Industry – University Collaboration on Under-Graduate Engineering Design Projects An Industrial Mentor's Perspective

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Introduction

For the past four years the Boeing Company at Mesa Arizona has sponsored several under-graduate engineering design projects including a global engineering design program with Arizona State University in Tempe, Arizona and Leeds University in the UK. A Global Engineering Design Team, i.e., GEDT, co-sponsored by Rolls-Royce, created project teams comprised of undergraduate engineering students from both universities. The industrial sponsors provided financial grants to the universities to support the projects. In addition, the companies have provided in-plant summer employment for student team members and made available engineering specialists to serve as project mentors.

The GEDT projects have focused on the design and analyses associated with integrating a propulsion engine into a helicopter. The objective of this paper is to summarize the Boeing mentor's perspective of the projects accomplished by the student teams. The Boeing mentor has served as the project's engineering technology point of contact.

Boeing's objective in being an industrial sponsor for university projects has included providing undergraduate engineering students an opportunity to work on real/meaningful engineering projects with guidance from industry mentors. Materials covered in the paper include a very brief overview of three helicopter engine integration projects accomplished by GEDT student teams. Rational for the project selection and scope are discussed. This is followed with a review of and comments on an overall student project model. The paper concludes with a brief discussion on project challenges and lessons learned.

The thoughts and materials presented in this paper are the sole responsibility of the author and are not intended to reflect the interests of Boeing, Rolls-Royce, Arizona State University, and Leeds University.

Projects Review

An objective of the helicopter propulsion system integration projects was to introduce the student teams to real, meaningful engineering design activities that required the application of multiple engineering disciplines. In addition, the students were required to develop and apply project management skills. Project scopes were defined such that it required the effective application of an engineering team to accomplish the goals of the program. It was assumed that industrial mentors would be readily available to provide technical and program management support to the students, similar to that offered to a junior engineer by a supervisor or senior engineer in industry. Most importantly, each project proposal was coordinated with and approved by the respective academic sponsors. This was to ensure that the respective universities' academic requirements were satisfied by the projects.

The propulsion integration projects were defined to reflect design and analysis requirements and procedures that would be accomplished by industry to perform a similar job. In fact, the student projects were designed such that the team members could utilize the same design and analysis philosophy as that utilized by the author for several helicopter/engine integration programs that he has been responsible for. This philosophy included the application of basic engineering principles equivalent to those acquired by third or fourth year engineering students coupled with problem solving skills as applied to complex engineering problems. The projects did not require and did not encourage the students to turn to and utilize large, commercially available engineering analysis computer models in order to accomplish design and analysis goals.

The technical content for each of the helicopter engine integration projects was focused on fluid mechanics, thermodynamics, heat transfer, selected structural mechanics, mechanical design, manufacturability, and life cycle costs. Care had to be exercised in sizing the project such that it could be successfully accomplished with the resources that were available to the student team.

Year 1999-2000: "Optimization of a Helicopter Engine Exhaust System"

The team was comprised of four Leeds students and two ASU students with one of the Leeds students in residence at ASU. The objective of this project was to optimize an existing helicopter engine exhaust system. Goals included reducing the weight of the exhaust system by 10%, a 2% reduction in fuel burn, and a reduction in the cost of ownership by at least 10%.

A multitask plan was developed by the team in order to accomplish the goals of the project. The following task breakdown is presented to show how broad the scope of the project was:

- Phase 1
    1. Characterization of the existing/baseline exhaust system
    2. Characterization of basic helicopter performance parameters
    3. Exhaust system performance sensitivities
    4. Definition of design goals
- Phase 2
    1. Ejector performance characterization
    2. Exhaust system ejector (jet pump) performance model
- Phase 3
    1. Exhaust system fluid mechanics characterization
    2. Identification of exhaust system performance loss generators
    3. Exhaust system performance loss calculations

