Design and Analysis of UAV Test Bench for Engine/Motor Characterization

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Abstract - *A thrust test bench is an instrument which can measure the Thrust, Rpm, Power, Torque, Temperature Explicitly etc. This is composed of the test bench architecture attached to the motor or the engine through the rotating shaft. An absorber being attached to the engine means nothing but an extra component which drives the energy of the motor, that is a propeller if assumed. The main objective here is to design a Test Bench which can maximum hold the weight of UAV Engines or motors within 15kgs and to conduct Structural Finite Element Analysis on different parts of the test bench to determine the stress behaviour. The parameters which the test bench can measure are Thrust, Velocity, Rotational Speed, Torque, Cylinder Head Temperature, Exhaust Temperature etc. This is achieved by using certain sensors introduced with a DAQ system for precise and accurate measurements of the parameters.*
Keywords: *Thrust, Axial Force, Torque, Sensors, Data Acquisition System, Static Dynamic, Strain Gauges, Angular Speed, Engine, Efficiency, Bearings Etc.*

I INTRODUCTION

An unmanned vehicle requires a propeller driven by a motor or an engine. A motor is an electric technology that has a very high rotation, low energy consumption, and is not easy to heat. Most drone engines are piston-driven internal combustion engines. Unmanned vehicles use a brushless motor or an engine to rotate the propeller to produce thrust. Unmanned vehicles are designed by choosing an energy-efficient motor or engine. Motor and engine efficiency is related to the flying durability of an aircraft, considering that the battery resources used are limited [1]. In unmanned vehicles with energy sources from batteries, the efficiency of using battery energy is very important to consider. Therefore, it is necessary to choose the right engine or motor and propeller. The power from the battery is one of the factors that influence how well an unmanned aircraft performs in flight. To extend the flight length of an unmanned aircraft, one of the attempts is to select an engine or motor with the lowest power consumption [2]. This allows the aircraft to fly longer. Experiments and testing must be carried out to determine the engine or motor's power output. When the power consumption of a motor is known, it may be used to determine an unmanned aircraft's flying performance. Engine, motor and propeller testing can be done using a test stand [3].

A test bench or testing workbench is an environment used to verify the correctness or soundness of a design or model. Its main purpose is to save time, effort and money through the ability to verify ideas and their implementation. Test benches are greatly used by manufacturers and drive system designers. One of the critical steps in the development of a UAV is the characterization of the propeller and engine and motor that is to be used in the vehicle. The application of Unmanned Aerial Vehicle (UAV) is increasing dramatically as design and control technologies for small flying objects merge with today's advanced sensors and embedded systems. This synthesis has made the control of UAV's more accurate and reliable. The propeller, motor and engine performance information is critical to accurately model the vehicle for various flight manoeuvre and to design an appropriate control. This paper proposes an engine, motor and propeller test stand which can be used for experimental testing of motors, engines and propellers [4].

II LITERATURE STUDY

The use of unmanned aerial vehicles has increased significantly in recent years, and different missions require different propulsion systems. This paper describes the creation of a dynamometer that uses thin beam strain gauge load cells to measure the performance of small air propellers for use in Unmanned Aerial Vehicles (UAVs). The purpose of the dynamometer is to obtain precise information about the propeller's performance characteristics, which is crucial for designing an appropriate controller for UAVs to achieve stable and smooth flight. The Propulsion System Measuring System analysis in [5] enabled a complete structural robustness validation, including an assessment of how loads were transmitted throughout the system structure and analytical calculations of the forces felt by the joints. The finite element model validated every analytical calculation done and provided a better understanding of how forces were carried inside each component, assessed the Von Mises stress distribution, and analysed the force flux. In to accurately characterize a propeller based on its thrust and torque, it is necessary to have a reliable propeller test stand. In this study, a propeller test stand was upgraded with specific features to ensure high repeatability and defined prediction bounds [5]. In the Propeller Test Bench is used to measure the performance parameters of a propeller, including thrust, torque, and speed. Propellers are used in aircraft engines to generate power and propel the aircraft forward. A propeller works by creating a pressure difference between the forward and rear surfaces of its blades, accelerating air behind the blade and converting rotational motion into thrust. This process is modelled using Bernoulli's equation and Newton's Third Law. This paper focuses on the design and construction of a propeller test rig to measure the thrust of a propeller and evaluate its performance [6]. The rig consists of a two-stroke spark ignition engine mounted on a bicycle frame, with a two-blade propeller attached to it. A load cell is used to measure the thrust, with one end of the load cell connected to the bicycle frame and the other end connected to a rigid beam. The engine rotates the propeller, producing thrust to move the bicycle forward. The objective of the study is to investigate the effect of advance ratio, thrust coefficient, power coefficient, and speed power coefficient on propeller efficiency at a constant blade angle. These parameters are important in determining the take-off thrust of an aircraft. The thrust of the propeller is recorded at different engine speeds using the load cell. The engine speed is varied using the throttle control to obtain different thrust values at different propeller speeds [7].

