

Optimization of Autogyro for Preliminary Development of Personal Flying Vehicle

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ABSTRACT: The paper aims at developing a Personal Flying Vehicle which can replace road transport as the mode of general transport with air transport. A PFV, catering to the demands of the society economically, and reliably, could be used for utility and emergency services in upcoming years. PFV requirements were studied, and comparison of aircraft that comply with these requirements was done followed by their analysis. And the autogyro was found to suit the PFV requirements due to its reasonable payload carrying capacity, easier control, maintenance, and high degree of stability. Its rotors providing both roll and pitch reduce a control mechanism and being single-piston-engine powered, it requires no more maintenance than an ordinary car. An autogyro design is inherently stable. The rotors generate lift by autorotation, enabling autogyro to glide instead of crash on loss of power, thus becoming an advantage for PFV. The problems of modern day autogyro such as C.G balancing, PIO & compact structure were identified and solutions have been devised through research, and pilots' experiences. Computational fluid dynamics simulations provided results for the flow over PFV fuselage whose drag characteristics affect power requirements and ultimately weight. And the design with an optimized volume with the least addition in drag was the desired configuration. Suggestions for increasing stability are also made. This configuration lays the foundation of development of a fully-functional PFV, expected to cover multidisciplinary fields like agriculture, recreation, private transport, and emergency services. This PFV, essentially a road-able aircraft rather than a flying car can also be readily used as a road vehicle when needed, with certain modifications and rotor folding mechanisms. The structural, rotor dynamics and powerplant details would be analyzed in future for advancement in concept of PFV.

KEYWORDS: Personal Flying Vehicle (PFV), CFD, Preliminary Study, road-able aircraft.

I. INTRODUCTION

With the increasing traffic volume, the average time spent travelling on roads has significantly increased for the same distance travelled. Due to this, the doorstep-to doorstep average speed of cars, is predicted to degrade phenomenally in the coming years. As per a recent report, burning one litre fuel leads to 2.5 kg of carbon dioxide emissions (2.3kg for petrol and 2.5kg for diesel). Based on these numbers, it is estimated that fuel worth \$8 million USD is wasted every year due to snarls at Delhi Toll Plaza [1]. But this could be declined by opting for the air transport in a modified form. And thus, this paper is directed towards developing a futuristic personal flying vehicle by aerodynamic and volumetric optimization in an autogyro. The study shows how augmented stability of modern day autogyro, with certain modifications can make it suitable for use on a large scale as a PFV. This PFV can be safe, economical and fuel efficient as it will be based on autorotation mechanism. This would fulfill the tasks that only air transport can, maintaining the safety at par with the road transport. We know that, the controlled airspace starts at 2,000ft, so there is a bit of unrestricted airspace below, which can only be used by pilots currently. But the idea is to make flying as easy as driving a car. Although autogyros have reached upto 20,000 MSL, our PFV would be designed to operate at cruising altitude of 1500 MSL – 2000 MSL [2]. But our proposed design wouldn't completely fit with all the aviation authorities' laws and regulations in various countries like US, UK, Australia. This is mainly due to the fact that our objectives behind the PFV design set it apart from Ultralight and Light Sport Aircraft (LSA) type rated aircraft

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category (currently law registers autogyros only under these categories) on the basis of the requirements like weight and the number of passengers [3].

The concept, after studying and comparing various possible approaches and systems like airplane, helicopters and autogyros, was to optimize the design and stability of an autogyro enabling it to be used as a PFV.

The first Cierva autogyro is a windmill of low pitch whose plane is inclined at a small angle to the relative wind; this windmill takes the place of the wing system of an ordinary aeroplane. The windmill rotates on a ball bearing, and each blade is hinged on a ball bearing, whose axis lies in the plane of rotation so that the blades are free to flap in a direction normal to this plane. In flight the windmill rotates freely under the influence of the relative wind caused by the forward or downward motion of the machine, while the blades are prevented from departing far from the plane of rotation by centrifugal force, but execute a slight flapping oscillation relative to the plane of rotation under the influence of the unsymmetrical aerodynamic forces [4]. The Figure 1 below shows Cierva autogyro



Fig. 1 Cierva C.4 Autogyro

The modern day autogyros comply with the needs of a PFV, but still face problems like Power Pushover (PPO), Pilot Induced Oscillation (PIO), etc. These have been discussed and possible solutions have been suggested based on pilots' experiences and research. After some critical design considerations such as articulated rotors, gyro having wings, conventional design, four designs, have been analyzed. The most economic, safe, and pilot-friendly configuration is tested for the drag and flow properties using Ansys Workbench. This can play the role envisioned, effectively with more considerations into the powerplant, propulsion and structures in further research.

