ATA-12

Final Design Report

AIAA Design Build Fly Competition
Raytheon Missile Systems
Tucson, Arizona

Submitted by
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Istanbul Technical University
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1. EXECUTIVE SUMMARY

This report details the design, manufacturing and testing processes of Istanbul Technical University's ATA-12 Team, which is participating in 2010-2011 Student Design/Build/Fly Competition of AIAA/Cessna Aircraft Company/Raytheon Missile Systems.

During design process, the team is focused on contest requirements to generate unique solutions for this year's contest. Before starting the design process, the team is divided into 6 groups and their responsibilities were determined. Their assignment areas were shown and the scheduling of the project is given in Management Summary.

1.1. Mission Requirements

The primarily issue of ATA-12 Team is to design the winner aircraft of DBF competition by getting the highest total score, which includes report score, flight score and RAC. The RAC is the maximum empty weight of the aircraft measured after each successful scoring flight and flight score is determined by three missions: Dashing to Critical Target, Ammo Re-Supply, and Medical Supply Mission. Before missions the most important issue is that the whole UAV flight system must fit in a commercially produced suitcase meeting airline carry-on bag. The suitcase must not exceed 45 linear inches and the single dimension must not exceed 22". The mission of Dashing to Critical Target is the aircraft must fly as many laps as it can in 4 minutes flight time. In the second and third missions, they are both payload missions, the aircraft should fly three laps. In the second mission the payload is a team selected steel bar, which must be a minimum 3" width x 4" length. In third mission the payload is team selected quantity of golf balls. Additionally, teams fly when entering and staging box and load the balls as part of the aircraft assembly and checkout (timed) prior to going to the flight line.

1.2. Summary of Design Project and Outcomes

The design process began with conceptual design. First of all, design and mission requirements are examined and keys to success are highlighted. Then, figures of merit analyses are utilized to select aircraft configuration and components to provide sufficient aircraft performance. Empty weight of the aircraft and the loading system mechanisms which affects aircraft's weight directly were the main parameters during the design because of the RAC effect on the score. Moreover, hand launch makes the gliding duration of the aircraft one of the most important parameters. To increase the gliding time of the aircraft, wing loading was tried to be decreased. In mission one, the aircraft's speed is extremely important to fly the maximum laps in 4 minutes. Due to the importance of the aircraft's speed, the team tried to design an aircraft which has minimum drag coefficient. For payload flight missions, second and third missions, lift was one of the most important parameters. For these missions, designed mechanisms to carry steel bars and golf balls should be light and loading time of the golf balls was important. Different vehicle concepts were developed and analyzed to select the best configuration that provides the highest performance. In light of FOM analyses and decision matrices, the alternative designs were investigated and final configurations were determined. Conventional, c wing, elliptical, biplane and flying wing configurations were evaluated and compared to each others to select the best concept. C wing configuration with a single propeller was selected due to a light weight, low drag design, ease of construction and the aim of getting experience, which has never had before in Istanbul Technical University. Each component was selected to provide sufficient aircraft performance with minimizing the system weight. After that, the propulsion system were considered and single brushless tractor motor with NiMh batteries was selected as the best configuration under the limit of 20A current and maximum of ¾ lbs. battery weight.

In preliminary design section, before starting the aircraft design, there are some parameters which are extremely important. The elevation of contest site and the average wind speed is investigated to determine the weather condition for design. After determining the flight conditions, design and analysis methodology were told, carry-on bag size was determined. Weight, wing loading, geometry and airfoils of wing, fuselage, tail, and static margin are considered as major design parameters. After weight and geometry of aircraft are determined, wing, fuselage and tail airfoils and shapes are selected based on their aerodynamic characteristics and calculations. Then propulsion system was optimized and by using the final design parameters, control surface sizing, stability calculations, aerodynamic and structural considerations were performed. Finally, the lift drag and stability characteristics were discussed and predicted mission performances are calculated.

In detail design, structural design of wing, tail, fuselage and landing gear were performed. After that, layouts of the payloads were considered and final aircraft geometry, weight and balance, flight performance and mission performance were calculated. Last section of detail design is the drawing package, which consists of aircraft's three dimensional view, structural arrangement, systems layout, and payloads accommodation are given.

In the end of the design process, the plan and processes of manufacturing were determined for each component. After the FOM's were considered, materials and alternative manufacturing process were investigated by using decision matrices. Then manufacturing process was explained in detail. Finally, manufacturing milestone chart was prepared.

In testing plan, testing schedule was prepared and testing objectives were determined. Additionally, preflight check list and flight logbook were given.

Finally, major subsystems were tested and compared to the predicted values, according to testing plan. After demonstration of key subsystems, test flights were performed to confirm the performance results which were documented in detail design.

1.3. System Performance and Capabilities

The final of these processes, the wing is sized to a 59.06 inches span, a 3.28 ft^2 wing area, a 15 degrees wing sweep, a 0.5 taper ratio. Performance and capabilities of the aircraft are show in the table 1.1.

Table 1.1 Executive Summary

	First Mission	Second Mission	Third Mission
Empty Weight (lbs.)	2.3	2.3	2.3
Payload Weight(lbs.)	-	5.31	4.46 (44 balls)
Hand-launch Weight(lbs.)	2.3	7.61	6.76
Number of Ni-Mh Cells	10	16	16
Wing Loading(lbs/ft^2)	0.7	2.313	2.06
Stall Speed (ft/s)	22.02	37.4	35.93
Cruise Speed(ft/s)	106	90	90

2. MANAGEMENT SUMMARY

The Design/Build/Fly ATA-12 team at Istanbul Technical University worked under the roof of Faculty of Aeronautical and Astronautical Engineering and consisted of undergraduate students from Aeronautical and Astronautical Engineering departments. The meetings to found a D/B/F team started in the beginning of August. Organizational plans were prepared and a milestone chart was prepared. After the contest rules were announced, the final plan was frozen; the leaders of the subgroups were determined in the following meetings.

2.1 Team Architecture

ATA-12 team consists of 50 students and the team was split into subgroups with a designated leader for each as shown in Figure 2.1. The leaders of the subgroups were the experienced members of the team, who were appointed to ensure the right operation of their group according to the plans. All the team members were allowed to work for more than one group. Weekly meetings were held by every group to evaluate the works done and to organize future duties. In addition weekly meetings were held by the team leader with the whole team in order to obtain sustainable communication between subgroups.

Figure 2.1 shows the subgroups of the team. Each technical group has responsibilities and duties, which are defined below.

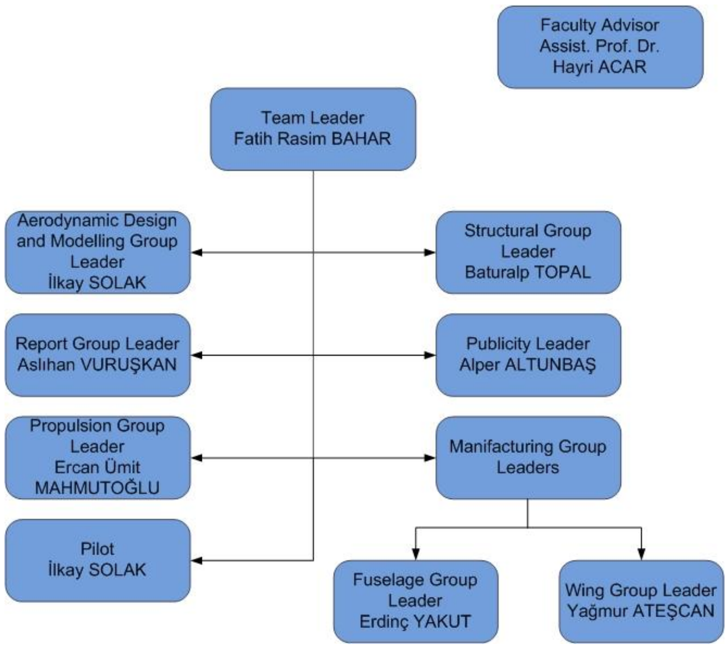

Figure 2.1 Organization chart of ATA-12

2.2 Groups and Responsibilities

The guide of the team through the project was the team advisor. He was ensuring that the team followed the contest schedule. The team leader was responsible for holding general meetings, organizing the subgroups through the project and performing the formal communications with the contest organizers and institutions. The duties and responsibilities of the groups are defined below. The team members and their working areas are shown in Table 2.1.

- **Aerodynamic Design and Modeling Group:** Responsible for aerodynamic force resolution, airfoil selection, wing sizing, wind tunnel testing, and programming for the Aerodynamics Module.
- **Propulsion:** In charge of propeller testing, coding for the Propulsion Module, and selection of components such as motor, batteries, and propellers. Also conducts wind tunnel testing on the optimized propulsion system to validate calculations.

- **Structures:** Responsible for laying out the overall aircraft's internal and external design, selecting materials, and preparing a manufacturing scheme. Other responsibilities including structural and material testing.
- **Publicity Group:**
- **Report:** In charge of writing the design report of the team according to the information from the other subgroups.
- **Manufacturing:** Makes the manufacturing plan and performs construction of the aircraft.

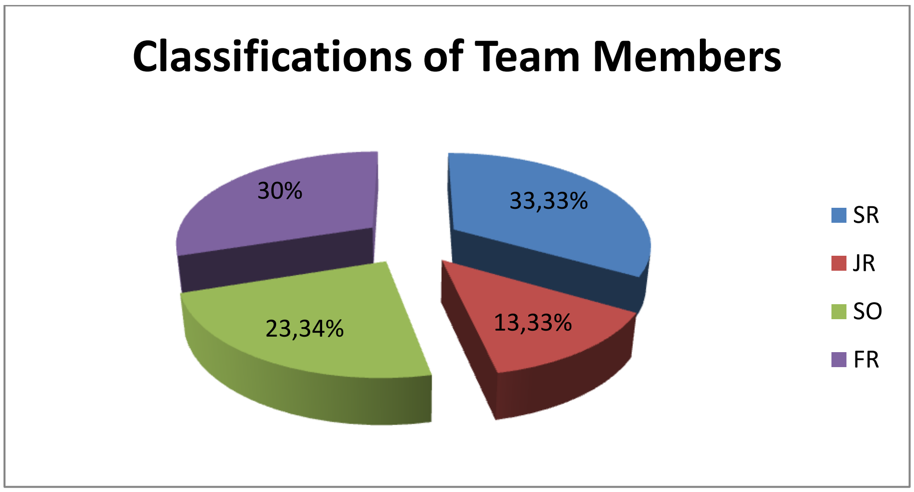

Figure 2.2 Classifications of Team Members

Table 2.1 Design Members and Assignment Areas

Member Name	ADMG					SG			PG			F/LG		RG	MG
	Conceptual Design	Preliminary Design	Performance Analysis	CFD Analysis	CAD Modeling	Detail Design	Structural Analysis	Structural Test	Propulsion Design	Propulsion Test	Flight Test	Sponsorship	Logistic	Report Writing	Manufacturing
Fatih Rasim BAHAR	3	3	3	2		3	3	3	3	3	3	3	3	3	3
İlkay SOLAK	3	3	3		3	3	3	3	1	1	3		1	3	3
Alper ALTUNBAŞ	1	1	1		1		1	1	2	3	2	3	3	3	3
Erdinç YAKUT	2	2	1		3	3	1	3	2	3	3	2	3	3	3
Baturalp TOPAL	3	3	1	3	1	1	2	2	1	1	2	3	2	2	3
Aslıhan VURUŞKAN	1	1							1	1				3	2
Yağmur ATEŞCAN	2	2				1		3		1	1			3	3
Eray KOÇ	1	1				1		2		1	1		1	2	3
Aykut ÖZBEYTEMUR	1	1				1		2	1	1	1		1	2	3
Kaan Berki KARABAY	1	1				1		1			1			2	3
Ercan MAHMUTOGLU	2	2						1		1	1	1	2	3	2
Erdinç DEVECİOGLU	1	1						1			1		1		3
Yasin ARSLAN	1										1				2
Göker ZORLUTUNA	1	1													2
Alparslan KOSİFOGLU	1										1			1	2
Yücel PAMUK	1	1								1					1
Mesut Cemil ÖZKET	1	1												1	1
Altuğ ÇİFTÇİ	1	1												1	1
Ömer F ÇAVUŞOĞLU	1														2
Demet ÇİLDEN	1														2
A. Umur ÇAKMAK	1	1							2	1					1
Neslihan GENÇKAL	1														1
Özlem ORHAN	1														1
Esra ACAR	1														
Tilbe KERKİ	2	2													
Caner SÜREL	1	1													1
R. Ömür İÇKE	3	3		1	2						1				1
Fatih ERGEN	2	2													1
Selin KAHRAMAN	2	2		1							1				
Mehmet AYYILDIZ															1

ADMG: Aerodynamic Design and Modeling Group **SG:** Structural Group **PG:** Propulsion Group
F: Finance **LG:** Logistics **RG:** Report Group **MG:** Manufacturing Group

2.3 Scheduling

According to the teams' past contest experiences, a detailed schedule was prepared before the design process. Figure 2.3 shows the deadlines and the timings of the important elements of the aircraft design process in detail.

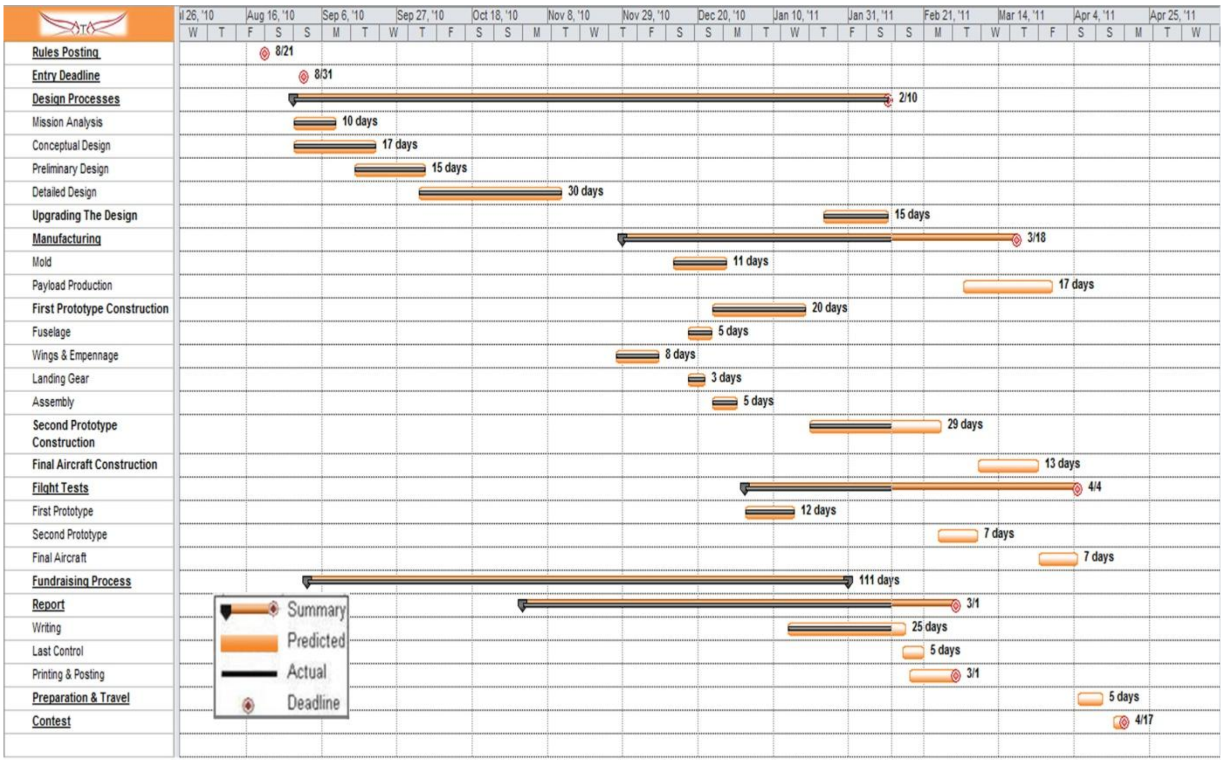

Figure 2.3 Planned and Actual Milestone of the Project

3. CONCEPTUAL DESIGN

The 2010-2011 DBF contest rules consist of two internal payload flight missions and a dashing to critical target flight mission. In the conceptual design process, the best configuration to get the highest flight score is selected due to competition's missions. Firstly, different configurations discussed to decide to work on the most appreciated one. Then, figures of merit were described to view the investigated concepts and consequently, decision matrices were used to evaluate the design alternatives.

3.1. Mission Requirements

Total score is affected directly with total flight score and written report score. First parameter of the contest score is the total mission score, which is sum of the three flight missions. Due to the fact that no optional missions are presented, the design is aimed to accomplish all the missions. Specified missions and vehicle requirements are as follows:

- Maximum battery weight of ¾ lbs. (only NiCad or NiMH batteries)

- 20 Amp current limit
- Maximum take-off gross weight with payload is 55 Ibs.
- Energy imparted by the hand launch in take-off
- Fitting the aircraft in total of 45 dimensional inches in commercially produced suitcase
- Dimension of the steel bar is minimum 3" width x 4" length
- As it is given figure the route should be completed in each mission which include one loiter in each lap.

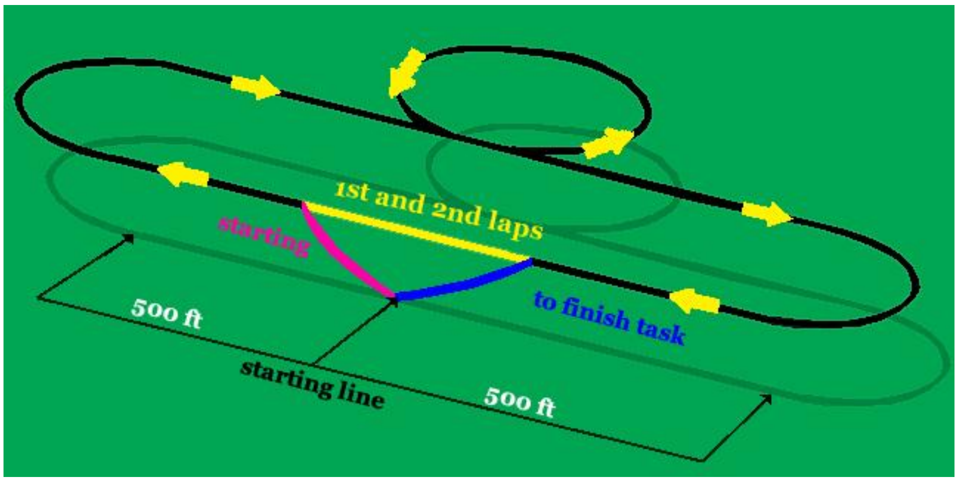

Figure 3.1 Flight Route

3.1.1.Mission 1: Dash to critical Flight

In first mission, Dash to critical Flight, the aircraft flies as many laps as it can in 4 minutes flight time in the flight course. The aircraft flies with pre-selected battery pack, which should produce less than 20 Amp current. Moreover, the aircraft's launch from pilot assistant's hand. As it is described, the flight time is from leaving the aircraft the launcher's hand to last scored lap's completion, which is passing start/finish line while it is still in the air.

