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Conceptual Design of a Primary Trainer Airplane (PTA)[*]

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Abstract: This paper describes the design cycle process as well as the manufacturing technique of a single engine Primary Trainer Airplane (PTA) designed in the Department of Aeronautical Engineering-Karary University. The PTA was specified to follow given specifications set by the customer and designed successfully to correspond to the specified mission profile.

Statistical data was collected and the information used to calculate the weight fuel fraction and subsequently the preliminary weights for the airplane. The conceptual design of the airplane took into consideration the major attributes required of a PTA as well as the aesthetic desires of the designers. All modules of the airplane such as the aerodynamics, stability and performance, were intended to be taken into account.

The fuselage was sized to incorporate a high wing, as well as to fit the tail and landing gears. The wings were sized using statistical data to suit the overall layout of the airplane. Likewise, the conventional tail was selected for the low level of weight which it added to the design. To conclude the conceptual design phase, a tricycle landing gear was selected with a fixed mechanism incorporated. The landing gear was designed to be mounted on the wings.

Weight and balance analysis were also undertaken to ensure an airplane which is stable and relatively well balanced in flight. In order to demonstrate its performance and stability, a scale model of the PTA was fabricated and has successful flights in April 2012.

Keywords: Aircraft design, aerodynamics, stability & performance, scale mode.

Nomenclature

PTA Primary Trainer Airplane
R/C Radio Control
KPP’s Key performance Parameters
VRI Vacuum Resin Infusion
RPV Remotely Piloted Vehicle

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1. Introduction

Learning "Real world project" is an educational process through which knowledge, principles and practices can be developed. This fact is particularly pertinent in engineering education as the majority of professional engineering work is conducted through projects. Therefore, it is logical to integrate this concept into undergraduate engineering education, alongside classroom-style coursework.

Through this means the students are encourage to critically analyze issues and to solve 'real-world' tasks in an educational setting, which establishes strong engineering judgment and decision making in addition, they are able to directly create the link between the theoretical knowledge and the practical problem and more easily bridge the gap between university and industry, (equipping graduates, with attributes such as teamwork and solution synthesis skills required for industry).

The aim of this paper is to provide a voice for students about project-based learning in an undergraduate education setting. During their final year of a five year undergraduate engineering degree a team of three aeronautical engineering students at Karary University, designed, and developed a Primary Trainer Airpalne (PTA), and successfully manufactured a scale model prototype, as an integrated project-based learning part of the curriculum.

The team set the task of the design, development and manufacture of a PTA and was responsible for all facets of the project, many of which were either not taught or overlooked in lieu of deeper theoretical understanding in their classroom-based courses.

The technical learning associated with the project contributed to a successful delivery of a PTA- R/C model. This included the design, development and manufacture of the airframe from conception, as well as the development and integration of the required systems. The key performance parameters (KPP's) for the PTA are presented below in Table 1.

Table 1 Key Performance Parameters for the (PTA)

Parameter	Value
Maximum Speed	347.8 *km/hr*
Endurance	2.5 hours
Range	1000 *km*
Maximum engine power	200 *hp*

2. Design Process

The design and development process consists mainly of mission requirements, conceptual design, preliminary design, prototyping, simulations and flight testing. It should be noted that, due to the limited time of this project, the preliminary design phase is not taken under consideration.

2.1 Mission Requirements

A simple flight profile including warm-up and take-off, climb, cruise, loitering, cruise back, loiter, decent, and landing was considered as representative of the mission profile of the PTA. Table 2 shows the weight data of the PTA.

Table 2 Weight of PTA

Type of Weight	Amount
Maximum takeoff weight	912 *kg*
Empty weight	549 *kg*
Mission fuel weight	184.3 *kg*
Payload & crew	181 *kg*

2.2 PTA Conceptual Design

Starts with the overall requirements and specifications derived from the analysis of the mission requirements imposed on the required PTA. It focuses on the requirements strategy, the preferred concept and estimation of the weights.