4. Exhaust duct de-swirl vane analysis

- Phase 4
  1. Exhaust system redesign with de-swirl vanes
  2. Supporting engineering analysis
  3. Drawing package
  4. Rapid prototype model of de-swirl vane assembly
  5. Final report and briefing

Year 2000-2001: "Optimization of a Generic Helicopter Exhaust System"

The GEDT team for the 2000-2001 school year included eight students, four from each university. The project's design objective included developing advanced cooling schemes and designs that could be utilized to lower an existing exhaust system metal temperature to a specified value while maintaining specific engine and helicopter performance requirements. The project was designed to leverage off the previous year's work with the students being encouraged to verify and use existing models, etc., hence allowing them to address their specific tasks without "re-inventing the wheel."

This team planned and executed a multiphase program that included a review of the previous year's work, identification of advanced cooling techniques and potential exhaust duct material changes, detailed modeling, analysis, design of selected cooling systems, and a design concept down-select based on overall helicopter performance, manufacturability, and cost. A detailed design of the down-selected cooling scheme was performed. The team completed the project with a set of engineering drawings, supporting analysis, a rapid prototype model, and final report and presentation. In addition, the team performed a comprehensive investigation into new exhaust duct materials.

Year 2001-2002: "Helicopter / Engine Integration and Design Considerations"

The team was again comprised of eight students, four each from ASU and Leeds University. Once again, one of the Leeds students was in residence at ASU for the 2001-2002 academic year. The objective of the GEDT Year 2001-2002 project was broader in scope than for the previous two years. The student team was required to develop analyses and design concepts to perform a more comprehensive systems integration of a turboshaft engine into a helicopter. The philosophy behind this project was to back away from the complexities of a real hardware based project and to provide the student team an opportunity to conceptualize and develop specific components that could then be integrated into a complete helicopter propulsion system design. Tasks included designing an engine inlet, a simple engine exhaust system including an ejector, engine nacelle fire detection and suppression system, and a main transmission oil cooler heat exchanger. An air management model was developed in order to relate the performance characteristics of each sub-system. As the designs evolved, component aerodynamic performance characteristics were calculated in order to estimate installed engine performance. Designs were optimized to maximize performance while minimizing weight and cost. Structural analyses of the exhaust system were performed in order to define mechanical properties and the selection of exhaust duct materials. Manufacturing and cost analyses were also performed on the exhaust system. This team also delivered a complete set of engineering drawings and supporting analyses, a rapid prototype model of the engine inlet, and a final report and briefing.

Project Model

The student projects have followed a loosely structured model comprised of the following elements:

- Project subject definition by academic sponsors and industrial mentors (January)
- Preparation and approval of a RFP (Request For Proposal) (March)
- Team membership selection (March-April)
- Summer internship at industry sponsor's facility
- Student preparation of project related tutorials (Summer)
- Preparation and approval of a CPP (Contract Performance Plan) (August)
- Fall semester team project activities
- End-of-semester interim report and preliminary design review (December)
- Spring semester project detailed design and supporting analyses
- End-of-semester final design review and delivery of the final report and rapid prototype model (April)

Project Subject Definition

For programs like GEDT that involve several industrial sponsors and universities, it is strongly recommended that the student design project be defined as early as possible, perhaps as early as January which is approximately nine months before the start of the academic year of interest. Lead-time is required for several reasons:

- Coordination and approval of project subject by university and industrial sponsors
- Project author must identify readily available resources that can be utilized in the project
- Project author must develop a project plan from which the RFP is developed

Emphasis must be made with respect to identifying project resources that the students and mentors will have access to. When dealing with "real/existing" systems associated with the respective industrial sponsors, consideration needs to be made for company proprietary data rights and export-import regulations. At no time were the GEDT projects given access to Boeing proprietary design data and information.

In preparing for the GEDT helicopter engine integration projects, the author had to identify and acquire supporting data and documentation from the open literature. Projects were then developed to take advantage of available data and documentation. Data and documentation required but not available for the project was "produced" by the mentor utilizing his professional experience in the field.

