A Product Realization Exercise for Aerospace Engineering Students

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Abstract
This paper describes a product realization exercise tailored for undergraduate aerospace engineering students. The project is a new component of a design course incorporated recently into the Aerospace Engineering curriculum at the University of Missouri-Rolla offered during the sophomore year. This component is designed to extend learning opportunities that apply the fundamentals of design along with hands-on experiences. The students are required to analyze and solve open-ended design problems, test and experiment with different concepts, and use engineering process skills such as teamwork and development of technical reports. An emphasis is placed on the connection between theory and design applications, comparisons of analytical work with test results, reporting, and working with peers. Details on this effort and organization of the developed material are given.

Introduction
In recent years, there has been remarkable changes in methodologies by which aerospace companies develop their products. As a result, the length of the design/prototype/manufacture/market/support cycle has been reduced dramatically. As a consequence of these changes, engineers need considerable breadth to function well in this rapid product development cycle. This includes understanding the interplay between various engineering fields; understanding the relationship between design and market considerations; and being able to communicate well. Perhaps one may recapitulate the most attributes desired of an engineer by listing the following ten attributes affirmed recently by Boeing:

1. *A good understanding of engineering science fundamentals.*
2. *A good understanding of design and manufacturing processes.*
3. *A multi-disciplinary, systems perspective.*
4. *A basic understanding of the context in which engineering is practiced, including economics, history, the environment, and customer and societal needs.*
5. *Good written, verbal, graphic, and listening communication skills.*
6. *High ethical standards.*
7. *Critical and creative thinking, both independently and cooperatively.*
8. *Ability and self confidence to adapt to rapid and major change.*
9. *Curiosity and the desire for lifelong learning.*
10. *Understanding and commitment of team work.*

These attributes require the university to alter its engineering curriculum and place more emphasis on combining engineering skills & disciplines, communication skills, and business knowledge. Further, since engineering curricula moved away from a design and hands-on emphasis to a more "engineering science" orientation in recent decades, universities are now encouraged to move back to curriculum relevant to applications. With this focus, most universities are incorporating new courses aimed at 1) Teaching applied as opposed to purely theoretical sciences where design, not analysis, is emphasized, 2) Providing opportunities for hands-on, testing, and experimentation with different design concepts, 3) Giving students opportunities to use intuitive thinking as a basis for concept development, and 4) Enhancing engineering process skills such as teamwork and technical writing skills. What is being emphasized in these courses is product realization: design, manufacture, test, and correlate product performance with analysis results.

With this motive, this article describes a product realization exercise integrated recently into a new design course. This course is introduced as a part of a restructuring of the aerospace engineering curriculum at the University of Missouri-Rolla. The primary goal of this new course is to introduce students to open-ended problems and to the processes of engineering design and to provide an environment that encourages students to interact with each other at early stages of their study program. The students are required to design a small radio-controlled model, analyze its performance, and construct it. Once the model construction has been completed and preflight check has been conducted by students, models are flown by experienced pilots for final flight demonstration.

Project Mission, Tasks, and Required Deliverables

First, the students are given a project package that describes the project mission, tasks, and required product/documentation needs to be delivered. A brief description of this material follows:

a. Project Work Statement: A memorandum describing the problem is first given to the students. The format of the memo is designed to put students through experiences that simulate real world engineering. The memo[4] asks the design engineer (student) to design a product that must meet specified requirements. The student is expected to respond back in a technical memo format to his/her superior in the company with a completed design. As an example, the students are asked to complete the design and development of an aircraft model with a given engine (a 0.049 cubic engine with a 5.7" x 3.0" two-blade propeller) and a fuselage. A given set of performance is requested. The following list is an example requested during the 1998 Spring Semester:

Maximum empty weight	<	1.35 lb
Stall speed	<	22.5 ft/sec
Wing Loading	<	0.72 lb/ft^2
Maximum speed	≻	60 ft/sec
Rate of climb	≻	300 @ 30 ft/sec
Static margin	≻	80% of the chord

The students are required to demonstrate their model can climb to 150 ft from a given station A, and cruise 300 ft to station B, make the trip at least four times, and monitor the time of flight for each leg. Knowing the distance between the two stations and the time of flight, they calculate the average speed of the model and show they achieved the requested maximum speed.