The first mission's score is function of the maximum number of completed laps by any team, which is symbolized by N_{max}, and the number of completed laps by the score's owner team, which is symbolized by N_{laps}. The score of first mission is calculated by,

$$M_1 = \frac{N_{laps}}{N_{max}} \tag{3.1}$$

3.1.2. Mission 2: Ammo Re-Supply

In second mission, Ammo Re-Supply, the aircraft starts its flight by hand launch and flies three laps of the flight course with a team selected and supplied steel bar payload. The steel bar's size must be a minimum 3" width x 4" length.

The second mission's score is calculated by using flight weight and payload weight. After the completion of the successful flight, the aircraft weighs to know "Flight Weight" for calculation of the second mission's score. Then, the payload removes from the aircraft and weighs to obtain "Payload Weight" in the calculation. The second mission score is calculated by,

$$M_2 = 3 * \frac{\text{Payload}_{\text{Weight}}}{\text{Flight}_{\text{Weight}}} \quad (3.2)$$

3.1.3. Mission 3: Medical Supply Mission

In third mission, Medical Supply Mission, the aircraft starts its flight by hand launch and flies three laps of the flight course with a team selected quantity of golf balls.

The third mission's score is function of the maximum number of carried golf balls by any team, which is symbolized by N_{max}, and the number of carried golf balls by the score's owner team, which is symbolized by N_{balls}. The score of third mission is calculated by,

$$M_3 = 2 * \frac{N_{balls}}{N_{max}} \quad (3.3)$$

3.1.4.General Score Calculation

Missions' scores play a big role on Total Flight Score with RAC. RAC is defined as maximum empty weight measured after each successful scoring flight. It is formulated as,

$$\text{RAC} = \text{Max}(E_{W_1}, E_{W_2}, E_{W_3}) \quad (3.4)$$

As it is seen in the formulation, E_{W_n} is defined as post flight weight after payload is removed.

Total flight score is the sum of scores' of Mission 1, Mission 2 and Mission 3. It is formulated as follows.

$$\text{Total Flight Score} = M_1 + M_2 + M_3 \quad (3.5)$$

$$\text{Total Flight Score} = \frac{N_{laps}}{N_{max}} + 3 * \frac{\text{Payload}_{\text{Weight}}}{\text{Flight}_{\text{Weight}}} + 2 * \frac{N_{balls}}{N_{max}}$$

Finally, the teams' scores are formulated as:

SCORE = Written Report Score * Total Flight Score / Sqrt(RAC)

3.2. Design Requirements

The participants of the DBF contest are requested to design, manufacture and demonstrate a propeller driven, electric powered unmanned air vehicle. There are three missions, which aircraft must have enough ability to success. The mission analysis helps to find out the concept of aircraft. Due to this year's missions, the aircraft must have certain abilities to success the mentioned missions.

In the first mission, the aircraft should be fast and agile. The aircraft must have an efficient propulsion system configuration and general aircraft system which has low drag coefficient. These are the first mission's keys to success. Key to success in second mission is that a high lifting aircraft design is required to carry steel bars, with respect to steels density extremely challenging. Moreover, the light payload systems should be designed for weight issue. To success third mission, the aircraft should have enough space to carry planned number of golf balls. Additionally, a light and efficient aircraft design is required for all missions due to the importance of RAC on the calculation of score.

3.3. Configuration Selection

Success throughout the design process relies on careful conceptual design. As a result, as it is seen in milestone chart of the project (figure 2.3) for the design process there was enough time to select the best concept. In order to this, aircraft types, wing vertical configurations, tail configurations, propulsion system configurations, landing gear configurations and payload system configurations were considered.

3.3.1. Aircraft Type

For the aircraft type, the team focused on conventional, c wing, elliptical, biplane and flying wing configurations. To determine the best type, the team considered on figures of merit.

Figures of Merit FOM

- **Weight:** RAC is the function of aircraft's weight in each mission. Because of the importance of the weight, it was scored as 35.
- **Drag:** An aircraft with less drag is faster and needs lighter battery packs. These two qualities affect mission scores; hence drag was scored as 20.
- **Handling Qualities:** Good handling qualities are necessary to perform flight missions successfully. Handling qualities were scored as 15.
- **Storage Size:** Decreasing the volume is needed to store the aircraft to suitcase. This case makes the aircraft smaller and lighter. It was scored as 10.
- **Stability and Control:** A competitive aircraft should ideally be as stable and controllable as possible to have successful completion in each mission and high performance. Thus stability and control was scored as 10.
- **Manufacturability:** Testing the configuration and practicing the missions to make necessary changes on the aircraft is crucial. To have enough time to make tests and practices, manufacturability is another parameter and was scored as 10.

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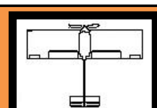
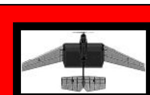
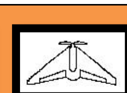
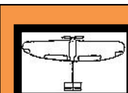
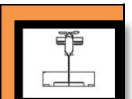
Due to mentioned FOM's parameters, following alternative configurations were analyzed.

- **Conventional:** The conventional aircraft, negative lift is usually produced by the tail in order to overcome the negative moment on the wing. The wing area, therefore the wing span, is increased in order to produce sufficient lift. Thus it makes a problem to fit in suitcase. Because of having good pitching stability, conventional aircraft has good handling qualities. It is easy to manufacture. However, the team participated in this competition with conventional aircraft in previous years. Consequently, the team does not have so much experience about the other aircraft concepts. The conventional aircraft is not selected because of having problems to fit in the suitcase and preferring to have experience on different concepts.

- **C wing:** The c wing aircraft, similar to conventional aircraft negative lift is generated with a tail. With sweep angle and taper ratio the load distribution on the main wing comes to the closer elliptic distribution. The effectiveness of the wing rises properly with decreasing induced drag. For a suitable design and for the suitcase wing span must be small and the designed wing must generate enough lift. To solve the problem, the fuselage of the aircraft must also generate lift to increase the payload weight and to reduce the load factor. Additionally, increasing the wing span and educing the wing loading with fuselage affects gliding ratio positively and for hand launching, these parameters are extremely important.
- **Elliptical:** Conventional configuration with an elliptical wing increases wing efficiency and reduces drag. However, manufacturing this configuration is extremely difficult and takes long time.
- **Flying wing:** In this configuration, the lack of tail and short fuselage length has a weight advantage. It seems that fitting in the suitcase issue is solved. In contrast, designing a flying wing causes stability problems, affects the handling qualities, take off, and landing characteristics. Considering the manufacturability, it is also difficult to manufacture this type of aircraft.
- **Canard:** Although it has good handling quality, its takeoff and landing characteristics are poor. In the missions aircraft must hand launch, so canard produces problems at takeoff.

Table3.2 Aircraft Configuration Weighted Decision Matrix

						
Figures of Merit	Weight	Conventional	C Wing Body	Flying Wing	Elliptical	Canard
System Weight	35	0	1	1	0	-1
Drag	20	0	1	1	0	-1
Handling Qualities	15	0	0	-1	0	-1
Storage size	10	0	1	1	0	-1
Stability and control	10	1	0	-1	1	0
Manufacturability	10	1	0	-1	-1	0
Total	**100**	**25**	**60**	**35**	**0**	**-80**

3.3.2.Wing Vertical Configuration

To determine the vertical location of the wing weight, internal payload storage and handling qualities were selected as parameters and investigated as follows.

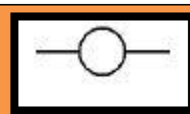
- **Weight:** Total weight is the most important parameter because of the RAC. Therefore, it was scored as 40.
- **Handling Qualities:** Handling qualities of the aircraft is extremely important to be successful in the missions. Selecting the vertical location of the wing affects the handling quality of aircraft so it was scored as 30.
- **IPS:** It is vital that the aircraft allows easy access to payload to shorten the loading/unloading times. Thus it was scored as 30.

Due to mentioned FOM's parameters, following alternative vertical locations of the aircraft were analyzed.

- **Low wing:** This configuration does not need any additional structure to support the spar box since the spar box of the low wing can also be connected to the landing gear. This advantage provides lighter aircraft. It also provides easy access to the payload however the handling qualities of the low wing are poorer than the other wing locations.
- **Mid wing:** In this configuration, spar box should be used. Since the spar box of mid wing passes from the middle of the fuselage, it is very difficult to place the payloads. Mid wing configuration provides the highest handling quality and more maneuverability than low wing and high wing. Mid wing and high wing configuration should have additional supports which increase the aircraft's weight.
- **High wing:** This location is advantageous in terms of handling qualities since high wing has a natural dihedral. However, because of the location of the spar box it needs supporters which increase the structural weight. There is no spar box in our design, the joining wing body and wing in the transition area with simple clips system. The other disadvantage is that high wing aircraft makes difficult loading the payload from top. But by reducing the spar box size this problem can be solved.

Following the evaluation of the wing vertical locations, a decision matrix was prepared to choose the most appropriate wing vertical location. High wing vertical location was selected as shown in table 3.2.

Table 3.3 Wing Vertical Location Weighted Decision Matrix

				
Figures of Merit	Weight	Low Wing	Mid Wing	High Wing
System Weight	40	0	0	0
Internal Payload Storage	30	1	0	1
Handling Qualities	30	-1	0	1
Total	**100**	**0**	**0**	**60**

3.3.3 Tail Configuration

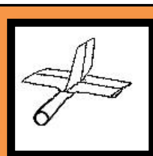
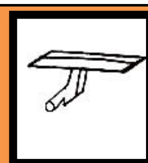
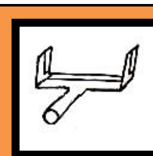
The figures of merit used for empennage type selection were weight, manufacturability, drag and aerodynamic efficiency.

- **Aerodynamic Efficiency**: The fuselage of the aircraft was expected to be short and wide due to spot size and payloads limitations. Therefore, empennage has the risk to stay in the wing and body wake region which decreases the aerodynamic efficiency of the empennage. Aerodynamic efficiency is the most important parameter for empennage selection, for this reason it was weighted as 20.

- **Weight:** Empennage is one of the large parts of the aircraft and has a great effect on the weight. Hence, it scored as 45.
- **Manufacturability:** Easy and fast manufacturing is important for team organization and scheduling. Manufacturability was scored as 15.
- **Drag:** The drag characteristic of empennage is another FOM to be considered according to the fact that drag affects the performance of the aircraft, so the missions' scores. It was scored as 20.
- **V-Tail:** V-tail is lightweight compared to the "T" and "conventional" tail since it has two surfaces instead of three. Providing the constant angle between the surfaces and manufacturing the connection between surfaces and fuselage is very hard and time consuming. However, its drag is least according the other alternatives. Its aerodynamic efficiency is moderate.
- **T-Tail:** For T-tail configuration, vertical tail should be strong enough to support the horizontal tail. That's why structural weight increases. Its manufacturability is easier than V tail while more difficult than conventional tail. T-tail's drag has more than V-tail, but less than conventional tail because it allows to built a smaller horizontal tail.

- **Conventional:** Conventional tail is lightweight and easy to manufacture. Since, the distance between the wing trailing edge and the horizontal tail is predicted to be short; its aerodynamic efficiency is bad because of being in the possible wake region of wing and fuselage. Moreover its drag is moderate. V-tail configuration was selected under the analysis of decision matrix, is shown in table 3.3.

Table 3.3 Empennage Type Weighted Decision Matrix

					
Figures of Merit	Weight	Conventional	T-Tail	U-Tail	V-Tail
System Weight	45	0	-1	-1	1
Drag	20	0	0	0	1
Aerodynamic Eff.	20	0	1	0	-1
Manufacturability	15	1	1	0	-1
Total	**100**	**15**	**-10**	**-45**	**30**

3.3.4 Propulsion System Configuration

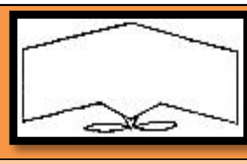
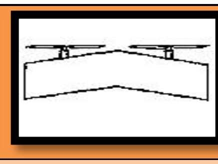
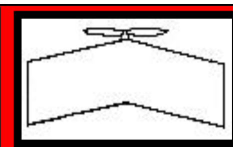
In this section, number of motors and motor, motor placement, battery and propeller types were considered. The most efficient form was selected to power the aircraft.

3.3.4.1 Orientation of Motor

- **Pusher:** This type of motor orientation requires a high landing gear in order not to hit propeller to the ground during takeoff. High landing gear means more drag and weight. Additionally, the pusher motor type is not safety while hand launching. Therefore pusher propulsion system is not advantageous for the contest.
- **Multiengine:** In this type of propulsion system two motors are mounted to the wing. Wing spars must be strong enough to carry the motors, thus the structural weight increases. Additionally, the consistency between the motors is extremely important. For these reasons multiengine orientation is not competitive.
- **Tractor:** This motor orientation does not need a high landing gear, which is an advantage in terms of drag and weight. Moreover, in tractor orientation, propeller exposed to clean air which increases the efficiency of the propulsion system when it is compared to the pusher orientation. In the light of these aspects, tractor orientation is preferred for the propulsion

system. Orientation of motor configuration was selected under the analysis of decision matrix, is shown in table 3.4.

Table 3.4 Orientation of Motor Weighted Decision Matrix.

				
Figures of Merit	Weight	Single Pusher	Dual Tractor	Single Tractor
System Weight	50	0	-1	1
Storage Option	10	0	-1	0
Ease of Mfg	10	1	-1	1
Pitching Moment Coupling	10	1	1	1
Drag	20	1	-1	0
Total	**100**	**40**	**-80**	**70**

It is essential to select a light and efficient propulsion system. In section 3.2.2, tractor propulsion configuration was selected. That's why, only motor, battery and propeller types were discussed in this section to determine a proper propulsion system.

- **Motor Type:** Brushless motors have higher performance than brushed motors because brushes reduce power. Moreover, brushless motors are lighter. As a result, brushless motor was preferred.
- **Battery Type:** As stated in the contest rules, only NiCad or NiMH batteries are allowed to be used. NiMH batteries have a higher energy density than NiCad batteries. Therefore, it would be possible to use lighter battery packs, which decreases system weight. Consequently, NiMH batteries were selected.
- **Propeller Type:** The three types of propellers are investigated in light of past years' experience: wooden propellers, plastic propellers and fiber-reinforced propellers. Wooden propellers are agile; however, they are easily damaged during instantaneous takeoff and high angle of attack landing. Plastic propellers easily deform under high loading. Therefore, fiber-reinforced propellers were selected because of being stronger than the other propellers.

3.3.5 Landing Gear Configuration

To select the best landing gear configuration from the alternatives, following FOM's were decisive factors:

- **Weight:** The weight of the landing gear affects directly total aircraft weight. Because of this importance, it was scored as 55.

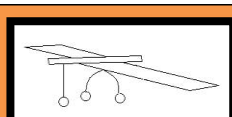
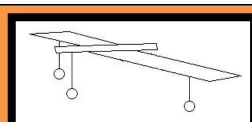
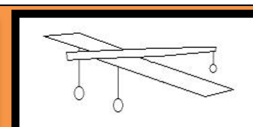
- **Drag:** A serious amount of drag is caused by landing gear. It is vital to reduce the drag generated by the landing gear. Producing less drag benefits faster aircraft and spending less time in a lap so it was scored as 35.
- **Ground Handling:** Ease of ground handling is only important during at landing. It was scored as 10.

Tail dragger, bicycle and tricycle landing gear were investigated and due to the determined FOM's.

- **Bicycle:** This configuration increases the drag and it is heavier than other configurations since the numbers of struts and the wheels are increased. The ground handling of bicycle landing gear is not as good as tail dragger landing gear.
- **Tricycle:** Tricycle landing gear has better ground handling than the others. In addition, Tricycle landing gear is lighter than bicycle landing gear with respect to the reduced number of wheels. This point is extremely vital for aircraft total weight. However the nose gear of tricycle configuration produces more drag than the tail dragger.
- **Tail Dragger:** This landing gear configuration is unstable on the ground. Tail dragger configuration does not have enough propeller clearance, because the auxiliary wheel at the backside is short. On the other hand, it has less drag and weight than the other landing gear configurations. Therefore to reduce weight properly tail dragger configuration is preferred.

After alternative landing gear configurations were determined, a decision matrix was prepared for selecting the configuration that best meets the FOM's. As seen in table 3.5, tail dragger configuration was selected.

Table 3.5 Landing Gear Configuration Weighted Decision Matrix

				
Figures of Merit	Weight	Tricycle	Bicycle	Tail Dragger
System Weight	55	-1	0	1
Drag	35	-1	0	1
Ground Handling	10	1	0	-1
Total	**100**	**-80**	**0**	**80**

3.3.6 Payload System Configuration

This year, there are 2 different payload combinations. These payloads consist of steel bars and golf balls. This means that the weight and dimensions of the payloads are variable. For this reason, the team decided not to use a commercial type of payload system. An appropriate payload system was designed to meet the requirements. It was designed such a way that aircraft center of gravity does not change with different payloads, while having all the payloads in minimum space. The drawings of the payload combinations located on the payload system can be seen in detail design section.

Concept Selection and Results

By using decision matrixes most convenient configurations for the aircraft and its components were determined. Then the conceptual design of the aircraft was concluded. The results are summarized in table 3.6 given below.

