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Design, Analysis and Fabrication of Experimental Aircraft: A Challenge for Pioneers

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***Abstract*— Aviation technology is a revolutionary emerging field. Aeronautical engineering stands as the pillar towards space science. In this regard the developing countries are stepping forward to expand their aviation field although materials and technological constraints play a significant hindrance. In the application of aeronautical engineering, a project of fabricating a homebuilt aeroplane with minimum cost and with alternatives of advanced material and technology is a desire. This may stand out to be the future guide for many others in developing countries who wish to develop the skill of homebuilt aeroplanes while keeping all constraints away to maintain pace with rest of the world.**

Developed countries may have gone for such projects long time ago because of their technical proficiency and availability of appropriate material. However, it is quite impossible for developing countries to have the support of technical skill and aircraft materials which are unaffordable for this project. Hence the unique indigenous effort on this project has been based on alternative materials and local workforce to have the ultimate final product. This paper will be a roadmap to the enthusiastic homebuilt aeroplane maker to consider affordable solutions to design with acceptable materials specially the low cost projects towards technology demonstration.

***Index Terms*—Conceptual design, preliminary design, roadmap, fabrication, execution.**

I. Introduction

Excellence in design is one of the principal factor that enables a developed nation to stay competitive in a global economy. Within this context, aircraft manufacture and operation is regarded as a desirable commercial activity. Many countries who previously were not involved in aeronautics are now moving into this field. However, as aircraft are made technically more complex involving increasing interdependence between component parts (airframe, engines and systems), and become more multi-national due to the large initial development costs, there is an increasing challenge to the industry. The aircraft design team is in the forefront of this challenge.

No single design paper will provide the key to good design. One can only achieve this through the acquisition of knowledge, hard methodical work, an open and creative mind. However, it is hoped that this paper will eliminate some of the minor stumbling blocks that young engineers find annoying, confusing and time-wasting at the start of their design work. By the same token the project group has not gone too far on the inclusion of advanced technologies and materials. Such developments will not affect the main design process and one could allow for them in future studies by establishing factors for use in the standard formulae (e.g. mass and drag reduction factors). However, allowing for these omissions, the project team has made a genuine attempt to commence a pioneer project that is a starting point for students who want to know more about the fascinating process of homebuilt aircraft design for the first time in Bangladesh [7].

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II. Road Map

Aerospace engineering design is one of the most complex activities carried out by mankind, and it is therefore necessary to take a somewhat idealized perspective. Of course, the designers use analytical tools all the time, but design is about decision making and analysis is, by contrast, an act of gaining understanding, and not of making decisions. Moreover, to be a good designer, the most of tencited personal prerequisite is experience–this view is backed up by observational studies in engineering design offices. So, even though design decision making is commonly preceded by a great deal of information gathering, and although the gathering of such information often use conceptual models which by itself is a skilled and time-consuming activity, it is essential to clarify that whatever may be the cost, this remains just a precursor to the decisions that lie at the heart of design [3].

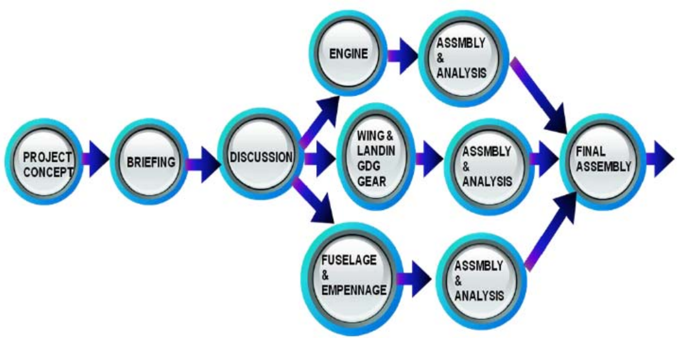

Fig. 1 Road map to design process

III. Design Sequence

No design is just made in one go. An aircraft being a complex engineering marvel needs a complex interactive and re-iterative procedure. Aircraft design philosophy deals with three split phases [6] viz. a) Conceptual Design, b) Preliminary Design and c) Final Product design

