

Design and Testing of Thrust Measurement System for Rotary Engine

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Abstract—At various propeller RPMs and in various weather situations, the static thrust of the rotary engine will be measured in the present project work. First, a review and analysis are done on the V-shaped slider arrangement employed as the current thrust measuring test apparatus. A modified thrust measuring test rig is used to replace the cantilever type load cell with a S type load cell and the V shape slider arrangement with a linear block ball bearing in the thrust measuring cradle. At varying propeller RPMs, in various weather situations, both at sea level and at high altitude, the experimental thrust results of the Rotary Engine were recorded. These data were compared to test results from the past and to software-generated thrust results.

Index Terms— Thrust, Thrust Cradle, Estimate Propeller Static Thrust, Propeller Speed, Sea level, High altitude, Universal Testing Machine.

I. INTRODUCTION

The force that propels a spacecraft through the air is called thrust. In order to overcome the drag of an airplane and a load of a rocket, thrust is used. The craft's engines produce thrust through a quiet system and an operating fluid to provide thrust the most prevalent source of thrust is the rapid reaction of a mass of gas. Given that thrust can be a force, it has both a magnitude and a direction. The thrust is produced in the incorrect direction by the accelerated gas because the engine works on the gas and accelerates the gas to the back of the engine. The magnitude of the thrust depends on the quantity of gas that's accelerated and on the distinction in the rate of the gas through the engine. The kind of system used on Associate in spacecraft might vary from plane to plane and every device produces thrust in a very slightly completely different approach. We'll discuss four principal propulsion systems; the propeller, the rotary engine or reaction engine, the ramjet, and therefore the rocket. Desrochers *et al.* [1] used a thrust measurement device that measured the results of rocket motor ground testing. The performance characteristics of rocket engines might be stated by this author collectively. The thrust output provides a jointly additional electrical gadget. Kakamil *et al.* [2] used the design and performance of linear block bearings. These bearings are also used in automobile applications, considering the application test rigs can be developed and it is carried out various tests like an endurance test and hysteresis of the linear ball bearings. Zheng Longxi *et al.* [3] used the Integration of a thrust measurement system and this system was also carried out by the thrust measurement of a liquid fuel engine in three different ways. The first method is a direct measurement, the Second method is indirect thrust measurement, and the third method is the impulse method

with a flat plate. Timothy Corners *et al.* [4] used by using a strain gauge direct thrust measurement technique. And this author can be described by the strain gauge installation and calibration process. And it is also conducted on experiments at different operating conditions. And the performance of the engine was checked out. Yang Juan [5] *et al.* Used the study of Classical magnetic force theory, were introduces the replacement of various reasonable propellant-less thrust measuring device microwave. it was to be used in the area. This device is also converted by microwave radiation into waves.

The primary goal of this study's main objective is to develop, build, and test a thrust measuring test rig. Using a variable helicopter rotary engine, it is examined how changing the thrust, blade rotation speed, fuel consumption, and engine temperature affect the engine. Both the motor's speed and the pitch of the propellers are controlled by a different electronic speed controller unit. The Thrust Cradle was made using Auto-Cad, a computer-aided design programme. The model will be useful for testing rotary engines, comparing actual data with threshold data, understanding thrust principles, and assessing the effects of various variables on propeller thrust. The objective is to build the full system for the smallest possible cost. We have the necessary understanding thanks to the mechanical system, electrical hardware, and software designs. The thrust's variation as a function of the design parameters will be shown by the experiment. The paper discusses the design particulars, the outcomes, and the conclusion. The brand-new building offers the potential for many appealing design options. Additionally, by switching out a linear sliding ball bearing for a roller bearing, it will be more efficient to achieve the thrust of the rotary engine, as well as more sensitive and lighter. These solutions can frequently result in space savings. To test the fuel-injected rotary engine at various high altitudes, the company needs to create a transportable thrust cradle platform.

II. MATHEMATICAL DESIGN AND FORMULATION

Design Procedure

1. Torque

Torque = Force x distance x f.o.s

2. Diameter of Shaft

Where, M=Bending Moment

D=Diameter of Shaft
=Bending Stress

3. Life of Bearing Span in Km:

$L_{10} = f_s (C/P)^n \times 100 \text{ Km}$

Where, f_s =Factor of Stroke Length

C=Dynamic Load Rating, N

P=Equivalent Dynamic Bearing Load in N

4. Life span in Hr.:

TABLE I. DESIGN PARAMETER USED IN STUDY. [REF.5-6]

Parameter	Values
Torque (N-mm)	919687.5
Diameter of Sliding shaft (mm)	36.05≈ 40
Life Of Bearing Span (Km)	415.864
Bearing Life Span (Hr.)	173.276 X 10 ⁶

