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Preparing the Future Aircraft Design Workforce: Filling Knowledge Gaps Using Engineering Design Tools

Melissa Lepe, University of California, Irvine

Melissa Lepe is a second-year Ph.D. student at the University of California-Irvine. Her research interests include aircraft sustainability, aeroacoustics, and engineering education. Through her work at the UCI Aircraft Systems Laboratory and the Buswell Research Lab, she has worked on merging her interests in aviation and education to promote inclusivity, equity, and diversity in the aerospace field.

Prof. Natascha Trellinger Buswell, University of California, Irvine

Natascha Trellinger Buswell is an associate professor of teaching in the department of mechanical and aerospace engineering at the University of California, Irvine. She earned her B.S. in aerospace engineering at Syracuse University and her Ph.D. in engineering education at Purdue University. She is particularly interested in inclusive teaching conceptions and methods and graduate level engineering education.

Jacqueline L. Huynh, University of California, Irvine

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Abstract

Upholding the current and projected growth in the aerospace industry starts in the classroom. Preparing students to engineer the future through quality courses is the fundamental mission of many universities. This study highlights efforts made to equip students for future aircraft design by creating a senior class project that incorporated computer programming and computer-aided design tools, while also addressing knowledge gaps through course-supporting modules. The research was prompted by observations of aerospace engineering students at the University of California-Irvine (UC Irvine) struggling to integrate design tools into their final projects. It was noted that approximately half of the aerospace engineering students in the study had not been introduced to fundamental computer-aided design, as it was not included in their program requirements. The study assessed the impact on student confidence in using these tools before and after the course, aiming to better understand their experiences and create course materials that more accurately reflect the challenges of aerospace engineering design. A backwards design approach was employed in the development of the modules, and a thematic analysis was conducted on student reflections. The analysis underscored the importance of challenging projects supplemented with supporting modules in gaining insights into engineering design tools for aircraft design.

Introduction

With the fast and ever-changing growth in the aerospace industry, it is necessary to meet the demands of the industry with individuals who are capable of meeting the rapidly changing demands and innovations [1], [2]. Amongst these changes, in commercial subsonic tube-and-wing transports, we see the emergence of aircraft designed with slimmer and longer wings designed to reduce the drag caused from airflow over the body while improving overall fuel efficiency. Besides the wings, aircraft fuselages, or the bodies that carry the payload, are undergoing design changes that increase internal space and allow for varying cabin configurations while incorporating improvements in aircraft performance and alternative fuel and propulsion systems. Aluminum has long been a common material in aircraft; however, the introduction of composites and lighter materials is proposed as a means to minimize fuel consumption and its associated emissions. An increase in smaller aircraft in the form of very light jets and unmanned aerial vehicles are currently gaining traction and are estimated to play an important role in air-taxi operations and eventually may be competitive with automobiles for regional transport. In addition to changes in design, materials, fuel and engines, we see technological advancements in the production stage resulting from additive manufacturing techniques [2].

In accordance with these industrial trends and changes in the aviation sector, engineers must be aware of how all phases of the aerospace system lifecycle operate. They should have the ability to formulate customer needs into a concrete problem definition to develop an appropriate business and technical plan. Subsequently, they must be able to design drawings, algorithms and any relevant systems needed in their outlined mission. Upon design, they should be able to implement their ideas into a physical or modeled product with hardware, manufacturing, coding, and validated measures considered. Finally, they should be capable of operating their product such that it delivers its intended proposition while accounting for its maintenance, potential upgrades, recycling, and disposal of the product once reached the end of its life cycle [3]. Additionally, the aerospace industry continues to expand international collaboration amongst projects. For example, one of the largest commercial aircraft, the Airbus A380, has design offices, engineering centers, and production facilities located throughout Europe and North America with some larger sites located in France, Germany, Spain, and the United Kingdom. As a result, in addition to being equipped with technical knowledge, engineers must be prepared to work in a diverse collaborative setting. Some identified skills that stem from such criteria include: creativity, innovation, problem-solving, decision making, metacognition, communication, collaboration, information literacy, technology literacy, citizenship, responsibility, cultural awareness, etc. [2].

Understanding the industry expectations and goals for its future engineers is essential in preparing students at the undergraduate level to successfully enter the working sector equipped with the skills, knowledge, and confidence to meet industry demands. As Bil, Hadgraft, and Ruamtham observe, the "…American industry needs the engineers who are able to solve open ended problems and produce quality design work whilst engineers schools are producing great scientist but average engineers"[4]. Studying student experiences and expectations provides insight into their perspectives on the aviation industry and the skills they believe are valued most. Identifying common pitfalls and misconceptions can be a way to ensure students feel prepared to enter the workforce. Student expectations have been shown to affect performance even when their abilities are deemed to be on par with their peers. Students with higher expectations have been shown to have a higher level of performance in comparison to their peers with lower expectations despite no notable differences in abilities between students with higher and lower expectations[4], [5]. Providing students with alignment between their coursework and industry practices increases their experience as engineers, their retention, and allows them to actively work towards meeting the identified industry expectations.