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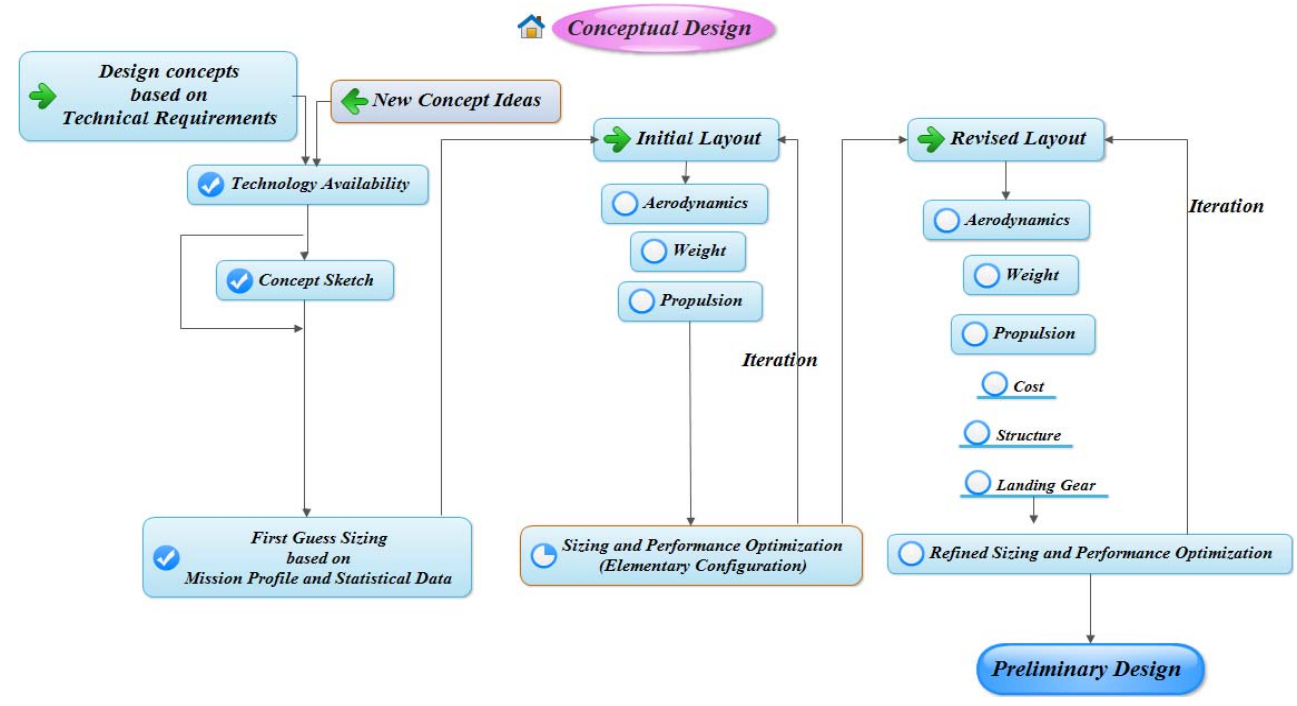

A. Conceptual Design

Conceptual design follows a sequential interactive execution process [1] as described in subsequent paragraphs.

Fig. 2 Conceptual design

1. Technical Requirements

To be a lead technological skill demonstrator, the requirements have been oversimplified keeping the skill and time availability in mind. The technical data for conceptual design [1] is as placed as TABLE-I below.