Table 3.6 Summary of Results

	Summary of Results
	Selected Configuration
Aircraft Configuration	Tractor C wing
Wing Vertical Location	High wing
Tail Configuration	V Tail
Motor Type	Brushless
Batteries Type	NiMh
Propeller Type	Fiber-Reinforced
Landing Gear Configration	Tail Dragger
Payload System	Self Design

4.0 PRELIMINARY DESIGN

In this section of the design process, firstly flight conditions were evaluated and the design and analysis methods were described. Secondly, design parameters and their importance to the missions were considered. Then, constraints of these parameters were determined. After performing necessary optimizations, the predicted mission performance was calculated.

4.1 Flight Conditions

To begin the preliminary design, firstly flight conditions were investigated. Tucson-Arizona's historical whether condition for April was obtained. By using the obtained data, density and dynamic viscosity were calculated. Historical weather conditions and calculated values are briefly stated in table 4.1 [1].

Table 4.1 Tucson Arizona Flight Condition

	Flight Conditions	
Elevation	2643	ft
Average Temperature	62.6	^{o}F
Average Pressure	29.825	inHg
Average Wind Speed	10.936	ft/s
Density	0.00234837	slug/ft^{3}
Dynamic Viscosity	3.8053797×10^{-7}	slug/ft-s

4.2 Design and Analysis Method

During the design process, a program, which is named as ATA-12 Design and Optimization Program (ATA12DOP), was generated by the team members using the stability derivatives and formulas from Nelson and Pamadi [2] and Raymer [3]. With help of the ATA12DOP; the lift and drag values of the aircraft, Cm-alpha graphics of the wing, tail and the whole system and some other results that effect the aircraft's performance provided exactly, by changing the size parameters of the wing fuselage and tail of the aircraft.

While generating ATA12DOP and designing the aircraft;

Firstly, the maximum fuselage, wing and tail dimensions were determined to prevent the aircraft from being oversize. Several carry-on bag options have been taken into consideration and the bag which has 21.65- 13.77- 7.87 inch outer dimensions is selected.

Secondly, the weight and center of gravity estimation codes were applied to the program. While applying these codes, the possibility of changing manufacturing methods and the electronic equipments were taken into consideration and these values were set as variable.

Thirdly, some formulas applied to calculate the required thrust. An optimization process was performed for the propulsion system to meet the hand launch requirement of the aircraft. The most appropriate motor and battery combination was determined as a result of this optimization.

Finally, by considering the required maneuverability of the aircraft areas and locations of the control surfaces were determined.

4.3 Design Parameters

The design parameters used in preliminary design period were weight, airfoils, geometry, wing loading, static margin.

- **Weight:** Weight was considered to be the most important parameter for the design. A lighter aircraft means better flight performance and efficiency. Also it is the only parameter of RAC which is used to calculate the flight score of the teams.
- **Wing Loading:** A high wing loading decreases the wing area, so it causes a geometric advantage. However, a high wing loading affects some important performance aspects such as stall speed, hand launch eligibility and turn radius negatively [4]. For this reason, wing loading was determined as one of the main optimization parameters.
- **Geometry:** The aircraft components as wing, tail, and fuselage are sized over and over using the ATA12DOP to have the best geometry to gain the highest score.
- **Airfoils:** Airfoils are crucial parameters for the aerodynamic characteristics of the aircraft. Lift, drag, moment, area, cruise, stall speed, and stall angle of the aircraft are dependent on the airfoils. So, a wide research was made to select the convenient airfoils.
- **Static Margin:** Static margin was considered as another parameter for flight performance. Low static margin causes the aircraft to be unbalanced but increases its maneuverability. However, a high static margin makes the aircraft stable while decreases its maneuverability. These two attitudes are both needed in flight so a convenient static margin was selected.
- **Propulsion System:** Propulsion system selection was very important in the design process of the aircraft because there were limitations like maximum 20A current draw and 3/4lb battery weight.

4.4 Calculation of Design Parameters and Constraints

4.4.1 Weight

Weight was one of the most important parameters to design the aircraft as a result of the effect of the RAC on the overall score of the competition.

First of all, a database was generated by the team members to calculate the average We/Wo ratio of the previous DBF teams and some other hand launch system UAVs.

Table 4. 2Previous DBF Aircrafts

	Previous DBF Aircrafts		
Name of The Aircraft	Empty Weight(lbs.)	Loaded Weight (lbs.)	W_e/W_0 Value
OSU Black 2011	5,25	11,5	0,343478261
Shadow Drag Purdue	3,65	10,65	0,297323136
Team Concrete MIT	3,02	10,23	0,276810266
0SU 0range 2009	6,8	11,3	0,486725664
0SU 0range 2011	4,66	10,91	0,305224565
Unstable Maple	5,7	11,7	0,423076923
Margin of Doom	6,8	12,91	0,404109589
ATA-9	6,355	13,55	0,371766

Table 4.3 Hand-Launch Aircrafts

	Hand-Launch Aircrafts		
Name of The Aircrafts	**Empty Weight (lbs.)**	**Loaded Weight (lbs.)**	**W_e/W_0 Value**
Dragoon Eye	4,5	5,5115	0,818563052
RQ11-raven	3,79	4,198	0,903232359
ZALA 421-08	4,629	5,2910	0,875
ZALA 421-12	6,3934	8,598	0,743589744
Bird-Eye 400	6,3934	9,038	0,707317073
Bird-Eye 500	9,0389	11,0231	0,82
Javelin	8,708	11,904	0,731481481

Secondly, The ATA-12 aircraft's structural properties have been applied in ATA12DOP and W_e/W_0 ratio was determined.

Table 4.4 ATA-12 Aircraft

		ATA-12 Aircraft	
Name of The Aircraft	Empty Weight(lbs.)	Loaded Weight (lbs.)	W_e/W_0 Value
ATA-12 (2. Mission)	2.43	7.3	0.332
ATA-12 (3. Mission)	2.43	7.72	0.314

Thirdly, the results were compared with each other to make certain that ATA-12 design solution has advantages against the previous year's aircrafts and hand launch aircrafts from other projects.

4.4.2 Wing Loading

Wing loading is a major parameter, which affects flight performance directly so its value should be in an appropriate interval to have a successful design.

High wing loading has a geometrical advantage but performance parameters for example stall speed, hand launch performance and turn radius were negatively affected. On the other hand, low wing loading results in structural weight and makes the control of the aircraft hard in windy weather.

Hand launching was considered as the biggest problem for mission 2 and 3 because of the high payload weight. By reducing the wing loading, hand launch is aimed to be easier.

Firstly, the successful aircrafts of the previous years were analyzed and their average wing loadings calculated to be between 2lb and 3lb per ft^2. Taking hand launch into account, the wing loading of aircraft is decided to be maximum 2.3.

4.4.3 Geometry

Using ATA12DOP, the sizing and geometry options have been compared to each other and the best suitable geometry is selected for the aircraft. The carry-on bag size and reducing the wing loading were the most important parameters during the process of deciding the geometry of ATA-12 C wing aircraft. To reduce the wing loading, the size of the aircraft is maximized under the boundary conditions of the selected carry-on bag size.

4.4.3.1 Wing Geometry

The parameters of wing design were aspect ratio, taper ratio, sweep angle, twist, dihedral angle and incidence.

- **Aspect Ratio:** The wing span was constant and the wing loading was determined as a result of the optimization, so aspect ratio was not a determined, but a calculated parameter. After including the fuselage because of its airfoil shape, aspect ratio was found as 7.4.
- **Taper Ratio:** Wing tip loss can be minimized by decreasing the taper ratio. It is set to be 0.6 to decrease wing tip loss.

- **Sweep Angle:** Sweep is a parameter usually used in high speed aircraft to increase the critical mach number. In addition to that, it has a positive dihedral effect which contributes to the rolling stability. To optimize the roll stability and center of gravity, it is set to be 15 degree.
- **Twist:** Twist is used to prevent wing tip stall. However, manufacturing twisted wings requires much more time and effort. So twist angle is 0.
- **Dihedral:** Dihedral angle increases the rolling stability of the aircraft. It is usually used in low wing configuration which was already discussed in conceptual design section. However, using dihedral makes the manufacturing difficult, especially for spar manufacturing and from sweep angle, the aircraft already has dihedral effect.
- **Incidence:** Incidence is the pitch angle between wing chord and fuselage center line. It is used to trim aircraft and to decrease drag during cruise. However, high incidence angles of wing can result in difficulties during takeoff since it limits the angle of attack of the aircraft and causes early stall. For this reason wing incidence constraints determined as 0° and 5°.

Table 4.5 Wing Geometry

				Wing Geometry	
Aspect Ratio	**Taper Ratio**	**Sweep Angle(°)**	**Twist(°)**	**Dihedral(°)**	**Incidence (°)**
7.3	0.5	15	0	0	0

4.4.3.2 Body Geometry

When deciding the body geometry, number of the golf balls was the main parameter to maximize the score of mission 3. As a result of the airfoil shape of the body, one of the dimensions, fuselage thickness, had to be small, and the other two dimensions were chosen to be biggest size that can fit the carry-on bag with the aim of carrying more golf balls.

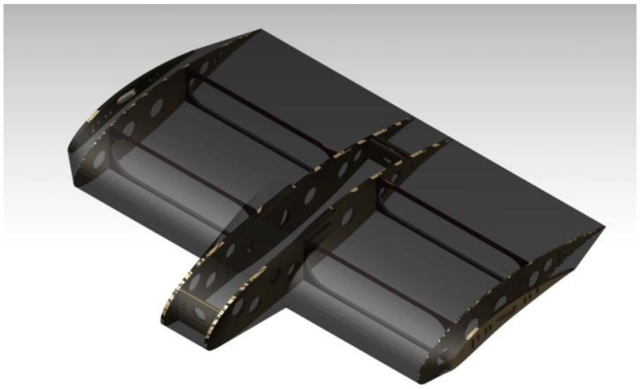


Figure 4.1 Body Geometry

4.4.3.3 Tail Geometry

Volume coefficient, aspect ratio, taper ratio, sweep/twist/dihedral angles and incidence were the parameters during the determination of the tail geometry.

- **Volume Coefficients:** While calculating tail areas, the volume coefficients in Raymer's book were used as optimization constraints. The volume coefficient values are between 0.5 and 0.8.
- **Aspect Ratio**: It was considered that tail should have a smaller aspect ratio than wing aspect ratio in order to be stalled after the wing.
- **Taper Ratio:** Empennage taper optimization constraints were specified as 0.6 and 1. After the calculations, it is decided to be 0.7.
- **Sweep/Twist/Dihedral Angle:** These parameters are mostly effective in wing performance. That's why it was considered that these parameters would not add any advantage and they were selected as 0.
- **Incidence:** The tail incidence angle is selected according to the trim condition. Tail incidence can vary in a wider range than wing. Optimization constraints were taken as -5 and +5.

Table 4.6 Tail Geometry

				Tail Geometry	
Aspect Ratio	Taper Ratio	Sweep Angle(°)	Twist(°)	Dihedral(°)	Incidence(°)
3.53	0.7	0	0	0	-5 to 5

4.4.4 Airfoils

In the selection of airfoil phase, multiple airfoils were researched to reach the optimum lift, drag and moment coefficients; also a database has been created. The database is consisted of airfoils which are used by teams that have been successful at AIAA DBF contests, previous ATA Teams' airfoils and some other airfoils used in unmanned air vehicle projects which have good features. As a result of the hand launch requirement, L/D ratios of the airfoils at low angles of attack are considered as the most important parameter. Additionally, lift, drag, and moment coefficients of the airfoils were investigated and manufacturability has been taken into consideration.

4.4.4.1 Wing Airfoil

As a result of small carry-on bag rule possible wing area is limited and airfoil lift coefficient gets higher importance and using an airfoil with high lift coefficient (Cl) becomes necessity.

Firstly, several airfoils were chosen from the database and compared to each other.

Table 4.7 Generated Airfoils for Wing

			Generated Airfoils for Wing				
Name	**t/c(%)**	**t/c at (%)**	**Cl_{max}**	**$Cl_{@0^o}$**	**$Cd_{@0^o}$**	**$Cm_{@0^o}$**	**$(L/D)_{max}$**
MH 114	13.08	30.00	1.6671	0.8559	0.00957	-0.1912	120
FX 63-137 smoothed	13.67	30.80	1.7970	0.9133	0.00950	-0.2075	118
sd 7062	13.98	27.22	1.6473	0.4545	0.00890	-0.0845	93.4
DA1002	10.5	30.00	1.2477	0.5499	0.01373	-0.1199	66.8
SD7043 (9,1%)	9.13	26.70	1.4918	0.4399	0.00665	-0.0949	99.1
Curtiss C72	11.73	30.00	1.3266	0.6744	0.00992	-0.0982	94.3
PATO 100	12.8	23.62	1.6559	0.9210	0.01064	-0.1470	104.53

Secondly, the DA 1002 airfoil is modified to reduce the moment coefficient, increase the lift coefficient, L/D and get an airfoil to manufacture wing easily and PATO100 airfoil was generated.

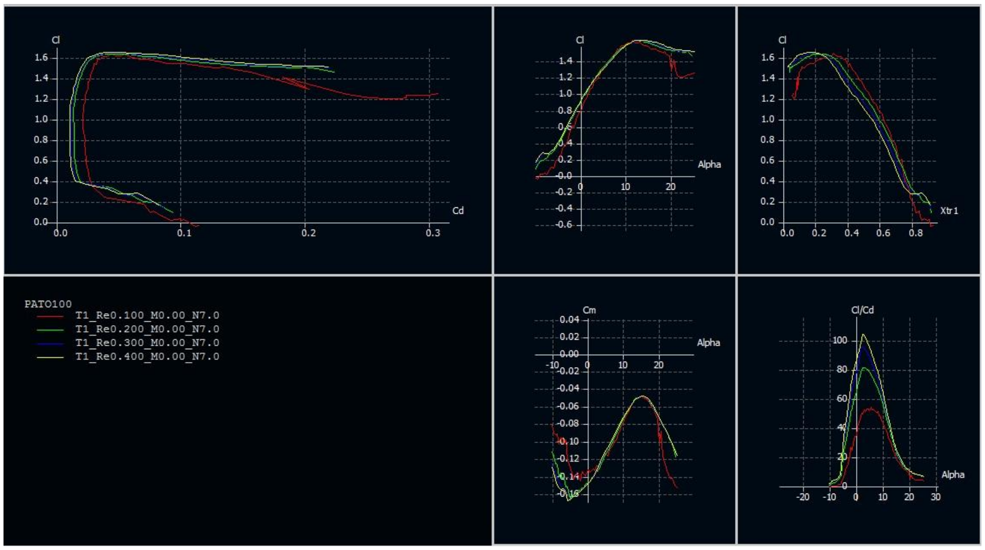


Figure 4.2 PATO 100 Airfoil Properties for Different Reynolds Numbers

4.4.4.2 Fuselage Airfoil

As a result of the aim of obtaining extra lift from the fuselage part of the aircraft, the body was designed to have airfoil shape.

First of all, the diameter of ball was considered and the payload combination was decided. Minimum of 4 balls had to be ranged from the leading edge to the trailing edge of the fuselage. The chord length of the fuselage was decided to be 11.8'' and the thickness of the airfoil, where the balls will be loaded, must be more than 0.87'' which is the diameter of golf balls. With these constraints, a new airfoil was generated which is named as Surfing Bird (SB).

Table 4.8 Generated Airfoils for Fuselage

			Generated Airfoils for Fuselage				
Name	**t/c(%)**	**t/c at (%)**	**Cl_{max}**	**$Cl_{@0}^{o}$**	**$Cd_{@0}^{o}$**	**$Cm_{@0}^{o}$**	**$(L/D)_{max}$**
SB 678	19.52	34.55	1.202	0.5381	0.01124	-0.0973	51.86
SB 678.1	20.43	34.53	1.1086	0.5145	0.01014	-0.0910	64
SB 678.2	19.16	34.59	1.2070	0.5185	0.01119	-0.0973	52
SB 678.3	19.35	35.57	1.5102	0.6274	0.01157	-0.1248	66.3
SB 678.4	20.06	32.17	1.5089	0.6061	0.01135	-0.1236	69.05

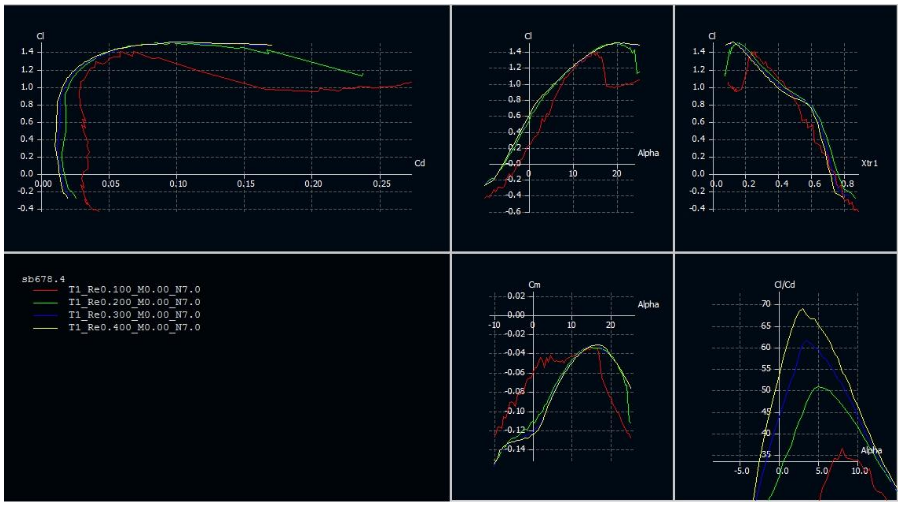


Figure 4.3 SB 678.4 Airfoil Properties for Different Reynolds Numbers

SB 678.4 was selected for the fuselage part of the aircraft after the comparison to the others taking into consideration Cl_{max}, C_d , C_m and $(L/D)_{max}$ coefficients. Finally a new airfoil, SB678.8 was generated for the mid fuselage where motor was mounted and battery package was loaded.

