

## **Developing an Aeronautical Engineering Technology Course for Commercial Space Operations**

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# **Developing an Aeronautical Engineering Technology Course for Commercial Space Operations (CSO)**

## **Abstract**

Purdue University's Aeronautical Engineering Technology (AET) program is engaging in curriculum development to cultivate the commercial space engineering technologists of the future. The engineering technologist is intended to be positioned between the design engineers who create the design, and the technicians who build and maintain the systems. The engineering technologist discipline has long been recognized in aircraft design and support, but is still an evolving area in the commercial space industry. The evolution continues as the new commercial space companies mature into organizational structures like legacy aerospace companies. The existing aviation focused engineering technology curriculum at Purdue prepares students for the needs of the aviation and aerospace industry today; however, the needs of the commercial space industry are different and require a different set of specialized knowledge in addition to the complementary knowledge. In this paper, the case is presented for the importance of the engineering technologist in the emerging commercial space industry. The case is also made for the value of having an engineering technology program that is combined with an external accreditation standard of sufficient standing to provide stability of the curricula in the program. Purdue's AET bachelor's degree program is accredited by the ABET – Engineering Technology Accreditation Commission (ABET-ETAC). Incorporation of the goals of Purdue's IMPACT program are also discussed. Finally, the development of program outcomes of a first sophomore/junior course in a planned minor in space operations program are developed and mapped to the educational outcomes established by the AET program.

## **Introduction**

The commercial space industry is evolving in ways unforeseen twenty years ago. The financial success of people like Elon Musk (Paypal), Paul Allen (Microsoft), Richard Branson (Virgin), and Jeff Bezos (Amazon) allows these individuals the freedom to invest in or start up their own commercial space companies. These people have been influenced by the grandeur of the Apollo Program in the 1960s, and they use their wealth to invest in the future of the space industry as individuals, not as a part of a government entity. Such investments are largely unseen in the corporate conglomerate paradigm of the late 20<sup>th</sup> century. This wealth and vision by individuals is a game-changer in the advancement of the nascent commercial space industry.

As a result of this new commercial space industry, another professional path for those with a passion for aviation and aerospace exists, and this path lies in the stars... or at least the solar system for now. In addition to efforts by NASA and other government-sponsored space agencies around the globe, companies such as SpaceX, Blue Origin, and Virgin Galactic, to name a few, are engaged in the ambitious goal of space travel to Earth orbit and beyond. To achieve these spaceflight goals, these new space companies need employees with specific engineering technology skills. One of the challenges today is educating enough people, quickly enough, with the appropriate knowledge and skills.

In the early 1960's, Purdue University began by successfully in training high achieving technicians for the aviation through a maintenance based aviation program. By the 1970's the graduates were beginning to find more and more success with aerospace companies in manufacturing and maintenance management positions. By the 1990's over half of the graduates were finding careers with major aerospace design companies and performing duties in engineering support. By 2010, the graduates were finding leadership positions across aviation and aerospace in positions ranging from maintenance development to program management of engineering programs. Also by 2010, graduates had begun finding opportunities in engineering and engineering support in both legacy and emerging space related companies. Today, Purdue's program continues to produce graduates who span the breath of flight that ranges from fabric wings to modern spaceflight.

Over the decades, the program has evolved to become what is it today. ABET's – Engineering Technology Accreditation Commission (ABET-ETAC) now accredits the program that began decades ago as an associates' level aviation maintenance program. Post-graduation educational opportunities continue at both the masters and Ph.D. level. A long and successful history has allowed the AET program to continue to grow both in numbers of students and their reach in the aerospace industry. The program maintains its roots strongly grounded in hands-on education and exposure to systems and construction techniques that engineering programs no longer require. The program continues to evolve to ensure its graduates can enter the aviation workplace in such varied positions as manufacturing engineering, production engineering, quality engineering, and logistics, among many others, and succeed.

Observing the changes in the space industry, Purdue identified a gap between current educational goals and industry needs. Purdue believes they can contribute to the commercial space industry in the same way they do in the aviation industry by filling that gap with their graduates. These gaps were identified through conversations with current industry leaders and review of the current job opportunities.

On March 15, 2017, SpaceX had 485 positions opened on their website [1]. Of those positions, approximately 100, or 20%, were positions that current AET graduates were competitive with other applicants, including those from traditional engineering science programs. However, with relatively minor adjustments to the curriculum of the AET program, Purdue's graduates would have been more than competitive; they could easily have been the frontrunners.

