A Technical Essay on the Gyroplane

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Abstract

A study of *"Gyroplane"* and its historical evolution, general characteristics, flight characteristics, various designs, potential applications and aerodynamics explaining its flight is attempted. *"Gyroplane"* is an official term designated by the Federal Aviation Administration (FAA) describing an aircraft that gets lift from a freely turning rotary wing, or rotor blades, and which derives its thrust from an engine-driven propeller. The focus is on highlighting the differences between a Gyroplane and a conventional helicopter, relative merits and demerits and to trace the development to helicopters from autogiros. What lies ahead in the future for gyroplanes is also discussed.

Motivation and Introduction

In early part of 20^{th} century a high percentage of aviation accidents were due to 'loss of speed'. Low Horsepower to weight ratio reciprocating engine and crude aerodynamic design of the airplanes aggravated the situation. Thus a need was felt for a flying machine unaffected by the loss of speed in the air and which can alight as slowly as a bird *(Ref. 1)*. This was attained in the autogiro, brain child of Spanish Engineer Jaun de la Cierva.
In this machine the fixed wings have been eliminated and the lift is produced by revolving wings on a vertical shaft projecting from the fuselage of an ordinary airplane. However, it doesn't belong to the family of helicopters since the sustaining propellers of the latter are operated directly by the engine, whereas in the 'Autogiro' the wind produced by the motion of the aircraft actuates the blades. This phenomenon is called *Autorotation.*

Cierva thought of designing a flying machine that remains stable, safe and controllable irrespective of its forward speed. He segregated the function of lift and forward propulsion, where the former was done by a freely rotating rotor (and not wings) and latter by a conventional pusher or tractor engine.
The rotor of an *Autogiro* (term coined and patented by Cierva) always works in a state of autorotation and a small upward flow is sufficient to rotate the disk. Thus, as long as the machine has forward motion the rotor would produce sufficient lift to keep it afloat with the disk tilted slightly back. Increasing or decreasing the forward speed would cause the

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machine to ascend or descend accordingly. In case of engine failure, the rotor being in the auto-rotative state enables the autogiro to land safely to ground.

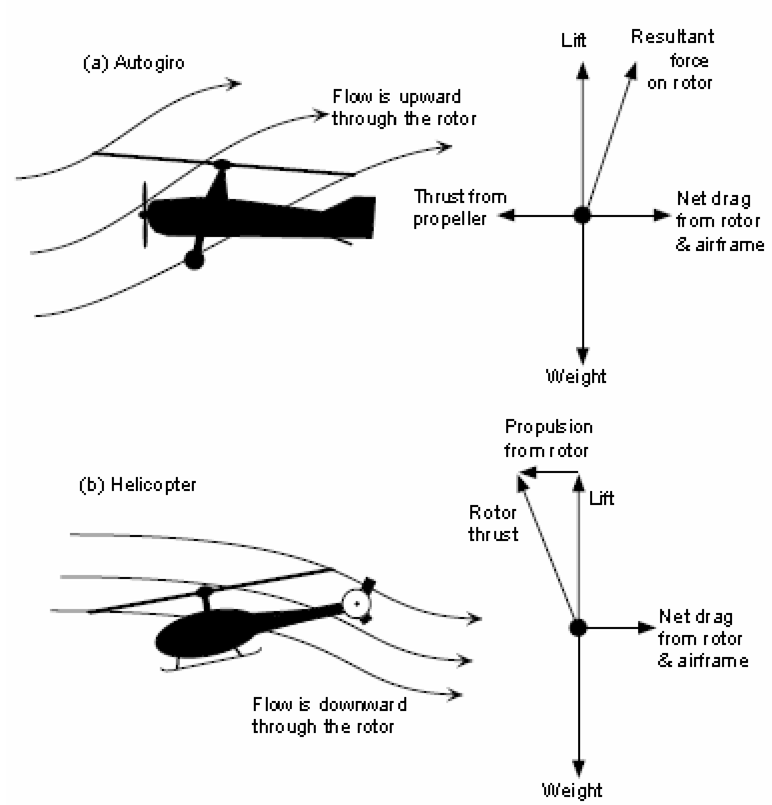

Fig. 1 Flow field of an Autogiro and Helicopter (Ref. 2)