Table 4.9 Generated Airfoils for Mid Fuselage

	Generated Airfoil for Mid Fuselage						
Name	**t/c(%)**	**t/c at (%)**	**Cl_{max}**	**$Cl_{@0^o}$**	**$Cd_{@0^o}$**	**$Cm_{@0^o}$**	**$(L/D)_{max}$**
SB 678.8	15.4	36.7	1.5079	0.4932	0.00908	-0.1062	54.3

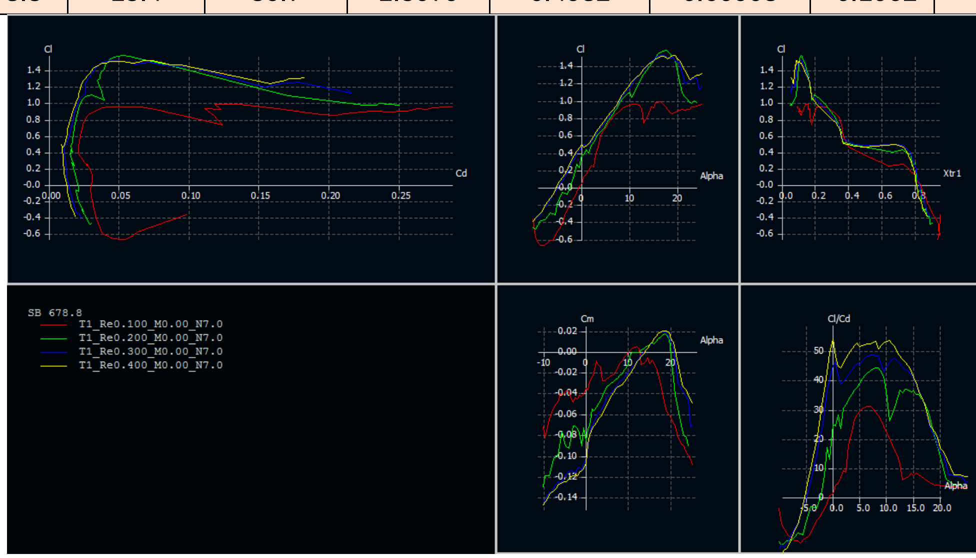


Figure 4.4 SB 678.8 Airfoil Properties for Different Reynolds Numbers

4.4.4.3 Tail Airfoil

NACA 2408 reverse profile were analyzed for tail. Symmetric profiles are causing to much structural weight due to larger tail surface. By using a cambered airfoil, tail dimensions have been lowered to appropriate values. After analyzing NACA 2408, a new airfoil was generated, camber ratio was increased and maximum camber placement was changed. Comparison chart can be seen in table 4.9, with values calculated for 400000 Reynolds.

Table 4.10 Generated Airfoils for Tail

			Generated Airfoils for Tail				
Name	**t/c(%)**	**t/c at (%)**	**Cl_{max}**	**$Cl_{@0}^{o}$**	**$Cd_{@0}^{o}$**	**$Cm_{@0}^{o}$**	**$(L/D)_{max}$**
NACA 2408 reverse	8	29.10	-1.1811	-0.2603	0.00570	0.0581	-79
OTAP 408	11.2	19.70	-1.7146	-0.6873	0.01097	0.1461	-99

4.4.5 Static Margin

Static margin is the distance between the neutral point and the center of gravity (c.g.) as a percentage of the mean aerodynamic chord. Selection of an accurate static margin is important for aircraft's stability and control. It typically varies between 10% and 25% for stable aircrafts [5]. Therefore, static margin interval was determined in this region. The static margin is decided to be %20.

4.4.6 Propulsion System

The propulsion sub team generated additional code to ATA12DOP and used aerodynamic models and selected the subcomponents of the propulsion system.

4.4.6.1 Battery Selection

Different battery optimizations were performed for all missions due to the flying time difference between the missions. For the first mission flight time was important, for the second and third missions high voltage required.

For the first mission, the flight time was evaluated to be about 5 minutes with extra half turn for landing. After optimization, it was determined that a configuration of 10, 1700 MAH cells would be the optimum configuration for the aircraft.

For the second and third missions, a battery configuration of 16, 1000 MAH cells were decided to use for the aircraft configuration.

4.4.6.2 Propeller Selection

Efficiency of the propeller was assumed to be about 70% and the propeller speed was considered to be %42 more than design cruise speed. From the pitch calculation, the speed of the propeller was calculated to be 1.43 times cruise speed.

4.4.6.3 Motor Selection

After declaration of the rules, a motor database was generated which includes 9 different motor brands and 680 different motor types with their technical specifications to decide which has the best efficiency at given conditions.

4.5 Optimization

4.5.1 Design Optimization Model, Constraints and Results

The values specified before and the values found by the optimization performed in the interval of constraints were shown in Table 4.10. The way followed for the optimization is shown in Figure 4.7

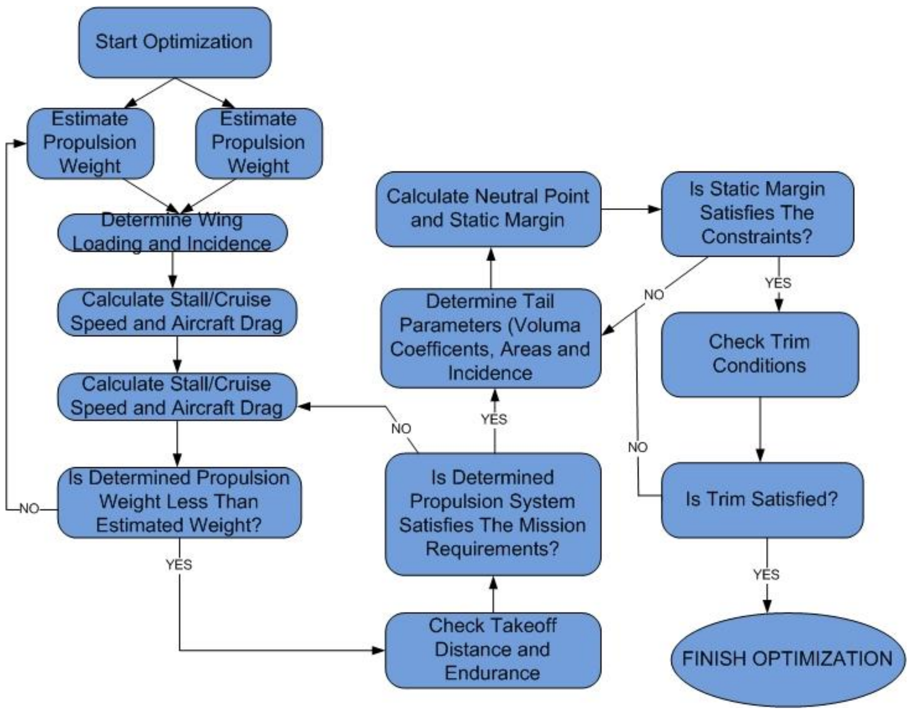


Figure 4.5 Design Optimization Flowchart

4.5.2 Propulsion optimization Model, Constraints and Results

Propulsion system was specified by following the steps in Figure 4.8. As a result, the propulsion system which provides the optimum performance values was determined.

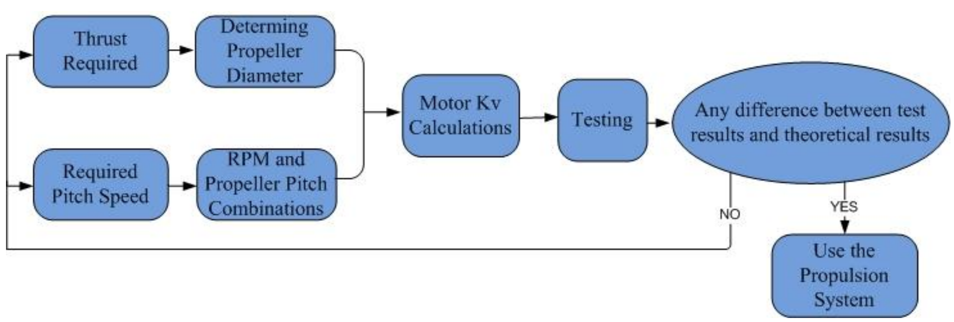


Figure 4.6 Propulsion Optimization Flowchart

Firstly, some formulations has been generated and applied to ATA12DOP to find out the gliding duration after hand launch using the initial speed, wind speed and aerodynamic characteristics like drag and lift coefficients of the aircraft without propulsion system. Then the required thrust and pitch speed were calculated to safe hand launch for empty and loaded flights.

The initial speed after hand launch and wind speed are assumed to be 2m/s and a dynamic optimization of the aircraft performed to calculate the required thrust for empty and loaded flights.

Table 4.11 Hand-Launch Analysis (Empty)

		Hand-Launch Analysis (empty)	
Thrust (lbs.)	**Minimum height (ft)**	**Minimum height time (s)**	**Initial Angle (°)**
0.6613	4.690	2.4	0
0.6613	4.836	2.3	10
0.8818	5.168	1.7	0
0.8818	5.316	1.7	10
1.1023	5.445	1.4	0
1.1023	5.595	1.3	10

Table 4.12 Hand-Launch Analysis (Loaded)

		Hand-Launch Analysis (Loaded)	
Thrust (lbs.)	**Minimum height (ft)**	**Minimum height time (s)**	**Initial Angle (°)**
1.543	0.446	6.8	0
1.543	0.804	6.8	10
1.763	1.249	5.9	0
1.763	1.631	5.8	10
1.984	1.864	5.2	0
1.984	2.263	5.1	10
2.204	2.349	4.6	0
2.204	2.761	4.5	10

Following the calculation of the static thrust, a value was defined as RPM^2*D^4 and calculated using equation 4.1. It should be noted that, RPM is defined as revolutions per minute, D (inch) is defined as diameter of the propeller, Cp (dimensionless) is defined as power coefficient of the propeller, P (inHg) is air pressure and T (°F) is ambient temperature.

$$\text{Thrust (lb)} = (2.83e-12)\left(\frac{\text{lb}}{\text{ft}^3}\right) * \text{RPM}^2 * \text{D}^4 * \text{C}_\text{p} * \left(\frac{\text{P}}{29.92}\right) * \left(\frac{528}{460+\text{T}}\right) \quad (4.1)$$

The specified RPM^2*D^4 value was used to find the RPM values for different D values. Pitch was calculated using the RPM^2*D^4-D pairs in the formula below. In the formula, pitch speed was specified as 1.5 cruise speed, taking the efficiency of the propeller into account.

$$(\text{Pitch Speed}) = \text{Pitch} * \text{RPM} \quad (4.2)$$

After the propeller diameter and pitch combinations were determined, power calculations were performed. The motor's RPM was decreased by propeller loading which was a function of RPM, pitch and diameter of the propeller. Therefore, expected RPM should be greater than the required RPM. In the light of experimental data, the RPM value of the motor was taken as 1.24 times of the required RPM value. Power was then calculated by putting RPM, pitch and required thrust values into Boucher's Formula which is given in Equation 4.3. V (Volt) is defined as the potential difference of the battery pack and A (Ampere) is defined as the current drawn from the package.

$$\text{Power(Watt)} = \text{V} * \text{A} = (\text{PRM} * \text{Pitch} * \text{Thrust})/(538.41) \quad (4.3)$$

The required potential difference was calculated by dividing power with 20 A current. According to experimental data, an extra 4 V was added to the calculated value because of internal resistance of batteries, cables, etc. To calculate the required number of batteries, the potential difference was divided by the standard potential difference of one NiMH cell, which is approximately 1.2 V. Kv, which indicates the RPM value of the motor's shaft per unit potential difference, is the most important parameter of an electric motor. With the help of RPM and potential difference values, the required Kv was determined.

It was decided by the team that AXI AC2826/12 motor would be used as the team's experience and created motor database show that AXI motors provide maximum performance. It was found in the calculations that AXI AC2826/12 supplies the thrust that is required. Due to the fact that empty weight of the aircraft is an important parameter for mission scores, the required battery capacities to accomplish missions in different cruise speeds and different flight times were calculated and compared for each propeller combination. This operation was performed for both empty and loaded aircraft and 13x17 APC propellers were decided to use. The results were shown in Table 4.12 and in Table 4.13 as follows.

Table 4.13 Unloaded Assignment with 13x7 Propeller

	Unloaded Assignment with 13x7 Propeller						
Battery Type	**Max Number of Cells**	**Weight of a Cell (lbs.)**	**Batt. Pack. Weight (lbs.)**	**Voltage (V)**	**RPM**	**Cruise Velocity (ft/s)**	**Flight Time (s)**
Elite 1500	13	0.0485	0.72	15.6	11856	179.8206	4.5
Elite 1500	12	0.0485	0.62	14.4	10944	153.2134	4.5
Elite 1500	11	0.0485	0.55	13.2	10032	128.7386	4.5
Elite 1700	10	0.0595	0.65	12	9120	106.3963	5.1
Elite 1700	9	0.0595	0.57	10.8	8208	86.18662	5.1
Elite 2000	8	0.0725	0.65	9.6	7296	68.10941	6
Elite 2000	7	0.0725	0.55	8.4	6384	52.13191	6

Table 4.14 Loaded Assignment with 15x7 Propeller

	Loaded Assignment with 15x7 Propeller							
Battery Type	**Max Number of Cells**	**Weight of a Cell (lbs.)**	**Batt. Pack. Weight (lbs.)**	**Voltage (V)**	**Gear box**	**RPM**	**Cruise Velocity (ft/s)**	**Time (s)**
ARTTECH 1000	16	0.0485	0.68	19.2	3	14592	90.81254	3
ARTTECH 1000	16	0.0485	0.68	19.2	2	14592	136.186	3
Elite 1500	12	0.0485	0.62	14.4	1	10944	153.2134	4.5
Elite 1500	11	0.0485	0.55	13.2	1	10032	128.7386	4.5
Elite 1700	10	0.0595	0.65	12	1	9120	106.3963	5.1
Elite 1700	9	0.0595	0.57	10.8	1	8208	86.18662	5.1
Elite 2000	7	0.0725	0.55	8.4	1	6384	52.16472	6

Table 4.15 Propulsion System

					Propulsion System						
Motor Type	**Motor's Kv (rpm/V)**	**Gearbox Ratio**	**Propeller Type**	**Propeller Pitch (in)**	**Propeller Diameter (in)**	**Power (Watt)**	**Voltage of Pack (V)**	**Maximum Current (A)**	**Battery Type**	**# of Batteries**	**Static Thrust (lbs.)**
AXI 282 6/12	760	1	APC	7	13	240	12	20	Elite 1700 MAH	10	1.181
AXI 282 6/12	760	3	APC	7	15	384	19.2	20	Art Tech 1000 MAH	16	2.892

4.6 Stability Calculations

Designing and manufacturing a stable aircraft is important for the quality of handling and control. Designing a stable aircraft is depended to select a desired value of stick fixed neutral point and static margin. The stability conditions calculated with ATA12DOP. Stability derivatives are also another important point for designing a stable aircraft. Calculations were mainly based on vortex lattice method.

4.6.1 Neutral Point Calculation

The most important parameters are the derivative of lift coefficient over angle of attack for horizontal tail and wing, the horizontal tail volume coefficient and dynamic pressure ratio at the horizontal tail for neutral point. Calculation of these parameters is mostly affected by the horizontal tail, wing geometry, and the location of them with respect to center of gravity. Taking the first estimations from airfoil selection, wing sizing and empennage sizing sections, the neutral point was calculated as 26% of mean aerodynamic chord of the wing.

4.6.2 Stability and Control Derivatives

Stability and control derivatives of the aircraft were calculated in order to estimate the aircraft's stability characteristics. The derivatives were calculated as in table 4.15 by using XFLR5 6.02 beta software[6].

Table 4.16 Stability and Control Derivatives

	Stability and Control Derivatives				
$C_{L\alpha}$	2.8518 rad^{-1}	$C_{m\alpha}$	-0.8536 rad^{-1}	C_{mq}	-3.3796 rad^{-1}
C_{nr}	-0.010007 rad^{-1}	C_{lr}	0.50373 rad^{-1}	C_{yr}	-0.076317 rad^{-1}
C_{np}	-0.2859 rad^{-1}	C_{yp}	-0.25662 rad^{-1}	C_{lp}	-0.357 rad^{-1}
$C_{y\beta}$	0.3372 rad^{-1}	C_{Lq}	4.8161 rad^{-1}	$C_{n\beta}$	0.06599 rad^{-1}
$C_{l\beta}$	-0.19838 rad^{-1}				

4.7 Aerodynamic Considerations

- **Lift:** Lift curve slopes, zero lift angles, maximum lift and design lift coefficients according to incidence angles, stall angles of wing and tail were calculated as shown in table 4.16. Stall speeds of loaded and unloaded aircraft were then calculated as 37.57 ft/s and 21.07 ft/s.

Table 4.17 Wing and Empennage Lift Properties

	Wing and Empennage Lift Properties			
Calculated Values	Lift curve slope (CLa)	Zero Lift Angles (α_{0L})	Maximum Lift Coefficient (C_{Lmax})	Stall Angle(°)
Wing	5.58061	-10.81	1.75	13.50
Empennage	6.01606	6.72	-1.72	9.50

- **Drag:** Parasite drag coefficient (C_{Do}) was calculated as 0.028 by using "Component Built up Method". Then, parasite drag, induced drag and total drag polar with respect to the aircraft velocity were obtained as shown in Figure 4.9. (k=0.056)

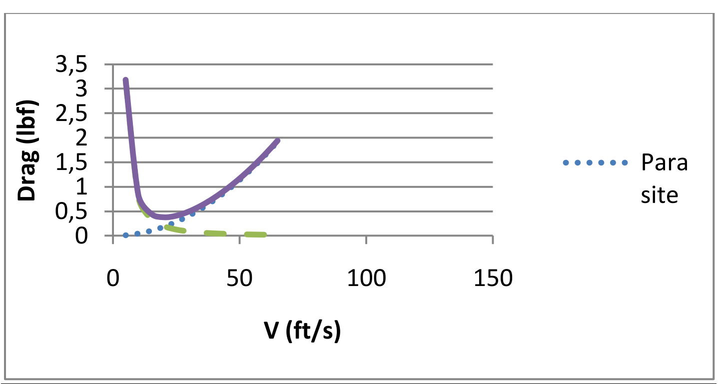


Figure 4.7 Component Built-up Method for Parasite Drag

4.8 Control Surface Sizing

Primary control surfaces for an aircraft are aileron, elevator and rudder. After the wing, horizontal tail and vertical tail were sized, the geometries of control surfaces were determined.