5. Theoretical Propeller Thrust

We have the input data,

- N = Propeller Revolution Speed = Variable from 3500 RPM to 6500 RPM
- D = Propeller Diameter in inches = 39.37 inch
- ρ = Air Density in Kg/m³ = 1.225 Kg/m³ at sea level and 1.053 Kg/m³ at high altitude
- K_t = Static Thrust Coefficient ≈ 0.53
- T = Propeller Thrust
- $T = 1.283 \times 10^{-12} \times N^2 \times D^4 \times \rho \times K_t$

TABLE II. THEORETICAL THRUST RESULTS AT SEA LEVEL AND HIGH ALTITUDE

Sr. No.	RPM	Thrust at sea level (Kg)	Thrust at high altitude(Kg)
1	3500	24.515	21.073
2	4000	32.019	27.524
3	4500	40.525	34.835
4	5000	50.031	43.006
5	5500	60.537	52.037
6	6000	72.044	61.929
7	6500	84.551	72.680

III. MOBILE THRUST CRADLE PLATFORM CONCEPT

A brand-new ship powered by a piston engine first needed to undergo tests at both low and high speeds before mobile flight tests. When the craft is conducted at low speed taking checks at the "idle" position at high speed taking checks at the "full throttle" position, the static thrust of the craft has been determined from "idle" as a minimum to "full throttle" as a maximum at completely different temperatures, and the boldness would be designed up once the craft has been conducted.

IV. PROPELLER THRUST MEASURED BY USING SOFTWARE

Computer-generated results can be found by using the online software 'Estimate Propeller's Static Thrust.' The software requires the input parameter like weather conditions that is temperature; the density of air depends on altitude. RPM and the pitch of the propeller is a very important parameters to calculate the thrust of the propeller. Thrust also depends on the diameter of the propeller. All the parameters are required to calculate the thrust by using the online software "Estimate Propeller's Static Thrust." After putting the values of RPM from 3500RPM to 6500RPM, the result obtained is as under. Also, the corresponding graphical results are shown.

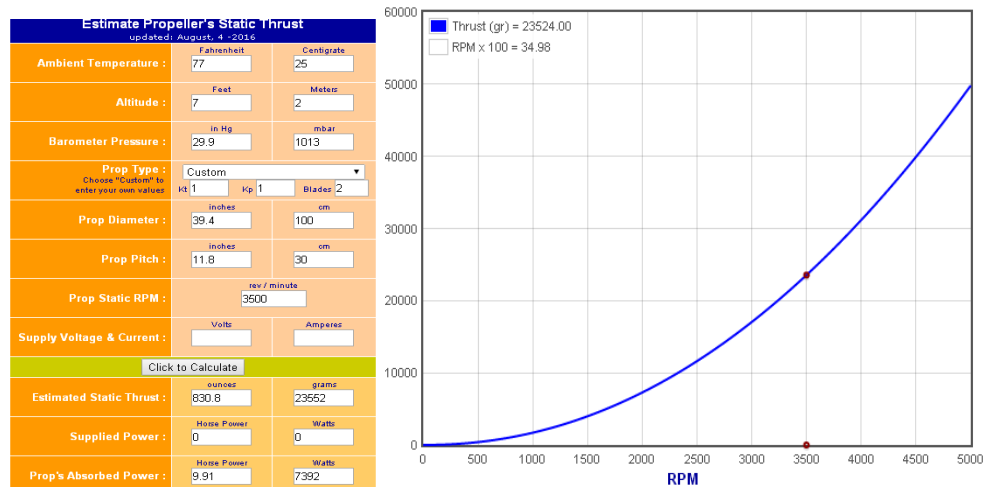


Figure 02. Thrust at 3500 RPM at sea level

Similarly, we were getting the software results as shown in the table.

TABLE III. COMPUTER GENERATED THRUST RESULTS AT SEA LEVEL AND HIGH ALTITUDE

Sr. No.	RPM	Thrust at sea level (Kg)	Thrust at high altitude (Kg)
1	3500	23.552	21.789
2	4000	31.175	28.841
3	4500	39.648	36.935
4	5000	49.466	46.081
5	5500	60.428	56.292
6	6000	72.542	67.578
7	6500	85.821	79.947

V. EXPERIMENTAL PROPELLER THRUST

In order to measure the engine's thrust at various propeller RPMs, the rotary engine is positioned on a thrust cradle. The engine is started by employing an engine-starting trolley to provide the initial rotary motion. Once the engine is running, it rotates a few times at the ideal speed, which is also the engine's minimum speed. Through a linear ball bearing block, the reciprocating plate, which is positioned on the reciprocating shaft, is connected to the load cell. The test setup is depicted in fig.03.