III OBJECTIVES AND METHODOLOGY

- To design the test bench by using software like SOLIDWORKS.
- To conduct structural analysis of different parts of test bench in ANSYS.
- To propose the design for further development of the Test Bench.
- To study and understand the need of a thrust bench.

IV OPEN SOURCE DATA COLLECTION

The details collected from the online sources are as follows:

- Engine Manufactures
- Engine Torque (in nm)
- Engine Weight (in kg)
- Engine RPM/ Speed (in RPM)
- Fuel Type
- Temperature

The data was collected from the sources and computed in excel sheet format for the ease and convenience to analyse and understand the trend in parameters of the engine.

It was observed that again some manufacturers give insufficient data about the engines, and its prominent enough that we need the test bench.

The details collected for BLDC motors available online are:

- Motor diameter
- Motor length
- Motor Weight
- Motor Speed
- Kv
- Current
- Voltage
- Power
- Torque

From this it was concluded that the given data was not completely useful to study and the required data was not given, this again tells us the need of a test bench

V SPECIFICATIONS

A. Parameters and Range

Table 1 refers to the parameters and range selected for the Test Bench.

Table 1: Parameters and Range

Parameters	Range
Engine/Motor RPM	10,000RPM
Thrust	125Kgf
Torque	100Nm
Temperature	0-300
Power	30KW

B. Backstory for Specifications

- The open-source data collected for engines, its types, rpm, torque etc.
- We narrowed our specifications to optimum values and it was observed that there were plenty of engines whose operating characteristics varied drastically also most lied in a common range.
- Drone's classification on the basis of weight: focused on mini(20kg), light(50kg), and small (150) drones.
- The range of specification is on a small-scale perspective, and won't be including any other category.
- Restricting to single- and double-cylinder engines up until 10000rpm the weight was optimized (at max of 28 kg).

VI GEOMETRY

The designing and assembly of the Test Bench is done using SOLIDWORKS. Then the design is imported into ANSYS.

A. Preliminary Design

The preliminary design was based on basic principle of load transfer and simple structure shown below

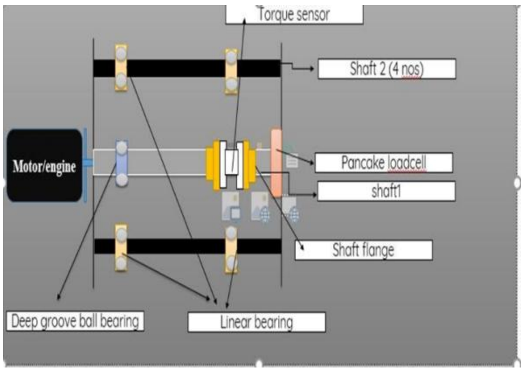


Figure 1: Preliminary Architechture

The Architecture has several components:

1. Shafts (one to carry torque other to carry the axial load)
2. Torque sensor
3. Thrust sensor
4. Pancake load cell

5. Linear and Deep Groove Ball Bearings
6. Shaft flange
7. Plates for the structure

B. Shaft Considerations

Shaft 1: The shaft that holds the engine or motor which holds the torque force of the diameter 75mm.

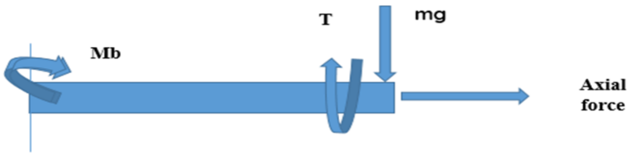


Figure 2: Shaft 1 with Overhanging Load

Shaft 2(4 no's): The shaft that carries the thrust load only towards the Load cell which is of the diameter 60mm.