Commercial space companies are not the only ones looking for employees in the commercial space sector. The FAA still has regulatory oversight and has open positions in their specialized Office of Commercial Space Transportation, a part of the US Department of Transportation. Per the FAA Office of Commercial Space Transportation [2], the FAA is seeking employees to, “support its safety responsibilities through the licensing and regulating of commercial space launches and reentries, and the operation of launch and reentry sites”. The FAA lists the required skill sets in five areas: aerospace vehicle systems, system safety and quality assurance engineering, structural and mechanical engineering, software engineering, and meteorology [3].

To take advantage of this exciting and challenging time for the commercial space industry, faculty at Purdue University are examining ways to expand its current AET program to include

coursework devoted to the commercial space industry. The existing AET program provides a blueprint for how to support the industry in a way few other programs can. Mirroring the success in the aviation/air breathing aerospace sector to the space sector, provides an established path for expansion. Commercial space focused coursework is a natural expansion of Purdue's existing AET undergraduate degree program. The intention is to start simply with the development and implementation of one single introductory course. Based on those results, a path to a minor area of study built on the AET program, or even a major area of study coexistent with the current AET program is to be evaluated. The content of that first single course is defined through five outcomes that are mapped to the ABET-ETAC outcomes. In addition, a preliminary set of objective measures is presented. This course is envisioned as being the foundational basis for a series of four courses. Each course builds on the previous course involving both theoretical and hands-on lab projects. These courses are built using traditional curriculum development activities enhanced by IMPACT training to maximize student learning and success. Graduates from Purdue's program are to have the essential skills for them to be successful workers in the commercial space industry.

### **Short history of the space and commercial space industry**

In 1961, Soviet cosmonaut Yuri Gagarin became the first human to orbit the Earth. A few weeks later, astronaut Alan Shepard became the first American in space. These were inspiring acts as evidenced by then United States President Kennedy, in his address to Congress on May 25, 1961, eager to establish the USA as a technology powerhouse, he challenged the country to “...*before this decade is out, of landing a man on the moon and returning him safely to the earth*” [4]. Even though this was an ambitious goal, even more so since the USA was behind the former Union of Soviet Socialist Republics (USSR) in both manned and unmanned spaceflight, the USA rose to the challenge. The US allocated billions of dollars of funding for research and development in space, cultivated massive space related engineering programs, and enabled NASA, and its civilian contractors, to land the Apollo manned lunar module on the Moon in 1969. Subsequent years saw the rapid advancement of technology and expansion of resources in the space industry. Early space industry was primarily a government endeavor with support by the civilian industrial base. It was not until 28 years later, in 1989, the first privately funded rocket, the Conestoga I by Space Services Inc of America, reached space [5]. In 2004, Scaled Composites, using their SpaceShipOne, won the Ansari X Prize for being the first non-government organization to launch a reusable manned spacecraft into space. Not just once, but twice within two weeks [6]. Many considered this event as the practical beginning to the commercial space industry. Since then the commercial space sector grew to a \$208B industry. The backlog at SpaceX alone is currently \$10 billion in contracts [7]. In 2013, there were eight non-federal FAA-licensed launch sites in use, with more proposed [8]. In the first quarter of the 21<sup>st</sup> century the paradigm had shifted. Now there were commercial space programs as the prime contractors, with the government in the advisory/regulatory role.

The commercial space sector supported over one million jobs in 2009 [8, 9]. In addition to satellite and other non-human payloads, the demand for commercial cargo and crew transport to space was forecast to be approximately 79 launches between 2015 and 2024 [10]. In 1995, the United States established the Federal Aviation Administration's Office of Commercial Space

Transportation to license and regulate commercial space launch and reentry activity; the current regulations are part of the United States Code of Federal Regulations [2].

### **Current commercial space industry and expectations**

All these changes bring a new human adventure on the horizon. With the evolution of the industry due to new players, and the lessening of absolute control from NASA, the roadblocks to entering the spaceflight industry have become less limiting. Between new regulations that enable commercial space transport and more economically attainable advanced materials and manufacturing for private companies, there is an influx of private equity into aerospace not seen since the early 20th century. These factors have led to the commercial space industry exploding in the United States and around the globe. Commercial space companies are forging a new path and developing technologies never before seen. Space is exciting again and attracting a completely new, younger generation of engineers, scientists, and technicians led by leaders that capture people's imagination like Elon Musk or Jeff Bezos. The Silicon Valley pioneers of the 1990's are changing the world beyond computers, and the new generation of young people are excited to get involved.

Indications are that while millennials are more interested in joining the space industry, they are not joining one of the legacy companies. They are more inclined to work for one of the new startups instead of legacy companies. Foust [11] observed, "The ranks of SpaceX and many other space companies, in particular emerging firms, are filling with young employees. Some are attracted to a field that appears to have a new-found vigor, particularly in the commercial sector" [11]. Legacy aerospace companies are solid places to work, but these companies typically take a more conservative and traditional approach to design and build.