I.I. Applications of a PFV:

Multidisciplinary fields like the following can be covered by a PFV:

- Agriculture
- Recreation
- Private transport
- Military operations
- Emergency and Utility services
- Roadable aircraft
- Disaster relief management

Over 1,000 autogyros worldwide are used by authorities for military and law enforcement [5]. In the US the police authorities are using these. Also, in Iraq autogyros are highly being preferred for airport security to prevent terroristic encroachments [6][7]. Tomball, Texas police in USA has evaluated autogyros for operations under crosswinds as large as 40 knots [8]. They are also being used to monitor and control approach and takeoff paths. This development and growing usage can extend to emergency and utility services as well. By increasing the payload capacity, we can make

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PFV suitable as a means of private transport & recreational activities for families and for agricultural activities over large tracts of agricultural lands.

It requires adequate payload carrying capacity both in weight and volume, ease in control and maintenance, and high degree of stability, for a PFV to be effectively operational in the expected fields.

II. BACKGROUND STUDY

Many of the technical problems associated with rotary wing flight had been discovered and rectified by the early autogyro pioneers most notably Juan de la Cierva's solution of installing flap hinges to accommodate non-symmetric lift from the rotor blades [9].

But limitations in the design and public understanding of the autogyro concept resulted in the loss of interest from industry and the autogyro became simply an interesting concept. However, with changes in the global focus on sustainability, the autogyro concept has been revived [10].

In this context, many reports and investigations have been made about what the autogyro was, its history, how it flew and how it compared to other conventional aircraft such as helicopters and airplanes. The literature is not sparse of the mention and tests about autogyro stability and performance. Examination of the literature shows a logical development of the study of autogyros, from the elementary theory of autogyro flight to the analysis of aerodynamics and performance and ultimately rotor behavior but only for steady flight. Further development also accounted for estimates in longitudinal stability and control derivatives for an autogyro [11].

From data on recreational flying activity in Australia, collected by the BITRE (Bureau of Infrastructure, Transport, and Regional Economics) for the 2004 to 2011 period it was found that the fatal accident rate for gyrocopters was significantly higher than for all other aircraft and operation type combinations in air transport and general aviation [12]. Gyrocopter Accidents in Australia). High autogyro accident rates prompted experimental investigation of this type of aircraft's low - speed pitch characteristics thus enabling low - speed pitch control by intentionally placing elevators in the propeller wake [13]. This corresponds to the conclusion that tail plane as a whole in the propeller wake region enables even low-speed pitch control for an autogyro. Similarly, the concept of thrust line, lift line, vertical stabilizer use and advantages/disadvantages of puller and pusher configuration have also been thoroughly discussed.

Early study results indicate that it is quite feasible to have on the order of 100,000 PAVs (Personal Air Vehicles) operating within the 100 radius of a major city, without chaos or air to air collisions[14].

There are regulations restricting the use of autogyros in metropolitan cities because of their unreliability in the current stage of re-development. As per the latest development in the laws, the CAA has given the permission in miscellaneous order number 1054 published on 31st October, 2014 for type approved gyroplane to be flown over 'any assembly of persons or any congested area of a city, town or settlement' [15]. The CAA issues type approval to autogyros under CAP643 Section T [16]. FAA issues Special Airworthiness Certificate to Amateur and Kit-built autogyros which fall under the Experimental Light Sport Aircrafts category. Other qualified autogyros that fall under the Ultralight category are issued Standard Airworthiness Certificate [17]. Laws under CAA (UK) are less stringent as compared to those under FAA (USA). This is because the development of autogyros has almost ceased after 1940s and the current accident rates are high. But the merits of autogyros have brought about their considerations and research again. So, in this paper a novel design has been proposed in which the position of tail boom with respect to thrust line and shape of fuselage have been radically changed in an effort to increase stability. With more experimentations and research in these, PFVs can become reliable and acceptable under the Aviation Authority Laws and Regulations.