Aerodynamics of Autorotation

Autogiro is operating in state of autorotation i.e. self sustained rotation of rotor without application of any shaft torque. The net torque required is sum of climbing torque and the torque required to counter the induced losses. The value of net torque depends on the working state of the rotor and the results are plotted in Fig. 2. The point where the curve intersects the autorotation line, $v_c + v_i = 0$ is referred to as *ideal autorotation.* It occurs at decent velocities of about 1.75 times the hover velocity. In reality there are non-ideal losses which tend to increase this velocity to 1.8 -1.85 times the hover velocity and state is known as *real autorotation*. These losses are dependent on rotor efficiency which in turn depends on the profile drag of the blades, airfoil section used, blades solidity, etc.

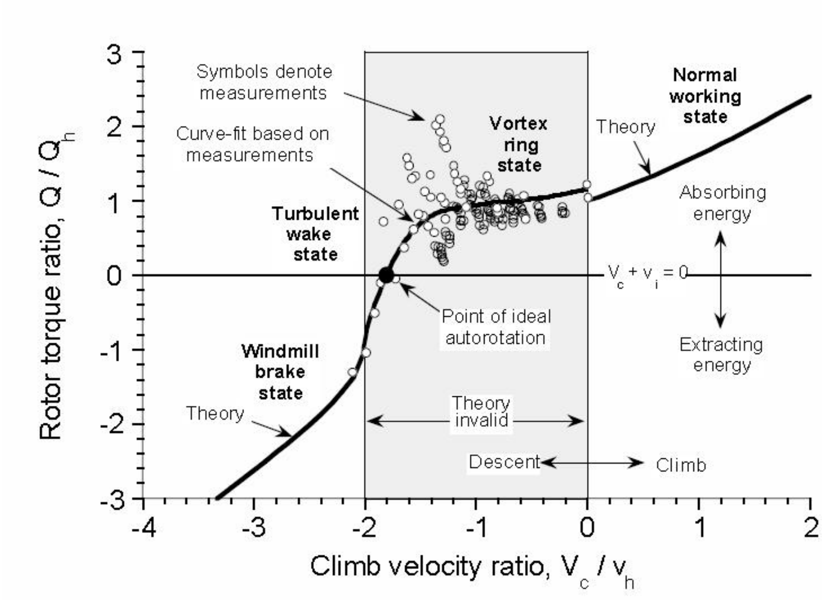

Fig. 2 Universal Torque Curve for rotor in vertical climb or decent (Ref. 2)

For detailed mathematical treatment see Ref. 2 & 3.

Refining the Autogiros

Early flight tests revealed that the autogiro had a tendency to roll toward left (for an anti-clockwise rotating rotor, viewed from above). This is attributed to the fact that rotor in forward flight experiences *asymmetric lift* on its advancing and retreating blades, lift being greater on advancing blade due to higher relative velocity as compared to retreating blade (Fig. 3) and hence producing a net moment to left.

