Exploration into the Use of Gas Power for Lifting Operations

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1. Abstract

Personnel lifting operations are essential for various industries, especially in high-altitude scenarios, such as mountainous terrains, high-rise buildings, and natural disasters. Despite the significant amount of research on human lifting devices, very few practical solutions have been implemented. Existing research suggests the use of internal combustion engines may be advantageous for such operations due to high energy density of engine fuels allowing for increased payload capacity and operation time. This report presents an investigation into this suggestion through the design, development and assessment of a gas-powered propeller device designed to lift users for high-altitude operations. The approach and methodology for the project includes research into existing solutions, an iterative design process, as well as benchmarking for performance. The device's performance was assessed by conducting a series of functional evaluations, such as payload capacity and flight time calculations. The results were analysed, and the device's viability was compared to the previously established criteria. The author's conclude that the gas-powered lifting device designed has potential to provide a versatile, low-cost solution that can overcome the challenges of existing lifting devices. While results are promising, they are not definitive however, and thus the authors' recommend significant future work to improve the performance and efficiency of the device.

2. INTRODUCTION

The need for efficient and effective personnel lifting methods has become increasingly important, especially in high-altitude settings, such as mountainous terrains and high-rise buildings. Few existing solutions for such operations currently exist, and are often limited in accessibility, height capacity and or cost. The lack of suitable devices for such operations warrants research and development into alternative methods of vertical human transportation. Accordingly, this paper presents an investigation into the use of a gas powered multi propeller device, with an attached structure for personnel, for use in lifting operations.

The literature review for this project examines the use of multi-propeller systems and devices which use internal combustion engines (ICEs), with focuses on engine choice, fuel, engine control, and propeller design. A propeller lifting device has the potential to address many of the challenges of current solutions by providing a solution which is versatile in a variety of different settings, while also maintaining a low cost. The benefits of using internal combustion for power are well known[1] [2]. Most notably, the high energy density of fuels, in contrast to batteries, results in excellent power to weight ratios[3]. This translates well for lifting operations, as this entails longer operation times, higher payload capacity, and quick refuelling, as compared to electric motors which are commonly used in multi propeller devices. However, ICEs also have slow response times, cause vibration and noise, and require engine control systems for stabilisation. These factors may significantly affect the lifting operation and thus must be addressed when implementing gas power into a device.

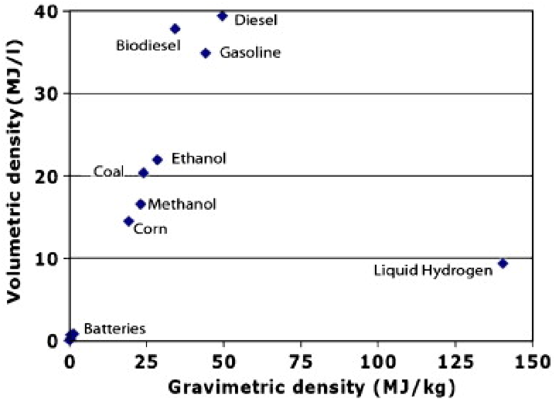

Figure 1 Caloric energy density of fuels compared to batteries [A]

The scope of this project involves the designing and building of a scaled model of a gas-powered device capable of supporting a structure intended to transport personnel. The design takes modularity in mind to accommodate different types of structures. The use of a scaled model allows for a cost-effective and risk-reduced investigation of the concept.

The approach and methodology of the project involve extensive research, iterative design process, and functional tests on the scaled model to assess its performance. Data from tests, such as payload capacity and flight time calculations, are analysed to evaluate the performance of the device and identify areas for improvement. The paper concludes with recommendations for potential future work and discusses the viability of a gas-powered lifting device for high-altitude operations.