TABLE I
REQUIREMENT FOR HOMEBUILT AIRCRAFT (TWO SEATER)

Maximum Velocity, V_{max}	209.61 ft/sec
Stall Velocity, V_s	68.35 ft/sec
Range	1.64×10^6 ft
Altitude	10000 ft
Take-Off Distance	2000 ft
Rate Of Climb	500 ft/ min

2. Weight Estimation Based on Mission Profile

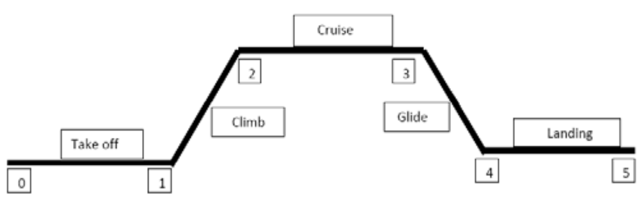

Fig. 3 Mission profile

Weight estimation is based on simplified mission segment [2]

W_0 = Wcrew + Wpayload + Wfuel + Wempty

Where, Gross weight = 1790 lb

Empty weight = 1133.07 lb

3. Performance Analysis

Aircraft performance is estimated depending on the mission requirements. These parameters determine the dimensions of aircraft structure and the choice of propulsion system. In the analysis the basic parameters are at a glance [4] given as Table-II below:

TABLE II
PERFORMANCE PARAMETER

Wing loading	18.64 lb/ft^2
Lift to drag ratio	12
Maximum lift co-efficient	1.7
Power to weight ratio	0.8

4. Configuration and Structural Layout

Aircraft configuration specification [1] is mentioned as TABLE-III below:

TABLE III
CONFIGURATION SPECIFICATION

Fuselage (Truss Type)	Length	20 ft
	Maximum Dia	3 ft
Wing (High Over-hanged)	Aerofoil	NACA 2412
	Span	24 ft
	Chord	4 ft
	Aspect ratio	6
	Sweep angle	0^0
	Dihedral angle	2^0
Engine (Piston Engine)	Effective Power	78 HP
Propeller	Blade No.	2
	Diameter	5.5 ft
Landing Gear (Tail-wheel, Fixed, Hydraulic brake in main wheels)	Wheel Track Length	3.9326 ft
	Wheel Base Length	15.86 ft
	Main Wheel Diameter	14 inch
	Tail Wheel Diameter	5 inch

5. Aircraft Design Sketch

Aircraft is designed using the Autocad and Autodesk Inventor software. In the Fig. 1, the 2D design of aircraft is first developed. Then this design is developed into 3D model gradually along with the design of internal structure with the help of Autodesk Inventor. However there are other design tools such as Catia, Pro engineer, Solid works etc.

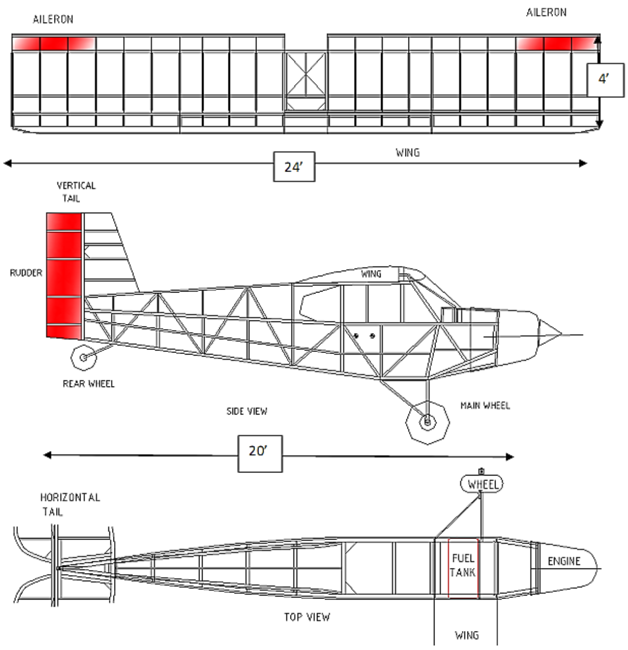

Fig. 4 2D CAD design (3 view)