The implementation of design is essential for engineering students to learn from concrete application of the abstract and theoretical knowledge learned in their courses. Constructivism theory is based on the belief that learners actively build or construct their own knowledge by testing concepts, applying prior knowledge, and reflecting on their experiences and outcomes to develop their learning [3]. As a result, Crawley outlines the importance of creating experiences for students to exercise designs and their implementation in order to help them gain technical skills while also gaining a deeper understanding of fundamental concepts [3]. Design-implementation is an important step in reinforcing student understanding and as a result, can often be found to be a major milestone in the completion of an engineering degree. Every year, graduating engineering students are meant to showcase the skills and knowledge they have acquired through a culminating senior design project such as aircraft design for aerospace engineers. Critical, analytical, and assessment skills are developed throughout the undergraduate experience and are essential in developing problem-solving engineering qualities that extend beyond a single course or project [6].

Project-based learning is often integrated in culminating projects as a means for students to participate in research that challenges their acquired skillset, create models based on design constraints and work towards addressing challenges that come from open-ended questions [7]. However, our team is interested in understanding and addressing what happens when students are not introduced to fundamental components of engineering design prior to reaching such comprehensive projects?

The following scenario was the reality of several aerospace engineering students at our institution who were struggling to complete their aircraft design senior project. The project involved an extensive use of computer programming and computer-aided design (CAD) to accomplish. However, a handful of students were walking into their senior design class without having any formal instruction on CAD tools. While the Accreditation Board for Engineering and Technology (ABET) highlights the overarching goals for engineering students as well as aerospace engineering students, CAD is not explicitly listed [6]. This is reflected at our institution, where an introductory CAD course is required for students in mechanical engineering but is not outlined in the aerospace engineering curricula. An internet search of the twenty best undergraduate aerospace engineering programs in the United States highlighted that this was not unique to our institution. Studying the top twenty programs outlined by the U.S. News & World Report in 2024, courses in the aerospace engineering curricula were classified as explicitly requiring a CAD course or not based on publicly available course descriptions. In fact, 50% of the institutions involved in this search also did not include a CAD specific class in their aerospace engineering programs.

As noted by Jaeger-Helton and contributing authors, developing unique solutions such as those introduced in capstone projects often requires multidisciplinary engagement that is not often included in traditional lectures or even experimental classrooms [8]. Understanding how deep learning occurs is fundamental in addressing how students can best be prepared for such prompts.

The following study was implemented during students' aircraft performance course to promote active learning of course topics while addressing existing knowledge gaps necessary for the completion of their degree. The course was redesigned to include an aircraft drag calculator project that was representative of processes students may face in academia or industry. The project challenged students' understanding of aircraft performance while allowing them to explore computer programming and CAD as design tools intended to obtain a representative analysis of their model.

In addition, students were provided modules designed to mitigate existing knowledge gaps and discover how these design tools can be used for aircraft applications. Students' preconception and confidence in these design tools was assessed to understand the impact of implementing project-supporting modules conducive to future projects in academia and industry.

Project Overview

As highlighted by ABET, senior culminating projects are expected to have high levels of critical thinking, research skills, inductive and deductive reasoning to design, validate, and present their findings. All of which are critical skills in engineering [6], [9]. However, with limited prerequisite practice in their courses, students have not developed the skills necessary to successfully produce and optimize an aircraft prototype given a mission profile. MATLAB® and SOLIDWORKS® will be highlighted as the main computer-programming language and CAD program as licenses are provided to all engineering students at our institution. As a result, it is expected to be their main language of proficiency. However, it is notable that an application to engineering problems is not always emphasized when taught. Without experience in CAD, aerospace engineering students face a disadvantage and lack preparation when expected to model their culminating senior design project. In efforts to support students in developing and practicing the necessary skills to obtain a higher level of thinking through creating [10], a drag calculator project was developed to incorporate both MATLAB® and SOLIDWORKS® while providing students with supporting modules as a form of active project-based learning. The preliminary study involved two cohorts of senior engineering students and took place during their aircraft performance course, which is a prerequisite to the aircraft design capstone course.

Project Description

Aircraft performance studies how different factors such as weight, atmospheric conditions, climb rate, configuration settings, etc. and governing forces acting on an aircraft (lift, gravity, drag, thrust) affect the performance of an aircraft. As defined by the Federal Aviation Administration (FAA), “performance is a term used to describe the ability of an aircraft to accomplish certain things that make it useful for certain purposes” [11]. For example, the ability to carry heavy loads while traveling long distances at a quick speed is a performance parameter that is of importance to airlines. Factors that affect performance the most include: takeoff and landing distance, rate of climb, ceiling, payload, range, speed, aircraft maneuverability, stability and fuel consumption. The aerodynamic relationships formed from studying forces on the aircraft while it interacts with air help define power and thrust requirements at different flight stages and conditions.

The different components of an aircraft play a critical role in performance. Figure 1 showcases an overarching view of the major aircraft components. The jet engine is the main propulsion system and is stored inside the nacelle, which is connected to the wing via pylons. The fuselage is the main body of the aircraft and is the designated area to carry passengers and cargo. The wing of an aircraft is shaped to help create a difference in pressure between the top and bottom of the wing that generates lift. The vertical and horizontal tail are stabilizing systems that help control the pitch and yaw. A rolling motion can be created using the ailerons located on the wings. To maintain steady level flight, the force of lift must be equal to the aircraft weight, and the thrust produced by the engines must be equal to the aerodynamic drag force. All outlined components are studied to understand how performance is impacted since the configuration of an aircraft has a great impact on forces such as drag. In particular, the induced component of drag is a strong function of the wing aspect ratio and the lift produced, while the parasitic component of drag is a strong function of the area of the surfaces that are in contact with the airflow, or the "wetted area". By minimizing the effects of drag and simultaneously maximizing the effects of lift, we can achieve a system that operates more optimally.[12].