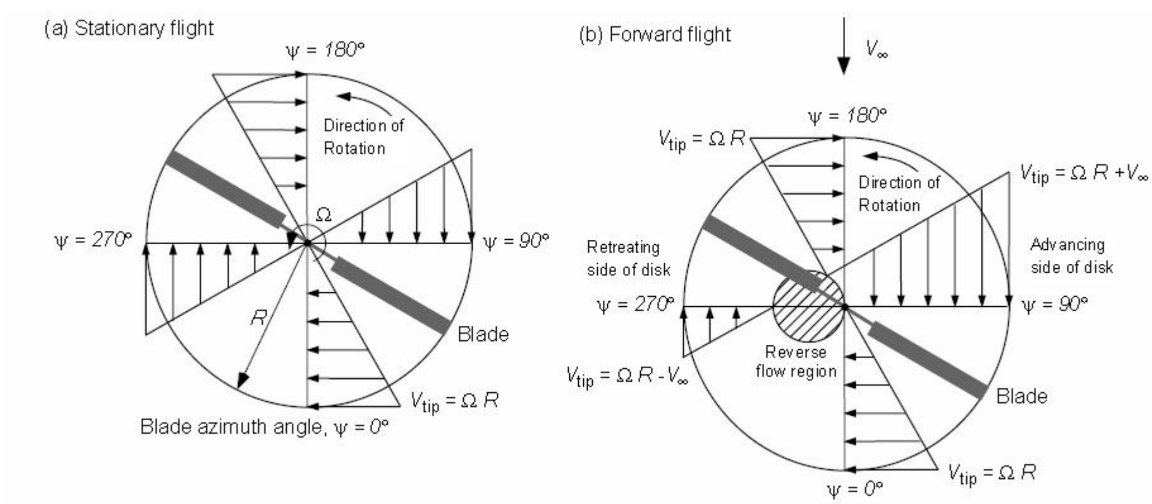

Fig. 3 Dissymmetry of Lift in Forward Flight (Ref. 2)

Cierva spotted this problem and suggested use of counter rotating co-axial rotors that would cancel the asymmetric effect of each other. But this didn't prove much rewarding as the flow became very complex and the aerodynamics of the individual rotors changed which caused new problems of aerodynamic moment balance.
He then decided to use compensating rotor in which the pitch of the blades were so altered as to compensate for asymmetric lift distribution. Although in principle it was a perfect method, but practically proved to be unrealizable due to its complexity and hence discarded.

Taking clue from his wind tunnel tests on small models, which had a slight flexible spar as compared to real full scale machine, which showed different aerodynamic effect, he provided for mechanical hinges in his rotor that would allow the blades to *flap* up and down depending on the equilibrium of the centrifugal, inertial and aerodynamic forces acting on the blade, thus allowing it to move in response to change / asymmetry of lift. This allowed for first stable flight of Cierva Autogiro *C – 4* on January 9, 1923 *(Ref. 1)*.
Having taken care of the out of plane flapping motion, Cierva faced another problem, this time with the in-plane Coriolis force due to large rotational speed of the rotor. This force caused the blade to jerk and finally it caused one of his autogiro blades to *fly off* the hub during landing causing severe damage. He was convinced to add another hinge that would allow for in-plane motion in response to this Coriolis force and hence the lead-lag hinge was added. This further added stability and safety to autogiro *C – 8*.

Choice of airfoil section was also a point of concern. In absence of detailed and systematic airfoil data, Cierva had to do make choice on trial and error basis with some basic requirements in mind. The material of blade construction was basically wood which is not structurally robust in torsion. A cambered airfoil although would have a greater lift to drag ratio and better stall characteristics but a nose down pitching moment would always accompany which had to be borne by the blades. Many blades failed because of this torsion load e.g. *C – 30* and hence a symmetric airfoil was used (Gottingen – 429) *(Ref. 2)*. This was a design compromise and only later on was cambered airfoil used when better construction materials were commercially available and viable.

Up to this point conventional airplane control surfaces were used to directionally control the autogiro. But at the time of landing these surfaces were rendered ineffective due to low speeds at which the autogiros used to land. This would lead to loss of directional control during landing.

This problem was solved by introducing a *directly orientable rotor control* which could change the rotor tip path plane and hence the direction of flight. A *hanging stick* design was used, which had a stick connected to rotor hub that helped the pilot to control both roll and pitch by moving it was used *(Ref. 2)*.