2.2.1 Preliminary sizing of the PTA

In terms of preliminary sizing, the numerical definition of the maximum takeoff weight, empty weight, mission fuel weight, wing loading, maximum required power, wing area, wing aspect ratio and the maximum required lift coefficient is determined, [1].

The following tasks are to be carried-out:

1. Weight Sizing, which quantifies the weight parameters mentioned above
2. Performance Sizing, which results in determination of values of wing loading, power loading and maximum lift coefficient with which the performance requirements are met.

As stated in [2], it is essential that a credible estimate of the wing loading and power loading be made before the initial design layout is begun. Wing loading affects stall speed, climbs rate, takeoff and landing distance, and turning performance, and has strong effect upon sized aircraft takeoff gross weight.

To ensure that the wing provides enough lift in all circumstances, the designer should select the lowest of the estimated wing loadings [2]. Consequently, the required wing area, maximum power for given aspect ratio and maximum lift coefficient, are determined.

2.2.2 Configuration design of PTA

Roughly speaking, this process includes the overall layout designs as well as the integration of the propulsion and the required systems. The configuration layout and design are carried out following sequence stated in [2]. Figure 1 shows complete 3D-CATIA model of the PTA.

2.3 Prototyping the PTA Model

Prototyping is a necessary step in most manufacturing processes. The value of a prototype lies in the ability to prove design intent and spot potential issues, whether in the manufacturability or in the application of the design, that were not noticed in a computer model or drawing. It gives the designers a good feel for the appearance and functionality of the design, [3,4].

The manufacturing process of the PTA model is designed based on the decision that it will be made on (1/16) scale made of plywood, balsa wood, foam and fiber glass. Drawings breakdown, PTA model drawings, manufacturing work flow diagram and manufacturing process sheets are prepared.