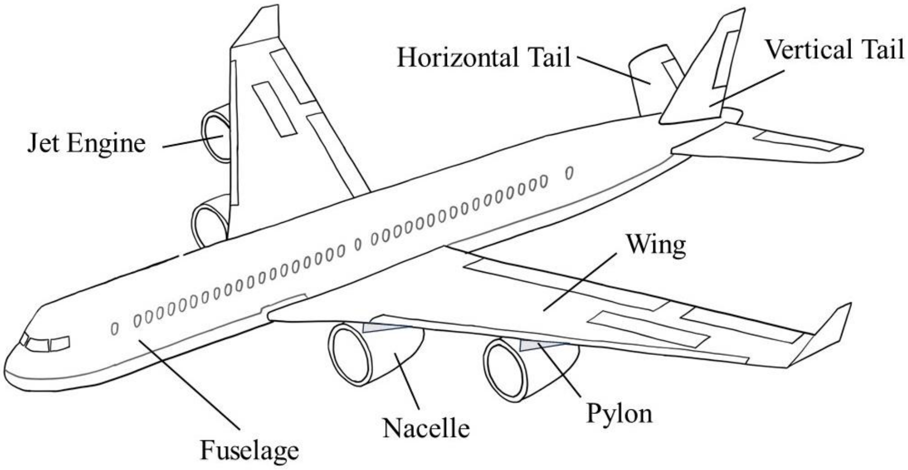


Figure 1. Aircraft Components.

The drag calculator project was introduced to students with the objective of showcasing how their knowledge of aircraft performance could be used to understand the effects of drag over an airplane as it is a fundamental step in aircraft design. The project incorporated topics covered in their course, discussion sessions and assignments while also challenging them to use design tools such as MATLAB® and SOLIDWORKS®. Table 1 showcases the high-level learning objectives of the project as introduced to the students.

Table 1 Drag Calculator Project Introductory Description

One of the most important goals in aerodynamics is to calculate the drag over an airplane. Interestingly you will find (in future design courses) that designing an airplane starts with quantifying the drag over it against the lift. Moreover, drag is not important only for design, it is important for finding the operating condition given an airplane configuration. In this project, optimum operating conditions is selected to be the point where Lift to Drag ratio is maximum.

Each student was required to use MATLAB® and SOLIDWORKS® for this project. They were presented with a table containing airplane geometry that was to be used to perform a component-by-component drag analysis as shown in Table 2. Students were given a set of standard values (shown numerically) and unique parameters (listed as a variable) and provided with two different sets of airfoil coordinates used at the root and tip of the wing. Students were required to construct a lofted wing using SOLIDWORKS® to obtain the remaining necessary parameters to complete their drag analysis. By using SOLIDWORKS®, students were able visualize an accurate representation of their wing to obtain a precise wetted area. Thus, an accurate representation of parasitic drag can be obtained as it is a function of the aircraft shape and airflow across the exposed aircraft surfaces.

Table 2 Airplane Geometry for Drag Calculator Project

Component	**Subcomponent**	
Wing	Span	b_{wing}
	Planform Area	SOLIDWORKS®
	Average thickness/Chord	SOLIDWORKS®
	Sweepback angle	$\Lambda_{c/4,wing}$
	Taper ratio	σ_{wing}
	Centerline Root Chord	$c_{r_{o,wing}}$
	Wing area covered by fuselage	SOLIDWORKS®
	Wetted Area	SOLIDWORKS®
Fuselage	Length	L_f
	Diameter	D_f
	Wetted Area	SOLIDWORKS®
Vertical Tail	Exposed planform area	$161\ ft^2$
	Thickness/Chord	$0.09ft$
	Sweepback	43.5°
	Exposed Taper Ratio	0.8
	Exposed Root Chord	$15.5\ ft$
Horizontal Tail	Exposed planform area	$261\ ft^2$
	Thickness/Chord	$0.09\ ft$
	Sweepback	31.6°
	Exposed Taper Ratio	0.35
	Exposed Root Chord	$11.1\ ft$
Pylons	Total wetted area	$117\ ft^2$
	Thickness/Chord	$0.06\ ft$
	Sweepback	0°
	Taper Ratio	1
	Chord	$16.2\ ft$
Nacelles	Total wetted area	$455\ ft^2$
	Effective fineness ratio	5.0
	Length	$16.8\ ft$

Student drag calculators had to be written in the form of a MATLAB® script over varying velocities to produce the plots outline in Figure 2. The effects of velocity on induced, parasitic, and total drag are explored. Total drag is defined as the sum of the parasitic and induced drag for a subsonic vehicle. Additionally, plot digitization was required to calculate the skin friction coefficient, form factor, body form factor, and airplane efficiency factors using the plots outlined in Shevell [12]. Students were presented with course supporting modules designed to assist them with their project.