b. Required Tasks

(1) Provide wind tunnel measurements of drag generated by the given fuselage.
(2) Calculate and measure engine performance and available thrust.
(3) Provide conceptual design of wing along with calculations.
(4) Compute optimum aircraft performance based on the conceptual design.
(5) Iterate conceptual design and generate final wing design.
(6) Construct designed wing.
(7) Assemble wing and fuselage and perform longitudinal stability analysis.
(8) Conduct preflight testing of engine and flight controls.
(9) Flight test the produced design and present comparison with predicted calculations.
(10) Assemble technical report with all details compiled in the above nine tasks.

c. Required Deliverables

(1) Complete assembled model ready for flight testing.
(2) A technical memo presents a summary of tasks conducted and results achieved.
(3) Complete technical report including detailed design and flight test results.

Project Activities

A ten-step guide is given to the students to help them conduct the required project tasks. The information covers all applicable material needed to accomplish each step, equations needed to process data, sample graphs of what the output data should resemble, and any pertinent background information relating to the task at hand. These steps are designed to break down a complicated project into components which help the students handle the project and make various tasks more manageable. Each step consists of three to four sections: 1) Resources, 2)Theoretical Considerations, if needed, 3) Required Tasks, and/or 4) Required Deliverables. The **"Resources**" section includes a list of material and equipment that will be made available to the students. This arrangement provides the students with information on types of tools and technology available to them to achieve a given result. The "**Theoretical Considerations"** gives background information on the material presented. It may cover the derivation of a key equation or the theoretical aspect of what is done in a given laboratory test. Under the **"Required Tasks"** section, a few guidelines on how to utilize the given resources in accomplishing the required tasks of a given step is discussed. The information is sufficient to set the students in motion and is not intended to provide instructions on how to fully complete the required design/hands-on tasks. The **"Required Deliverables"** section shows the students what is expected of them after successful completion of the required task. This may include several items such as a technical memo, plots of produced data, test results, etc. In previous projects[2], the process outlined above has proven quite successful. The students know from the beginning how the design project will progress to completion.

Due to space limitations, the full details of each step can not be included in the paper. However, the information provided on each step should be sufficient to develop similar projects . For more details, the reader may refer to the technical report by Finaish[3]. A brief overview of each step follows.

STEP 1: ***Assemble fuselage, engine, and radio gear***
The students are provided with a fuselage, horizontal & vertical stabilizers, a 0.049 in^3 engine, a 5.7" X 3.0" two-blade propeller, engine mount, associated hardware, and radio gear. In this step they determine appropriate locations for the receiver, control servos, and battery. The students are required to deliver a fuselage/tail assembly with engine and control servos installed and secured.

STEP 2: ***Measure static engine thrust and thrust performance as a function of aircraft speed***
In this step the static thrust must be determined by mounting and running the engine on a test stand. The available static thrust produced by the engine is read directly from the test stand load cell. Once the measured static thrust has been determined, the available thrust vs. aircraft velocity must be determined using theoretical relationships based on the momentum theory analysis[5]. The students are required to determine the available static thrust produced by the engine and produce a plot that depicts the dependence of available thrust on aircraft speed.

STEP 3: ***Provide wind tunnel data of generated drag and its dependence on flight speed***
In this step, each team employs an 18" X 18" subsonic wind tunnel and a two-component force balance and instrumentation for flow velocity measurements. They are required to measure the aerodynamic drag generated by the completed product of Step 1. Drag measurements should be made as a function of the flow speed. The drag data obtained will be employed later to predict performance parameters of Step 5. They are required to determine drag coefficient of the fuselage tail combination for the model speed range of interest. A technical memo and attachment of produced data and plots are submitted by each team.

STEP 4: ***Develop conceptual wing design***
Here the students are provided with aerodynamic performance of a set of airfoil sections which can be employed to select an appropriate airfoil section that is capable of producing the required performance such as lift to drag ratio and maximum lift coefficient. After reviewing this data, it is required to select an optimum airfoil profile to be used. During this process they determine the wing aspect ratio, a total wing area needed. They are required to select an appropriate airfoil profile which will produce satisfactory aerodynamic performance (Cl_{max}, Cl_{α}, maximum lift to drag ratio). Logics for selecting a specific section, advantages and disadvantages, and complete drawings of the designed wing, showing size and plan form, are documented in this step.

