Using Active Learning and Team Competition to Teach Gas Turbine Cycle Design

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Abstract

An elective, Analysis and Design of Propulsion Systems, has been a traditional lecture course teaching gas turbine engines from a design perspective. This past fall semester additional active learning modules were introduced to make the course more interactive. Students formed teams of four and each team was designated a company. The task was to design a replacement engine for the B-52H which served as the basis for learning about gas turbine engine design. The companies picked a name, developed a logo, and wrote a mission statement. Competition was encouraged and the "companies" were tasked to eventually design the lowest cost, most efficient high bypass turbofan engine to replace the existing engine. A three part design project led to a final report on the engine design. To conclude the process, each team presented their engine as if they were a company trying to sell their product to a customer. The customer, the professor, picked an overall winner based on the information presented. Assessment of the course showed that the students appreciated the competitive environment giving them insight into how a gas turbine company, such as Rolls-Royce, GE, or Pratt & Whitney, might operate. In conclusion, the active learning modules and the design project were effective in challenging and exciting the students about the design of gas turbine engines. The company context for teams prepares students for what they might encounter in industry.

1. Introduction

Since 2007 Baylor University has been involved with the Kern Entrepreneurial Engineering Network (KEEN). KEEN is "a national partnership of universities with the shared mission to graduate engineers with an entrepreneurial mindset so they can create personal, economic, and societal value through a lifetime of meaningful work." [1] This is accomplished by incorporating entrepreneurially minded learning into the classroom, instilling curiosity, connections, and creating value in the students. What results is a mindset and skillset which prepares Baylor students to be competitive in the workplace. Making our students more aware of what will be faced in the workplace was a motivation to modify this course project to reflect the company setting for the gas turbine engine design process.

This course, Analysis and Design of Propulsion Systems, is an elective for the B.S. in Mechanical Engineering degree. Typically taught in the fall semester, the course is for seniors who have previously taken Advanced Thermodynamics. It meets two days a week, Tuesday and Thursday, for 29 lessons. In the course the students design, as a team, a turbofan engine cycle for a designated aircraft, this semester the B-52H. Comprehensive Assessment of Team Member Effectiveness (CATME) was used for the first time to determine team composition based on instructor weighted criteria [2, 3]. The B-52H re-engine is a real world engineering challenge that has recently been in the news. [4, 5] Figure 1 shows the current engine/nacelle on the B-52H. Figure 2 displays a typical engine cutaway for a high bypass turbofan engine illustrating the engine design choices, the overall compressor pressure ratio, OPR, the fan pressure ratio, FPR, and the bypass ratio, ALPHA. The

Fig.1 B-52H Engines and Nacelle [6]

OPR is the air pressure rise occurring from the inlet to the fan compared with the exit air pressure of the compressor. The FPR is the air pressure rise across the fan (outer portion of the flowpath) and ALPHA is the ratio of air bypassing around the center core of the engine to the air passing through the center core of the engine. In all, 21 students were formed into five teams (four teams of four with one team of five). The teams remained the same throughout the semester and sat together in the classroom to do Think-Pair-Share exercises [7, 8] or example problems. Table 1, at the end of this paper, displays an abbreviated syllabus showing where in the course assessment activities occurred and when they were due.

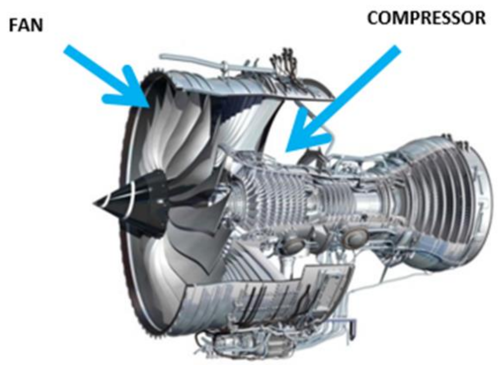

Fig. 2 High Bypass Ratio Turbofan Engine [9]

2. The First Day

Active learning was used throughout the course. Student teams were asked to do Think-Pair-Share exercises or to work on example problems at their seats. An example of active learning was the module presented on the first day of class. Teams had already been selected using the CATME software prior to the first day of class.