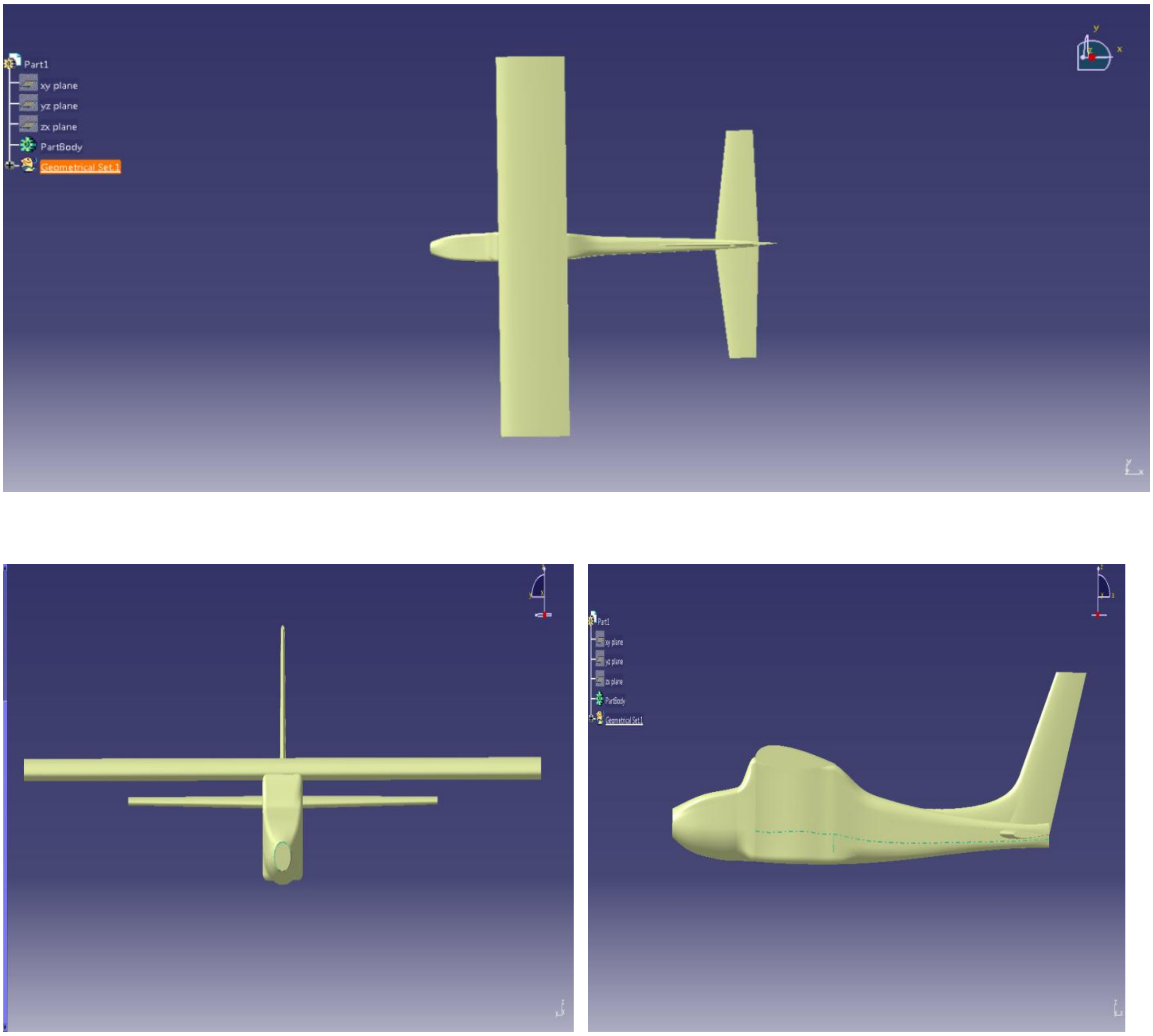

Fig. 1 3D-CATIA model of the PTA

In the following, the manufacturing process is explained, together with the installation process of the propulsion and other required systems.

2.3.1 Wing design and fabrication

Wing design is an extensive topic with many potential areas of specialization including aerodynamic force production and structural design that are beyond the scope of this research.

The manufacturing technique described in this work was studied extensively and where possible, it was attempted. Table 3 shows the geometric data of the wing.

The wing prototype was created with a foam core covered with a single layer fiber glass using hand lay-up method. Templates were cut from plywood and marked in increments to match the cutting rate for both sides of the foam piece.

The templates were fixed to opposite ends of the block and offset at the correct angle prior to commencing cutting. A small, thin metal rod was glued into the leading edge of the template for the hotwire to rest upon. Inset areas were cut into the top and the bottom of the template so that reinforcing fiber strips could be included on the foam cut-outs without any surface irregularity.

Table 3 Geometric Data of the Wing

Description	
Wing chord	1.37 *m*
Wing span	9.50 *m*
Wing area	12.94 m^2

A large hotwire was used to trim away the excess foam and leave a core in the shape of the wing. Any rough-cut areas were trimmed and sanded. The sides where the wing parts would be bonded together were cut at the appropriate angles.

The layup procedure involved vacuum bagging the wing and laying up fiberglass over the wing using a vacuum resin infusion (VRI) process. Half of the wing was done at a time. After the first try, adjustments were made, and a useable wing skins were produced. This method proved to be successful, and suitable for the project.

Figure 2 shows the wing covered with fiber glass, and figure 3 shows the process of bonding the two parts of the wing.

Fig. 2 Wing covering with fiber glass

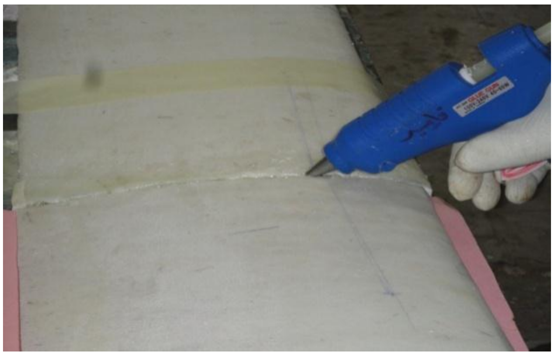

Fig. 3 Bonding two parts of wing

2.3.2 Fuselage and tail unit design and fabrication

The layout of the fuselage and the tail unit is determined following methods presented in, [1,2]. Table 4 shows the geometric data of PTA fuselage. The fuselage is relatively simple and is made of foam core covered with fiber glass. 2D templates are made of plywood using conventional saw. To make the 3D shape of the fuselage, a hot-wire cutting is used then the 3D- foam fuselage is covered with one layer of fiber glass, as seen in figures 4 and 5.