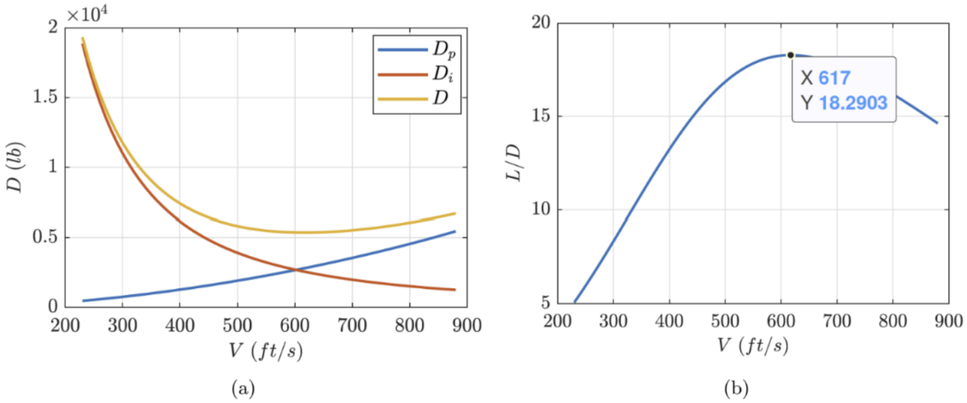


Figure 2. Sample drag project plot deliverables where (a) models the parasitic, induced, and total drag trend versus velocity and (b) represents the lift to drag ratio behavior defining the operating condition at L/D_{max}.

Development of Course Modules

Each module was designed to support students through a scaffolding process such that relevant examples and methods were presented, but students had to apply this knowledge to their own project. The creation of these materials was done using backwards design development [13] such that the learning objective and end goal was used to determine critical information, assessments, and evaluation. The learning objectives outlined in Table 3 were used to determine the necessary content for each of the three supporting materials developed: a SOLIDWORKS® Wing Layout, MATLAB® Curve Fitting, and MATLAB® Support Guide.

Table 3 Learning Objectives for Course Supporting Materials

Module	Learning Objectives
SOLIDWORKS® Wing Layout	• Identify the span, planform area, taper ratio, root and tip chord, and centerline root chord on a two-dimensional and three-dimensional wing • Examine airfoil coordinates from airfoil coordinate database • Organize airfoil coordinates into translatable SOLIDWORKS® curve parameters • Construct aircraft wing given unique parameters using SOLIDWORKS® to perform a surface loft • Solve for the planform area, wetted planform area, thickness over chord ratio of their unique wing
MATLAB® Curve Fitting	• Recognize how to obtain Curve Fitting Toolbox and other MATLAB® applications • Identify the steps necessary to take an existing digital plot and use a numerical data extraction tool to obtain its dataset • Distinguish and contrast the plotting methods that best represent their dataset and export a representative function of their curve using the MATLAB® Curve Fitter toolbox • Construct a method for data interpolation by comparing some of the presented processes

MATLAB® Support Guide	- Recognize how to prepare to write a code, the relevant MATLAB® windows, folders, and pathways - Identify how MATLAB® processes loops and how arrays must be used with appropriate operators - Organize outputted data using plots that easily reflect outcomes using appropriate titles, legends, colors, fonts, and chart styles - Implement debugging techniques by identifying some commonly outlined errors and strategies to apply before, during, and after wiring a code to facilitate the process

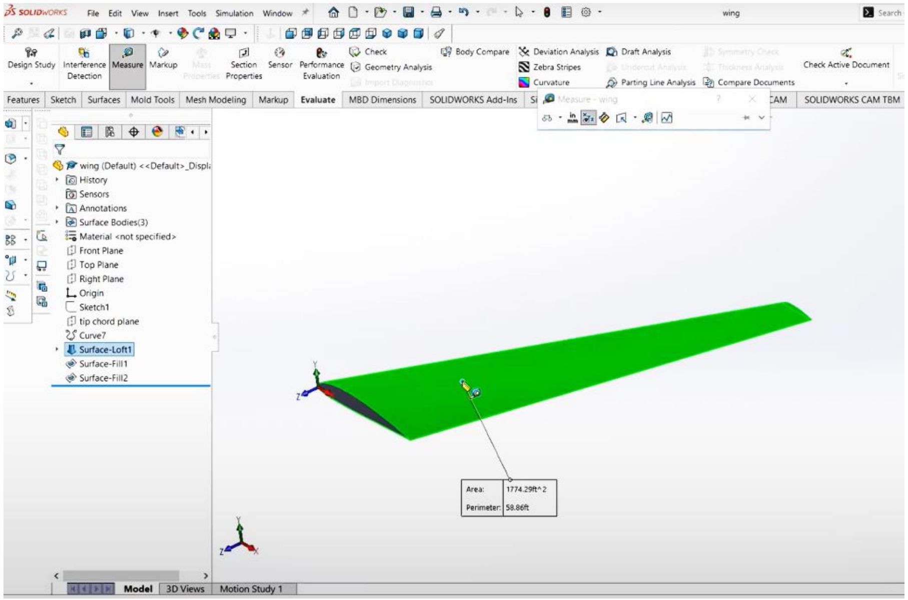
The SOLIDWORKS® Wing Layout and MATLAB® Curve Fitting Modules were presented via a video format while the MATLAB® Support Guide was shared as a digital document. Each module is described in more detail below.

SOLIDWORKS® Wing Layout

Through this module, students were presented with a two-dimensional sketch of a wing where main components such as span, root chord, and quarter chord, etc. were defined and located. The relationship between these parameters was explained. The process of sketching from given parameters was showcased for arbitrary dimensions in a two-dimensional manner that would be used to set the framework for lofting a wing in SOLIDWORKS®.

Students were introduced to an airfoil database [14] containing coordinates for common aircraft airfoils and widely discussed National Advisory Committee for Aeronautics (NACA) airfoil series covered in their course. Reading and reorganizing airfoil coordinates is an essential step in the process of lofting a wing using SOLIDWORKS®. The significance in placement was related to the X,Y,Z coordinate system in SOLIDWORKS® and students were tasked to identify the proper rearrangement for their given cross section. Understanding how to read, organize and apply their knowledge when creating their own designs, students are expected to be able to transfer this knowledge on different wing configurations, sizes, and orientations.