Later *Hafner*, a competitor of Cierva introduced a *Spider blade control* system that could change both the collective and cyclic pitch of the rotor blades. This was more efficient and responsive control as compared to hanging stick design. This paved the way for a fully articulated rotor hub (Fig. 4).

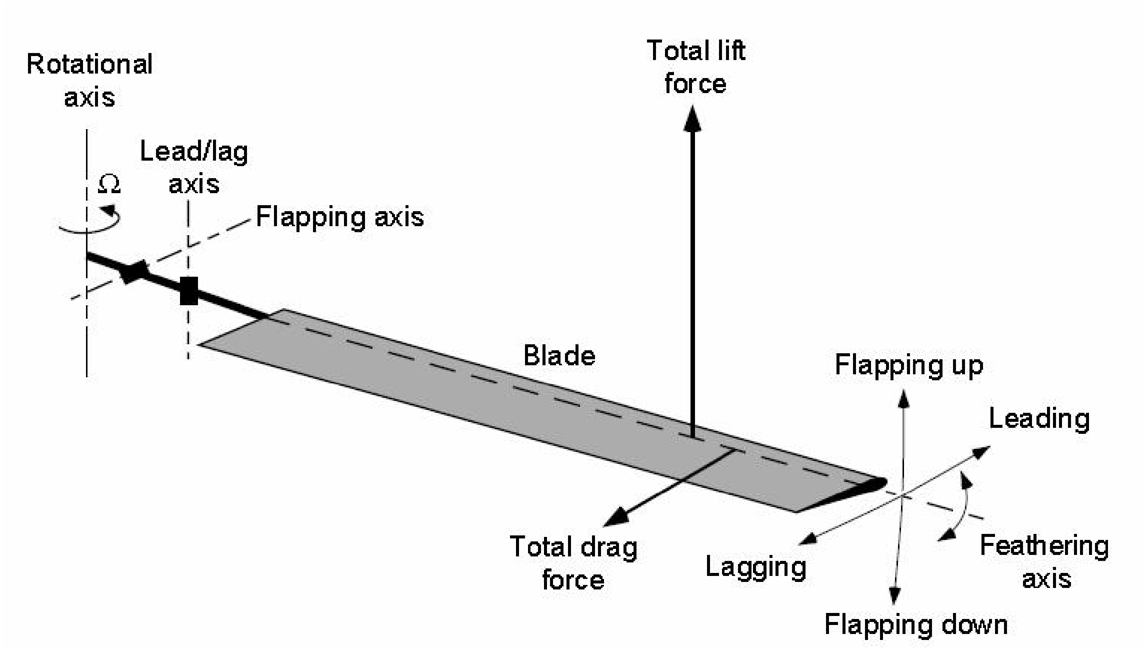

Fig. 4 Basic arrangement of fully articulated rotor hub (Ref. 2)

Vertical take – off capabilities were also lately incorporated in the autogiros by means of some mechanical starters which would *over spin* the rotor when the machine was at ground so that it could generate sufficient speed for take – off without running on ground. Later on this was replaced by a variable pitch system that would simultaneously de-clutch the rotor and increase collective pitch to avoid any torque reaction and lift vertically.

Differences between Autogiros and Other Powered Aircraft (Ref. 4)

When comparing an autogiro to an airplane, an autogiro has two distinct advantages, first the area it needs to take off and land, second is its low speed flight characteristics. Autogiros do not require as much area to take off and land as do airplanes.

The other main advantage autogiros have over airplanes is their ability to fly slow and not stall. In an autogiro, the wings are the rotor and are moving through the air at the speed at which the rotor is spinning, not the speed at which the aircraft is moving. The aircraft does have to be moving forward some to maintain the autorotation, but this is a much lower speed than the speed airplanes must maintain to produce lift. Autogiros have a larger speed envelope, or they are capable of flying in a greater range of speeds than airplanes.