Figure 03. Rotary Engine on the test setup

TABLE IV. EXPERIMENTAL PROPELLER THRUST AT SEA LEVEL AND HIGH ALTITUDE

Sr. No.	RPM	Thrust at sea level (Kg)		Thrust at high altitude (Kg)	
		Old	Present	Old	Present
1	3500	20.13	22.53	19.63	20.73
2	4000	28.57	30.27	25.17	26.80
3	4500	35.87	38.57	31.25	33.93
4	5000	44.35	47.78	38.52	41.52
5	5500	54.68	58.98	46.47	50.10
6	6000	65.54	70.87	53.21	59.81
7	6500	76.27	83.18	63.75	69.23

From the above experimental test results of static thrust values and from the table we can observe that the static thrust at high altitudes increases with an increase in the speed of the propeller.

VI. RESULTS & DISCUSSION

A. Theoretical, Analytical and Experimental results at sea level

TABLE V. COMPARING THE THRUST THE OF PRESENT ARRANGEMENT WITH THE OLD ARRANGEMENT AT SEA LEVEL

Sr. No.	RPM	Theoretical Thrust (Kg)	Software result Thrust (Kg)	Experimental Thrust (Kg)		Error Analysis %
				Old	Present	
1	3500	24.515	23.552	20.13	22.53	11
2	4000	32.019	31.175	28.57	30.27	6.65
3	4500	40.525	39.648	35.87	38.57	7
4	5000	50.031	49.466	44.35	47.78	7.178
5	5500	60.537	60.428	54.68	58.98	7.29
6	6000	72.044	72.542	65.54	70.87	7.52
7	6500	84.551	85.821	76.27	83.18	8.307
Total =						53

From above table 05, we have to calculate average the error.

Therefore, Average Error=Total/7= 53/7=7%.

Error in the estimated values is average. Therefore, it is accepted for 7%.

We can see that the static thrust of the rotary engine increases from the ideal speed which is 3500RPM to full throttle speed which is 6500RPM at sea level. The static thrust increases from 22.53Kg to 83.18Kg. The theoretical values, analytical values, and experimental values of the static thrust are approximately the same

B. Validations of the result are in graphical form given as follows

The thrust values of the new model and old model as shown in graphical form are as follows. Fig. 4 shows the graph generated RPM Vs. Thrust at sea level, & Thrust at high altitude.

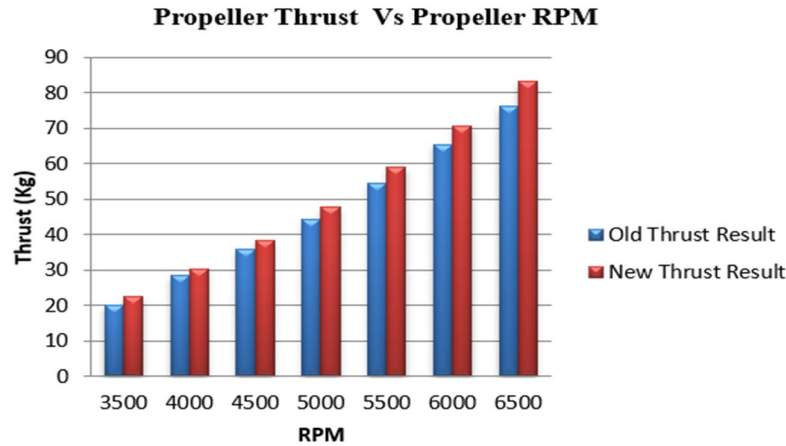


Figure 04. Graph of Comparison between Old Thrust result and Present Thrust results at sea level

C. Theoretical, Analytical, and Experimental results at high altitude

TABLE VI. COMPARING THRUST OF THE PRESENT ARRANGEMENT WITH THE OLD ARRANGEMENT RESULTS AT HIGH ALTITUDE

Sr. No.	RPM	Theoretical Thrust (Kg)	Software result Thrust (Kg)	Experimental Thrust (Kg)		Error Analysis
				Old	Present	
1	3500	21.73	21.789	19.63	20.73	5
2	4000	27.524	28.841	25.17	26.80	6.475
3	4500	34.835	36.935	31.25	33.93	7.89
4	5000	43.006	46.081	38.52	41.52	7.225
5	5500	52.037	56.292	46.47	50.10	7.245
6	6000	61.929	67.578	53.21	59.81	11.03
7	6500	72.680	79.947	63.75	69.23	7.95
Total=						51

From above table 06, we have to calculate the average error.

Therefore, Average error =Total/7=51/7=8%

Error in the estimated values is average. Therefore, it is accepted for 8%.