The RFP

The author feels that the RFP is one of the keys to a successful student project. The RFP is a document that a customer uses to request an organization to make a proposal to accomplish a specified activity. The RFP should be completed and approved by the academic sponsors and industrial mentors before the student selection process is initiated. The RFP will give the student candidates a comprehensive overview of the project and should help them evaluate their interest in becoming a member of the team.

Typically the RFP format/contents included the following:

- System Background Overview: A general description of the system that is associated with the project. For GEDT this included an overview of a typical helicopter propulsion installation and how each component functioned and was related to each other.
- Project Objectives: Defines what the customer requires from the project, typically in general terms.
- Statement of Work: Identification of specific tasks and activities that the customer requires to be performed to accomplish the project.
- Design Requirements: Tabulates/summarizes specific design and performance goals and requirements for the project, i.e., 2% decrease in fuel burn, etc.
- Deliverables: Project deliverables are itemized in the RFP so that the student team knows exactly what is expected from them to accomplish the project. Specific deliverables for the projects have included:

    - Contract Performance Plan: The contractual document that the student team submits to the academic sponsors and industrial mentors to accomplish the proposed project. The CPP is based on the project requirements as specified in the RFP. It includes the student's proposed statement of work broken down into specific manageable tasks and their proposed approach to accomplish said tasks. A key element of the CPP is a structured plan typically formatted as a Gantt chart that shows both task schedules and the interdependencies of the several tasks. The CPP development process also requires the students to estimate the hours to accomplish each task.
    - Letter Progress Reports: Prepared every two weeks, utilized such that the team must evaluate their progress regularly plus it provides a snapshot project status to the mentors.
    - Monthly Performance and Cost Report: Requires the student team to both report hours expended per task and compare to estimated hours.
    - Interim Report and Presentation (December): A formal report and presentation to the academic sponsors and mentors. Typically this serves as a preliminary design review for the project. A successful preliminary design review will result in authorization to proceed with detailed design. Alternatively, an unsuccessful preliminary review will typically result in the team being instructed to go back and do more preliminary design studies before they can proceed into detailed design.
    - Final Report and Presentation (April): The student team is required to not only prepare a final project design report but to also present a formal final project briefing to industrial mentors and academic sponsors.
    - Rapid Prototype Hardware Delivery: The student teams have been required to produce a rapid prototype hardware model of a component of their design. This allows the students to see the evolution of a design from conceptualization, to design, to engineering drawings, to manufacturability, and finally to the actual production of a piece of hardware.

Team Membership Selection

Student team members should be selected in the March-April time frame. The selection process typically includes an interview with the industrial mentor with final team selection made jointly between the academic sponsors and the industrial mentors. The selection process was accomplished in this time frame such that the students could make plans for the required travel, summer internship, and joint training activities.

Summer Internship

The GEDT students have had the opportunity to perform summer internships at either Boeing Mesa or Rolls-Royce, UK. The internships were typically 7-8 weeks long with two ASU and two Leeds students both at Rolls-Royce and Boeing. The summer activity has been concluded with all students meeting in Arizona at the end of August for a two week joint team working session.

Student Tutorials

Each student was expected to prepare a tutorial on a related project subject as part of the summer internship. The tutorials were the mechanism by which the students initiated basic research into their GEDT design project. Each student was expected to become a focal point resource for the selected subject matter. During the final two weeks of the summer session each student presented their tutorial to the team and mentors. Typical tutorial subjects have included turboshaft engine thermodynamic cycles, installed engine performance characterization, helicopter engine inlet and exhaust system design parameters, ejector performance parameters, propulsion system air management, fire suppression concepts, design to cost parameters, and design for manufacturability. Tutorial preparations included an extensive literature and data review and a considerable amount of verbal interaction with the engineering staffs at both Boeing and Rolls-Royce during the summer internship.