As previously mentioned, aerospace engineering students in this study are not required to take a course in SOLIDWORKS® or other CAD programs. As a result, the video made sure to describe the essential extruding, cutting, and lofting applications in a step-by-step process. The two-dimensional sketch was recreated on a SOLIDWORKS® plane to outline construction lines that allowed students to visualize the relation between their prior knowledge in a two-dimensional space with a three-dimensional perspective. In addition, some of the basic SOLIDWORKS® evaluation tools were presented and used to demonstrate the wetted surface area of a wing as shown in Figure 3. The construction and evaluation procedures outlined were applied to students' unique aircraft configurations to determine their planform area, average thickness to chord ratio, wing wetted area, and fuselage wetted area. With these tools, students were expected to identify and evaluate the components needed from their lofted wing to complete their drag analysis calculations.



Area: 1774.29ft^2
Perimeter: 58.86ft

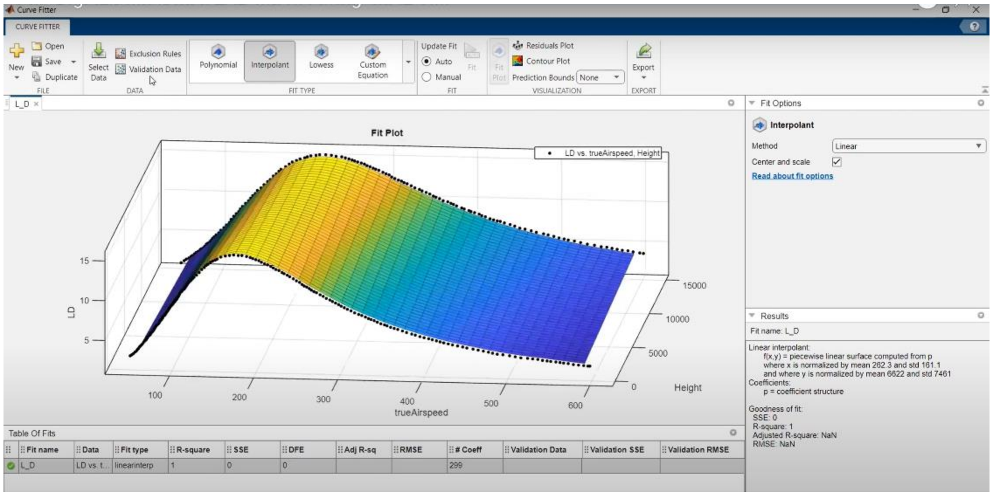
Figure 3. Measuring the wetted area of a lofted tapered wing using SOLIDWORKS® measuring tool.

MATLAB® Curve Fitting

The following video was created to introduce students to the concept of plot digitization as a method to develop mathematical representations of existing plots that can later be applied to data analysis - a common practice in reverse engineering. Students were referred to an online semi-automated tool [15] to obtain numerical data from their respective plots. The use of other existing numerical extraction tools was not discouraged. An example case was exhibited using a multiple line plot representing the lift over drag ratio at different altitudes as a function of true airspeed. The following case was selected as a form of guided practice to reinforce students' learning of a new skill.

The presented exercise was designed to incorporate all necessary components for students to identify how to best apply the showcased methods to their own plots. To find a representative mathematical function of the extracted data, students were referred to the Curve Fitter toolbox in MATLAB® where they were also shown how to access apps from the Mathematica library. Research questions were presented to guide students on how the presented problem was assessed and thus, guide the type of questions they should consider in their own analysis. The best curve fit is subjective to the dataset in question, and as a result, is necessary to demonstrate the importance of analysis and interpretation of the various mathematical representations to confidently apply in their project.

Additionally, complex multiple line plots with two inputs and one output are likely to require interpolant calculations. Using the dataset from the presented problem, a demonstration of multiple representations was provided to instill the various approaches an individual may choose to take when writing a code. These included interpolation via the construction of a *cfit* object from a three-dimensional surface plot as shown in Figure 4, and loop operations through *if* statements.



Interpolant

Method: Linear

Center and scale ☑

Read about fit options

Fit name: L_D

```
Linear interpolant:
     f(x,y) = piecewise linear surface computed from p
     where x is normalized by mean 262.3 and std 161.1
     and where y is normalized by mean 6622 and std 7461
Coefficients:
     p = coefficient structure

Goodness of fit:
  SSE: 0
  R-square: 1
  Adjusted R-square: NaN
  RMSE: NaN
```

Table Of Fits

	Fit name	Data	Fit type	R-square	SSE	DFE	Adj R-sq	RMSE	# Coeff	Validation Data	Validation SSE	Validation RMSE
✓	L_D	LD vs. t...	linearinterp	1	0	0			299			

Figure 4. Sample Interpolant Method using MATLAB® Curve Fitter Toolbox to construct a *cfit* object from two inputs and single output via a surface plot.

MATLAB® Support Guide

Aerospace engineering students at UC Irvine are expected to take MATLAB® within their first year of undergraduate coursework and transfer students can satisfy this requirement by taking a course in approved programming languages. Unless constantly used and applied, concepts may not have been transferred from working memory into long-term memory. Memory involves reconstruction and is influenced by the learner's environment such that it impacts how future knowledge is integrated [16], [17]. While expected to be proficient in MATLAB® by their senior year, students may have difficulty applying past knowledge without having adequate practical experience from the time the course was taken up until required to do so in their senior design project.