United Launch Alliance (ULA) still builds expendable rockets very like how rockets were designed 30 years ago. An example of how new commercial companies approach design is SpaceX's recovery of the 1<sup>st</sup> stage of the Falcon 9 rocket. The stage lands vertically at either the launch site or on a barge off a coast. In contrast to the expendable 1<sup>st</sup> stages and reusable rocket boosters of the past, the launch vehicle design of today allows for recovery and reuse. On March 30 2017, during the SES-10 satellite mission, SpaceX launched and successfully landed a 1<sup>st</sup> stage booster that had previously flown during the CRS-8 on April 8, 2016. Another example is Blue Origin, and how it has landed and flown the same New Shepard suborbital booster four times and the capsule flew six times [12]. These are just a couple of examples of how the new players are changing how the industry works, and how they need employees who young, and without decades of legacy thinking to get in their way.

Being at the cutting edge of technology results in a demanding place to work. Developing new hardware, software, and technology with aggressive schedules leads to long workweeks and high stress. According to Drew Hendricks [13], SpaceX engineers may work 80-120 hours per week when needed. Weeks are long and include weekends, schedules are short, pressure is high, and the work is plentiful in a company where the work/life balance tilts heavily toward work [13]. This, however, does not stop commercial space companies from attracting a young and eager workforce ready to make sacrifices.

Even the FAA understands that the employment world is changing for these new space pioneers. Realizing that the new commercial space employee is different from those of the past, the FAA Office of Commercial Space Transportation is offering a “start-up work environment” in its most recent advertisements for commercial space positions [2].

The evolving industry from public to private brings many challenges from a new way of thinking and new work/life expectations. These changes mean commercial space companies are looking not just for experienced workers, but arguably, new workers. Workers who understand the new paradigms, willing to work hard, and with experience in current techniques and materials. Educational intuitions need to adjust to meet the new demands. Purdue believes it is in an ideal position due to its AET program to meet those needs.

### **Purdue University’s AET program**

For many decades in aviation and aerospace industry, the engineering technologist has been invaluable in the middle ground between technician and engineer. This success is built on the combination of engineering, authentic workplace learning situations, and professional development outcomes in the program. Students, for instance, when given a math equation look beyond the simple solution and ask deeper questions like “What does this mean?”, “How does this impact what I’m doing?”, and “How do I use this?”. These students are not only conversant in the theoretical knowledge, but also enjoy developing the skills needed to make a design physically come to life.

There are multiple tools utilized by Purdue to develop successful graduates. Third party validation through either ABET and the FAA provides constant evaluation to ensure the program is providing graduates with desired successful outcomes. The program itself is filled with opportunities for learning through multiple methods such as hands-on laboratories and collaborative learning. The program does not stop with only the technical training of its graduates, but also includes multiple opportunities for developing skills for program management and professional skills.

### **ABET-ETAC accreditation**

ABET-ETAC requires programs to dedicate themselves to a broad range of criteria and outcomes, with an emphasis on continuous improvement. While the outcomes of an FAA CFR 14, Part 147 school are not an exact match those of an ABET accredited program, these outcomes can support one another. The detailed task and evaluation rubrics detailed by the Federal regulations are exactly the form and format held as ideal standards for the development of ABET outcomes assessment.

### **FAA validation of airframe and powerplant certification**

One of the important parts of the AET curriculum is the option for students to earn an FAA airframe and powerplant (A&P) certificate. Like the engineering F.E. and P.E. tests, the testing for the A&P certificate is not granted by the school, but rather by external evaluators. Earning

the A&P requires independent and outside certification and provides an additional validation of the quality of the graduates.

This third-party validation allows companies to hire rapidly with more confidence. In major aerospace companies where the graduate is never expected to perform any kind of hands-on work, the FAA certification is still highly valued. Purdue AET graduates enter the workforce with a known, stable body of detailed technical knowledge. This ability by the companies to count on the graduate to perform is where the value of the FAA certification shines.

Even more importantly, having an external certifying body, supporting the external accrediting body, provides for programmatic stability. Where academic programs can wind up yielding to political pressures to reduce credit hours and program content, being required to adhere to external government certification, provides a level of learning stability. The application of both ABET accreditation and FAA certification provides feedback on both the engineering and the applications aspects of the program.