- **Aileron Sizing:** Aileron is a control surface which is used to control the movements around the roll axis. In order to provide desired roll conditions proper constraints of aileron, 0.2c-0.3c and 20%-30% of semi-span, were used. It was determined 0.25c and 28% of semi span. The total area of aileron was calculated 0.472 ft^2.
- **Elevator and Rudder Sizing:** Elevator is the most important control surface for longitudinal control. Also the rudder affects landing turning performance. Because of the ATA-12 tail configuration which is V tail, the control surfaces will be used as an elevator and a rudder together. At these conditions the sizing of the control part of the tail as determined 0.3 times the mean tail chord. With this ratio, the control surface area is calculated 0.315 ft^2.

4.9 Estimated Mission Performance

Table 4.18 Estimated Mission Performance

	Mission Performance		
Parameter	**First Mission**	**Second Mission**	**Third Mission**
Minimum height after hand launch (ft)	5.595	2.761	2.761
# Laps	6	3	3
Lap Time (sec.)	40	55	55
Cruise velocity (ft/s)	106.3963	90.81254	90.81254

5. DETAIL DESIGN

In detail design, dimensional parameters and structural characteristics/capabilities of final design are documented.

5.1 Dimensional parameters of Final Design

Table 5.1 Final Dimensional Parameters of ATA-12

Final Dimensional Parameters of ATA – 12

Fuselage				
	Mid. Fuselage		Side Fuselage	
Airfoil	sb678.8		sb678.4	
Root Chord (ft)	1.31		0.98	
Span (ft)	0.32		1.31	
Area (ft^2)	0.37		1.29	
Taper Ratio	0.75		1	
Thickness (%,@)	15.40	36.7	20.06	32.2
Chamber (%,@)	3.44	36.7	4.50	42.4

Tail		
Airfoil	OTAP 408	
Root Chord (ft)	0.65	
Semi Span (ft)	0.98	
Semi Area (ft^2)	0.54	
Taper Ratio	0.7	
Thickness (%,@)	11.20	19.7
Chamber (%,@)	-6.00	39.5
Vertical Volume Coeff.	0.04	
Horizontal Volume Coeff.	0.54	

Wings		
Airfoil	PATO100	
Area (ft^2)	1.61	
Span (ft)	3.28	
Root Chord (ft)	0.65	
Aspect Ratio	7.05	
Sweep angle(°)	15	
Thickness (%,@)	12.80	23.6
Chamber (%,@)	8.88	38.35

5.2 Systems and Sub-Systems Design

5.2.1 Fuselage

Fuselage structure was designed in order to provide additional lift and adequate strength to support the aircraft throughout the flight with minimum weight. It should also provide easy access to the payloads and critical components, such as and batteries, motor, esc and receiver in order to load and assemble them with minimized time loss. Firstly the maximum dimensions of the fuselage were calculated that can fit in the suitcase. The dimensions were determined as 1.64x0.98 inches with the tolerance of %5. Then the airfoil shape of the fuselage was determined to maximize the number of golf balls for the third mission and designed a new airfoil to increase the Cl and reduce the Cd and Cm coefficients of fuselage to gain more lift and minimize the drag and moment. Finally the final dimensions of the fuselage were determined as 1.64x0.98 inches.

Monocoque structure was preferred and 4 bulkheads were determined to be sufficient to support the fuselage in the light of past years' experience. After solving the structural troubles, bulkheads were designed with considered payloads. To make more space for golf balls they were designed like as thin skinned structures. Their structural capabilities were solved with idealization method (boom) in Aircraft Structures for Engineering Students, Third Edition, T.H.G. Megson[7].

5.2.2 Wing and Tail

In Preliminary Design, wing span was calculated as 4.92 ft with an area of 3.28 ft^2. The wing was designed to carry out wingtip test and overcome landing impacts. The wing consisted of 9 ribs in order to support the surface covering properly, keeping the airfoil shape along the wingspan. It was decided to reinforce the first and the last ribs by birch plywood since the first rib was located at the root and the last rib was carrying the endplate. The main spar was located at the quarter chord, which has I profile shape to strengthen in the direction of lift/weight, is made of balsa to reduce the system weight. The auxiliary spar, which is also made of balsa, lay between the fuselage and the last rib in order to overcome the moment and add extra strength to the spar. Ailerons were located between the fifth rib and last rib and servos were located in the 4. rib.

Wing main spar was chosen in the light of Finite Element Method (FEM) analysis. Balsa rods with different dimensions ranging from 0.2" x 0.157" to 0.7" x 0.157" were analyzed assuming that wingtip test was done. Stresses and displacements were compared. While rods with small dimensions bended too much, rods with larger dimensions were causing problems to fit in the ribs. Finally 0.591x0.157" dimensions were selected since its displacement was reasonable and it was not so heavy. In analysis, spar was meshed as shown in Figure 5.1 while the results are shown in Figure 5.2

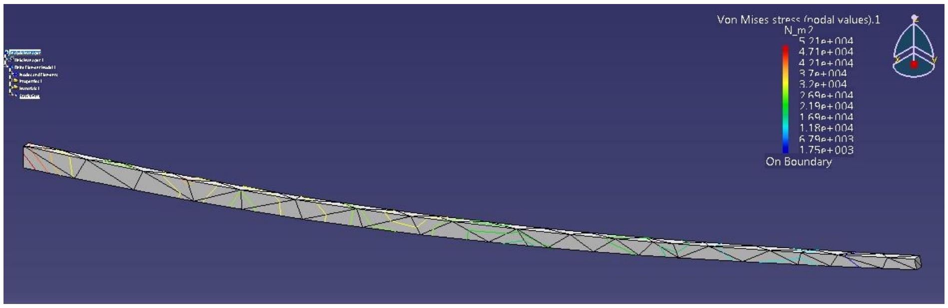


Figure 5.1 Meshed Spar

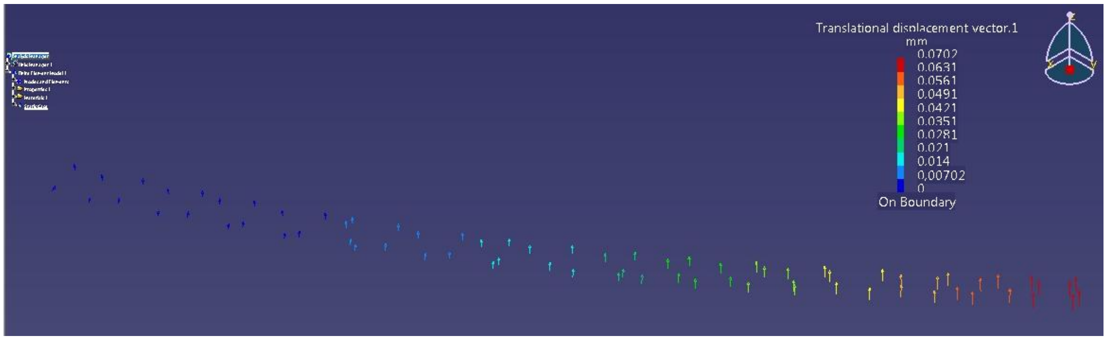


Figure 5.2 Von Misses and Deformation Results of Spar Analysis

Wing and body connected with a simple plywood structure. This system is lighter than complex spar box. Also with this system additional structural element is not required. System configuration and coupling process is shown in figure 5.3

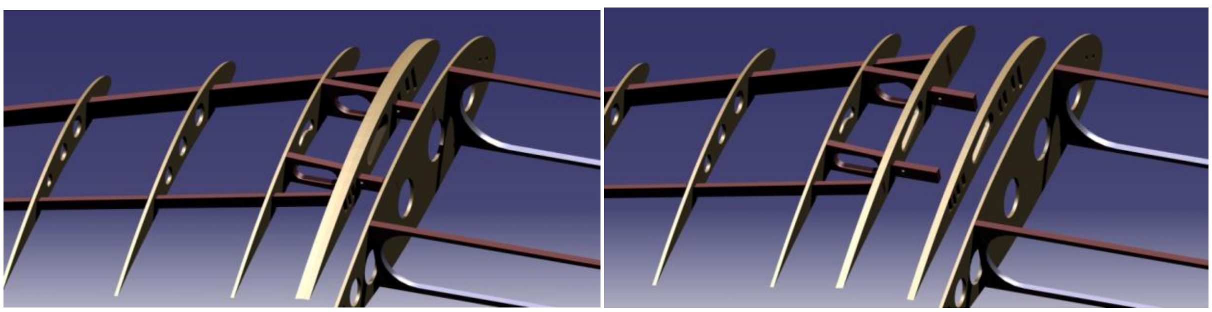


Figure 5.3 System Configurations and Coupling Process

5 ribs were decided to be sufficient for the tail. The first and last ribs were reinforced by plywood in order to hold tails tight and prevent corrosion in the connection part between tail and boom. To spars were used to hold the tail stable and they are located along the entire tail. Control surfaces were located along the entire tail span and the servo was placed at the center ribs. Front spar was located as fore as possible, noting the thickness of the airfoil while rear spar was located as aft as possible, again noting the thickness of the airfoil. The reason for locating two spars as far as possible is to transfer the moment generated by the horizontal tail to the fuselage comfortably.

V tails' plates are connected tail boom a similar system with the wings. Only required additional structure elements are on the boom. So there is no increasing tail weight much. This system also maintains a base to arrange V tail dihedrals. Tail-tail boom connection is shown in figure 5.4

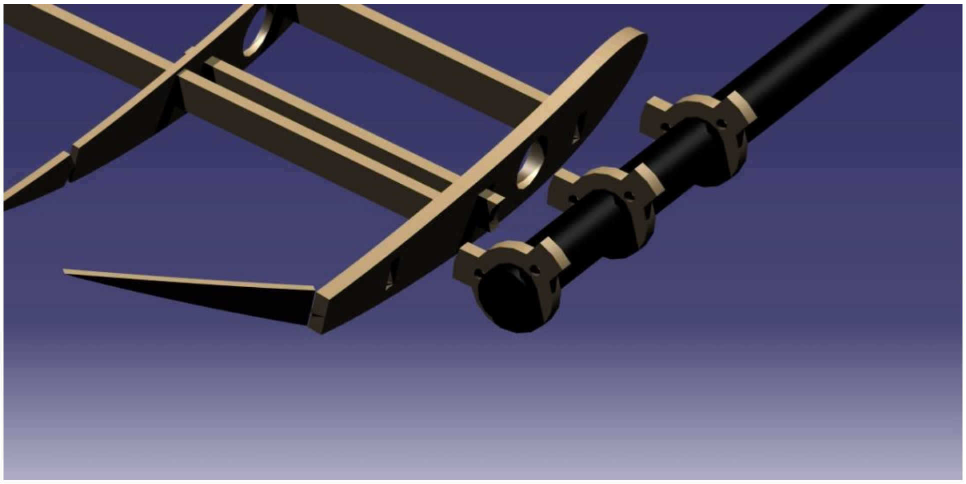


Figure 5.4 Tail – Tail Boom Connection

Both wing and tails surfaces were covered with balsa from leading edge to quarter chord in order to increase the smoothness of the surface. The rest were covered with microlite film. In Figure 5.5, the final structures of the wing and empennage are shown.

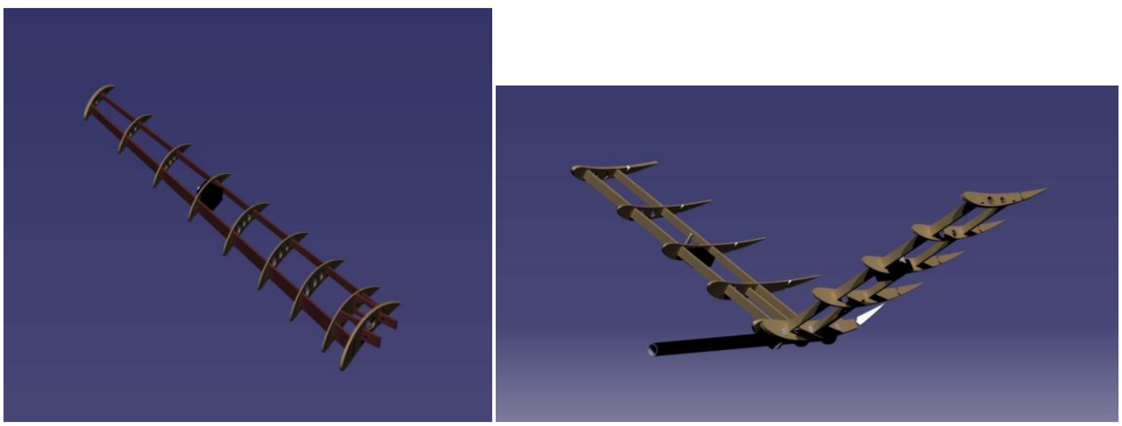
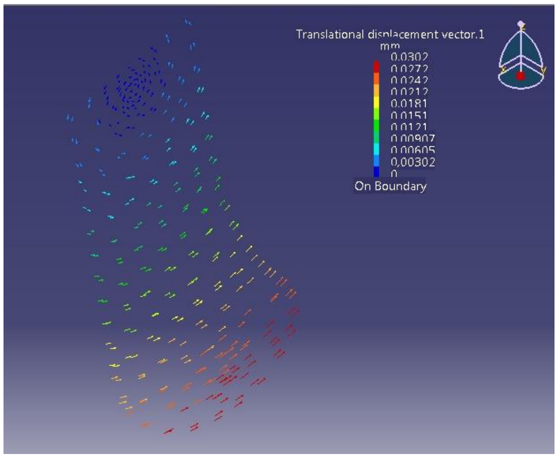


Figure 5.5 Final Structures of The Wing and Empennage

5.2.3 Landing Gear

The team decided to use ready-made aluminum tail landing gear, since constructing a new one would have been difficult. The main landing gear was mounted between wing and fuselage to prevent generating vortex and reducing the efficiency of fuselage. The main landing gears were fixed to the plywood plates which were located in the edges of the fuselage with a plastic metric four (M4) cap screw. When the aircraft touches the ground, the total weight of the aircraft firstly acts on the main landing gear. So main landing gear must be strong and light enough. Carbon fiber reinforced balsas were used to meet these requirements. FEM analyses were performed by using CATIA V5[8] in order to find how many layers of carbon fiber would be sufficient. Landing gear was analyzed for the worst landing case. After loads were calculated according to 3g load condition, they were applied to the landing gear. The structure was meshed and boundary conditions were applied to the landing gear as shown in Figure 5.6. The results are shown in Figure 5.7.



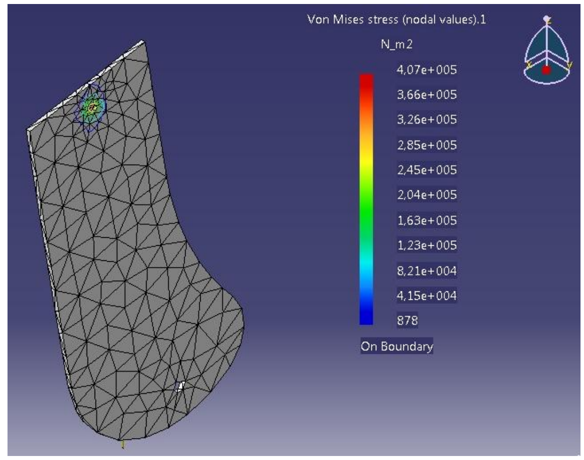


Figure 5.6 Meshed Landing Gear

Figure 5.7 Von Misses and Deformation Results of Landing Gear Analysis

5.3 Payload System Architecture

5.3.1 Mission 2

For second mission; steel bars attach to body with adhesive clip as shown in figure 5.8. Due to there is no time limitation in loading issue for the second mission, this system has any disadvantages. Considering low weight of clips; this system is really beneficial application for ATA-12. In figure 5.8 system and sample steel bar were shown to explain system.

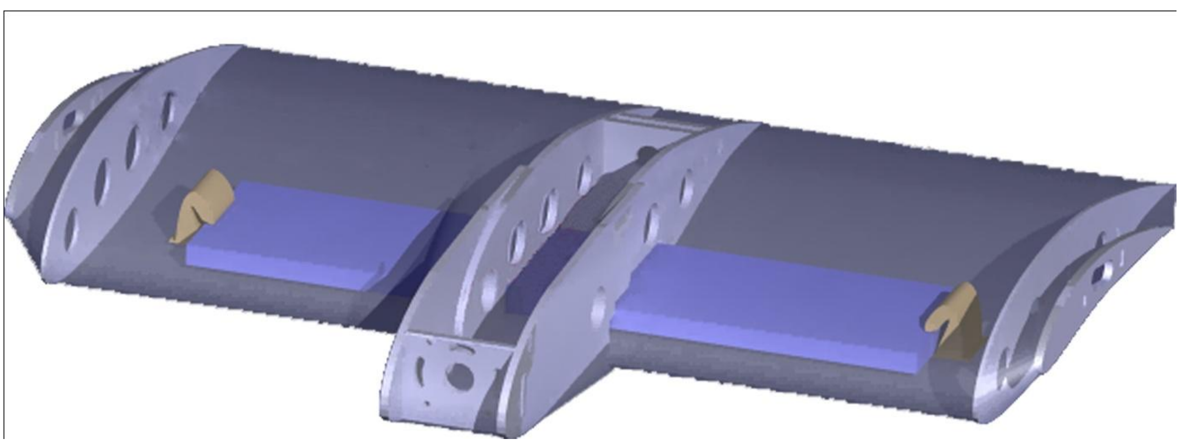


Figure 5.8 Payload System Architecture for Mission 2

5.3.2 Mission 3

Golf balls put in to balsa tools like as a specific nesting-box for balls' configuration. Balsa tools are necessary to fasten up golf balls at side parts of the body. But for the mid-part of the body is fixed the balls naturally. As shown in figure 5.9 in ATA-12 body take into 44 golf balls.

