple teams operating in separate locations, constant 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 are held via Skype™, allowing for both audio and visual communication. Documents are shared through cloud computing.

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 could refinement 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 development 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 resume their efforts. This constant effort allowed for three days' worth of work to be completed in 24 hours.

The large number of Hyperion members makes this task very complex. Between the three universities there are 32 students and several 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 FTS 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.

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 essential.

The second generation Hyperion 2, the blended wing body aircraft was designed based on the available center body from Hyperion 01. The wings were changed to have a different sweep angle, which led to a qualification as blended wing body aircraft by having the required lift distribution. This aerodynamic analysis was done by the Colorado team with some confirming calculations by the German team.

Manufacturing

The problems faced by Boeing's Dreamliner team highlight the complexity of international manufacturing [5]. 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 [6]. 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 produced at the University of Stuttgart, with very little margin to allow for time over-runs. If the production schedule is not met, it will be very difficult for the Hyperion team to meet their objectives. This constraint highlights the problems faced by global industries.

Risk mitigation is undertaken to ensure that this possibility of failure to deliver does not come about. The German team, experienced in composite manufacturing, began work on the negative molds, while Colorado, manufactured the internal structure of the plane, Fig.7. 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.

After the internal structure was shipped to Germany for integration with the outer shell, the Colorado team shifted their manufacturing efforts towards four 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 one remained with Colorado.

LESSONS LEARNED

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 FTS activity is unlikely for any student team. Therefore, for some tasks, 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 before handed over to the next team.

The largest benefit to FTS activities came in the form of the CAD design of the aircraft. One week was dedicated to scheduling and identifying the design synergy which would allow for the most efficient use of time. Having each team distributed 8 hours apart allowed for the student's ideas to be shared and critiqued amongst each team in a 24 hour period. The CU team was able to start with their ideas, and then obtain critical feedback from Sydney and then both CU's and Sydney's ideas and critiques could be reviewed by the Stuttgart team before the next day and vice versa. FTS allowed for each university to have a chance to learn from one another and facilitated a global exchange of knowledge. During the preliminary and critical design phase, every week had a new set of deliverables. Each part to be designed was identified as being independent of everyone else's development for that respective week, allowing for the individual student to manage their own weekly time to devote to the work. At the end of the week, all of the newly developed parts were integrated into the model and verified based on the requirements. Each week the process repeated with a new round of distributed parts to be designed. 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. As more and more detailed designs were produced, more personal attention was necessary to integrate and manage the files. Allowing two primary engineers take the lead (one at CU, one in Stuttgart) after the "little stuff" was complete, also allowed the remaining students to shift their efforts on the remaining subsystems where more work was required. The second advantage was it greatly reduced the 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. The inability to secure funding for the Sydney's project efforts constrained the scheduling of the wind tunnel test program. This problem was eased significantly by the CU funding, but the smaller team size resulted in more work spread across less students.

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 schedule. 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.

International Collaboration

Due to the semester scheduling in Australia and Germany, which are very different to the USA, the continuation of the project got in trouble. First, students and faculty focused their full attention to get Hyperion 1.0 to fly and there was little effort going into idea development for a continuation. This led the University of Sydney to start a different global collaboration with another university.

During Hyperion 2.0 the University of Stuttgart struggled with a new problem related to their changed curriculum: finding thesis students with the appropriate skill set. The students who finally joined the project started very late in the project, thus the main work of designing the blended wing body rested on the shoulders of the Colorado students. The Stuttgart team could provide later primarily valuable refinements of the baseline design.

CONCLUSIONS

The Hyperion project not only produced a novel and new aircraft, but more importantly, incubated an educational experience for more than 50 students around the world unlike any other; preparing them for working in the 21st century of the aerospace industry. 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. Availability of students with the right skill set can become an issue leading to delays. Funding requirements of global projects is also significant, which can terminate any efforts. Preparation of a global project tends to require more time than one expects.

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.

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Biographical Information

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