The following module was intended to serve as a refresher for concepts that may have been covered in introductory programming courses while also incorporating practical recommendations on how to write a code to minimize errors and debugging difficulties. It was designed as an interactive manual such that students could click on hyperlinked tables and figures relevant to specific questions or topics they were seeking. Aircraft performance problems discussed in lectures were translated into MATLAB® codes that students could copy and paste into their MATLAB® main or command window to run as shown in Figure 5.

```
% For Loop Example Code
% The following code uses a for loop to calculate the induced drag
% coefficient over a range of aspect ratios
cl = 1.5; %coefficient of lift
e = 0.8; % oswald efficiency factor
for AR = [6:12];
    Cd_i = cl^2/(pi*AR*e); %induced drag coefficient
    formatSpec = 'CDi = %f when AR = %f \n';
    fprintf(formatSpec,Cd_i,AR) %note: fprintf inside loop displays all loop outputs
end
```

Figure 5. Sample code provided in MATLAB® Support Guide calculating induced drag over a range of aspect ratios.

Students would be reviewing or in some cases, learning for the first time, essential concepts for data processing and post-processing analyses. As a result, a section of the manual provided debugging techniques and practices prior to writing, during the process of writing the code, and after finalizing the code. Common errors they may encounter were addressed and a series of recommended steps were outlined. Lastly, students were equipped with useful features in MATLAB® that could be used to review sections of code for the purposes of facilitating the debugging process.

Evaluation Methods

To evaluate the presented modules as well as student's perception of their learning and confidence using the outlined design tools, students were surveyed at the beginning of the course and after completion of the drag calculator project. The provided surveys included an attitude scale to measure student self-perception and confidence performing specified MATLAB® operations through a Likert scale [18], [19]. The pre-assessment was used to determine students' past experiences using MATLAB® and SOLIDWORKS®. The post-assessment received students' input on the clarity and perceived value of the supporting materials using a Likert scale. The post-assessment also asked students to reflect on their experiences during the course project and supporting modules. Their responses were analyzed via a thematic analysis. A cumulative of 197 survey responses was collected from both senior classes. From these responses, 166 answered both the pre-assessment and post-assessment. For analysis measuring changes in perception throughout the course, only students who answered both assessments were included. The data was analyzed both separately for each cohort and collectively to identify trends.

Results and Discussion

The pre-assessment was designed to better understand students' relation and prior experiences to MATLAB® and SOLIDWORKS®.

Students surveyed were asked to identify their perceived confidence: using loops (for, if, while), importing data, calling functions, curve fitting, and plotting in MATLAB®. The following operations were defined to be crucial to the completion of the drag calculator project and future senior design. As a result, assessing student's prior knowledge of these was used to gain an understanding of students' skillset as they perceived them. Loops, importing of data, plotting and functions are all topics covered in the required first-year introductory programming courses. Table 4 summarizes student reported values for the last time they used MATLAB® and SOLIDWORKS® for a course, project, or work. Most students reported using SOLIDWORKS® and MATLAB® within the last 6 months of taking aircraft performance. It is notable that students taking the course in Fall 2023 are returning to classes from summer break and a decrease in MATLAB® use reflects this timeline. However, it is interesting to note that the summer break did not affect student's use of SOLIDWORKS® when comparing Winter 2023 and Fall 2023 reports.

Table 4 Student Reported Last Use of SOLIDWORKS® and MATLAB®

SOLIDWORKS®							
	<3 months	3-6 months	1 yr	1.5 yrs	2 yrs	3+ yrs	Not used
Winter 2023 (% of 92)	45.7%	16.3%	10.9%	2.2%	5.4%	5.4%	14.1%
Fall 2023 (% of 78)	42.3%	24.4%	10.3%	5.1%	5.1%	1.3%	11.5%
Total (% of 170)	45%	19%	10%	4%	5%	4%	13%
MATLAB®							
Winter 2023 (% of 92)	64.1%	15.2%	9.8%	2.2%	5.4%	3.3%	0%
Fall 2023 (% of 78)	20.5%	47.4%	14.1%	5.1%	7.7%	3.8%	1.3%
Total (% of 170)	45%	30%	11%	4%	7%	4%	1%

The use of MATLAB® is prevalent throughout the year and suggests that despite most students taking an introductory programming course in their first year, it is to some extent being incorporated in other facets of their degree. Given the high number of students reporting using MATLAB®, it is surprising to see that a substantial number of students do not feel confident performing operations needed for their success in and out of the course. MATLAB® is an integral part of their engineering preparation, and as their survey results indicate, simply incorporating MATLAB® in the curriculum is not enough to support students in developing a deep understanding of these tools such that they can confidently apply them to build representative models for the purposes of aircraft design.