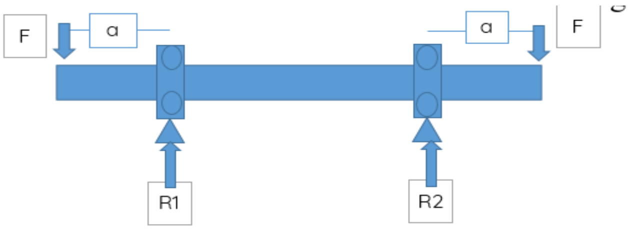


Figure 3: Shaft 2 with Simply Supports

C. Torque and Thrust Sensor

The sensors were selected based on the Specifications, Uncertainty and combined error. The dimensions of the sensors were already given in the brochure and then it was modelled in Solidworks.

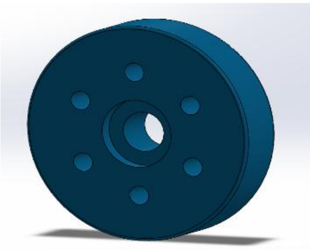


Figure 4: 3D Modelled Pancake Load Cell

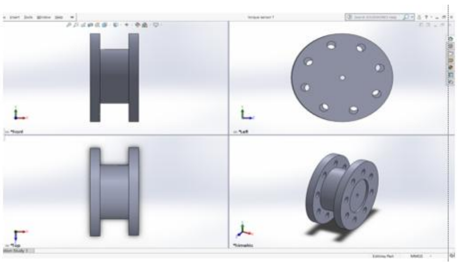


Figure 5: 3D Modelled Torque Sensor

D. Linear and Deep Groove Ball Bearings

The linear (LMK 60) and deep groove (SKF 6215) ball bearings were selected on the basis of shaft diameters.

Figure 6: 3D Modelled Linear and Deep Groove Baall Bearing

E. Shaft Flange

We require flanges to keep the shafts intact with the structure and also two different flanges to keep the torque sensor intact with the middle plate.

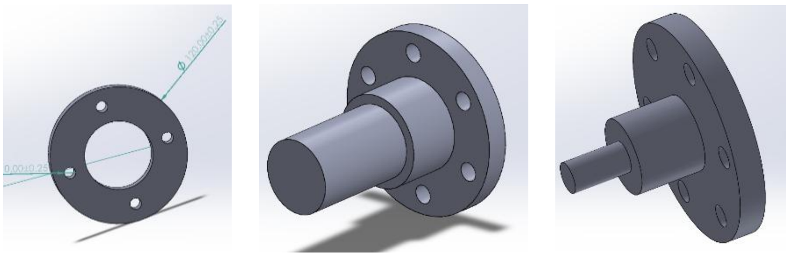


Figure 7: Flanges for the Structures and Torque Sensor

F. Plates for the Structure

The design of the Test Bench consists of the top, bottom, front, back, middle plates (2 no's). These are designed according to the placement of the sensors, shafts, and some tolerance.