We can see that the static thrust of the rotary engine increases from the ideal speed which is 3500RPM to full throttle speed which is 6500RPM at high altitude. The static thrust at high altitudes is comparatively less than the static thrust at sea level. In that case, the thrust would be increased by using a turbocharger. The static thrust increases from 20.73Kg to69.23Kg. The theoretical values, analytical values, and experimental values of the static thrust are approximately the same.

D. Validations of the result are in graphical form given as follows

Fig.5 shows that the present thrust cradle result is more than the old thrust cradle result at sea level. It increases at 6500 RPM as about 6 to 7 Kg.

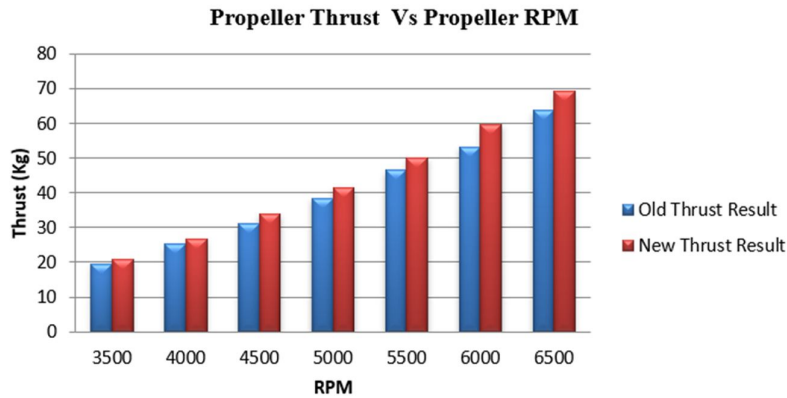


Figure 05. Graph of Comparison between Old and New Thrust Results at high altitude

VII. CONCLUSION

In this system, the thrust transfer arrangement with a roller is replaced by the thrust transfer arrangement with Linear Ball Bearing Block. It will be more smoothly slide & sliding motion is required and then get transfer more thrust. The actual thrust of the rotary engine at sea level & high altitude is achieved very nearly to the theoretical thrust and software thrust of the rotary engine. The thrust gradually increases with the RPM of the propeller. The rotary engine at an ideal speed of 3500 RPM gives a minimum thrust 22.53Kg and at a maximum speed, 6500RPM gives a maximum thrust 83.18Kg. The thrust produced by the rotary engine at high altitudes also increases with an increase in the speed of the propeller of the rotary engine. The thrust produced by the rotary engine at high altitude is comparatively less than the thrust produced by the rotary engine at sea level.

REFERENCES

- [1] Desrochers, M.F., Gary W. Olsen, and Hudson, M.2009. "A Ground Test Rocket Thrust Measurement System" Department of Applied Science and The Graduate Institute of Technology University of Arkansas at Little Rock, Little Rock, AR 72204 USA.
- [2] Kakamil, A., Kashiara, K., Takeshida, K., and Yano, Y.2015. "A new thrust measurement method for evaluating higher frequency variation by applying acceleration measurement to null-balance method" Presented at Joint Conference of 30th International Symposium on Space Technology and Science 34th International Electric Propulsion Conference and 6th Nano-satellite Symposium, Hyogo-Kobe, Japan July 4 – 10.
- [3] Jie, L., ZhengLongxi, Zhiwu W., Changxin P., and Xingu, C. 2014. "Thrust measurement method verification and analytical studies on a liquid-fueled pulse detonation engine School of Power and Energy", Chinese Society of Aeronautics and Astronautics & Being University Chinese Journal of Aeronautics Northwestern Polytechnic University, Xi'an 710072.
- [4] Timothy, R., Conner's, and Robert, L. 1998. Flight Envelope Direct Thrust Measurement on a Supersonic Aircraft Dryden Flight Research Center Edwards, California July National Aeronautics and Space Administration, California.
- [5] Juan Y., Wang Y. and Pinged, Y.2011. "Net thrust measurement of propellant less microwave thrusters" (Northwestern polytechnic AL University, College of Aeronautics, Xi'an 710072).
- [6] Polk J., Pancotti A., Haag T., King S., Walker M., Blakely J., and Ziemer, J.2013. "Recommended Practices in Thrust Measurements" IEPC-2013-440 Presented at the 33rd International Electric Propulsion Conference, Washington, and DC October 6-10.
- [7] Mingtai, C.2012. Static Thrust Measurement for Propeller-driven Light Aircraft Shanghai Aircraft Design and Research Institute Shanghai, China the 2nd International Conference on Computer Application and System Modeling.
- [8] Jeruzal, C., and Brinker, K.2003. "Development of a Jet Engine Experiment for the Energy Systems Laboratory" A. Pourmovahed Graduate Assistant ASME International Mechanical Engineering Congress Washington, D.C.