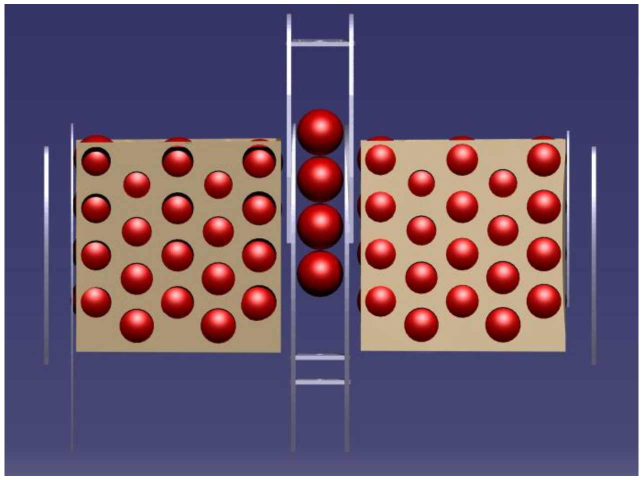


Figure 5.9 ATA-12 Body Take into 44 Golf Balls

5.4 System Architecture

An AXI 2826/12 motor was selected for the first mission, and an AXI 2826/12 with 3:1 planetary gear box was selected for the second and third missions to obtain sufficient torque. A 13x7 APC propeller was chosen according to propulsion test results. Moreover, final configuration of battery pack was determined as offset brick shaped 10 cells of ELITE 1700 for the first mission and offset brick shaped 16 cells of Art Tech 1000 for the second and third missions. JETI Advance 40 pro SB high voltage brushless electronic speed controller was chosen because of being light and having low internal resistance. For connection of Electronic Speed Controller (ESC) and battery, Dean's© ultra plug connectors were chosen due to fail-free design and conductivity. 4mm Venom micro bullet plugs were chosen for connection of motor and ESC. Futaba 72 MHz receiver was replaced by a Futaba 2.4 GHz R608FS 8-Channel Receiver because of its reliability and its frequency system which prevents interference with other frequencies. A Futaba 9CAPS was used as transmitter with a 2.4 GHz module, since it is capable of transmitting signal with PCM1024 resolution and has many features, required for flight. A four-cell of Great Planes 250mAh NiMH pack was used as receiver battery to get the desired power with a light battery package. Because of RAC, the lightest servos were researched and Hitec HS-81 servos were decided to be used. From the last year's experiences, Hitec HS-81MG servos with metal gears were preferred. Control surface servos were placed into the wing and tail. The servos were placed close to the control surfaces to decrease the drag of the pushrods, which have 0.08" diameter. Ball links were used to connect the servo and control horns, because they only transmit the force in one axis and tolerate the misplacements of control horns.

5.5 Performance

5.5.1 Hand Launch

Table 5.2 Hand-Launch Analysis

		Hand-Launch Analysis (Loaded)		
Flight	Thrust (lbs.)	Minimum height (ft)	Minimum height time after hand launch (s)	Initial Angle (°)
Empty	1.1023	5.445	1.4	0
Empty	1.1023	5.595	1.3	10
Loaded	2.204	2.349	4.6	0
Loaded	2.204	2.761	4.5	10

5.5.2 Flight Performance

Table 5.3 Flight Performance

	Flight Performance		
Parameter	Empty	Steel Bars	44 Balls
Hand Launch Weight (lbs.)	2.3	7.71	6.86
C_{Lmax}	1.75	1.75	1.75
L/D max	14	14	14
Stall Speed (ft/s)	22.02	37.4	35.93
Cruise Speed (ft/s)	106.4	90.8	90.8
Wing Loading (lbs/ft^2)	0.7	2.35	2.09
Static Thrust (lbs.)	1.181	2.892	2.892

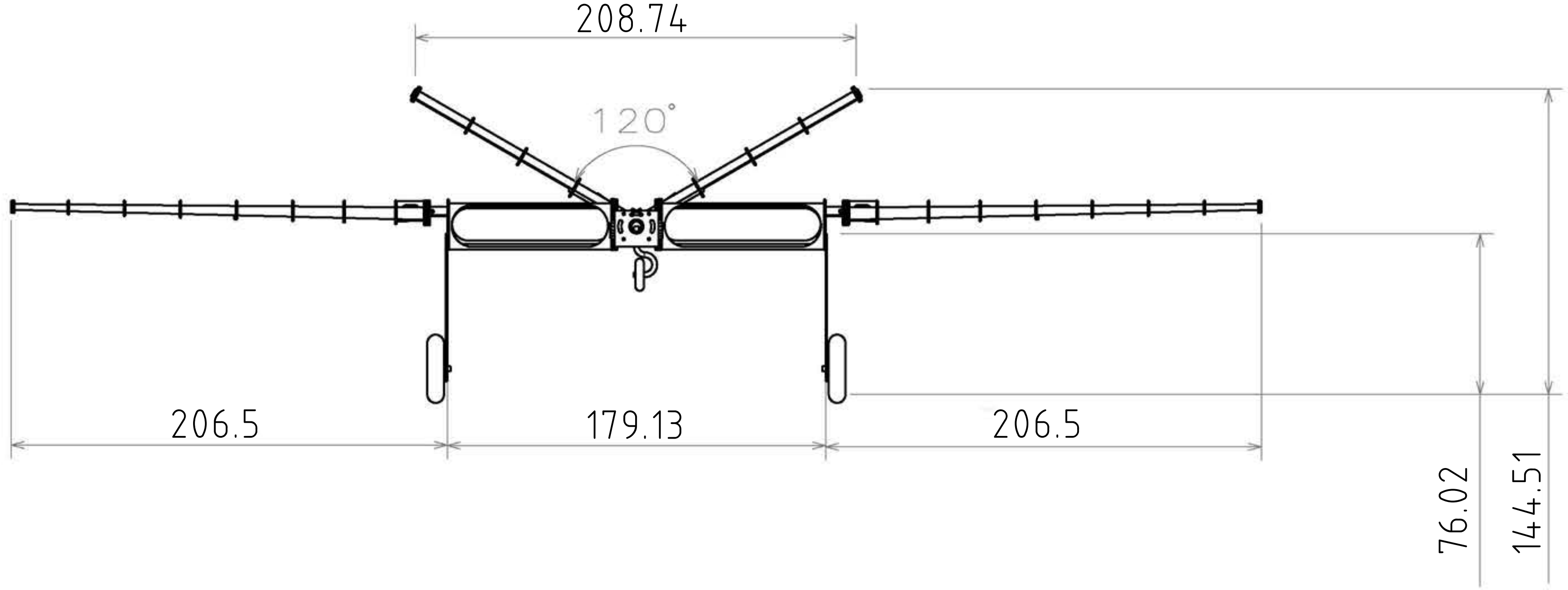
Table 5.4 Weight and Balance Detail

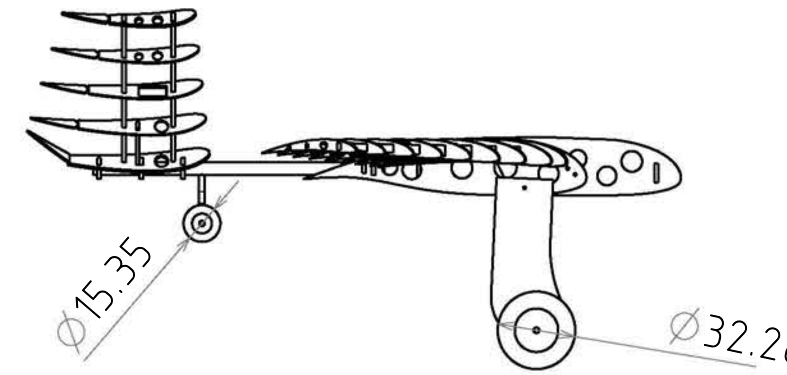
Weight and Balance Detail			
Parameter	Empty	Steel Bars	Golf Balls
Airframe (lbs.)	0.3086472	0.3086472	0.3086472
Shell (lbs.)	0.1543236	0.1543236	0.1543236
Wing and Tails (lbs.)	0.5103701	0.5103701	0.5103701
Propulsion & Control Sys. (lbs.)	1.2610441	1.2610441	1.2610441
Landing Gears (lbs.)	0.2425085	0.2425085	0.2425085
Battery Weight (lbs.)	0.65	0.68	0.68
Payload Weight (lbs.)	0	4.4621562	7.7161792
Total Weight (lbs.)	2.3937792	6.8559354	10.109958
Center of G. (x/y/z) (ft)	0.067/0/0.079	0.067/0/0.029	0.067/0/0.079

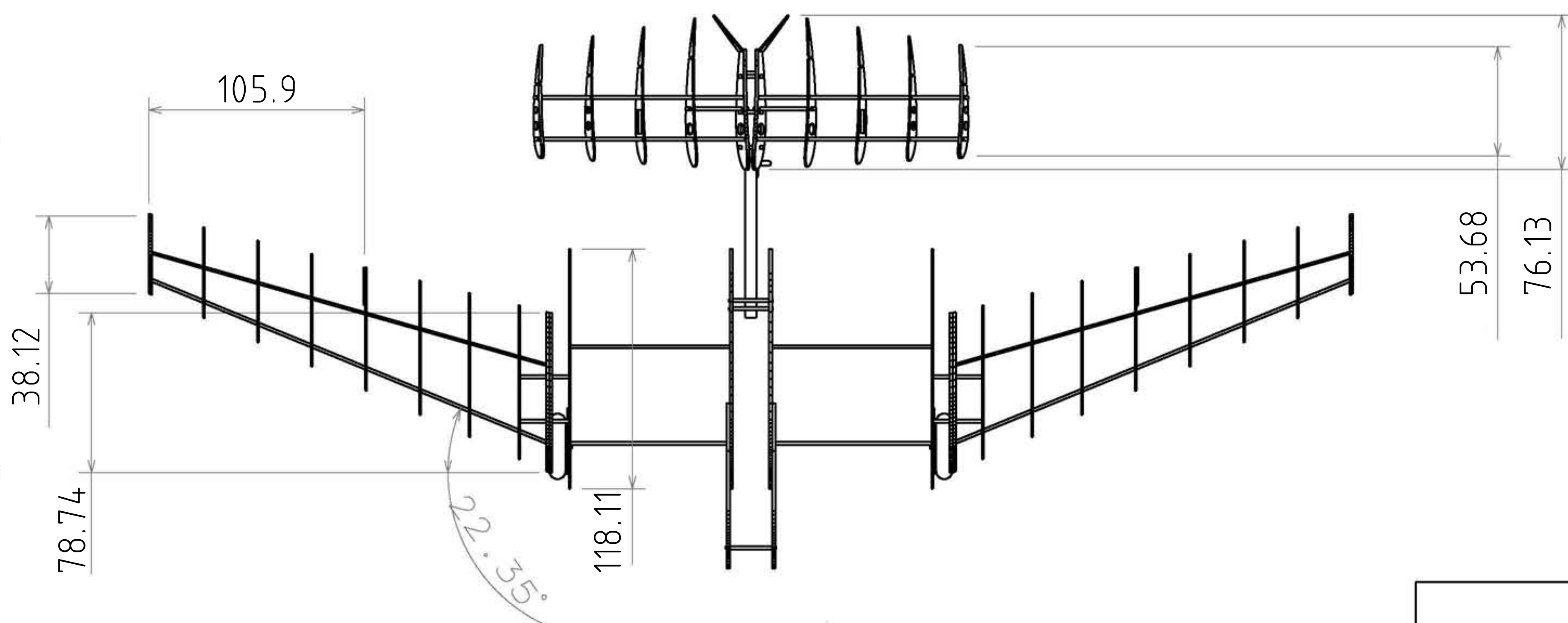
5.3 Mission Performance

Table 5.5 Actual Mission Performance

Mission Performance			
Parameter	First Mission	Second Mission	Third Mission
Minimum height after hand launch (ft)	5	2	2
# Laps	4	3	3
Lap Time (sec.)	50	65	65
Cruise velocity (ft/s)	106.3963	90.81254	90.81254

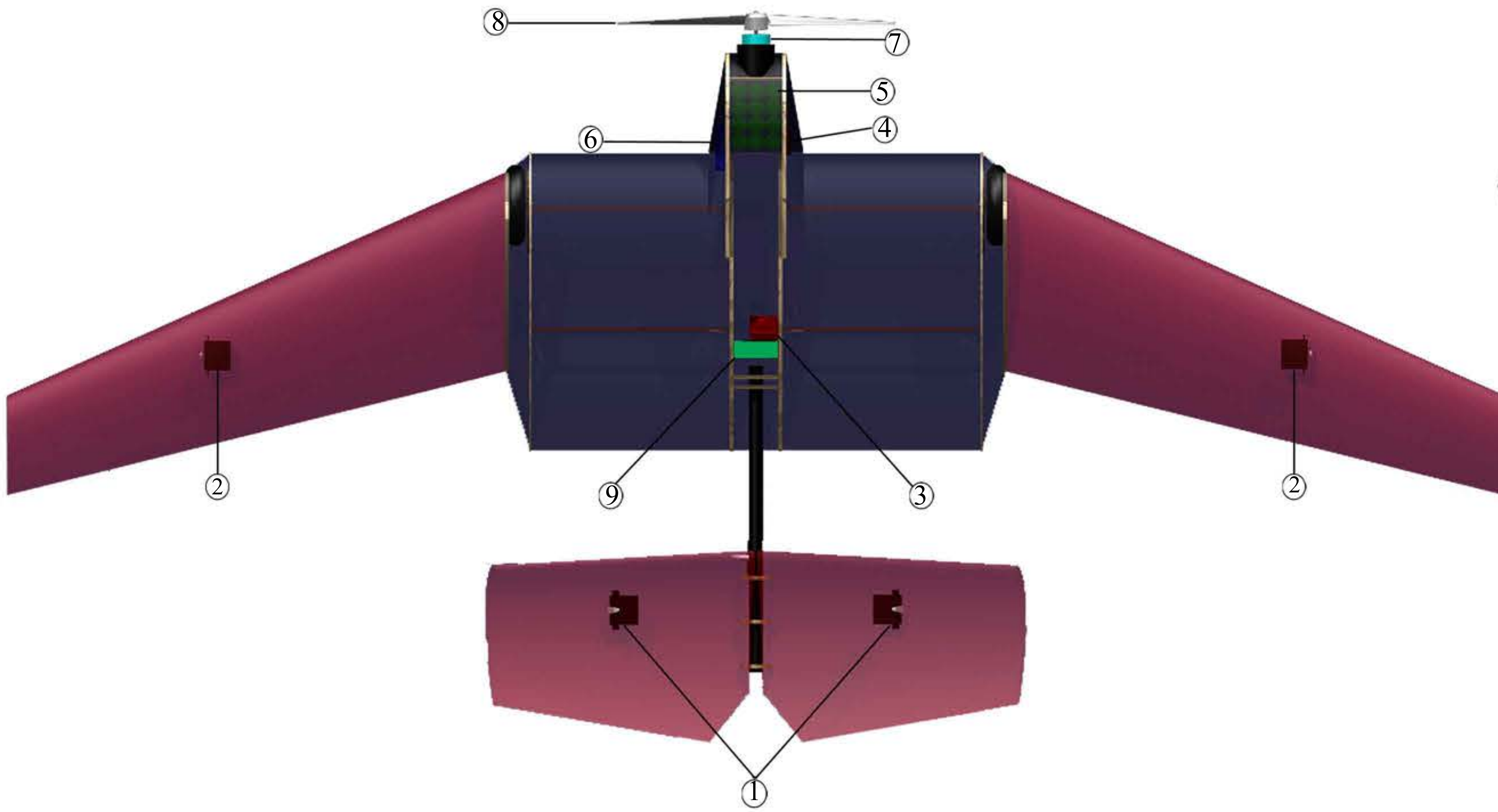






All dimensions are in inches

ATA -12	**ISTANBUL TECHNICAL UNIVERSITY**			
	**AIRCRAFT 3 VIEW**			
	DRAWN BY İlkay SOLAK		ADVISOR Assist Prof. Hayri ACAR	
	23.02.2011	SCALE 1:8	SIZE B	SHEET 1/4



NO	ITEM		NO	ITEM	
1	Tail Servo	Hitec HS81 MG	8	Propeller	APC 13''x 7''
2	Flaperon Servo	Hitec HS81 MG	9	Receiver Battery	JR Extra 1650 mAh
3	Receiver	Futaba 9 Channel PCM			
4	Fuse	20 Ampere			
5	Battery Pack	Elite 1000 mAh 16 Cell			
6	ESC	JETI Advance 40 PRO HS			
7	Motor	AXI 2826/12			