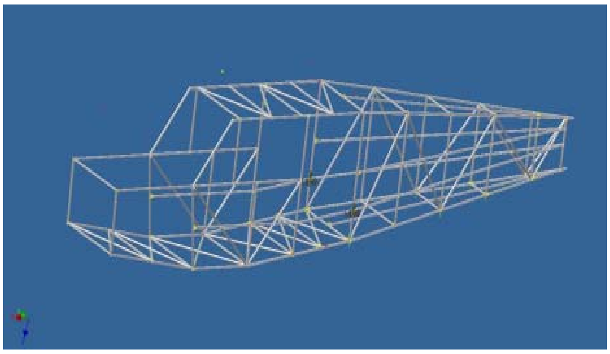

Fig. 5 3D Fuselage design (internal structure)

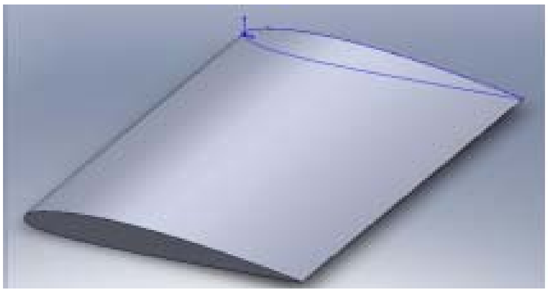

Fig. 6 3D Wing design

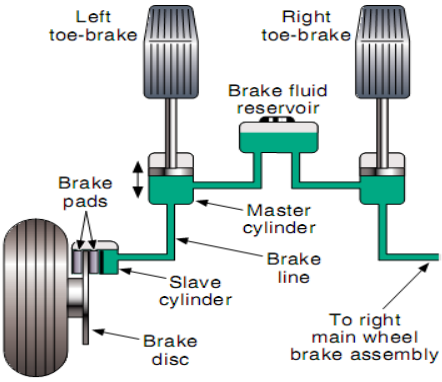

Fig. 7 Hydraulic brake (modified automobile brake)

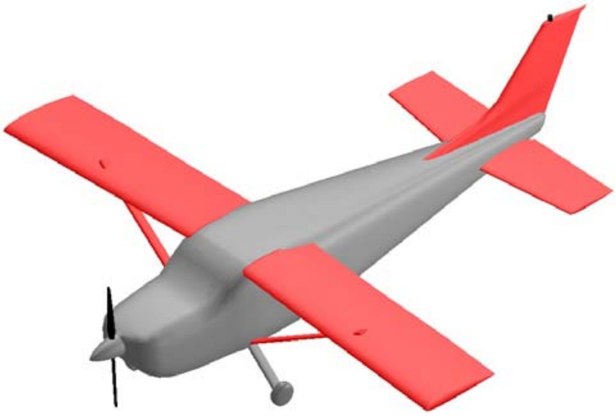

Fig. 8 3D Aircraft external design

B. Preliminary Design

Before the detailed design process, different models are conceptualized and tested. Subsequent to thorough analysis of experimental data visa-viz. the design requirements, the design process has been stepped forward for detailed design stage.

1. Paper Model of Wing

Wing paper model is designed for the understanding of wing actual internal structure. Mainly the spar and the rib parts are focused here. The spar is shaped I-section beam which are inserted through the hole of the rib. The rib is made according to aerofoil shape of NACA 2412. Skinning of the whole paper model is covered by the celluloid plastic to give the aerodynamic shape. This paper model is done in the preliminary design process.

2. Paper Model of Controls

Fig. 9 Control Paper Model

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Control design is the most complex design in the whole design process, because there are many factors acting such as functionality, weight, accuracy and so on. For this reason, the control design is done using paper, hardboards to check its operational functionality. Thread is used as the movable connecting link among the control surface with the control stick .

3. Metallic Mock Model of Controls

On successful demonstration of paper model, the control model is now made using metallic material (Aluminum). At this time, the nylon ropes are used instead of thread and they are aligned using pulley. The difference is that the weight factor has no influence here, as the model control surface is of negligible weight. But the functionality is 100% reliable and the sensibility of the control surface in relation to control stick movement is maintained.

Fig. 10 Control Metallic Mock Model

4. Scale Model of Aircraft

After conceptual design, a test model of scale 1:24 is made using wooden material. It is covered with aluminum sheet for wind tunnel testing.