### **Applied learning**

The AET program provides a blend of hands-on and applied skills to students. This type of learning provides many benefits to the students. Examples of applied learning situations include laboratory activities related to reciprocating and turbine engine overhaul, composite structure fabrication, sheet metal work with riveting and bending of aluminum, avionics repair, welding, and aircraft airframe repair, among others. These skills are important for those going to the operational world, but also provide a level of machinist level thinking that is critical in the design and implementation of nearly all aerospace mechanical systems. This is also a case where the students gain close experience with the operation of aerospace systems. By its very nature, there is a level of inherent danger in the hands-on operations, even in training and education. Even the associated minor physical risk learning greatly raises the societal awareness of the students. Additionally, applied learning also increases the retention of women and underrepresented groups by increasing the self-confidence and empowerment of these groups [14].

### **Program management skills and professional development**

In addition to technology skills, students are exposed to and participate in project management and professional development skills. Students are expected to manage teams, develop schedules, and assign tasks. At the same time, they are developing skills in communication and contingency planning. Additionally, the combination of alternative learning and training result in a unique combination of skill sets that means many of the AET graduates act as a liaison between production workers, upper management, and engineers. Purdue AET graduates are immediately fully contributing team members when they enter the workforce.

They think in terms of systems of systems including the ability to communicate across a broad range of professional and managerial areas and the ability to learn and understand the critical time line and cost elements of a program. It also seems to provide a high degree of self-actualization of its graduates, by providing a defined focus of personal significance. This is especially true in aviation or aerospace, where the student can easily understand the impacts of

specific actions upon the health and wellbeing of other people. From that understanding, students develop a sense of personal responsibility and drive to professional integrity. Such programs also provide the graduate with a substantial amount of life skills and so-called soft skills that are often missing from many higher education programs.

### **Differences between AET and Commercial Space Operations (CSO)**

There are areas where the AET and CSO programs overlap that are significant. The alternative learning, program management and professional development skills, and ABET accreditation are foundational to any course or program to be developed in the AET program. However, as much as the AET and CSO programs overlap, there are a few differences.

#### **Technical knowledge**

The course Purdue University is developing introduces students to a broad range of business and technology topics of the commercial space industry. The topics begin with the history of the United States space industry including additional focus on international contributions from countries such as France, India, China, Germany and Russia. Next, the course connects the science of orbital mechanics and thermodynamics to the other preparatory courses in the AET curriculum such as physics, statics, and aircraft science. This introductory course is not an engineering course, so the focus is on the application of the knowledge and on developing an understanding of the fundamentals to be conversant with engineering and technician coworkers when working in cross-disciplinary teams. In addition to science and history, the course includes satellite communications, navigation, and material science.

#### **No FAA validation**

The FAA has been developing regulations and flight worthiness standards for over fifteen years for space vehicle operations. However, currently, there is not a FAA CFR 14, Part 147 equivalent program specific to the development of technical personnel in commercial space operations. In the absence of an established, regulated, educational structure for training support personnel, a space operations course or minor focused on commercial space operations using the ABET-ETAC program criteria for AET is a solution whose time has come.

#### **Multiple instructors**

Unique to this course, the number of instructors is not just one, but three. This change provides students with multiple approaches to the material and subsequently creates an environment where the students are more engaged and excited about their learning. The use of multiple instructors results in greater flexibility in the classroom, assistance in developing collaborative focused programs, and provides students multiple options for learning.

#### **Formalized IMPACT incorporation**

The AET program always pursues collaborative and authentic learning in the classroom. However, it has been done without consistency and formalized structure. The positive outcomes



associated with these pedagogies is well documented, and Purdue is committed to pursuing student-centered learning. Instead of implementing these efforts into the CSO course in the non-structured manner of the past, this course is built from the beginning, following Purdue's established program, Instruction Matters: Purdue Academic Course Transformation (IMPACT) program. Establishment of IMPACT began in December 2010 (IMPACT, 2015). According to the IMPACT Annual report [15], "IMPACT aims to create a more student-centered environment by engaging students in their own learning in order to improve student success as well as completion, retention, and graduation rates, in large enrollment, foundational classes". This viewpoint may be thought of as collaborative learning.

"Collaborative learning is based on the idea that learning is a naturally social act in which the participants talk among themselves. It is through the talk that learning occurs" [16]. Collaborative, student-focused, learning environments are shown to greatly increase and deepen a student's understanding of the topic. Discussion among the students while doing an activity engages higher level thinking resulting in better outcomes in the course.

This collaborative learning environment is a new way of teaching for many instructors, including Purdue faculty. The IMPACT program has four goals. Those goals are:

- Refocus the campus culture on student-centered pedagogy and student success.
- Increase student engagement, competence, and learning gains.
- Focus course redesign on research-based pedagogies.
- Reflect, assess, and share results to benefit future courses, students, and institutional culture.