All dimensions are in inches

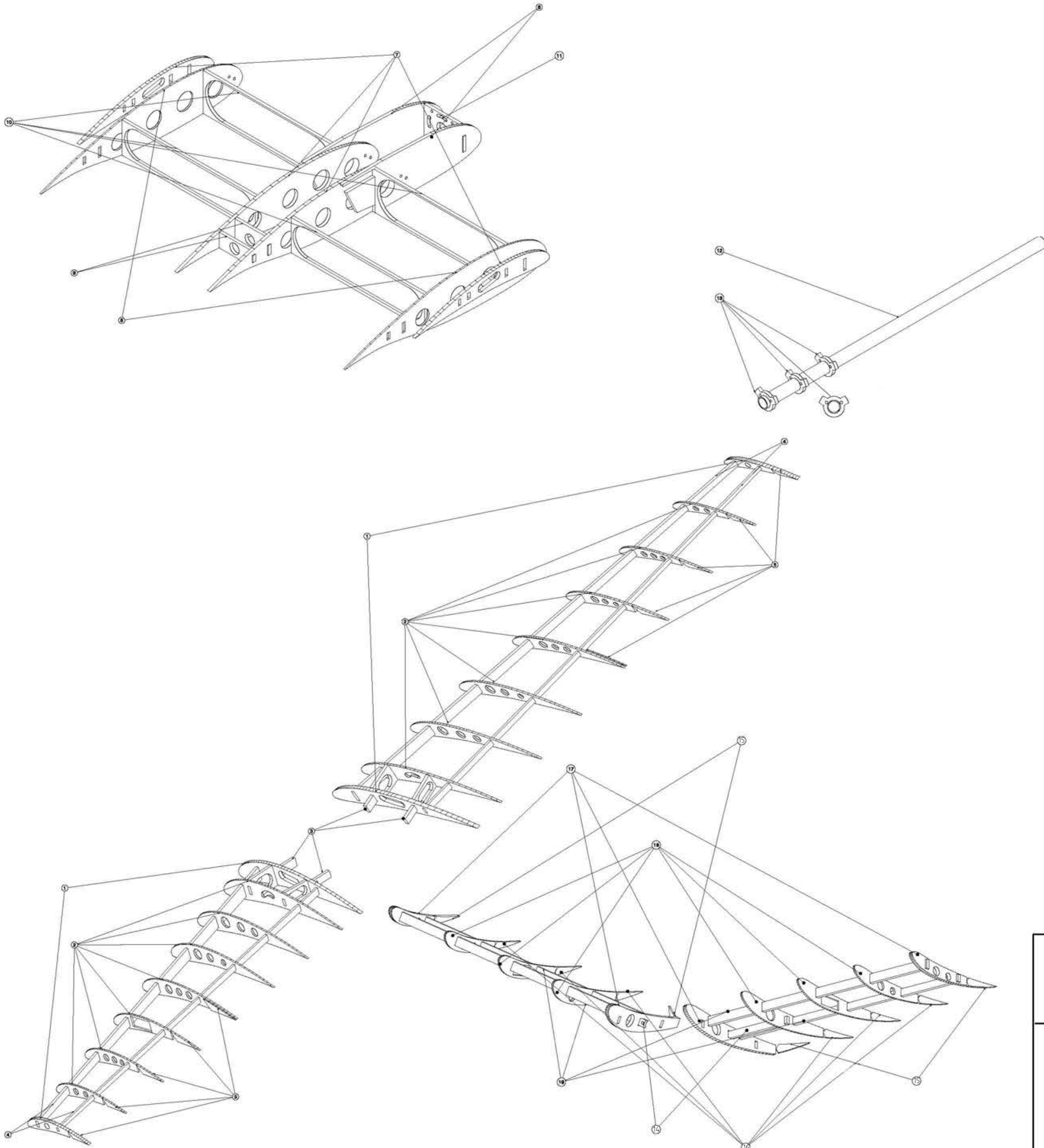
ATA -12

ISTANBUL TECHNICAL UNIVERSITY

SYSTEMS LAYOUT

DRAWN BY	ADVISOR
İlkay SOLAK	Assist Prof. Hayri ACAR

23.02.2011	Scale 1:7	SIZE B	SHEET 3/4



NO	ITEM	MATERIAL
1	Wing Rib	Plywood
2	Wing Rib	Balsa
3	Body Connection	Plywood
4	Wing Spar	Balsa
5	Aileron Rib	Balsa
6	Front Body Rib	Plywood
7	Body Rib	Plywood
8	Body Rib	Plywood
9	Tail Boom Holder	Plywood
10	Bulkheads	Plywood
11	Motor Bulkhead	Plywood
12	Tail Boom	Carbon
13	Tail Boom Holder	Plywood
14	Tail Spar	Plywood
15	Tail Control Rib	Plywood
16	Tail Control Rib	Balsa
17	Tail Rib	Plywood
18	Tail Rib	Balsa
19	Tail Spar	Balsa

All dimensions are in inches

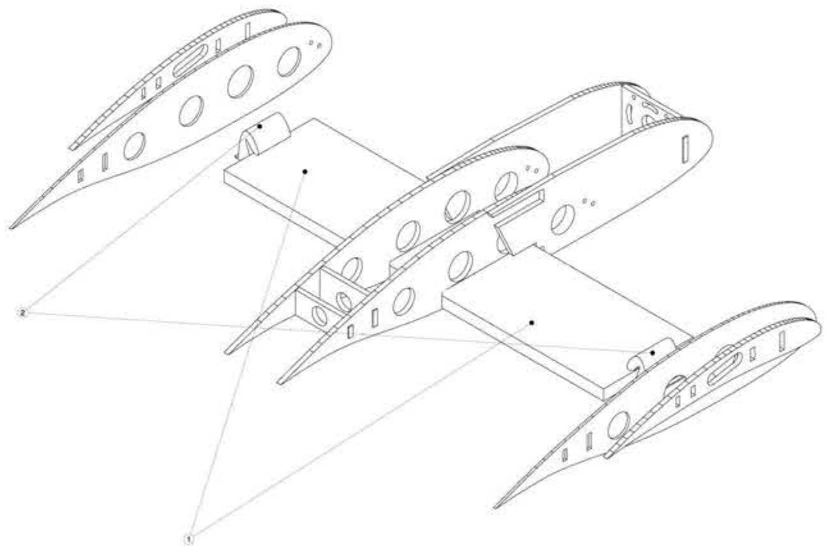
ATA -12

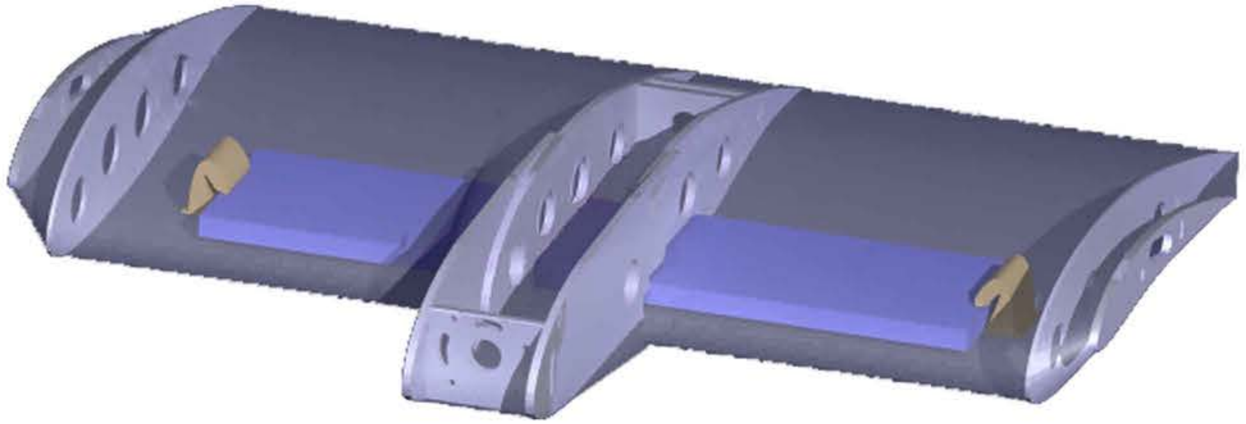
ISTANBUL TECHNICAL UNIVERSITY

STRUCTURAL ARRANGEMENT

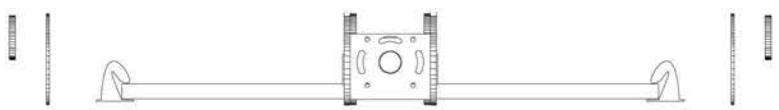
DRAWN BY	ADVISOR
İlkay SOLAK	Assist Prof. Hayri ACAR

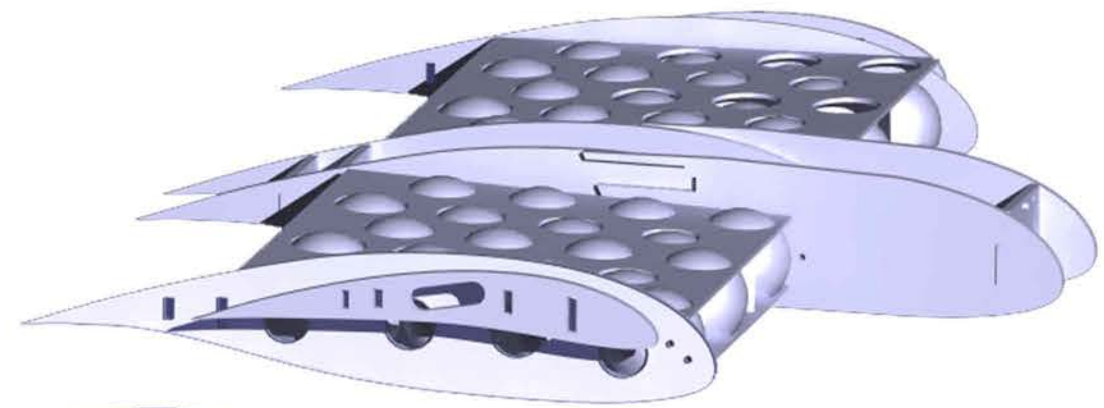
23.02.2011	Scale 1:5	SIZE B	Sheet 2/4

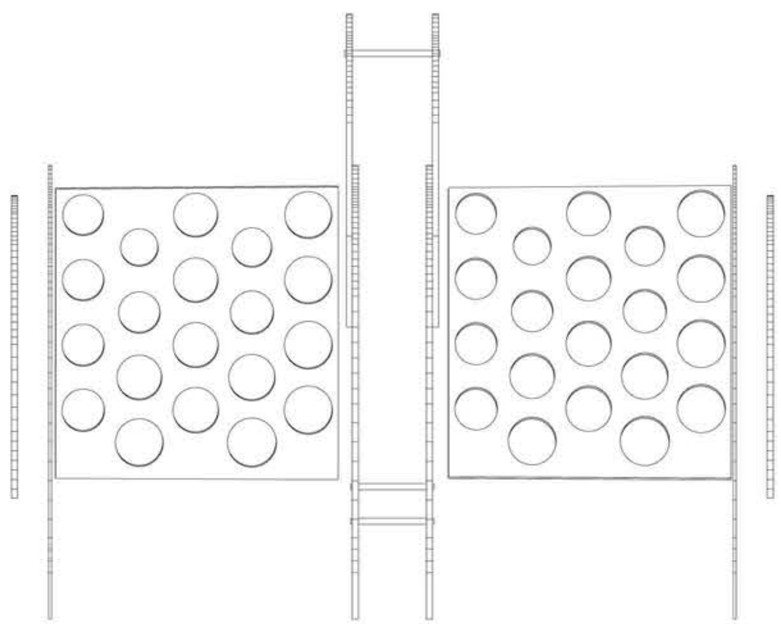


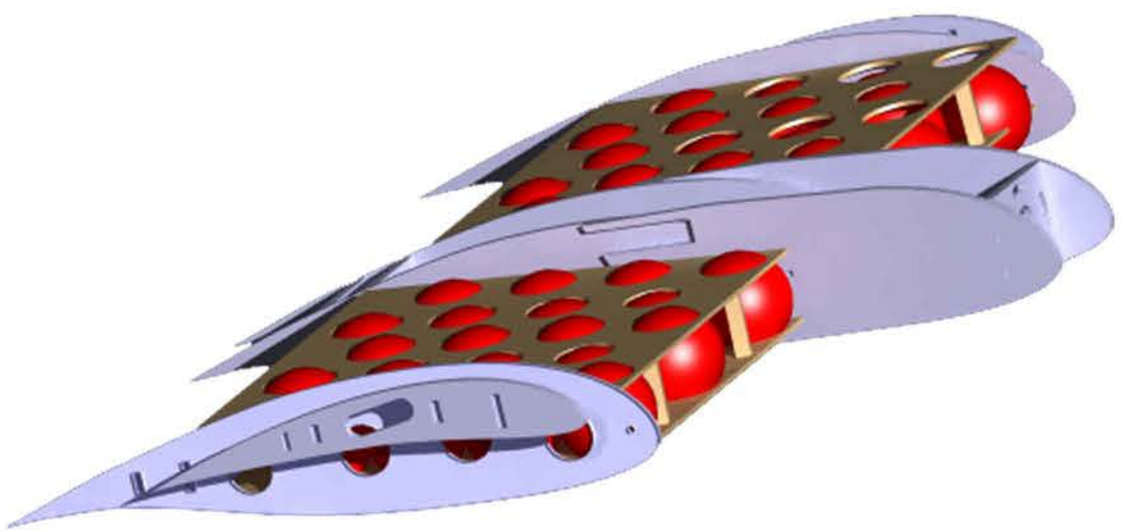


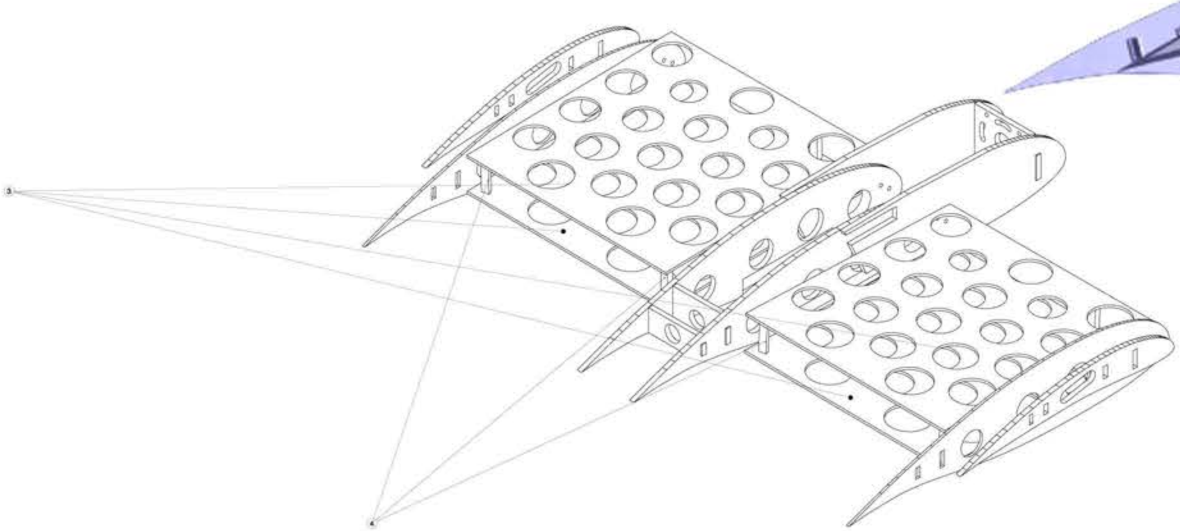
NO	ITEM	MATERIAL
1	Steel Bar	Steel
2	Adhesive Clip	Plastic
3	Nesting Box	Balsa
4	Supporting Bar	Carbon Fiber











All dimensions are in inches

ATA -12

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PAYLOADS ACCOMODATION

DRAWN BY	ADVISOR
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23.02.2011	Scale 1:5	SIZE B	Sheet 4/4

6.0 MANUFACTURING PLAN & PROCESSES

In this section, determined figures of merit and manufacturing techniques of aircraft components which are fuselage, wing and empennage spars tail boom and landing gear, are explained. Furthermore, a milestone chart, shown in Figure 6.1, that specifies dates of planned events is formed.

6.1 Figures of Merit

For each component, the selected FOM were discussed and weighted out of 100 points according to their importance, in order to evaluate the alternative materials and processes ability by using the decision matrices. The alternative manufacturing processes were graded as 1, 0 and -1 according to their advantages, indifferent or disadvantages, so these are figured at Table 6.1.

- **SWR:** Strength-to-weight ratio was the first FOM, which was discussed because weight is the most effective parameter on the total score. Not only weight, but also strength is important for the designed aircraft to be successful. For this reason, SWR was considered as an important parameter for the selection of the manufacturing materials and processes.
- **Availability:** In order to perform the manufacturing processes as planned in the schedule, the materials must be easy to obtain. Availability is important, because since it does not matter how light or cheap the material is, if it cannot be obtained. According to these reasons, availability was determined to be the second FOM.
- **Production Accuracy:** The differences between the designed and the manufactured aircraft are related to the accuracy of the design process. Unexpected errors, such as bad surface finishing, are occurred because of human factors. Therefore, the aircraft becomes different from the designed shape of the aircraft and aircraft performance is affected. The methods, which are less dependent on human factor, ensure production accuracy.
- **Production Time:** Manufacturing processes which consumes less time should be selected to shorten the manufacturing period, which is the longest period of the project. This will let the team to perform more flight tests, so production time was selected as another FOM's parameter.
- **Cost:** Materials are usually ordered from abroad. The materials are used in the manufacture of the aircraft are expensive and usually ordered from abroad. That means the total cost will increase because of the cargo fees and custom taxes. Therefore, cost was selected as a parameter.
- **Required Skill Level:** The required skill level is determined to be another FOM in order to build the aircraft effectively. The experience of the team directly affects the aircraft's production quality. Experienced methods are preferred to be used since trying new manufacturing methods is always risky and time- consuming. The team's skill levels are graded from 5 to 1, from experienced to inexperienced as shown in Table.

Table 6.1 Skill Matrix of Team

Skills	Laser Cutting	Wood Working	Composite Working	Film Covering	Vacuum Bagging	Mold Production
Skill Level	*5*	*4*	*3*	*4*	*5*	*4*

6.2 Investigated Manufacturing Processes and Materials

In order to build a competitive aircraft, existing manufacturing processes and materials must be well known. Most of the investigated materials and processes were eliminated at the beginning because of not being convenient for the design and mission requirements. The remaining ones were discussed for the major components as follows.

6.2.1 Fuselage

- **Wooden Construction:** Low cost and high availability are the advantages of this method. Also the team is experienced in this process, therefore production time is shortened. However, wooden construction is heavy and its production accuracy is not as good as composites.
- **Sandwich Construction with Honeycomb Core:** In this method, honeycomb is used between fiberglass layers. Therefore, this construction method has the highest strength-to-weight ratio, but being very expensive and difficult to obtain are the main disadvantages of this construction.
- **Fiberglass Construction:** This process takes too much time because of mold production. Cost and availability is moderate. However, the team was very experienced in composite works from previous year. Its strength-to- weight ratio and production accuracy is better than wooden construction.
- **Carbon Fiber Construction:** This process is similar to fiberglass construction. The only difference is that carbon fiber is used instead of fiberglass. Carbon fiber is more expensive than fiberglass but this construction has higher strength-to-weight ratio than fiberglass construction.

Table 6.2 Decision Matrix for Fuselage Manufacturing Processes and Materials

		SWR	AVL*	PAC*	PRT*	CST*	RSL*	SCORE
	Weight Factor	50	15	10	10	10	5	100
Fuselage	Sandwich Construction with Honeycomb Core	1	-1	1	-1	-1	1	30
	Fiber Glass Construction	0	0	1	-1	-1	1	-5
	Carbon Fiber Construction	0	0	1	-1	0	1	5
	Wooden Construction	-1	1	-1	1	1	1	-20

*AVL: Availability, PAC: Production Accuracy, PRT: Production Time, CST: Cost, RSL: Required Skill Level

6.2.2 Wing and Empennage

- **Foam Construction with Fiberglass Covering:** Since the composite lay-up, increases weight and strength simultaneously, strength-to-weight ratio is moderate. The materials are available and cheap; however, the skill level of the team at hot wiring is not sufficient. Therefore, this construction takes a long time. Besides, difficulties at forming the foam decrease production accuracy.
- **Balsa Construction with Film Covering:** The materials' availability is moderate. Since a laser- cutting machine is available in Istanbul Technical University, cutting the ribs does not take too much time. Film covering makes the construction very light with sufficient strength. Although the team is experienced in wood works, production accuracy is less than the first method because of the leading edge. This method is expensive than the first method due to the materials.
- **Balsa Construction with Balsa and Film Covering:** This process is similar to the previous process; however, the only difference is covering the section which starts from the leading edge and ends in maximum camber with balsa under film. This construction method is slightly lighter than the first one. The accuracy of leading edge is much better than the second construction method; besides, the cost of this production is nearly the same as the previous method.