This paves way for a new era of aviation technology, by introducing Personal Flying Vehicles. Most of the requirements are being fulfilled by the autogyros, and with elimination of certain risks and enabling VTOL capabilities, we shall have flying-made-easy. As these new planes will be able to take off and land in much smaller spaces, getting a pilot's license could become the new rite-of-passage to adulthood in the 21st Century [19].

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III. METHODOLOGY

Exemplar based Inpainting technique is used for inpainting of text regions, which takes structure synthesis and texturesynthesis together. The inpainting is done in such a manner, that it fills the damagedregion or holes in an image, with surrounding colour and texture. The algorithm isbased on patch based filling procedure. First find target region using mask image and then find boundary of target region. For all the boundary points it defined patch andfind the priority of these patches. It starts filling the target region from the highestpriority patch by finding the best match patch. Thisprocedure is repeated until entire target region is inpainted.

The methodology involved, first assessing the need of a PFV in present scenario keeping in mind the future prospects and the requirements it should meet. A comparative thorough study of a helicopter, a plane and autogyro model was made. After assessing the benefits and liabilities of each one of them, the autogyro model was chosen.

While assessing the features especially size and commonly faced problems, now-a-days autogyros were found out to be non-capable of meeting the requirements of a PFV, considering safety prime objective. A study conducted in autogyros underlined many problems like mast bumping, PPOs, PIOs, and ground resonance which are needed to be resolved before autogyros could be utilized as PFVs. The change in the fuselage-tail design w.r.t. the propeller which is different from conventional autogyros, positioning of C.G. w.r.t. thrust line and lift line, and a mechanism of shifting of C.G. to counter movement of lift line were implied.

Different designs were tried for the autogyro and a preliminary CFD analysis was conducted on them.

III.I. Comparative Study of Characteristics Of Airplane, Helicopter, And Autogyro

Various aspects considered were based on the requirements and utilities needed from PFV. These included many characteristics like safety, reliability, ease of flying, run up for takeoff, maintenance, economic feasibility, simplicity in different mechanisms, convertibility to and from road vehicle, ease of handling, fuel consumption, low speed characteristics, etc.

This table 1 shows comparing a helicopter, plane and autogyro. After comparison, it was found that the structure of an autogyro with variable arrangement and positioning of rotors and propellers can make it feasible to be reassembled easily. This reassembly can also make it a transport on roads without much change in the mechanism. Such transformations are not possible with the helicopters and fixed-wing aircrafts. As compared to airplanes and helicopters individually, it has advantages over both airplanes and helicopters.

Table1. Comparison of helicopter, plane and autogyrocharacteristics [20]

Characteristics	Helicopter	Airplane	Autogyro
Stability	Poor	Good	Good, even at low speeds
VTOL	Engine powered main rotor	Possible, with limitations	Tip-jets or pre-rotators used
Hovering	Possible	Not possible	Slow flight speed of about 5 m/s are close to hovering.
Stall speed	Stalls. And can crash if mishandled	It can stall.	None. Fully controllable to zero airspeed
Maneuvering	Complex	Simple	Simple

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Over airplane, the autogyro have two distinct advantages:

- Runway required is less. Also pre-rotors or ramjets on rotor tips can enable VTOL.
- Excellent low-speed flying characteristics as shown in Figure 3 below, which shows power curve for a typical autogyro. The line of the **available power** (continuous line) and the line of the **required power** (dashed line) are shown. This is because the rotors provide lift as they still spins when flight is at low speed. The distance between upper and lower curves represents excess power. With increase in flight speed, the excess power increases, reaches a maximum, and then decreases, and so does the rate of climb which is directly proportional to it [21]. Autogyros can fly at speeds at 15 mph. this makes it near hovering. So it is ideal for general public use as low speed is desirable.

