DESIGN ISSUES RELATING TO ULTRALIGHT HELICOPTERS WITH LARGE COMPOUND ROTORS OPERATING IN GROUND EFFECT

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Abstract

Ultralight Helicopter with large compound rotors operating in ground effect offers great possibility for agriculture, sport aviation and military applications. Drawing from research and development experience in Remote Control (RC) and Human Powered Helicopters and Aircrafts, much design insights can be gained. These include aerodynamic, structures, flight mechanics etc. “Low power” means less fuel. “Slow rotation” means less noise. “In ground effect” means very low altitude hence enhanced safety for the operator for agriculture use. These new application of old concepts will give rise to an exciting and useful derivative of the conventional helicopter.

Keywords

Large Rotor, Low Power, Ground Effect, Slow Rotation.

1.0 Introduction

This paper will address the design of an ultra light helicopter that utilizes very low power. This will be achieved by using four very large chord rotors rotating at very low RPM (revolution per minute). The “Ground Effect Phenomena” is important in determining the hover performance. If the hover performance can be predicted correctly, better helicopter design can be made. These new types of helicopters will use less power and hence less fuel. As their rotors are rotating at low RPM, they will also produce less noise. These environmental issues are of prime importance to helicopter designers.

The proposed new helicopter can be used as an agricultural tool for manned or unmanned spraying. This will provide a better solution than the current Remote Control (RC) helicopters used for crop spraying in Japan. Agriculture in the 21st century will see a trend of more machine use as manual labor become scarce. External pressures and diversification of agricultural products will demand high technology, precision and future automation.

Currently, helicopters are utilized greatly in agriculture and forestry. In agriculture, they are mostly used for insecticide spraying. A helicopter, used as “agriculture equipment” is basically a “flying utility vehicle” not unlike a tractor. That is, by changing an attachment, it can be used to scatter seeds, fertilize, kill weeds, spray insecticides and other useful purposes. This feature makes for more diversified usage of helicopters in farming.

In Japan, up to the year 1996, 620 units of the Yamaha R-50 RC helicopters were sold. This helicopter was primarily used for remote control agricultural spraying. This shows that there is a need for helicopters in agriculture. The challenge is to design a better and cheaper helicopter. A primary design objective is to obtain maximum payload to hover to low speed flight. The way to go is to improve on the pioneering work of Dr. Akira Naito on the YURI 1, a human powered helicopter designed at Nihon University. Refer Figure 1.

Another possibility for this new helicopter is that it can be used for fun and recreational flying. Because of the low power and low fuel consumption, it can also be used as a cheap platform for helicopter flight training. There is also some strategic use for the armed forces such as an observation platform and as a hovering transponder.

2.0 Relevant RC Helicopters and Ultralight Helicopters Research

In 1980, the Japan Agricultural, Forestry and Fishing Aviation Association (Nosuikyo) decided to invest in the development of an RC helicopter for unmanned spraying. [1]. Several types of RC helicopters were considered but the set design goals were finally met by a helicopter developed by Yamaha called the R-50 in 1986. Extensive spray mission flight tests were completed during 1986-87. A satisfactory spray pattern was obtained. Field tests were carried out in 1988 and demonstrations performed at over 100 sites throughout Japan in 1989.

Using unmanned helicopters for agricultural spraying in Japan became practical in 1991. Since then, the farms sprayed by unmanned helicopters have reached 100000 hectares in 1995. Currently an unmanned helicopter can spray one hectare in 15 minutes or about 20 hectares per day. In 1995, 500 such RC helicopters were used for agricultural spraying with about 2000 operators.

However, with RC helicopters, there are some limitations on payload capacity, endurance and effective spray width. The high velocity downwash due to high rotation speed also poses a problem in getting an effective spray pattern. A better solution is needed and work on the “Human Powered Helicopter “ (HPH) can be used as a “baseline” to address these issues.

In 1989 the first documented human powered helicopter flight, was achieved by the helicopter Da Vinci III designed by the team from Cal Poly St. University at San Luis Obisopo, California. [2]. This helicopter is a single rotor helicopter. It manages to fly but was very unstable.

On December 5, 1993, YURI 1 of Prof. Akira Naito, a four-rotor human power helicopter manages to fly in a very stable (somewhat too stable) hover mode. This proves that this concept of low power helicopter really works but of course, there are many unresolved problems [3].

To design a successful low power helicopter demands new approaches in aerodynamics, structures, mechanics, stability & control and physics. It is truly a multidisciplinary design exercise in optimization of a total flying system.

In aerodynamics of rotor design there are some important work by Prof Eugeene Larabee of MIT. He has proposed the “Minimum Induced Loss Propeller Design Theory”. This theory can be extended and used to design helicopter rotors. [4],[5]. In similar vein, Adkins and Liebeck extended the work to design optimum propellers in 1983. [6].