Table 6.3 Decision Matrix for Wing and Empennage Manufacturing Processes and Materials

		SWR	AVL*	PAC*	PRT*	CST*	RSL*	SCORE
	Weight Factor	50	10	20	10	5	5	100
Wing and Empennage	Foam Construction with Fiberglass Covering	0	1	0	-1	1	-1	0
	Balsa Construction with Microlite™ Covering	1	0	-1	1	0	1	55
	Balsa Construction with Balsa and Microlite™ Covering	1	0	1	1	0	1	75
*AVL: Availability, PAC: Production Accuracy, PRT: Production Time, CST: Cost, RSL: Required Skill Level								

6.2.3 Wing and Empennage Spars

- **Wooden Construction:** In the manner of availability and reduction of cost, birch plywood is the most appropriate material. With a good structural modeling, the strength of a wooden spar is high. However, weight of such a spar is considerably high. Even though the strength-to-weight ratio is moderate, this method does not contribute to a competitive one. Besides; time consumption and lack of accuracy comes out as additional disadvantages.

- **Hand-made Carbon Tube:** Hand-made spars are built from carbon hoses. The carbon fiber lay-up provides great strength; therefore strength-to-weight ratio is moderate. The team has enough experience to produce handmade carbon tubes; but the method is time consuming and availability of the material is poor.
- **Ready-made Carbon Tube:** Ready-made carbon tubes are lighter than hand-made carbon tubes and the accuracy is increased because of fabric manufacturing. However, unavailability and cost of the carbon tubes are the disadvantages for manufacturing.
- **Balsa Construction:** Balsa has some disadvantages because of bad production accuracy and production time. However balsa is lighter than Carbon tubes and Strength-to-weight is enough for this design that has less weight for using Carbon tubes. And as mentioned before, weight is the most important criteria on the total score.

Table 6.4 Decision Matrix for Wing and Empennage Spars Manufacturing Processes and Materials

		SWR	AVL*	PAC*	PRT*	CST*	RSL*	SCORE
	Weight Factor	50	15	15	10	5	5	100
Wing and Empennage Spars	Balsa Construction	1	1	-1	-1	1	-1	40
	Wooden Construction	-1	1	0	0	1	1	-25
	Hand-made Carbon Tube	0	0	-1	-1	-1	1	-25
	Ready-made Carbon Tube	0	-1	1	1	0	1	15

***AVL: Availability, PAC: Production Accuracy, PRT: Production Time, CST: Cost, RSL: Required Skill Level**

6.2.4 Tail Boom

- **Hand-made Carbon Tube: Hand-made Carbon Tube:** As shared before carbon fiber has well strength to weight ratio. However; produce hand-made carbon tubes conduces loss of time and get access to this materials is expensive and difficult.
- **Ready-made Carbon Tube:** Although using ready-made carbon tube has some disadvantages because of unavailability and cost, strength to weight ratio and production accuracy are better than hand-made carbon tube. Also this method decrease time consumption. So, preferring ready-made carbon tubes secure more advantages for our team.

Table 6.5 Decision Matrix for Tail Boom Manufacturing Processes and Materials

		SWR	AVL*	PAC*	PRT*	CST*	RSL*	SCORE
	Weight Factor	50	15	15	10	5	5	100
Tail Boom	Hand-made Carbon Tube	0	-1	0	-1	0	1	-20
	Ready-made Carbon Tube	1	-1	1	1	0	1	65

*AVL: Availability, PAC: Production Accuracy, PRT: Production Time, CST: Cost, RSL: Required Skill Level

6.2.5 Landing Gear

- **Ready-made Carbon Landing Gear:** It has high strength-to-weight ratio and accuracy; however, it is expensive and difficult to obtain. Therefore, production time is moderate with low RAC.
- **Hand-made Carbon Landing Gear:** This alternative is more available and cheaper. Production accuracy is low, but strength-to-weight ratio is nearly the same as the ready-made landing gear.

Table 6.6 Decision Matrix for Landing Gear Manufacturing Processes and Materials

		SWR	AVL*	PAC*	PRT*	CST*	RSL*	SCORE
	Weight Factor	50	15	15	10	5	5	100
Landing Gear	Ready-made Carbon Landing Gear	1	-1	1	0	-1	1	50
	Hand-made Carbon-Balsa Gear	1	1	0	-1	0	1	60

*AVL: Availability, PAC: Production Accuracy, PRT: Production Time, CST: Cost, RSL: Required Skill Level

6.3 Selection of Manufacturing Processes and Materials

Alternative manufacturing processes and materials were compared analytically with respect to the determined FOM's. Since each component has different functions and sizes, weights of the FOM's were different for each component. Manufacturing materials and processes, which have the highest score in the decision matrix, were selected as shown in Tables 6.1, 6.2, 6.3, 6.4, 6.5 and 6.6.

6.4 Final Manufacturing Plan

After the most appropriate manufacturing processes and materials for the components were determined, the results were summarized for each component as follows.

- **Fuselage:** The fuselage was split into two parts for ease of construction. Firstly, drawings were prepared for inner part and the laser cutting was done in accordance with them.

Obtained ribs were combined each other. After that, for the outer part, two molds were produced by lathe machine in the laboratory of the school because the frame is not symmetrical in the horizontal profile. Then, the outer part, which was produced with fiberglass and honeycomb by sandwich method, was placed by lay-up technique to the molds and was waited in vacuum. Finally, the inner and the outer parts were assembled each other.

- **Wing and Empennage:** Firstly, carbon tube and balsa spar were prepared for assembly. After that to produce ribs, CAD drawings of profiles were cut from balsa plates by using laser-cutting machine. Prepared ribs were stabilized by using balsa rods on leading and trailing edges. Then these rods were sanded according to airfoil geometry. Finally control surfaces were placed and the hole structures were covered by film.
- **Landing Gear:** Firstly, drawings were prepared for landing gears and the laser cutting was done in accordance with them. Obtained parts were covered with carbon fiber and epoxy was applied to them. Landing gears which were vacuumed are assembled to fuselage. Then wheels were mounted to the landing gears.

6.4.1 Milestone Chart

According to previous years' experience, a milestone chart for both prototype and final aircraft construction was developed through the end of the design process. The effect of the manufacturing processes on each other was considered in order to shorten construction time. The milestone chart showing the deadlines, planned and actual timing of major elements for the manufacturing processes is given in Figure 6.1.

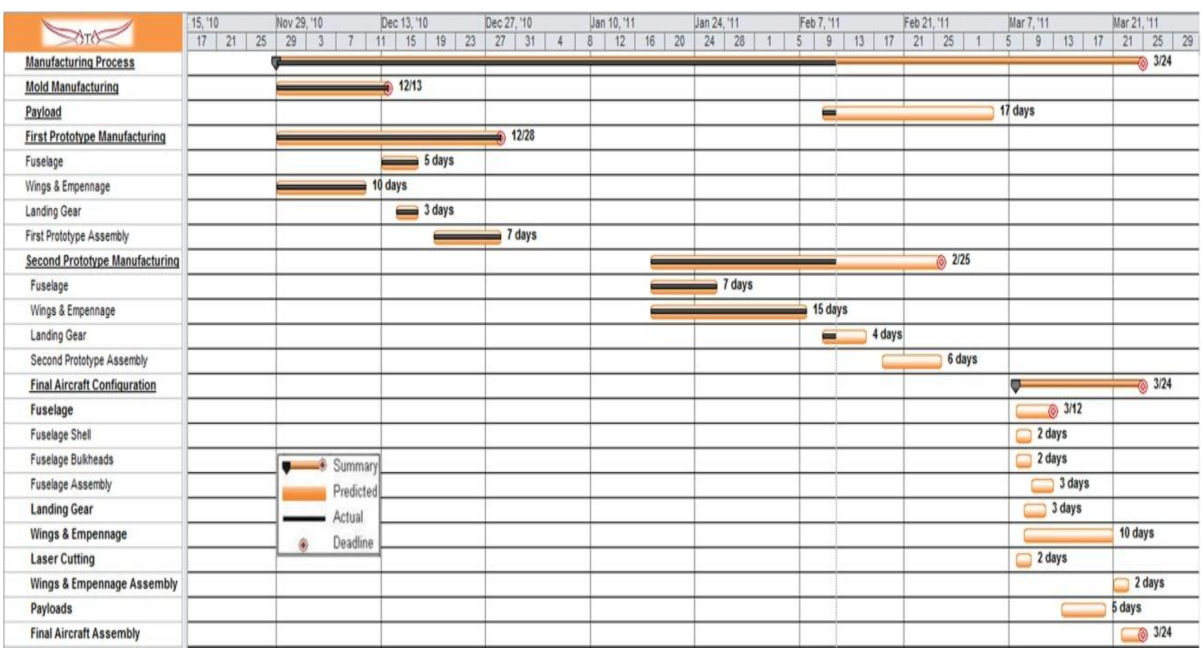

Figure 6.1 Manufacturing Plan & Processes Gantt Chart

7. TESTING PLAN

Testing of the system and subsystems were performed to ensure that they successes the missions well and they are ready for competition. In this section test objectives and test sections are described. After this description check-list is given.

7.1. Test Objectives

It is necessary to design optimum configurations and to practice missions many times in order to be competitive in the contest. Testing is one of the most important stages of designing the optimum configuration since physical results are obtained. The tests which were planned to perform and their objectives are shown in table 7.1.

Table 7.1: Test Objectives

	Test	Objective
Subsystem Tests	Landing Gear	Verify the strength of the landing gear
	Propulsion	Compare theoretical thrust with practical thrust and modify if necessary
	Spar	Verify the FEM analysis results with test results
Dynamic Tests	Take off Distance	Verify calculated take off distance with flight tests
	Lap Time	Compare the estimated lap time to the performed lap time in flight tests
	Loading Time	Practice loading times for payload missions

7.2. Test Scheduling

The complete test scheduling was prepared in a Gantt chart as shown in Figure 7.1 to show testing time period. In the chart, subsystem's tests were planned to begin with the end of the conceptual design to continue until the prototype flight tests. The other tests which belong to dynamic tests were being planned. Some conditions were considered and given below.

- Difficulties of team organization,
- Possible delays in manufacturing,
- Bad weather conditions.

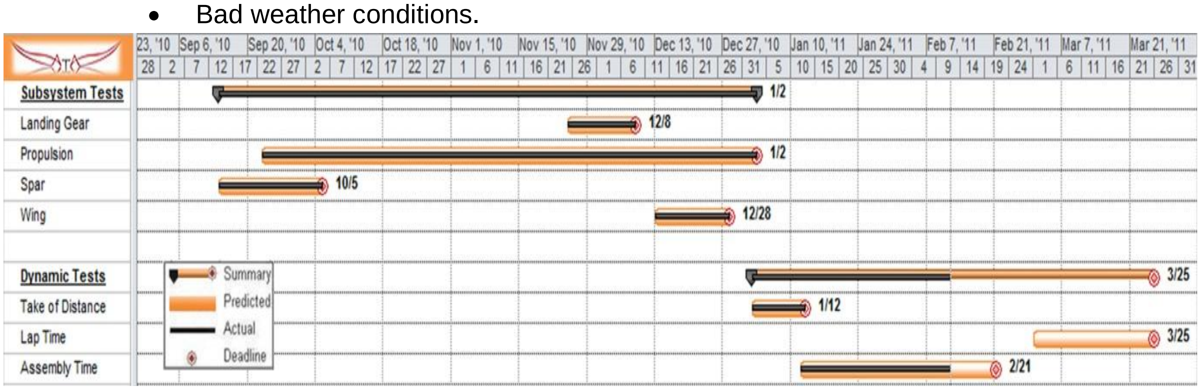

Figure 7.1 Testing Gantt Chart

7.3. Flight Checklist

Checklist is vital and it must be done before flight to secure the team and the aircraft. A small overlooked can result crashes and serious injuries. Therefore, great effort was made to prepare preflight checklist which is given in table 7.2.

Table 7.2: Preflight Checklist

Preflight Checklist					
1	Wings located securely		11	Tires attached securely	
2	Spar connection rod installed		12	Payloads fastened securely	
3	No scratch on coverings		13	c.g. location correct	
4	Servos connected securely		14	Radio range and fail-safe check	
5	Servo horns connected securely		15	Switch-B is down and receiver is connected properly	
6	Stabilizers structurally secure		16	Fuselage cover taped securely	
7	Batteries charged and connected properly		17	Fuse is installed and works properly	
8	ESC connected properly		18	Stabilizer directions correct	
9	Propeller tightened properly		19	Stabilizer deflections correct	
10	Landing gear tightened securely		20	Castoring wheel direction correct	

8. DEMOSTRATION

In this section, predicted performance of the aircraft and its subsystems, which were described in detail design, are compared to demonstrated performance. At the end of section compared results can be seen in Table 8.2.

8.1 Aircraft Subsystems Demonstration

8.1.1 Landing Gear

After main landing gear was constructed as it was designed according to CATIA V5 analyses results, It was tested in order to verify the strength. Firstly, a landing gear test bench, which was a wooden triangular plate, was produced and landing gears were mounted on it. Then 23.2 lbs weight is added carefully to the system and observed that the landing gear was strong enough to endure 3 g loading, which was considered as the worst case. In conclusion, the predicted strength of main landing gear matches with the test results.

8.1.2 Propulsion System

In order to test the propulsion system, a test bench was constructed as seen in Figure 8.1. The principle of the test bench is equilibrating moment of the test system and applying equal forces from equal distances. The propulsion system was mounted on vertical leg and electronic balance was located under the horizontal leg. When the motor ran, the thrust could be easily measured from the electronic balance.

Firstly, different kinds of propellers were tested to verify calculated values in Preliminary Design. However, it was observed that, some propellers' current was more than contest's current limitation. In order to find out the optimum propeller, which proves adequate thrust with current limitation, APC propellers were tested and lined up according to energy consumption. Finally, APC 13x7 propellers were selected for the designed aircraft.

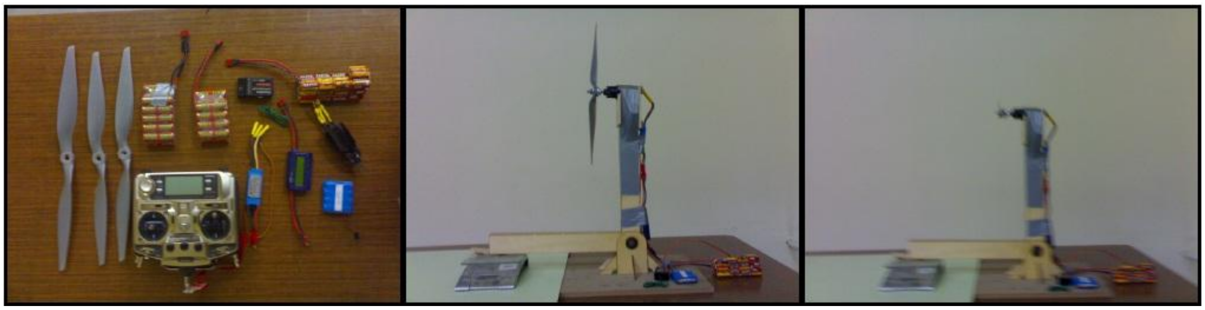

Figure 8.1 Propulsion System Test Bench

8.1.3 Spar

In detail design, the displacement of the spar was analyzed considering that the aircraft was in wingtip test. According to analysis, displacement of one spar was found as 1.08 in. at the tip. Therefore, 2.36 in displacement was estimated for wing tip test. In order to perform wing tip test, two spars and wing carry-through structure were assembled. Then, wing carry-through structure was exposed to the weight of final aircraft. The displacement of the wing carry-through structure was measured as 2.5 in. When the results were compared, there was 6 % error which can be acceptable for FEM. In the light of test results, this spar was considered to be used in the wing structure.

8.2 Complete Aircraft Demonstration

8.2.1 Weight

Estimated system weight was 2.5 lbs. Although, the weight estimation depended on historical data, team always focused to reduce weight of the aircraft during manufacturing process. After prototype was manufactured, system weight was measured as 2.75 lbs, which was 10 % heavier than predicted weight. The reason of this difference was the aim of making strong aircraft for flight tests. For the second prototype, the manufactured aircraft was 2.3 lbs, which was 8% lighter then the estimated weight.

8.2.2 Center of Gravity Estimation

In first fly test aircraft's handling qualities were disrupt flight conditions because of the CG positions is aft team estimations. The first design in figure 8.2 had no component at the front of the body and T tail configuration preferred by team. To solve CG positioning problems design was updated like figure 8.3. A mid body part improved with geometrically similar airfoil with body's airfoil. Static margin value is much more desirable after that. Also tail configuration was converted to V tail. V tail configuration leads to reduce in the total weight of the system.

Figure 8.2 ATA 12 First Prototype

Figure 8.3 ATA-12 Second Prototype

Table 8.1 Tail Weight Difference

	First Prototype (T tail)	Estimation	Second Prototype (V tail)
System Weight (lbs.)	2.75	2.5	2.3

8.2.3 Lap Time

While estimating the lap time, turning radius was thought wider than normal, as a safety factor. During flight tests, average lap time was a few seconds less than estimated value which was 48 seconds. But it did not affect the total lap number for the first mission.

Table 8.2 Estimated Values and Actual Values

	Estimated	Actual
Landing Gear	3g	3g
Propulsion System	13x7	13x7
Weight(lbs.)	2.5	2.3
Lap Time(sec.)	40	48
Assembly Time(sec.)	150	184

Flight logbook is an important table to check and compare the results of flight performances. Therefore, flight logbook which is shown in Table 8.3, is prepared in order to evaluate flight tests and have a good database for future projects.

Table 8.3 Flight Logbook

Flight Test No:							
Date:							
Location:							
Mission	Laps	Propoller	Battery	Wind Speed	Battery Consumption	Structural Observation	Flight Time
Notes:							

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