There are three models to choose from when redesigning a course for IMPACT. One option is the Supplemental model [17]. This model retains the traditional lecture format but supplements the teaching with additional online activities, such as discussions and activities. These activities give students the chance to delve deeper into the topics and engage other students creating a collaborative learning environment. The CSO course follows this model.

A second option is the hybrid/replacement model [17]. This model takes the collaborative learning a step further by flipping the classroom entirely. The face-to-face time is spent in active learning activities. This is the time the students spend working on solving a problem, for instance. The lectures are typically recorded and watched online at the student's convenience.

Finally, there is a completely online option. Regardless of the model chosen, the students are active participants in their learning. The instructor sets the expectations and rubrics. They develop the outcomes and goals for the class and develop the scenarios for student group work. The students are responsible for engaging their peers for true learning to occur.

## **Purdue University's Commercial space operations course**

The initial course being designed was a sophomore/junior level introductory course. Because this course was being designed for the engineering technologist, and not for an engineer or technician, the required curriculum was not fully defined. The only model for this kind of curriculum came from the engineering technology courses developed for the legacy aerospace industry. Here the role of the engineering technologist was better understood based on the kinds of jobs and career opportunities of generations of engineering technology graduates in that field.

In legacy aerospace the level of applied understanding of theory and hardware needed by the successful aeronautical engineering technologist was well understood at a detailed level. The role of the engineering technologist in legacy aerospace was one of supporting the design effort, integrating the design into manufacturing, development of vendor and supplier relationships, forecasting maintainability and supportability, projecting hardware and personnel utilization, prediction of costs of supporting the design over its lifetime, managing the manufacturing and vehicle operations, detailed planning of systems maintenance, and managing systems operations and maintenance. For the engineering technologist in commercial space, it was known that these same roles would be performed. However, what was unknown was the type and level of unique systems and operations knowledge the new commercial space technologist needed.

For example, in legacy aerospace, the engineering technologist needed to have a firm understanding of the theory and applications of lift and drag. The right balance between having enough understanding to successfully support aircraft systems design, but not to the level required for the engineering science design effort of the professional engineer. Additionally, the balance was known between the detailed level of hardware use necessary for vehicle operations and maintenance, versus the formulaic analysis that was required to supply the professional engineer with the data to make valid design decisions. Again, unknown was the balance for the commercial space technologist.

If in commercial space, orbital dynamics were substituted for lift and drag, how much orbital dynamics understanding was necessary? To what level was non-computational theory acceptable versus the level of formulaic understanding required? For hardware, at what level was an understanding of the relationship of the components to each other physically and operationally sufficient, versus the level of mathematical understanding of the environmental challenges of hardware required?

Surveys and personal communications with alumni already working in commercial space operations were a starting point. However, it was just that, a starting point. After the review of textbooks prior to the course, it was evident that there was some level needed beyond that indicated by the survey and communication information. As textbooks for spacecraft operations were compared empirically against textbooks on legacy aerospace, it was evident that the answer to the balance question was still undefined.

It became evident that conducting a traditional "chalk and talk" course on commercial space for the engineering technologist was not practical. As such, the introductory space operations course referenced in this paper was set up as a seminar type course. The course was offered as an

elective credit course, for interested students. Over a dozen students were initially interested, which was a substantial number given that the course was not advertised. In the end, only three students could fit the course into their semester schedule due to other class schedule conflicts.

The textbook, *Handbook of Space Technology*, by W. Ley, K. Whitman, and W. Hallman, was selected for this course [18]. This textbook was chosen because of its comprehensive overview of all aspects of space operations, the fact that much information was distilled into discrete collections of information, and it presented a non-domestic US perspective on space operations. An initial assumption was that interested students might already have some extent of space operations knowledge taken from a U.S. perspective, so looking at the industry from the European side of the Atlantic, seemed to be a good way to provide additional perspective.

The use of the *Handbook of Space Technology* proved to be both bad and good. It was bad from the perspective that since the sections of the book were provided by so many different contributing authors, the focus, continuity of level of detail, and style were not sufficiently constant for the interested neophyte beginning study in this discipline. Additionally, many contributing authors provided an inconsistent of presentation of formula variables and their definitions. The book was good from the aspect that it was a "handbook". For a person of some knowledge, it did pull together a comprehensive overview of nearly all the topical areas. The handbook had a clear structure and order. It was this clear structure and order that was ultimately of most importance to the current course in question.