When an autogiro slows to a speed less than that needed to maintain autorotation, lift is not instantly lost. Instead, the rotor just starts slowing down. Since it's still spinning, it's still creating lift. The result of slowing an autogiro down too much is just that the aircraft will descend gently.

There are also several advantages that autogiros have over helicopters, namely simplicity, speed, and weight. A helicopter rotor must be complex to a certain degree. It provides the lift, thrust, and control for the aircraft. It needs a method for cyclic and pitch control. An autogiro also uses the rotor for control, but it does not need collective control. Some of the more complex autogiros have collective control, but it is not a necessity for the smaller autogiros. This reduces the complexity of the system, and by eliminating controls reduces weight. The weight in an autogiro is also reduced because it does not power the rotor in flight. To power the rotor in flight typically requires that it be connected to the engine through drive shafts and gearboxes. These must be strong enough to handle the torque driving the rotor, and add up to a significant weight. An autogiro does not need these systems, so it can be made lighter. Even if the autogiro has these systems for pre-rotating the rotor for a jump takeoff, they do not need to be as robust as those in a helicopter because they will not need to handle the same amount of torque, and also because they are not flight critical, they don't need to be over designed.

An autogiro can also fly faster than a helicopter. This is due to the fact that the rotor is providing only lift, whereas the rotor in a helicopter is providing both lift and thrust. For a rotorcraft to stay balanced, it must produce the same lift on both the advancing and retreating blades.

Autogiros give way to Helicopters

Autogiros, although had a higher speed envelope than airplanes, had a higher drag and so were not as efficient at higher speeds, and absolutely could not attain the maximum speeds of the faster airplanes. Although helicopters had a smaller speed envelope than autogiros, they were capable of hovering, and their envelope could fill the role that airplanes couldn't. In other words, anything an autogiro could do could be done by another aircraft. Also, Cierva, who was doing most of the development of autogiros, was funding much of the development on his own. When the army ordered the VS-316, that money went in to Sikorsky's company. This gave Sikorsky the funding for development that Cierva was running out of. Without the money, Cierva just couldn't fund the research. And then, on December 9, 1936, Cierva was killed in a plane crash (a DC-2 operated by KLM). He was only 41 years old. There were other people developing autogiros, but Cierva had been one of the main driving forces behind the movement. Much was lost when he was killed.

Autogiros after Helicopters

The interest in autogiros was revived in 1950s with several prototypes being built in Britain and USA. They aimed at incorporating the hover capability of the helicopter in gyroplane and overcome the speed limitations of the conventional helicopters. Few companies even started commercial production but lack of general interest forced them to shut down. At this point the most active autogiro market is the homebuilt autogiros. People now fly autogiros as a flying experience or as a hobby. Some scientific study is also in progress so as to improve the capabilities of autogiros.

Two US companies are taking active interest in autogiros namely *Carter Aviation Technologies* and *Groen Brothers Aviation, Inc.*

Carter Aviation Technologies is a research and development company, pioneering new aviation concepts. Their primary focus is the slowed-rotor compound aircraft, a vertical takeoff and landing aircraft that uses the rotor for takeoff and landing, and a small, efficient wing for high speed flight, up to 500 mph, all with much less complexity than a tilt-rotor or other vectored thrust vehicle *(Ref. 5)*.

Groen Brothers Aviation, Inc has developed the first turbine powered autogiro *(Ref. 6)*.

Conclusion

Autogiros were the first successful rotary wing aircraft and first heavier – than – air aircraft to fly successfully other than conventional airplane. Although they are not the main stay in modern aviation but it is unquestionable that the step by step and systematic way in which the designers and engineers approached and solved the problems led to development of both theoretical and technical knowledge in field of rotary wing flight that proved critical to development of Helicopters. The most significant was the development of articulated rotor hub. The success of autogiros paved the way for the helicopters and the modern aim of combining the advantages of autogiros with helicopters, if achieved, would make the modern Gyroplane to meet both military and civilian requirements.

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