3. Design Process

The design process was split into several sections. First, a requirement analysis, based on the specific problem statement established in the introduction was completed. Several different design criteria were considered, with characteristics focusing on the robustness, strength, endurance, size, and safety of the design. Next, preliminary concept designs were made through a systems method. A black box system diagram was created along with the division of several subsystems. Once these subsystems were established, brainstorming of different solutions for each subsystem was conducted. An evaluation of each solution was completed based on knowledge gained from the literature review along with the criteria set in the requirements analysis. It was determined from this evaluation that a two stroke gasoline engine would be well suited to propel the scaled model, due to their cheap cost along with relatively high power to weight ratio. A radio control car platform powered by a two stroke engine was utilised, as this solution provides essential components such as the fuel tank, exhaust, gearbox, and chassis to use as a base to build the quadrotor device from.

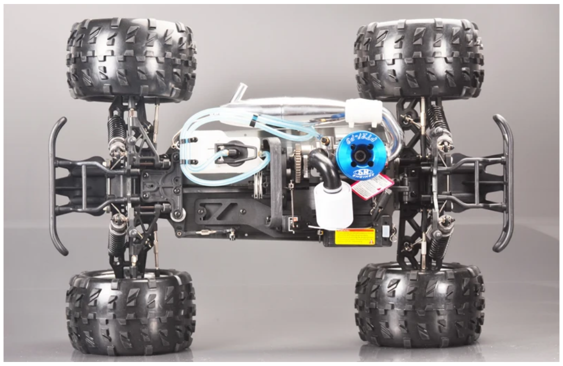

Figure 2 RC Car platform with 28SH Nitro Engine [4]

Design calculations and considerations were completed for several different sections of the scaled model, these being the design of the powertrain, the design of the device structure, the design of the transport structure, selection of materials, selection of bearings and fasteners, and propeller loading. Each section listed progressed through multiple different iterations before a final design was realised. To estimate an accurate factor of safety for subsystem components, the von Mises and Goodman failure criteria seen in Eq 1, 2 and 3 were used. The finalised design was the culmination of these various iterations. The powertrain used exclusively bevel gears and machined shafts, and the body was constructed from 3D printed parts, reinforced with stainless steel threaded rods and other fasteners. The final device can be seen in Figure 2.

Figure 3 Final design of VTOL device

$$\sigma_a' = [(\frac{32K_f M_a}{\pi d^3})^2 + 3 (\frac{16K_{fs} T_a}{\pi d^3})^2]^{1/2} \quad (1)$$

$$\sigma_m' = [(\frac{32K_f M_m}{\pi d^3})^2 + 3 (\frac{16K_{fs} T_m}{\pi d^3})^2]^{1/2} \quad (2)$$

$$\frac{1}{n} = \frac{\sigma_a'}{s_e} + \frac{\sigma_m'}{s_{ut}} \quad (3)$$

4. Results and Conclusions

Assessing the benchmarking tests, the scaled model of the device achieves the required level of performance for material strength, physical footprint, and safety. However, it falls short of the set criteria for payload capacity and operation and thermal endurance. A success criteria of 20N of thrust was established, however the device was unable to reach this target due to a low maximum achieved propeller speed of 5000 RPM. The analysis shows that the OEM nylon clutch was unable to sustain the loads exerted by the powertrain, causing the device to lose power and fail. Operation time was evaluated for endurance, however while the fuel consumption was found to be adequate, the small fuel capacity of the system led to a shorter operation time than desired.

Table 1 RPM vs Thrust based on Propeller Specifications [5]

Propeller Speed (RPM)	Theoretical Lift Generated (N)
4000	5.724
5000	8.975
6000	12.975
7000	17.742
8000	23.296
9000	29.664
10000	36.877

It was determined that the power train design resulted in significant loss of power due the transferring of power from the engine to the propellers was done through an excessive amount of stages. To avoid this in future iterations, utilising a system with multiple separate engines would allow for a simpler powertrain design, ultimately reducing the losses experienced in the system. In addition, the vibration experienced by the system is negligible during operation, but stability could be improved by utilising more stable engine layouts in the future.

The gas-powered propeller device has shown promise for personnel lifting operations in high-altitude scenarios. However, further research and development is required to overcome obstacles such as the slow response time of ICEs and to improve payload capacity and operation and thermal endurance. The paper recommends pursuing further improvements in the design and performance analysis of each mechanical component and in the use of multiple different power sources.

5. References

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