On the first day students, in their teams, addressed the question "What do I need to know to design a jet engine?" In a short ten minute session, called a Quick Think (an extended Think-Pair-Share), teams listed all the topics that might be important in the design of a gas turbine engine without access to any outside references. The information was collected, collated, and presented on lesson two. Most of the topics proposed were incorporated into the course syllabus, which was also provided on lesson two. The teams were given an assignment on the first day to write a persuasive/position paper, supported by research, either for or against replacing the engines on the B-52H. Three teams supported the United States Air Force (USAF) re-engine project and two surprisingly were against. All defended their positions with documentation. The position paper gave the students a chance to learn about the aircraft, its current engines, and mission capabilities. This made the students very familiar with the details surrounding the re-engine project.

"**SKYBEAR** is committed to providing safe, clean, and cost-effective air travel for all nations of the world by designing, manufacturing, and servicing jet engines."

Fig. 3 Example of a Student Team Logo, Name, and Mission Statement [10]

While writing this position paper, the teams were to pick a team name, a logo, and a mission statement (Fig. 3). These items are what identifies commercial companies to the public and provided a team "branding" which would unify them throughout the semester. The teams became a company in competition with the other teams.

3. The Request for Proposal

Early in the semester, the students were exposed, for two lessons, to the concepts of creativity/innovation and the essentials of writing a Request for Proposal (RFP). In the past, an RFP would be given to the student team listing the design constraints for the project. An exercise in writing an RFP would give the students an appreciation for the difficulty in defining the design scenario for any product.

Working in teams for the first lesson, creativity brainstorming exercises were accomplished in class with a homework assignment of coming up with new uses for gas turbine engines. The second lesson focused on introducing the concept of an RFP and ended with a homework assignment having the student teams write an RFP for replacing the engines on the B-52H. The RFP needed to be specific enough to provide guidance to a company considering the request yet at the same time not be so specific as to limit possible solutions. A new engine was desired which meant that new technologies needed to be addressed. This exercise helped prepare the student teams understand the origin of the RFP and its purpose. Teams examined the current B-52H aircraft mission capabilities such as range, endurance, altitude, and speed and modified them appropriately assuming the impact of a new engine on the aircraft's performance. A typical RFP format was used for the report. The proposals by the teams were evaluated by the professor and some of the student concepts were incorporated into the actual design project RFP used for the course.

4. Design Project

The companies (student teams) were given an RFP with the mission specifications which needed to be satisfied for the project to be successful. While the project was introduced in class, there were still topics that needed further explanation and research. The basic premise of the project was to determine the drag of the airplane under cruise and loiter conditions which would then determine the amount of installed thrust the engine would need to produce. Adjustments had to be made for engine performance not installed on the aircraft, as this is the metric the engine companies actually use for design. While an RFP listing the desired performance specifications was supplied to the companies, the unrealistic expectations for the engine performance was anticipated to be questioned as the project progressed. The actual design project covered most of the course and was used as a means to understand gas turbine operation and the engine design process. The project was broken into three parts with written reports required for each, the final report being a formal compilation of all three phases along with a final presentation.

4.1 Design Project I – Mission Analysis

Design Project I, Mission Analysis, effectively studied the RFP mission and led to the determination of the important figures of merit for the engine design, the specific fuel consumption (TSFC), specific thrust, and engine design point. Specific fuel consumption is the "miles per gallon" for engines, meaning that this value gives us the amount of fuel burned per pound of thrust produced. This number, the result of Mission Analysis, needed to be as small as possible and had to be calculated using the aircraft drag, which corresponds to the thrust required by the aircraft in steady, unaccelerated flight. The specific thrust is the amount of airflow through the engine divided by the thrust produced by the engine. This number should be as small as possible which means the frontal area (diameter) of the engine would be smaller and produce less drag. The bypass ratio, ALPHA, is the ratio of air flowing around the engine's central core divided by the air flowing through the engine's central core. Higher ALPHA values mean the engine is more propulsively efficient which results in a lower fuel burn. An engine could be any combination of these values, however, only certain combinations will satisfy the mission requirements and tradeoffs must be realized for optimization.