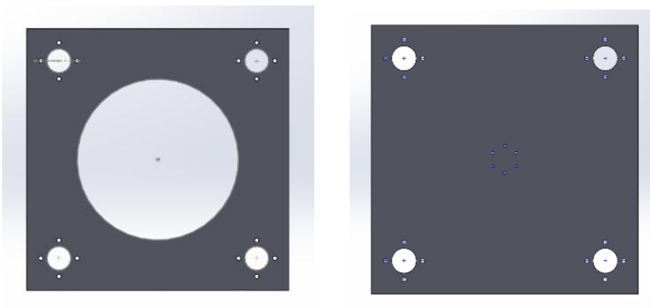


Figure 8: Front Plate and Back Plate

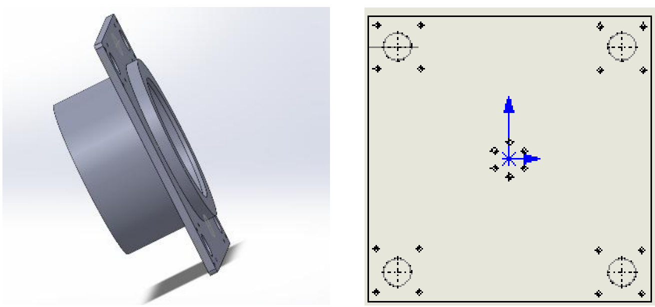


Figure 9: Mid plate 1 and Mid plate 2

G. Complete Assembly

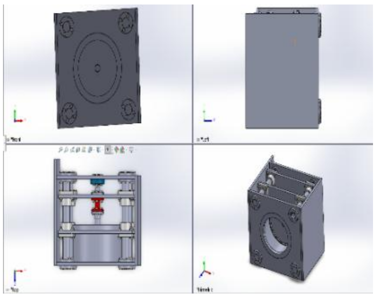


Figure 10: Structure Assembly

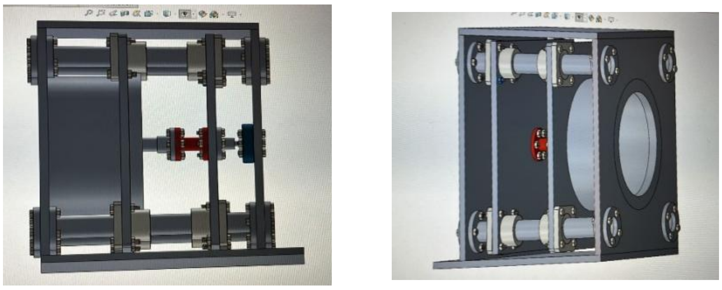


Figure 11: Final Asssembly

VII SENSORS AND DAQ SYSTEM

The below listed sensors were selected for the thrust bench to measure the parameters and along with the DAQ the data could be utilized and other parameters could be calculated from that.

Table 2: List of Sensors and DAQ System

Parameter	Sensor	DAQ
Thrust(125Kgf)	Stark Embsys Pancake load cell	C-DAQ SL1100 Bundle
Torque(100Nm)	Stark Embsys Reaction torque sensor	C-DAQ SL1100 Bundle
RPM (10,000)	Magnetic pickup sensor MT-190W	C Series Digital Module NI-9401
Temperature	Thermocouple	C Series temperature input module NI-9211

VIII STRUCTURAL ANALYSIS

In order to get accurate results, it is required to have smaller aspect ratios and hence tetrahedron meshing is used for meshing as it provides aspect ratio close to unity.