This course was to be conducted as a seminar type class, where sections of the book were read and discussed by the team. The instructors wanted to capture six things from each section read. These things included:

- 1) What did we learn that we did not know before?
- 2) What was interesting?
- 3) Did this information serve the purpose of the course?
- 4) What part of this learning would be well served in a hands-on learning lab setting?
- 5) How does this information fit with the inputs from the previous surveys by people from the commercial space industry?
- 6) Does this information belong in the first (or potentially a single) space course, or should it be in a follow-on second, third, or fourth course?

On the very first day of the seminar course, the purpose of the course was developed, discussed, and agreed to by the team. The purpose as defined by the instructors, and clarified by the participating students, generally defined as being to:

“Provide information for use by the engineering technologist, to allow that person to enter the commercial space profession, and on the first day have a working vocabulary of the ubiquitous terms and comments, that everyone in the profession ‘just knows’. Also to have sufficient knowledge to support commercial spacecraft design, manufacture and operations, the same way that aeronautical engineering technologists support legacy atmospheric vehicles.”

This purpose repeatedly provided the scope and delamination on the purpose of this specific course activity at the classroom level. The purpose was not to create astrophysicists, it was not to create astronautical engineers, nor was it to create a graduate who was to design spacecraft. The role of the engineering technologist in legacy aerospace was one of supporting the design effort, integrating the design into manufacturing, development of vendor and supplier relationships, forecasting maintainability and supportability, projecting hardware and personnel utilization, upfront projecting the cost of supporting the design over its lifetime, managing the manufacturing and vehicle operations, detailed planning of systems maintenance, and managing systems operations and maintenance.

The students and instructors met three times per week to review the chapters, discuss the content, and evaluate the material. Topical information from on-line sources and current events were brought in and added depth to the discussions. For 9 weeks, out of a 15-week semester, subjects from the Handbook were read and evaluated. At the end of 9 weeks, it was determined that the maximum amount of material had been covered to adequately fill the course. The remaining course periods for that semester were spent going over the topical information selected, evaluating how the materials should be presented to the next cohort, searching for better reading materials, gather online sources, populating the Blackboard on-line learning system with information, and evaluating how to accomplish applied learning for selected topics.

By mid-semester, the group of students and instructors had developed several important takeaways for the course.

- 1) While an excellent handbook, the *Handbook of Space Technology* was not the book to be used for a traditional course.
- 2) While everyone in the course was a space, "enthusiast", it was evident that basic knowledge of the history of spaceflight that was common only to the instructors who had grown up with the Mercury-Gemini-Apollo-Space Shuttle programs and not common to the students.
- 3) Two of the instructors had experience working in commercial aerospace, and an understanding of technical operations that had become subconscious common knowledge to them and was not common to the others in the class.
- 4) Adherence to the purpose statement of the course had become critically important to maintaining focus.

### **Course development**

In the spring of 2017, the independent study course described above was established with a purpose to develop the framework for the CSO course. A team of three students and three instructors participated in the course. Over the semester, a curriculum and structure for the CSO course were established. The team used the *Handbook of Space Technology* from AIAA and John Wiley & Sons Ltd publishers as a textbook stand in to review the foundational technical knowledge a CSO course would need to include. The team also developed outlines for the topics and collaborative learning experiences.

When it comes to the structure, as previously stated, the CSO course is being built using IMPACT's supplemental model. Therefore, on the side more familiar to the students there are two hours per week of the traditional lecture format. These two hours are to be used to provide background knowledge and scaffolding for the learning activities. An additional two hours are to be devoted to those student-centered learning activities. Some activities are shorter and focused on a topic for the week such as the acquisition and use of the correct industry-specific terminology and acronyms. Others are longer and provide the students a problem to solve as a team. One possible activity is the planning of a mission where students must determine equipment, supplies, orbit, and duration of a launch of payload to the International Space Station.

### **Outcomes**

As part of the development course, the team established outcomes that are in alignment with multiple needs. First, are the AET program outcomes which focus on knowledge application in both a hands-on and applied manner, abilities to conduct and interpret tests, design processes, communication skills, professional responsibility, global citizenship, and continuous improvement. Second, outcomes need to meet is that from the commercial space industry. The industry has jobs to fill with people who are committed, focused, and knowledgeable about the commercial space industry. Additionally, the students should be fully functioning employees immediately upon hiring, but also have enough knowledge and skills to be promotable. The goal is to provide quality hires to companies, not those who need significant further education and training. Lastly, is to continue to meet ABET-ETAC accreditation requirements. This course and any future courses are part of an ABET program and outcomes should be connected to ABET-ETAC outcomes.