The overall thrust required for each mission leg needed to be calculated and then divided by the number of engines, eight for the B-52H, to determine the amount of thrust required by an individual engine over the different mission legs. The aircraft was initially to climb to 43,000 ft, fly for 4,000 nm, loiter for 4.7 hours, deploy munitions, climb to 50,000 ft and return 4,000 nm to base, ending the mission with a 20% fuel reserve. The companies were actually given an impossible scenario in the RFP, however, at this point in the design process they were unaware of the challenges facing them. The students developed a spreadsheet which calculated aircraft performance and used an optimization function to determine an average specific fuel consumption necessary for the RFP mission which would allow the aircraft to land with the proper fuel reserve. The companies were also to determine the appropriate design point for the engine. This design point is the altitude and airspeed where the aircraft will be operating for extended periods of time and where the engine will need to be very fuel efficient. The companies were required to research current values of compressor pressure ratio, fan pressure ratio, and bypass ratio and to determine the trends with time that could be found in the literature. With the average specific fuel consumption required to accomplish the mission and the design point identified, the companies were ready for the next phase, Parametric Cycle Analysis.

4.2 Design Project II – Parametric Cycle Analysis

With this information, Design Project II had the students accomplish an on-design Parametric Cycle Analysis looking at many different engines (combinations of OPR, FPR, and ALPHA) to see which combinations would satisfy mission requirements. Knowing the required TSFC

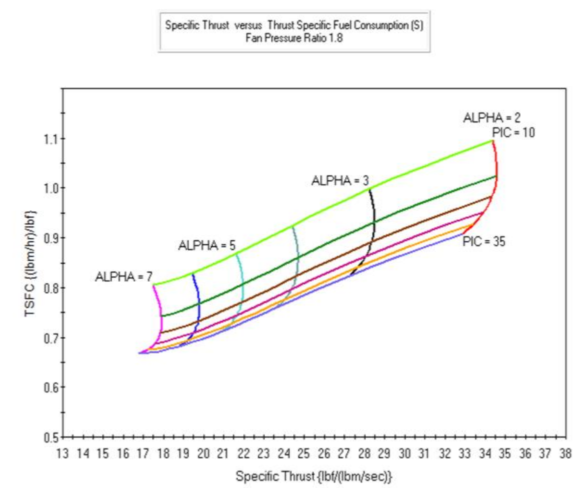

Figure 4 Carpet Plot of TSFC vs Specific Thrust

from Mission Analysis, Carpet Plots were accomplished plotting TSFC vs. Specific Thrust for various combinations of compressor pressure ratio, bypass ratio and fan pressure ratio (see Fig. 4).

Each point on the plot represents an engine cycle that will operate but may not satisfy the average TSFC requirement. The RFP given the students was designed to be impossible to accomplish because the required average TSFC with the initial mission constraints was lower than found on the carpet plots. Once the companies realized this, each company had to negotiate with the customer (the professor) to relax some of the RFP requirements. This resulted in reductions in range, loiter time, speed, altitude, and payload. In essence, each team chose different combinations of mission requirements which had to eventually be justified in the final presentation by stating how the changes impacted mission capability. Companies had to examine tradeoffs between engine component values to decide on a final compressor pressure ratio, bypass ratio, and fan pressure ratio that delivered an appropriate average TSFC at the design point (altitude and airspeed).

4.3 Design Project III – Engine Performance Analysis

With the engine design choices made, the engine was then sized and flown off-design in Design Project III, Engine Performance Analysis (EPA), to determine if the chosen engine combination of design parameters could satisfy the mission. The purpose of EPA is to test one engine over all the mission legs to check acceptability. Formulae were available to determine engine weight based on component selection and, from the weight, a cost estimate could be accomplished. After verification of the chosen engine, a sensitivity analysis was performed to determine if any variation of the chosen components around the design choices would result in better performance.

A formal report encompassing all the design phases was accomplished. To finish the process, each company presented their engine to the class as if they were trying to sell the engine to a customer, the professor. While all engines satisfied the mission requirements, the customer picked an overall winner based on the information presented (i.e. engine component design choices, performance, weight, cost, and mission capability). A prize (aviation related books) was given to each member of the winning team.

5. Assessment

An assessment survey of the course was accomplished by the students and a summary of the results follows. Most students indicated they selected the course because of their interest in jet engines and gas turbine design. The majority of students felt the course met their expectations and they feel confident in their understanding of gas turbine engines. They stated the material was presented at the appropriate level. CATME was used to pick teams and to provide student peer-to-peer feedback but the students did not feel that was CATME was effective. Part of the disconnect lies with the author's inexperience with the software and the lack of peer-to-peer comments. The peer-to-peer feature has since been added to the current version of CATME and will be used in the future. Students indicated that they were prepared by their Baylor education to be a good team member however, some did not enjoy working in teams. The first two lessons were generally thought of as a good introduction to the gas turbine design project in the course, namely to re-engine of the B-52H, a real-world scenario. They found the position paper valuable because it provided the context for replacing the engines on the B-52H. It gave them the background they needed for the rest of the course. The RFP demonstrated how difficult it is to define a need but not to over specify the design with constraints which would suppress creativity. The Design Project in its three phases was an effective means of teaching the design of a gas turbine engine according to the students. The students indicated they clearly understood the purpose of Design Project I, II, and III. Students felt there should have been more lectures instead of the discovery nature (active learning) of the classroom environment. Students' response to whether they would recommend the course to others was low, probably due to the workload involved. Comments from the students summarized the impact of the course.