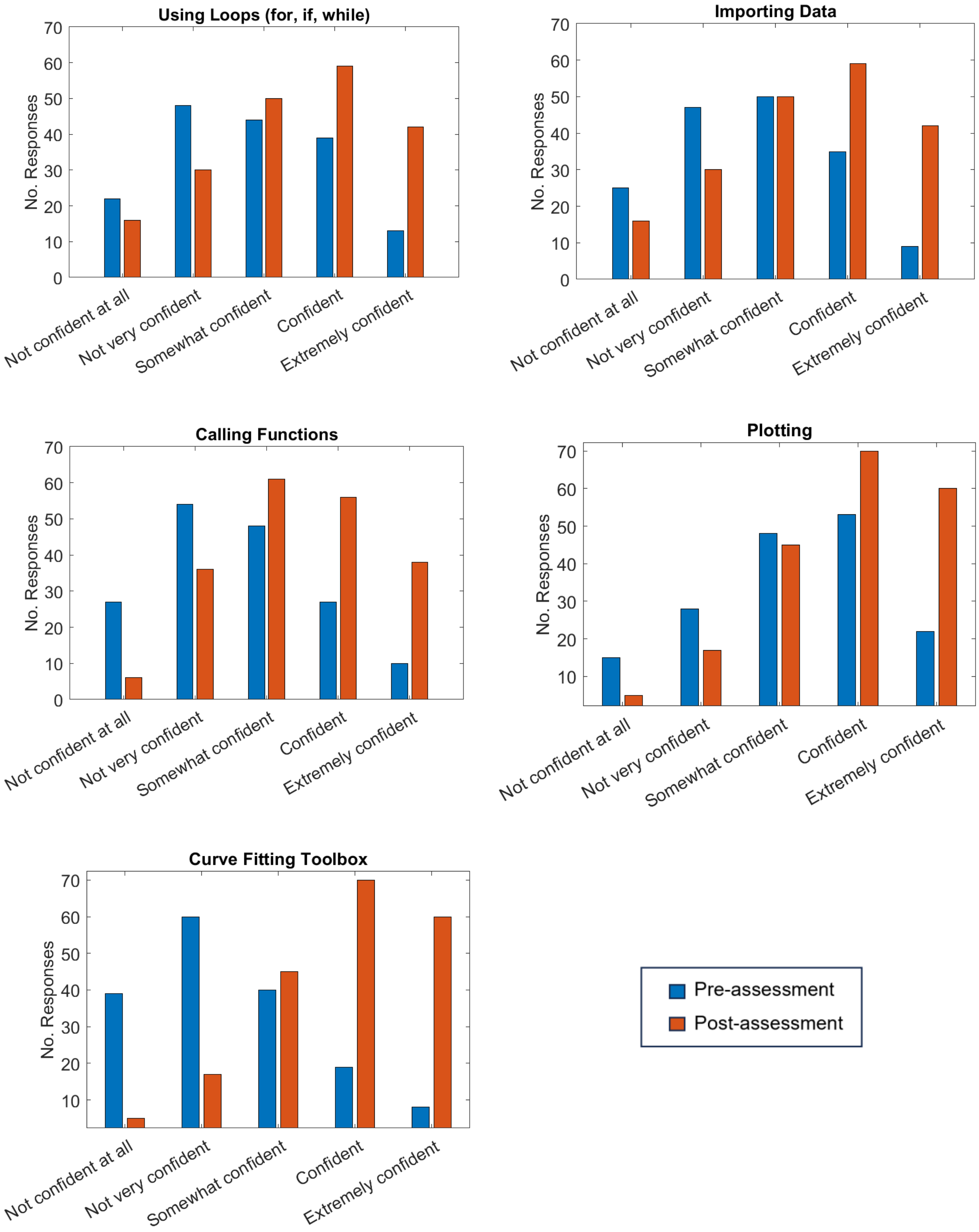


Figure 6. Comparison of student rated confidence in MATLAB® operations at the start of course and after completion of the design project.

Figure 6 summarizes students' perceived confidence prior to receiving the previously discussed supporting modules and completion of the drag calculator project and compares their change in confidence via a post-assessment survey. As can be seen, overall, students indicate an increase in confidence for every defined MATLAB$^{®}$ operation after completing the course project.

While it was evident most students had taken MATLAB$^{®}$ in the past as part of their required set of courses, the same could not be said about SOLIDWORKS$^{®}$. Currently, CAD is not outlined as a topic requirement in ABET for aerospace engineering and as a result, may be included as an optional technical elective. As previously mentioned, current program requirements at UC Irvine do not outline CAD as a required course in the aerospace engineering program. Thus, it is of interest to assess the magnitude of students in the classroom who had previously taken an introductory CAD course.

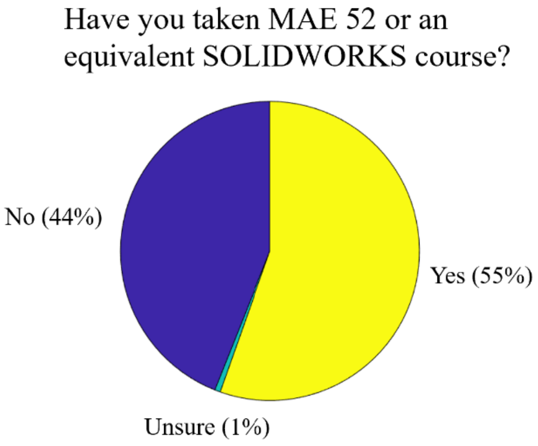


Figure 7. Total surveyed students' response to taking a formal SOLIDWORKS$^{®}$ course.

Figure 5 summarizes student responses to taking a formal SOLIDWORKS$^{®}$ course for all surveyed students (166 respondents). A formal SOLIDWORKS$^{®}$ course was not limited to the course offered at UC Irvine, MAE 52, and an equivalent course at another institution was deemed acceptable for the purposes of this survey.