Table 4 Geometric Data of Fuselage

Description	
Fuselage overall length	7.65 *m*
Fuselage cabin length	2.56 *m*
Fuselage height	1.15 *m*

The structure of the horizontal and vertical tails is produced from one piece of balsa wood fabricated to give the required profile and covered by a layer of fiber fabric. Elevator and rudder are produced from balsa wood and covered with plastic sheet; each is attached to its tail using hinges.

This design was adequate for the conceptual design phase. It was sufficiently stiff and robust enough to withstand the time necessary to simulate the desired flight test.

Greater care was taken to reduce the weight in the hopes that this version would be capable of tethered flight. The fully assembled PTA prototype is presented in figures 6,7,8. in different views.

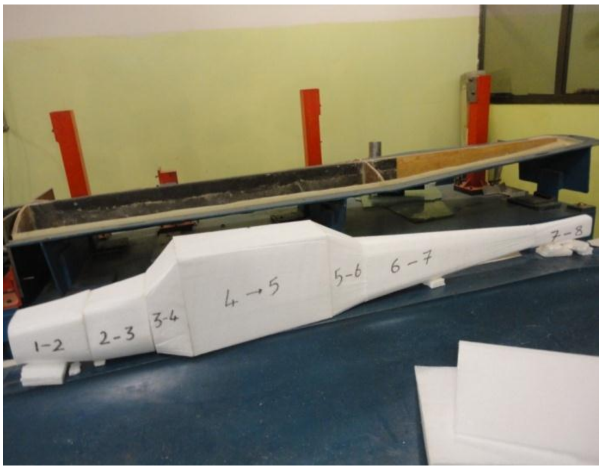

Fig. 4 Fuselage made of foam

Fig. 5 Fuselage covered with fiber glass

Fig. 6 Fully assembled PTA prototype

Fig. 7 PTA Prototype cover with stickers

Fig. 8 PTA prototype in another view

3. PTA Performance

It is important at this stage to understand the performance characteristics of the PTA. In this study the expression (performance) will be taken to refer to task relating to the flight path of the airplane rather than to those involving its stability control or handling qualities, performance can also regarded as a measure of safety, [5]. It is necessary to predict the performance of a proposed airplane in order to determine whether it will be able to fulfill its required role, e.g. it is necessary to be able to predict its maximum and minimum speeds, its range, its landing and take-off distances, etc.

The following results are obtained.

3.1 Stall Speed

Stall speed is required to achieve horizontal flight in order to force the weight (W) and specified angle of attack; it is given by equation (1) as, [5]:

$$V_{Stall} = \sqrt{\frac{2W}{\rho S C L_{max}}} \qquad (1)$$

V_{Stall} increase with higher plane, as the altitude increases the density decreased and the speed increase. The relationship is illustrates as in figure 9.

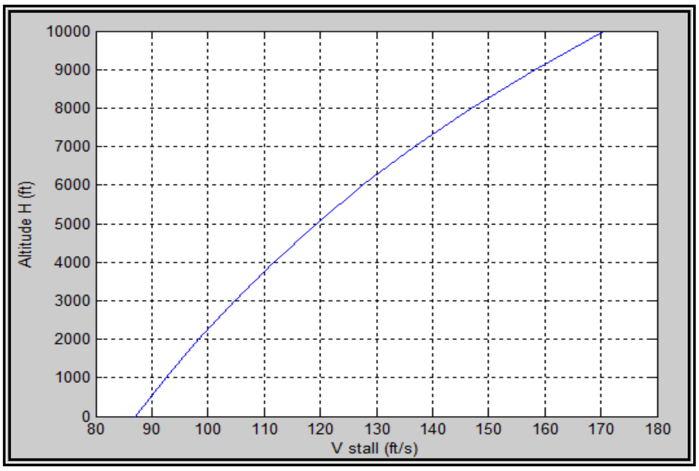

Fig. 9 The variation of stall speed with the altitude

3.2 Power Required

The required power for various air speeds is given by equation 2, and plotted as in figures 10,11.

$$P = \frac{1}{2}\rho V^3 S C D_0 + \frac{2KW^2}{\rho V S} \qquad (2)$$

3.3 Rate of Climb

In the overall mission of the aircraft there will be a climb phase in which the aircraft increase its height to the required cruising level, see figure 12.