CPP Preparation

In addition to preparing the tutorials, the students were expected to essentially plan for and prepare the CPP during the summer internship. Summer CPP preparations required the team to start to develop "long distance" communication and teaming skills. Final CPP preparations and submittal were completed during the final two-week joint session of the summer.

Fall Semester Team Project Activities

The GEDT student teams formally started their projects as soon as the school year commenced. The fall semester work was typically geared to defining and performing trade studies, design concept development, down-select processes, and finally a final design proposal with supporting documentation. In addition, considerable efforts have been expended by the individual team members learning to work together as a cohesive team, communicating, and in developing working relationships with the mentors.

End-of-Semester Preliminary Design Review

A required deliverable is a formal interim report and briefing to be presented at the end of the fall semester. The objective of the interim report is both to report the progress on the project and to present a preliminary design review. The continuation of the project is dependent upon a successful preliminary design review. Should the mentors and academic staff determine that insufficient progress has been made on the design project, the team will be ask to continue their preliminary design trades and studies and re-present a preliminary design review at a later date.

Spring Semester Detailed Design

Typically the spring semester was utilized by the team to complete the detailed project design and supporting analysis required to substantiate the design process. The CAD drawing packages were prepared and a selected component of the design was selected for rapid prototype production.

Final Design Review and Final Report

The student projects required a formal detailed project and engineering report including an assessment of how the team did against the contract they proposed in the CPP. A formal presentation is also presented, typically via video conference, where the final design and supporting analyses are presented to the mentors and the academic staff. The team also delivers the rapid prototype hardware component during the final briefing.

GEDT Summer Format at Boeing

The author has had the privilege of sponsoring three groups of GEDT summer students at Boeing Mesa. The students were assigned to work stations along side the Boeing engineering staff, essentially encouraging an interaction between the students and the staff engineers. They were provided computer resources including Internet access. Arrangements were made for the students to have access to the Boeing corporate-wide library resources. In addition, access to data fax and international calling resources were provided for communications to the UK.

The author's philosophy on the selection and assignment of GEDT student summer projects was: "IF THEY DON"T DO IT, I'LL HAVE TO." Projects were selected that would be challenging but within the realm of the students' educational experiences to date. In addition, the scope of the tasks was such that they could be accomplished comfortably within the time frame of the summer internship. The projects were defined such that the students could relate their work to a specific identifiable component or system on the helicopter. Typically the projects were accomplished with the students first familiarizing themselves with the particular system of interest and then building a simple physics model, whether fluid losses, heat transfer, or what ever, followed by the calculation of design and performance calculations of interest. Essentially all models were developed in spreadsheet format. Several of the spreadsheet models have found their way into the author's engineering toolbox. When available, representative test data would be provided for model and assumption confirmation.

Examples of summer projects at Boeing included modeling and the calculation of flow losses through a complex fuel system and through a pressurized air system, engine installation performance sensitivities, engine bay cooling heat transfer modeling, data reduction and data analysis of flight test activities including that from several missile and rocket firing programs, and test planning including defining instrumentation and data acquisition requirements and then performing the test and reducing and documenting the measurements. The students were supervised with their work being periodically reviewed. In addition, the students were able to shadow engineers at the assembly line and at flight test. All of the summer projects were concluded with an engineering report, several of which were passed directly to Boeing's customers.

Project Challenges and Lessons Learned

The following summarizes several of the challenges and lessons learned from the GEDT projects that the author has been associated with as an industrial mentor. The author's goal was to mentor the GEDT such that the students would have meaningful real engineering projects to work on and to address the design issues similar to the way they would be addressed in industry. It is believed that the students were both challenged and enjoyed working projects that were associated with real aircraft design issues. These projects added a layer of inherent realism to the design process in that "flight-worthiness and safety of flight" considerations had to be integrated into the student's design process.