a) Front Plate

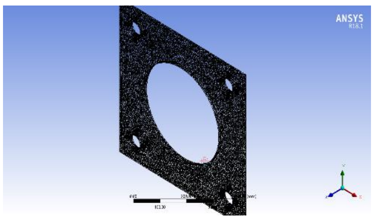


Figure 12: Mesh

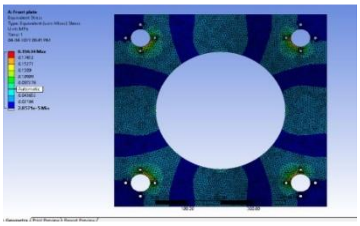


Figure 13: Von Mises Stress

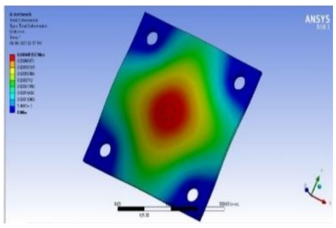


Figure 14: Total Deformation

b) Mid Plate

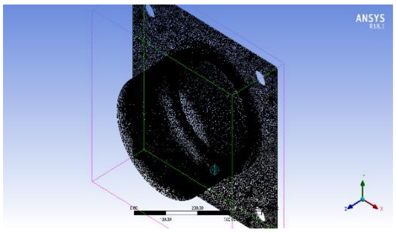


Figure 15: Mesh

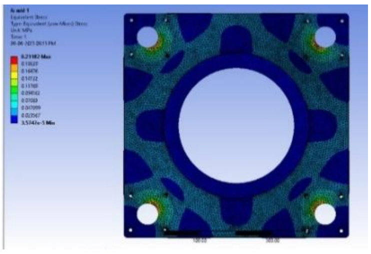


Figure 16: Von Mises Stress

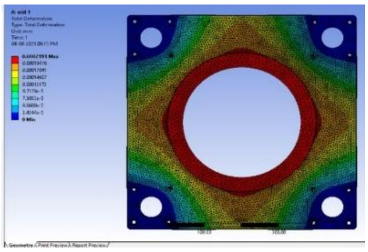


Figure 17: Total Deformation

c) Back Plate

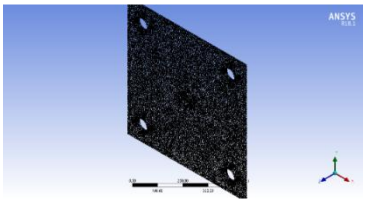


Figure 18: Mesh

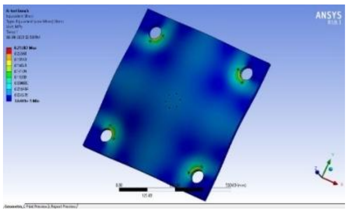


Figure 19: Von Mises Stress

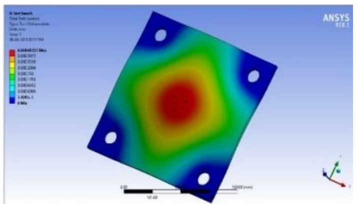


Figure 20: Total Deformation

d) Shaft

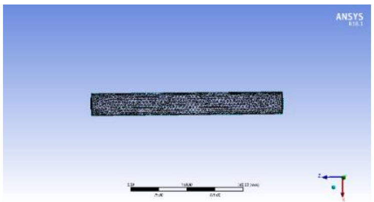


Figure 21: Mesh

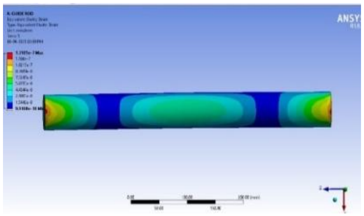


Figure 22: Von Mises Stress

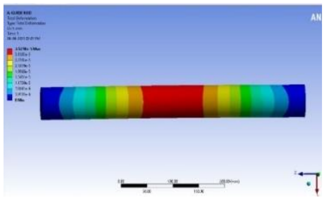


Figure 23: Total Deformation

e) Flanges

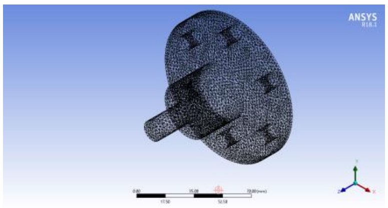


Figure 24: Mesh

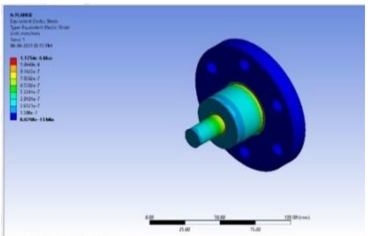


Figure 25: Von Mises Stress

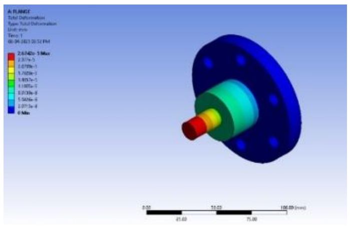


Figure 26: Total Deformation

f) Structure

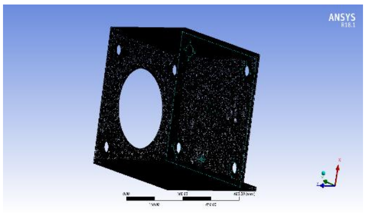


Figure 27: Mesh

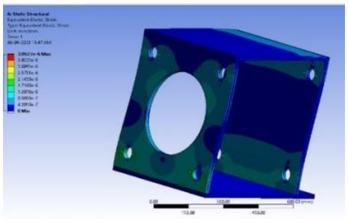


Figure 28: Von Mises Stress

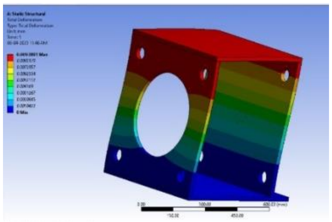
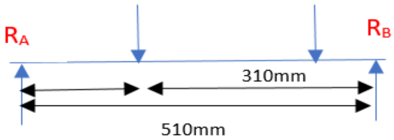