Fig. 11 Scale Model

5. Aileron Skeleton Model

Fig. 12 Aileron

IV. Results And Discussions

A. Wind Tunnel Test

The test model of scale 1:24 is fabricated for wind tunnel testing. From this test, it is observed the result is satisfactory which paves the path to make approach to the fabrication steps.

Fig. 13 Scale model in wind tunnel

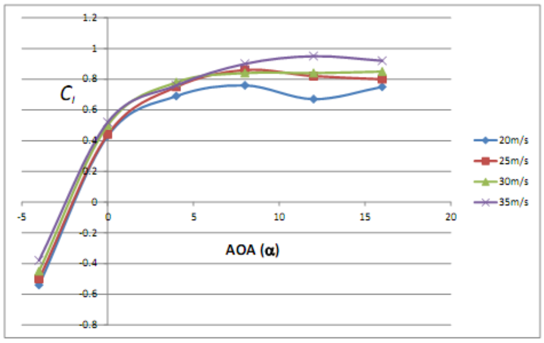

Fig. 14 Angle of attack vs lift co-efficient at various speed

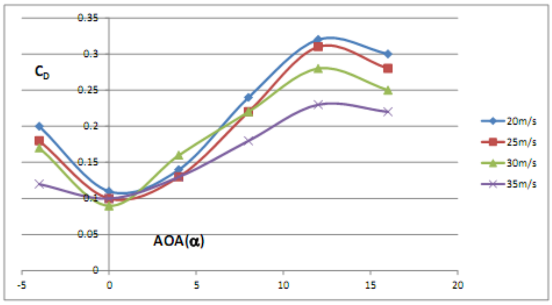

Fig. 15 Angle of attack vs drag co-efficient at various speed

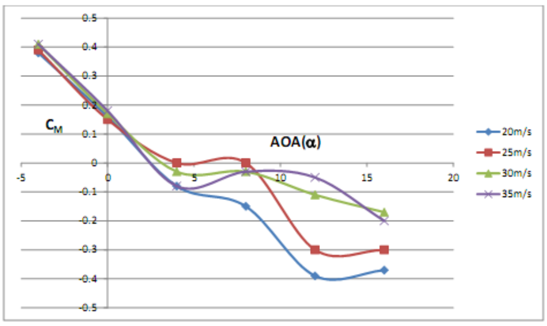

Fig. 16 Angle of attack vs pitching moment co-efficient at various speed

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B. Engine Performance Curve

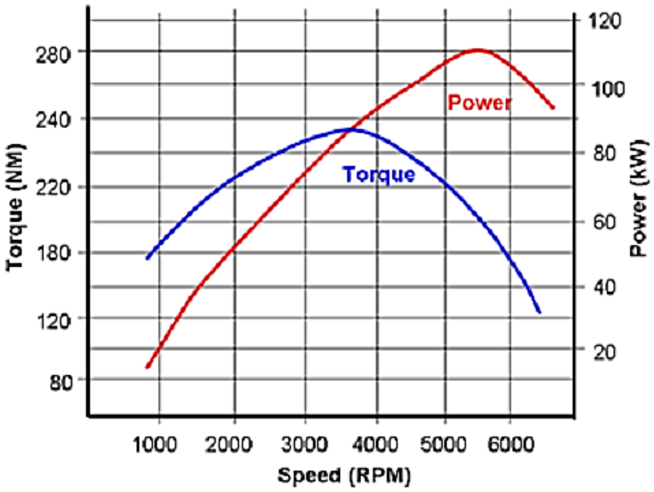

Fig. 17 Engine power and torque curve

C. Test of Paper Model of Control

Control paper model has been tested moving the control stick. All the controls are working with correct sense. So the model is accepted for its operational behavior. Depending on this, the model is further modified to use the actual design and then again it will be tested for the application on the actual wing structure. At this level, the control paper model is validated.

D. Test of Metallic Mock Model of Control

Mock model of control is the miniature version of the actual controls system, only ignoring the weight factor. Here almost all the parts are metal except ropes and pulleys. Bearing is used to eliminate the effect of friction of the moving or rotating parts. Correct movement of the control surfaces is properly visualized. Hence the model has been considered as the valid model to be applied in the actual aircraft control system.