Mentors

The author strongly believes that in order to conduct complex GEDT projects similar to the helicopter engine integration activities performed for the last three years there are requirements for strong active mentorship by those who are experienced in the selected subject area, have engineering management experience, and are good communicators. In addition, the author has found that industrial mentors will need to dedicate considerable time and resources to the project, both in addressing specific student questions and in reviewing and checking progress and to aid in finding supporting data and information. The author estimates he has spent on the average at least eight hours a week during the school year supporting GEDT in addition to attending team meetings, presentations, and project reviews.

It is challenging to plan and organize international student projects while maintaining company proprietary and export-import rules and regulations. Great care has to be exercised by the industrial mentors to ensure that company proprietary design and data rights are not compromised. In addition, all GEDT team participants must observe their respective countries' export-import rules and regulations. Because of these concerns, the author tailored the GEDT engine integration projects around literature and data that were available in the open literature.

Plan and Organization

The author has found that the student teams struggled with the concept of the CPP and the long term planning and coordination that was required for a project of the magnitude of GEDT. The student teams tended to be over-optimistic as to what they could realistically accomplish in the calendar period of time in addition to under-estimating the amount of time and resources that were required to perform specific tasks. One of the key roles of the industrial mentor is that of introducing realism to the student team for project planning, scheduling, and organization. Hence, it is critical that the mentors work very closely with the students during the summer when project planning and CPP preparations are being accomplished.

The CPP is essentially a contract that is agreed to by all parties before the project starts. There is a tendency for the academic sponsors and mentors to change the scope of the project mid-stream mainly by adding and/or changing tasks and scope that were not in the original RFP and CPP. This tends to upset plans and schedules. This should not be allowed to happen once the CPP is approved. It is just as important for the mentors and academic sponsors to understand the project and the scope of the tasks proposed by the students in the project's beginning as it is for the student team.

Student Teams

It has been observed that at the beginning of each of the GEDT projects the students seem to have a difficult time working together as a team. It typically has taken several months into the fall semester before the team starts functioning as an effective engineering organization. There has been a tendency for the students to want to work independently and not share their results and resources with other team members. The GEDT have been encouraged to utilize the individual talents and knowledge base of each of the student members when addressing complex engineering problems. However, inevitably, individual team members have first asked the mentors for help and in doing so have ignored the resources of the assembled student team.

The CPP presents the student's plan and schedule to accomplish the project, but it seems the first thing the team forgets about is the schedule and the interdependencies of each of the tasks as defined on the Gantt chart. It has been observed that some student team members have a difficult time knowing when to end a particular task, i.e., often time performing extra non-value added work that adds very little value to the overall project. One of the biggest contributions a mentor can make to a project like GEDT is to work with the team on a regular basis reviewing schedules and the status of each task. The biweekly status reports have been an excellent tool to initiate this interaction between mentor and team. Active mentoring also allows the mentor to provide assurances to each team member that their engineering approach for each task is correct and that they are investing their time and resources efficiently.

Engineering Preparations

It has been observed that several of the students selected for the GEDT projects have struggled to apply basic engineering principles to solve semi-complex engineering problems. If they can't "find the equation" in the book or find what they need on the net, it "doesn't exist." This mentor has spent considerable time with student team members reviewing basic engineering principles, deriving applicable equations, reviewing literature and data, etc. The author feels that this is part of mentoring and one of the reasons industry is so interested in sponsoring projects like GEDT. It is much more advantageous for the students to experience this engineering maturing process as a member of a student team than as a new employee in the industry.

Tools

The sponsoring universities must make available common computer software tools at each of the participating schools. For example, utilizing a common CAD package will allow the students to exchange engineering drawings, hence minimizing component interface issues. Compatible spreadsheet tools and word processing tools are also required to facilitate the exchange of analyses and documentation.

Summary

The objective of this paper has been to present an industrial mentor's perspective of the GEDT student engineering program. Engineering projects completed by the GEDT student teams are considered to be of high quality and of value to the industrial sponsors

Biographical Information

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