Creation of any course or program requires the development of outcomes with a measurable way to ascertain success in meeting those outcomes. In addition, for Purdue there is a requirement to align with the outcomes of ABET-ETAC so that it immediately may fit into the AET program. ABET-ETAC accreditation for Engineering Technology consists of 11 outcomes that are typically referred to as the a-k. There is no expectation that this single course can meet all the ABET requirements. At this time, the intent is for this first course to address these five outcomes specific to commercial space:

- Ability to demonstrate knowledge of types of spacecraft, launch methods, propulsion methods, and assembly philosophies in the context of the space vehicle lifecycle.
- Ability to demonstrate the application of physics and mathematics to the estimation of resource requirements to build a spacecraft section.
- Ability to function effectively as a team member or leader to complete a team project to explore and explain new space technologies and materials.
- Ability to identify areas of competence needed in space careers and paths for acquiring those competences.
- Ability to use appropriate industry-specific vocabulary and identify the technological breakthroughs in the history of space exploration.

In table 1 below, the course outcomes are mapped to the ABET-ETAC outcomes and objective measures for the course outcomes are proposed. This course not only has a significant focus on the technology and science of space programs, but also focuses on industry knowledge, planning, and leadership abilities of the students. Expectations for the course, though high, are obtainable.

Table 1: Initial Commercial Space Operations Course mapped to ABET outcomes

<b>ABET Outcomes</b>	<b>Space Operation First Course Outcomes</b>	<b>Objective Measures of Course Outcomes</b>
An ability to select and apply the knowledge, techniques, skills, and modern tools of the discipline to broadly-defined engineering technology activities	Ability to demonstrate knowledge of types of spacecraft, launch methods, propulsion methods, and assembly philosophies in the context of the space vehicle lifecycle.	70% of the students will correctly identify terms and technologies used in space vehicle life cycle.
An ability to select and apply a knowledge of mathematics, science, engineering, and technology to engineering technology problems that require the application of principles and applied procedures or methodologies	Ability to demonstrate the application of physics and mathematics to the estimation of resource requirements to build a spacecraft section.	70% of the students will correctly estimate the number of materials required to build a spacecraft structure, its mass, and thrust requirements.
An ability to function effectively as a member or leader on a technical team	Ability to function effectively as a team member or leader to complete a team project to explore and explain new space technologies and materials.	70% of the students will achieve a peer review score of at least 4.0 out of 5.0 by the end of the project that spans six weeks (on a Likert-type scale from 1 to 5, where 5 is highest).
An understanding of the need for and an ability to engage in self-directed continuing professional development	Ability to identify areas of competence needed in space careers and paths for acquiring those competences.	70% of the students will prepare a competence map that contains at least five competences and identify at least three specific paths to acquire those competences
A knowledge of the impact of engineering technology solutions in a societal and global context	Ability to use appropriate industry-specific vocabulary and identify the technological breakthroughs in the history of space exploration.	70% of the students will score 80% or higher on a written essay about a technological breakthrough. Or 70% of the students will be able to correctly place 90% of the specific technologies along a historical timeline of space exploration.

Based on the work completed by the development team, the experiences of students and faculty in this course, and informal feedback from the commercial space industry; a pilot version of the course is to be offered in the Fall 2017. Once that first pilot version of the course is completed, it is modified to better reflect the needs and outcomes of the industry. Another independent study with established curriculum is to be offered Spring 2018. The course development team plans to formally propose the course for inclusion in the catalog beginning with Fall 2018.

The planned phased progression is to 1) pilot this introductory course, 2) propose, develop and teach three additional courses for a minor, and 3) formally propose a minor in commercial space operations. The timeline for the progression depends on industry and student demand, and resource availability from the university. The intent is that at all phases, for the commercial space operations curriculum be part of the existing AET program. In addition, as the FAA develops requirements for commercial space technicians, that these federal requirements be included as well.

Though the timeline is dependent on many variables, assuming success, a preliminary timeline for the course and future CSO minor is illustrated in figure 1 below.

Figure 1. Preliminary timeline

	CSO Course #1	CSO Course #2	CSO Course #3	CSO Course #4	Minor
Spring 2017	Develop				
Fall 2017	Pilot	Develop			
Spring 2018	Firm	Pilot	Develop		
Fall 2018	Included in catalog	Firm	Pilot	Develop	
Spring 2018		Included in catalog	Firm	Pilot	
Fall 2019			Included in catalog	Firm	Propose minor
Spring 2020				Included in catalog	
Fall 2020					Minor established

## **Challenges to establishing new programs**

Establishing a new program is not without its challenges. The establishment and maintaining of required credit hours are something every program faces due to the general reduction in required hours over time. Additionally, the financial hurdles to overcome in the establishment of any AET or CSO program are not insignificant. Purdue feels it is in a fortunate situation to overcome both of these challenges because of their ABET accreditation, FAA oversight, and an already established similar program.