V. Aircraft Fabrication

A. Airframe Fabrication

Internal structure of fuselage is fabricated using available aluminum circular tube of 1 inch diameter. It required material cutting, fitting, riveting and welding [5]. Wing ribs are given proper aerofoil shape while spars are made of steel of I-section. The whole structure is covered with aluminum sheet with the use of rivet gun. Also the control system is fabricated using cable, metallic pulley, bell-crank, control stick etc. Weight factor has been kept under consideration during control system set up by using fire-resistant fabric.

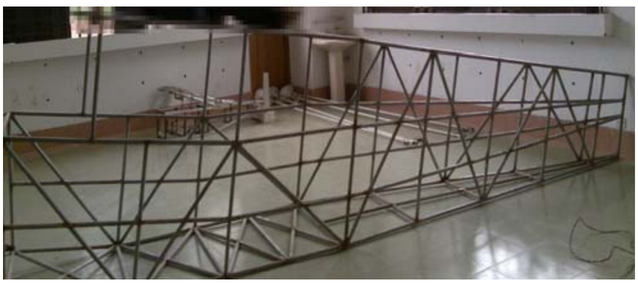

Fig. 18 Fuselage skeleton structure fabrication

Fig. 19 Wing set-up with fuselage

Fig. 20 Empennage skeleton structure

B. Engine Installation and Modification

Fig. 21 Engine installed in engine compartment

To provide a streamline shape with a reduced frontal area, the engine axis is installed parallel to the longitudinal axis of the aircraft. The engine mount is primarily used to connect the engine to the airframe or fuselage. Some of its secondary features are to distribute the weight of the engine and spread the torque and vibration generated by the engine. The engine is not bolted directly onto the mount; this would result in vibrations from the engine to the aircraft. Instead, rubber shock mounts of varying strength and thicknesses are used. This dampens the vibration and movement, giving a much smoother flight and running engine.

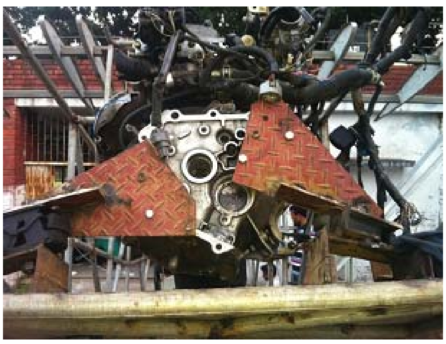

Fig. 22 Front and back mounting and clamp

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Fig. 23 Left and Right side rubber shock mount

Fig. 24 Propeller shaft support

Fig. 25 Mechanical linkage of the carburetor

Fig. 26 Exhaust pipe modification

VI. Final Execution

Fig. 27 Aircraft being prepared for ground run

After accomplishing final assembly of all aircraft components internal systems are inspected. Assuring safety and airworthy condition, the aircraft was set for actual ground operation which successfully made the milestone history by taxiing at 30 kmph in the MIST playground with Dean Academics and subsequently the Commandant, MIST on board.

Fig. 28 Experimental aircraft

VII. Conclusion

MIST X-1 is the first indigenously designed practical aircraft in Bangladesh which is unique, low-cost technology demonstrator and reliable working model of a conceptual design. This aircraft is capable to taxi and demonstrate ground operations for the orientation of maintenance philosophy of enthusiastic aeronautical engineers. It is also capable to fly and the design conditions meet the primary performance criteria. However, it has not been tested in the air due to employment of non-airworthy and substandard material, non-availability of airworthy aero-engine and above all, the absence of permission from Civil Aviation Authority. Nevertheless, it is the permanent asset of MIST to motivate the future generation of aeronautical engineers. It can be used as a guide for creation of future training project. This is the macro project which can pave way for many micro projects. Present project will build the foundation for understanding the micro-issues of aviation, e.g. maintenance, operation, stability and inspection.

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