We see that almost 50% of students report no formal instruction in the use of SOLIDWORKS$^{®}$ at a point in their educational trajectory where they are an academic term away from completing their senior capstone project. However, when comparing these results to those in Table 4, about 74% of students reported using SOLIDWORKS$^{®}$ for a course, project, or work within the past year. It is evident by their use that students are expected to use SOLIDWORKS$^{®}$ as part of their engineering coursework, but almost half of these students lack the fundamental development necessary for proficiency in its use- with up to 14% of them reporting never having even used it.

This is concerning when noting that "…advances in computing power, computational analysis, and numerical methods have also significantly transformed and impacted the way design is conducted, bringing new challenges and opportunities to design efforts…" [9] in the aerospace community. Design methods in aerospace engineering are heavily reliant on computational tools and the shift towards using more of these tools to model design constraints and optimize desired characteristics should thus be reflected in undergraduate aerospace design.

To form connections between their subject matter, professional interests, and ability to analyze and define methodology to approach ill-defined complex problems, it is necessary to emphasize learning in real-world situations. As noted by Blair, "the success of problem-based learning is contingent upon the design of good problems" [20]. To prepare students for cooperative and problem-based learning with the rigor expected in their senior capstone design projects, it is necessary to integrate their knowledge base with guided intuition into self-directed learning.

The value, growth, and impact of the highlighted project redesign and supporting materials was investigated via a thematic analysis on student's open-ended reflections. Table 5 summarizes the themes associated with students' responses and indicates the extent to which emerging themes were shared by different students. It is notable that although a total of 197 responses were accrued during the post-survey, only 131 students provided a reflection. The outlined percentages in Table 5 are thus in accordance with 131 students. The emergence of two prominent themes were identified. Student's responses indicated they gained insights during the project while also highlighting how the clarity of instruction and presentation of modules, support guides, project description, and deliverables was fundamental in their understanding and application of topics in their drag calculator.

Table 5 Emerging Themes from Student Reflection of Modules

Theme	Description	Student Responses (% of 131)
Recall	Students revisited past topics when using the modules	3.68 %
Clear Instructions	Students felt the modules were presented clearly and this aided in their understanding of the content	33.82 %
Attainable mastery	Students described feeling capable of mastering tools highlighted during the modules and felt they could complete the drag calculator project	6.62 %
Gained insights	Students listed specific tools and applications that were learned whilst completing the project	42. 65%
Unclear instruction	Students felt instructions were not clear and made it difficult to obtain	3.68 %
Transference	Students discussed how modules were used to gain understanding of material, but were capable of seeing how they applied to their own problems	8.09 %
Future Application	Students identified insight on how their new set of skills could be used in the future	6.62 %
Unnecessary	Students felt the presented modules were not necessary to complete the project	2.21 %

Implications

The following analyses were created in efforts to understand student's perception of their learning while assessing the effectiveness in which course-supporting modules and practical projects could be used to assist in developing skills necessary to their success in future coursework and professional development. Some essential outcomes that are applicable to other engineering programs include: the role of academic preparation in student confidence, the importance of self-directed project-based learning, and the value of defined learning objectives in project-development. By presenting challenging tasks to students while offering indirect guidance, students were provided with the requisite resources for problem-solving.

Additionally, developing a growth-mindset is crucial in overcoming challenging work. Theory of incremental intelligence is rooted in the understanding that intelligence is developable and can increase [21]. Thus, it is crucial for students, instructors, and institutions to intervene when academic setbacks arise. ABET has stated the importance in continual growth and development- a belief that should be rooted in all engineering coursework [6]. By preparing students for problem-based learning, they will actively work towards forming connections with prior knowledge, scaffolding new skills, and develop an intuition for the implications that must be considered in aircraft design [5], [20]. Developing meaningful connections via projects and application is an important part of learning that develops interest, motivation, and a deeper understanding of their subject matter [16], [20], [22].

With these takeaways, the limitations of the study must also be assessed. The study was conducted over the duration of an academic term, limiting its ability to assess the long-term retention and future application of students' skills, particularly in relation to their senior design projects, external courses, and projects. Furthermore, the observations and conclusions drawn are based solely on student-provided responses through a survey. While students were assured of the anonymity of their responses and encouraged to respond honestly, inherent limitations persist regarding the complexity and accuracy of their feedback. Moreover, the thematic analysis conducted includes only 66.5% of the total respondents, which may introduce a degree of sampling bias. It is noteworthy that the surveyed cohort experienced their initial exposure to computer programming during the peak of the pandemic. While this study does not account for external factors, it is important to acknowledge circumstances that could have influenced students' learning, memory, and retention abilities.

The present study aims to investigate how students' perceptions and retention evolve with the inclusion of the modules presented in this paper. Although not addressed in this study, the longevity of these course modifications over the course of an academic year is currently under assessment. The authors seek to gain insight into students' confidence, perceptions, and application of the presented materials within the aircraft design course. A focus group study of their experiences is expected to provide greater understanding of these topics.

Conclusion

A project design with supporting modules was introduced in student's aircraft performance course to help address some of the knowledge gaps addressed from not having a formal CAD course outlined in their curriculum. The project aimed to include MATLAB® and SOLIDWORKS® to help students master fundamental design tools necessary to successfully size, design, and optimize an aircraft. By analyzing student responses in a pre and post assessment, insights into the importance of well-defined projects, learning objects into student metacognition and perceived confidence was gained. To promote learning it is necessary to establish meaningful connections through active and project-based learning. Preparing students through project-based learning is seen to be an effective method to generating their own inquiries, interpretations, and solutions.

Resources

The course modules presented in this paper are available via Engineering Unleashed here. Alternatively, the general card number, #4159, may be used to search for the modules.

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