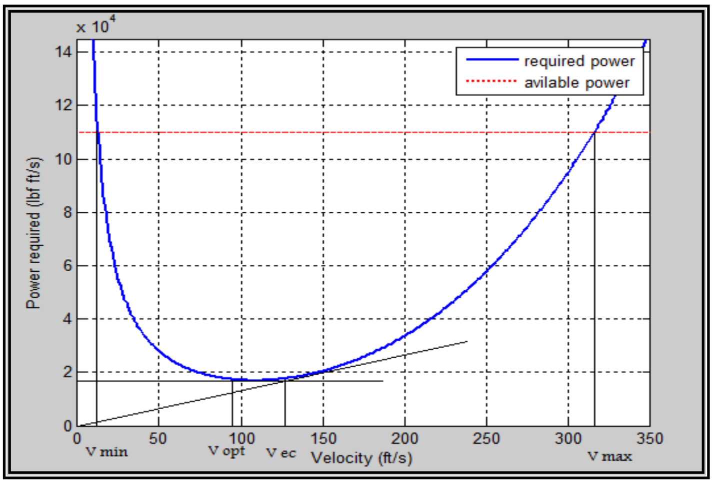

Fig. 10 The power required

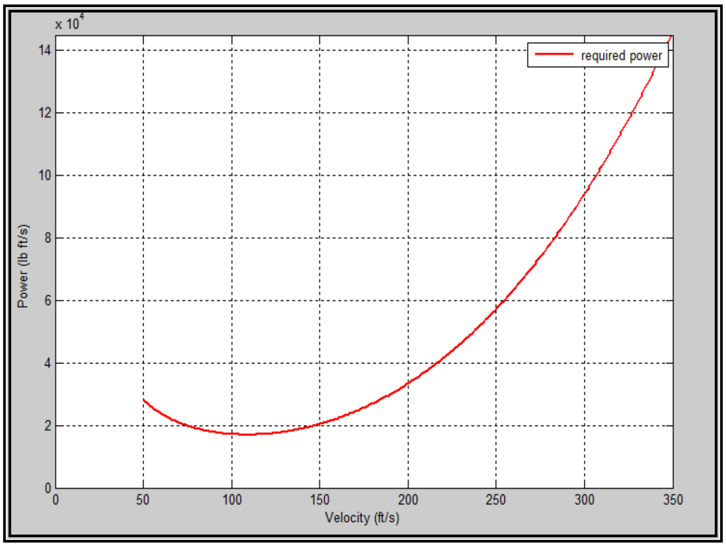

Fig. 11 The power required versus velocity

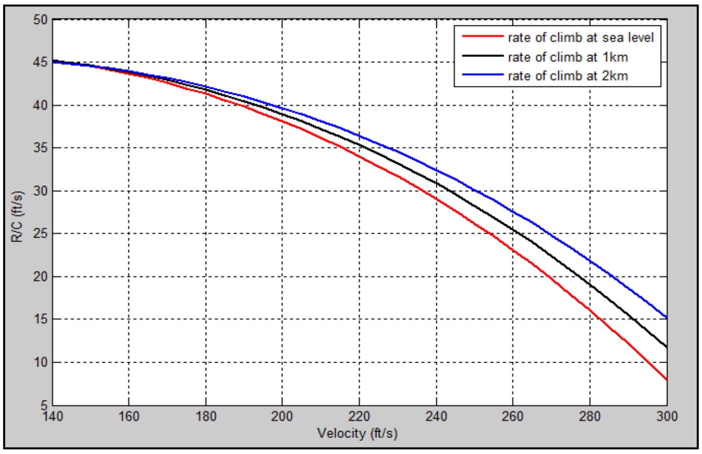

Fig. 12 Rate of climb

4. Stability Analysis

Static stability

Figure 13 shows the relationship between pitching moment and angle of attack. From this figure it is observed that:

$$C_{mo} = 0.157 \; > \; 0$$
$$\alpha e = 3.6^{\circ}$$
$$cm_{\alpha} = -0.0436 \; < \; 0$$

This means that the airplane is statically stable.