The ABET credit hour requirements and program content have historically been the standard deferred to by academic management, higher education bodies, and state governmental legislative bodies. Due to academic oversight bodies applying pressure to reduce the number of credit hours required for B.S. in engineering have decreased by over 40 credit hours; additionally, hands-on laboratories for engineers were eliminated [19]. Over this same period, the federally regulated aviation technician programs, with their mandated numbers of required education hours, topical areas, and performance level requirements, remain constant. So where economic and political pressures have forced the content of B.S. programs to be reduced over the decades, the content of the FAA programs have remained relatively constant. While the merits of Federal mandates of academic programs and standards have both protractors and detractors, in this case, these standards have helped to support the engineering technology B.S. program content from further educational content reductions.

An aeronautical engineering technology program requires dedication and resources to the art and technology of aircraft construction, maintenance, and repair. Included in this program are projects in airframe and powerplant maintenance, development of testing techniques, technical communications, and professional development. This concentration of study provides an understanding of systems and processes that are critical not only for maintenance, but for program management, applied engineering, project planning, and resource allocations. The Purdue AET program has proven to be successful in developing graduates in careers that span the spectrum from fabric wings to commercial space. The creation of this kind of program is very expensive and capital intensive to start from scratch. The AET program at Purdue is estimated to have between \$15M and \$20M in aerospace assets used exclusively for student education. This capitalization is the result of over 40 years work by a dedicated and creative faculty, who frugally and continually build the program slowly over time. When it came time to move the Purdue program to an engineering technology program, the extensive available resources gave this program a unique edge that other schools typically do not have. To create a new program with this level of technical resources is cost prohibitive for the clear majority of technology programs.

## **Conclusion**

The challenges in achieving a viable commercial space industry are numerous. Engineering technologists are needed to bridge the gaps between engineers and technicians. While there are already specialized education programs for FAA A&Ps and for ABET-ETAC AETs, there is the need for the development of a program attuned to the needs of commercial space. The developers of a potential commercial space degree program at Purdue focuses on bringing the



same level of integration of engineering and professional development to a commercial space program as it does to its current AET program.

Space programs are different from aviation programs with different flight environments, materials, fuels, and processes, however, there are similarities as each program produces engineering technologists prepared to turn designs into a practical operational reality. The method of accomplishing that is the same: learn the details of the hardware and processes, and facilitate making designs become a reality and operations happen.

The course the developers created is based on the technologies that are specific to the commercial space industry operation and support functions such as the following: fuels and propulsion, navigation and guidance, mission assurance, and vehicle assembly and integration. Additional focus is placed on the importance of vocabulary so students can converse with coworkers about the history and technology of the industry using the unique language of the industry. The first step in course creation is the establishment of course outcomes.

The first established course has multiple outcomes that connect to some of the ABET-ETAC accreditation outcomes. Those outcomes are established with an eye both to industry needs and to a broad foundational base for the students to continue to build upon in their careers as well as connecting to ABET-ETAC outcomes. The five outcomes, without the associated ABET-ETAC outcomes and measures, are listed below.

- Ability to demonstrate knowledge of types of spacecraft, launch methods, propulsion methods, and assembly philosophies in the context of the space vehicle lifecycle.
- Ability to demonstrate the application of physics and mathematics to the estimation of resource requirements to build a spacecraft section.
- Ability to function effectively as a team member or leader to complete a team project to explore and explain new space technologies and materials.
- Ability to identify areas of competence needed in space careers and paths for acquiring those competences.
- Ability to use appropriate industry-specific vocabulary and identify the technological breakthroughs in the history of space exploration.

The course is developed from the ground up to include goals of the IMPACT program. By developing courses that are informed by the IMPACT program, the faculty may provide students with an enriching learning environment focused on student-centered learning. This allows students multiple opportunities for peer and instructor learning mimicking the workplace environment where teams work together toward a common goal learning and teaching each other along the way.

Development of the course with significant student input was completed in Spring 2017. Using the materials created during that semester, and further developed by the course instructors, the pilot version of the course will be offered in the Fall of 2017. All the information needed for a successful program cannot be accomplished in one semester. Therefore, an additional course or courses can be subsequently be developed to provide more depth and additional information. If

successful, the final program for a minor in commercial space operations is expected to consist of four courses.

The developers hope that someday their program can provide additional career avenues for graduates and better-equipped employees for the commercial space industry. Resulting in well-educated employees that are part of future commercial space companies that can someday take us all to the stars.

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