STEP 5: ***Compute model performance, iterate, and generate final wing design***
In this step, the students calculate the model performance based on the designed wing of Step 4. It is required to determine the lift slope, and the oswald efficiency factor of the wing, lift and drag coefficients, and lift to drag ratio. The required and available thrust and power are determined and plotted as functions of aircraft speed. These results are employed to determine the maximum and minimum aircraft speeds and excess horsepower at any speed. For easy access of these calculations, the reader may refer to chapter 6 of reference 1. They also calculate other performance parameters such as stall speed and wing loading. They go through several iterations of wing sizing to achieve the performance specified in the project work statement. The students are required to deliver a summary of all performance parameters calculated, required and available thrust chart showing maximum velocity, required and available power chart

showing maximum excess power, hodograph for climb performance, and time to climb chart.

STEP 6: ***Construct aircraft wing***
Here, the students are provided with Balsa and Bass wood, glue, and plastic shrink covering, and construction procedures. They are required to produce full scale templates for the wing layout and wing ribs to be drawn. The wing designed in Step 5 should be constructed according to the given construction guidelines. They are required to deliver a constructed wing ready for assembly with fuselage-tail combination produced in Step 1.

STEP 7: ***Assemble wing and fuselage-tail combination and prepare weight and balance report***
A test stand to determine the location of the aircraft center of gravity and an electronic balance are provided for determining the aircraft weight and balance. The center of gravity of the aircraft for a given wing location is determined by selecting a datum line and summing the moments produced by the weights of all assembled items on the aircraft. The students verify these calculations by determining the aircraft center of gravity experimentally utilizing the provided test stand. Once the aircraft model is balanced, the distance from the aircraft engine mount and the balance point can be measured to determine location of the model center of gravity. The students deliver a weight and balance report for various wing locations.

STEP 8: ***Conduct stability analysis and select optimum wing location***
In this step, it is required to determine the arm of the aircraft tail, horizontal stabilizer and wing-body combination aerodynamic centers, the lift slope of the horizontal stabilizer, tail volume ratio, and a few other parameters needed to calculate the model neutral point and static margin. Detailed calculations can be found in chapter 7 of recreance1. The students are required to deliver a memo with the calculations and the obtained results of the neutral point location and static margin.

STEP 9*: Prepare model for flight test*
Prior to flight testing, teams are required to conduct preflight tests of engine and flight controls at the laboratory. Once this step is accomplished, models can be carried to the airfield after mounting the wing at the appropriate location determined in Step 8. Teams will assist the pilots in preparing their aircrafts for flight. This includes fueling the aircraft and checking controls for proper operations. Once the aircraft has been cleared for flight, pilots from a local flying club fly the models between two pylons as straight and level as possible. The pilot will then turn the aircraft 180^o and fly the aircraft in the opposite direction. On each pass, the time required for the aircraft to pass between the two pylons is recorded by use of a stopwatch. Knowing the distance between the pylons and the measured times, the actual aircraft speed is estimated. This data is compared with the predicted theoretical speed. The students are required to submit a one page report outlining the flight performance observed and any other important observations recorded during preflight testing.

STEP 10: ***Assemble technical report***
Each team is required to prepare a technical report on the activities conducted during the course of the project. This report should include a three-page technical memo describing all aspects of the project. The memo should start with an executive summary that presents the most important

information to be conveyed. Following this summary, the memo is divided into three main sections that describe the three main activities; design, construction, and flight testing. The information should be extracted from the work conducted in the ten steps of the project. The details (designs, analysis, calculations, testings, iterations, drawings, ...) of the activities performed in all steps should be enclosed with the memo in an organized clear form so information can be easily located by the reader.

Concluding Remarks

A new course component on design, construction, and testing of small radio-controlled aircraft models has been developed. The material is introduced to sophomore aerospace engineering students at UMR. Student enthusiasm for the exercise has been extremely encouraging. They were very proud of what they accomplished since this was the first experience for them to analyze a given physical reality, bring it to existence, and test it to verify their analysis. Furthermore, other principle benefits of the design project are not related to design but rather to the students exposure to teamwork in an academic setting. The students are required to work together constructing models, preparing test plans and executing them, and developing reports where they experience the merging of individual sections into a final report in a highly integrated manner.

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