Figure: 29 Total Deformation

IX NUMERICAL INVESTIGATION



Reaction forces, Shear forces, Bending Moment for Shaft 2: (Simply Supported Beam)

- Data: Y= 210GPa, Tensile strength= 540MPa, Yield strength= 250MPa,
- Poisson's ratio= 0.3, Diameter=60mm, circular cross section(pi*r2) =13266.5mm2
- Moment about A: RB *510= (12.26*410) +(12.26*200); RB=14.6659N; RA =9.8540N
- Shear force: at B=14.6659N, at C= 2.4059N, at D= -9.8540N, at A= 0N
- Bending Moment: at B=0 N-mm, at C=1466.59 N-mm, at D=1971.829N-mm, at A=0.009 N-mm

X MATERIALS SELECTED

Table 3: Materials

Part	Material
Front Plate	Mild Steel
Back Plate	Mild Steel
Top Plate	Mild Steel
Bottom Plate	Mild Steel
Mid Plate 1	Cast Iron
Mid Plate 2	Mild Steel
Flange	Stainless Steel
Shaft 1	Stainless Steel
Shaft 2	Stainless Steel

Table 4: Material Properties

PROPERTIES	
MATERIAL	MILD STEEL
DENSITY	7850 Kg/m^3
TENSILE STRENGTH	400 MPa
YIELD STRENGTH	250 MPa
POISSON'S RATIO	0.29
YOUNG'S MODULOUS	210 GPa
PROPERTIES	
MATERIAL	CAST IRON
DENSITY	7140 Kg/m^3
TENSILE STRENGTH	884 MPa
YIELD STRENGTH	758 MPa
POISSION'S RATIO	0.30
YOUNG'S MODULOUS	120 GPa
PROPERTIES	
MATERIAL	STAINLESS STEEL
DENSITY	7850 Kg/m^3
TENSILE STRENGTH	540 MPa
YIELD STRENGTH	250 MPa
POISSON'S RATIO	0.30
YOUNG'S MODULOUS	210 GPa

XI RESULTS

The analysis of the model designed for a maximum load of 15 kg has revealed that it has the ability to withstand a 10 kg load without experiencing any significant deformation. When the results of the model analysis were compared to the design report provided by external guides, it was found that the results were consistent. However, it was observed that the results obtained were influenced by the length of the mesh elements. Further analysis revealed that the major load on the back plate of the model was concentrated towards its centre, where the pancake load cell is attached. This implies that the thrust can be accurately measured through this point. In addition, the structural assembly analysis indicated that the majority of the movement takes place towards the mid-half to the top of the model.

To determine the performance of the shafts, numerical results were calculated based on reaction force and bending moment. The analysis revealed that the shafts are capable of withstanding the loads exerted on them without experiencing any significant deformations. These findings suggest that the model is well-suited to meet its intended purpose and can be relied upon to perform effectively.

XII CONCLUSIONS

This study highlights the critical role that test benches play in the development of unmanned aerial vehicles (UAVs) by characterizing the propeller and engine/motor used in the vehicle. By exploring the different parameters that can be measured using a thrust test bench, including thrust, motor rpm, power, torque, temperature, and efficiency, the study demonstrates the importance of using advanced sensors and data acquisition systems (DAQ) to obtain precise and accurate measurements. The front plate of the structure also consists of the mounting plate which can be designed accordingly with the selection the motor/engine used to be tested. Overall, the study emphasizes the significant benefits of using test benches in the design and implementation of various systems and models, which can save time, effort, and money while ensuring the reliability and efficiency of the final product.

XIII FUTURE SCOPE

In the future, there is potential for modifying the design and structure of a thrust stand to accommodate different motor/engine uses, with changes made only after real-time structural testing to validate the design for mass production. The thrust stand can also be scaled for different specifications and developed for indigenous use.

The future of thrust bench technology is likely to involve advancements such as integrating advanced sensors and data processing algorithms to improve measurement accuracy and reliability, incorporating new materials and designs for durability and stability, and developing new testing protocols and standards for more accurate and consistent measurements. This includes the use of high-resolution sensors for detailed data on engine performance, as well as the establishment of best practices for data analysis and reporting. Overall, the future of thrust bench technology will be driven by advancements in sensor technology, materials science, data processing, and testing methodologies.

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