For the problems of structure in the design of large chord rotors, a lot can be gained from the experience of Human Powered Aircraft (HPA). Their wing structure and method of construction can be used to design lightweight large chord rotors for ultra light helicopters. Details on construction techniques using CFRP (Carbon Fiber Reinforced Polymers) can be found in the works of MacCready P.B. and Longford J. Among their noted Human Powered Aircrafts are Gossamer Condor, Gossamer Albatross, Daedalus and Monarch. Recent works by Aerovironment Incorporated in designing High Altitude Long Endurance Lightweight Drones using solar power and fuel cells called HELIOS is a perfect case study in robust lightweight structures. A lot of these works can be adapted and adopted for detail design of robust large chord lightweight rotors with a radius of approximately 5 to 6 meters. [7],[8],[9].

Stability and Control of such very lightweight helicopters can also be studied by extending further the work of Raymond Prouty and W.B. Patterson [10],[11].

There are also some new works on the computational and experimental methods to predict hover performance. This will form the basis of the analytical work for the design of the proposed ultralight helicopter. These important works are by Ramos et all, Tung et all, Ramachandran et all and Del Bianco. [12],[13],[14],[15].However these study are done on conventional helicopters. It will be interesting to see their utilization of such methods to a large slow moving wide chord helicopter rotors. A study on a four-rotor system that contra-rotates will definitely add more to the body of knowledge in helicopter design.

3.0 Problem Identification for future development

Current flying human power helicopter cannot be used as a test bed because of their fragile conditions. A dedicated test bed must be constructed to study the following. Once these issues are resolved, a robust ultralight helicopter suitable for use outdoor can be constructed.

a) Slipstream near the ground
The flow around the rotating blades is entirely unknown. The stream is too complex to solve using the momentum theory. It is also not accurate to model these types of rotors as an actuator disk. This is only for a single disk. For the proposed counter rotating rotors not much is known, hence the heavy experimental approach at the first instance. At the same time, current computational methods can be used as comparison.
b) Change of airfoil characteristics near the ground
An airfoil moving near the ground plane suffers considerable modification of its free-air pressure distribution. The negative pressure decreases on the upper surface and the positive pressure increases on the lower surface. The flexibility of such lightweight rotor blades makes the proximity of the ground uncertain even for a known pilot position. Experimental data can then be used to propose an empirical design equation not unlike the “Sherwin” equation.
c) Flow condition in the test space
Tests of current Human Powered Helicopter are usually conducted indoors in large stadiums because even very low wind would have a strong effect on performance. But as test runs in a large enclosed space proceeds, the rotor reaction can set the whole air mass rotating. Soon a large vortex ring is formed that acts to decrease lift. Therefore, a carefully planned test bed needs to be designed to address this issue especially in providing a relatively undisturbed flow condition.
d) Structural problems
The loads on a helicopter rotor, rises strongly towards the tip in contrast to the loads on an aircraft wing. This produces very high bending moment at the blade root. The input torque to drive the rotor also produces a high stress at the blade root. In counter rotating lightweight rotors such as the HPH rotors, large torsional stresses occurs on the blades as they passes each other. All these large but somewhat uncertain loads make the design of the blade spar very difficult. However, current work in CFRP design and fabrication can be utilized to solve these problems.
e) Dynamic stability
The dynamic stability is affected by the position of the center of gravity relative to the rotor disk. These problems were discussed 50 years ago in the early days of the “flying platforms”. The conclusions were that that particular vehicle is dynamically stable with the c.g. just above the rotor disk and unstable with

the c.g. under the disk. However the flight conditions and characteristics of these “flying platforms” were very different to those of an ultra light helicopter. The premier reason being the rotor blades rotates extremely slowly. Dynamically unstable helicopters do not pose much of a problem nowadays. Recent work on active controls on COMANCHE attack helicopter has shown that the associated problem with dynamic stability can be overcome.

4.0 Conclusion

This study will provide new insights on the design of large chord rotors that rotates slowly. The improvement in aerodynamic and structural design will be of use to new helicopter design especially at the “near ground” or under “ground effect”.

There are a lot of possibilities for efficient ‘ground effect” helicopters as have been proven by the ground effect airplanes or fondly known in Russia as ERKANOPLANE. Among the most promising attributes of such ground effect crafts are the reduction in fuel consumption and the reduction of noise or acoustic pollution.

Their immense possibility in agriculture and forest management cannot be denied. These helicopters can also be used as a sport helicopter to encourage people to fly. Due to extremely high cost of fuel in conventional helicopter, flight training is very expensive and is way beyond the reach of ordinary people. Ultra light helicopter with large chord rotors can be the answer for relatively cheap flight training for the common folk. A flying culture among the masses will help spur technological advancement in aerospace engineering as exemplified by all the early aviation pioneers. Almost all aviation pioneers are flyers. They are passionate about flight and this passion helps them break technological barriers. “C’est la passion qui va pousser” loosely translated “It is the passion that will push or create action”.

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Figure 1. YURI 1