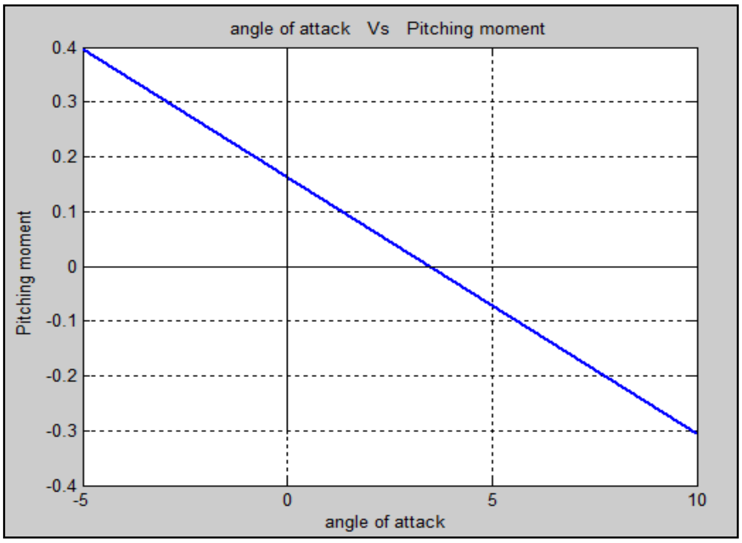

Fig. 13 Relation between pitch moment and angle of attack

5. The Flight Demonstration

The concept of geometric scaling of the PTA and flight testing of the scaled model has two primary objectives. The first is to develop a cost-effective, geometrically scaled, remotely piloted vehicle (RPV) to investigate the known geometrically behavior associated with the PTA configuration. The second objective is to design and perform flight test experiments to demonstrate measure and characterize the performance behavior in flight.

Flight demonstration is divided into three parts, with the complexity and scope of the tests increasing with each part.

Part 1: System Tests - This part includes the integration and testing of all onboard systems, including instrumentation and data logging capabilities, verification of control surface mixing and experimentally finding the center of gravity.

Part 2: Flight Readiness Tests - This part includes the static thrust testing, and ground testing of the complete geometrically scaled RPV.

Part 3: Flight Tests - This part includes all flight test operations of the RPV. Taxi tests, takeoff tests and maneuvering tests are all included in this part.

5.2 Flight Testing of PTA Model

The PTA model is tested on ground for its response to signals by the remote control, figure 14.. Then, the engine is started and the completed mechanism was thoroughly tested. The PTA model flew successfully in April 2012.

Fig. 14 The PTA model tested on ground

6. Conclusion

The work described in this document represents a significant research effort towards advancing the concept of "learning real world projects" in undergraduate level. Several significant contributions have been made which have indeed advanced this concept.

The evidence presented supports the authors' own experiences that "learning real world project" is an effective form of engineering education, which complements the traditional classroom style education method to better achieve graduate attributes.

However, the results of this study do highlight the importance and development of non-technical skills among the student cohort, it demonstrating the effectiveness of real world project to address some of the expectations and graduate attributes of students and perceptions of their own learning.

Finally, the technical learning associated with this project contributed to the successful delivery of a PTA. This included the design, development and manufacture of the R/C model airframe from conception, as well as the development and integration of the required systems. The result was a PTA platform with the following attributes and performance capabilities:

- 912 *kg* maximum take-off weight
- 181 *kg* maximum payload
- 2.5 *hour* flight endurance
- 200 *hp* maximum engine power
- 347.8 *km/hr maximum* speed
- 1000 *km* operational range

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