> "I loved working in teams, and it really gave me a better understanding of the design process when companies are trying to win a contract."

> "The design project was a simulated real world application with real world expectations. The ability to design our own engine that could be applied to an already existing aircraft was a very cool project."

> "It gave an insight into industry which I appreciated. Not many classes cover aerospace topics, granted this course is an aircraft and rocket propulsion (course), but it showed what it is like to work in industry and got me up to speed to understand what is going on in industry. The design project was the culmination of everything we were learning in class. We didn't come up with a great engine but it's cool how companies will soon be bidding on their own B-52 replacement engine soon."

> "It was a good way to go through a simplified engine design process and see what the process is like in industry. Researching current technology and anticipating future trends is also (a) useful skill to practice"

> "I enjoyed getting to see how companies actually go through the process to get the engines to work. Using the Para and Perf programs where great to get to see how iterations are simulated on the computer and how companies are able to consider 100s of engines and compare them in order to find the best one to fit the mission analysis."

> "Working on a team was a great experience and contributed to my overall understanding of the course greatly."

Students obviously understood the objective of the course and did enjoy addressing a real world problem that was done in a team/company competition.

Improvements to the course revolve around communication issues. CATME is a valuable tool and it needs to be explained to the students so they understand the purpose of using this tool. The formal writing format for the project was not given to the students until the final report, Design Project III. Students were not assigned a format for the first two phases and that made them uncomfortable. They will be asked to write using the assigned format for all reports. This is not unlike what would be required in a company, to use a prescribed format.

6. Conclusion

In conclusion, active learning modules and the design project are effective in challenging and exciting the students about the design of gas turbine engines. The company context for teams better prepares students for what they will face in industry. The initial day module was an effective way to introduce the topic of a B-52H Re-engine and to get students thinking about what that might require. Writing an RFP gave the students experience and understanding of the purpose of the RFP and its role in the development of new products, in this case, a gas turbine engine. The three part design project was an excellent way to have students become familiar with the engine conceptual design process, not unlike that found in industry. Having an impossible RFP forced the students to make decisions about mission changes and then negotiate with the customer for changes to the RFP, also something found in industry. Throughout the entire process, tradeoffs were made in the design requiring the student teams to make sound engineering judgements based on available data. Choosing a "winner" also reinforces the nature of competition in the business world.

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Table 1 Abbreviated Course Syllabus (T – Tuesday; R – Thursday)

LSN	TOPIC	ASSIGNMENT DUE
1 T	Course Introduction Design Challenge	
2 R	Momentum Engine types Engine Operability	
3 T	Creativity exercise 1-D Compressible Flow (1DCF) Isentropic Flow, MFP	**Persuasive Paper Due**
4 R	Design Project Introduction **RFP exercise**	
5 T	**Design Project I Overview** Inlets, Nozzles Fans, Compressors, Turbines	
6 R	Fans, Compressors, Turbines Combustors, Afterburners	**RFP Due**
7 T	Normal Shock Waves Oblique Shock Waves	Mission Analysis Spreadsheet Milestone
14 R	Introduction to Engine Design Process and Parametric Cycle Analysis (PCA) Design Project II	**Design Project, Part I (4pm, 200E)**
16 R	Turbojet engine PCA Exercise	Carpet Plot Milestone
18 R	TF Trends In-Class Exercise Engine Performance Analysis of Turbojet/Turbofan engines	**Design Project, Part II (4pm 200E)**
20 T	EPA: Real TJ/TF Trends Analysis Throttle Hook	Size the engine milestone
21 T	Buckingham Pi Theorem Corrected Parameters for TJ/TF	Run engine off-design milestone
26 R	Rocket Engines Rocket Performance	**Design Project, Part III (4pm 200E)**