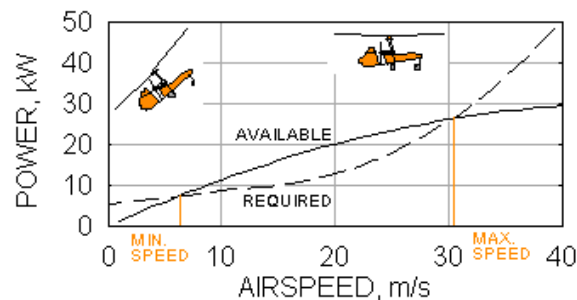


Fig. 3 Power vs. airspeed curve for autogyro

Over a helicopter, autogyros are advantageous as:

- For same power, they can fly faster than a helicopter. This is because helicopter engine powers rotors, which give lift as well as thrust but autogyro engine only powers propellers which gives thrust and lift is provided by unpowered rotors. For a rotorcraft to stay balanced, it must produce same lift on both the advancing and retreating blades. Therefore an angle must be maintained. Since helicopter has to generate more force with rotors, thus autogyro is faster.
- Simple in complexity and components and therefore, low weight.
- The autogyro doesn't witness problems like blade stall and vortex ring so it's inherently stable than a helicopter as shown in Figure 4.

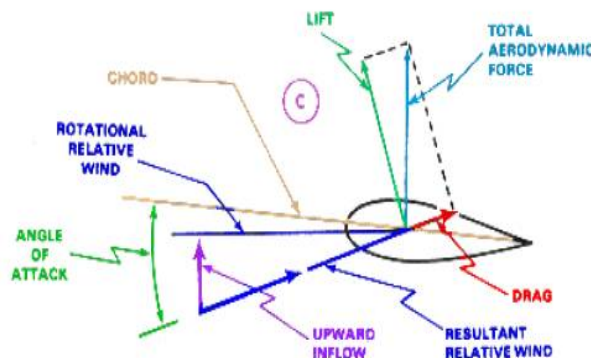


Fig. 4 Aerodynamic forces on the auto rotating blade during steady state descent

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- Collective pitch control is not necessary. Thus lower weight.

Shown in Figure 5 is the lift curve for an autogyro. With an increase angle of attack, the coefficient of lift also rises.

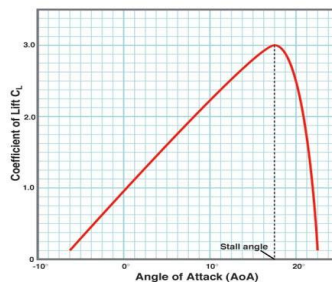


Fig. 5 C_L vs α curve

But once the critical angle of attack has been passed through, the coefficient of lift begins to decline significantly. It does not stall, it glides!

So, an autogyro is desirable as:-

- Its rotors can produce lift in case of engine failure and cannot suffer from *vortex ring state* due to which majority of rotorcrafts crash, so it's safe [22].
- Autogyros consume majority of fuel only during takeoff which can be further reduced by using tip jets.
- Majority of costs for any flying vehicle is in its maintenance, autogyro being only a single piston engine powered machine requires no more maintenance than an ordinary car.
- Flight control components are not complex, the autogyro is easily maneuverable.
- The reduced weight makes it a desirable flying substitute to helicopters and airplanes. It gives much scope to the cargo.

Table 2 gives a comparison of some of the important specifications of both the RAF 2000 and the Robinson R22, where, Robinson R22 is one the world's most popular entry level helicopters and RAF 2000 is one of the top of the line Autogyro's around.



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Table 2. Robinson 2006 and RAF 2005 comparison

Properties	RAF 2000	Robinson R22
Gross Weight	1540 lbs	1370 lbs
Power Plant	Subaru EJ25 165 HP	Lycoming O-360 131 HP
Avg. Fuel Consumption	6.5 Gallons per hour	8-10 Gallons per hour
Minimum Speed	10-12 MPH	N/A
Cruise Speed	90 MPH	110 MPH
Maximum Speed	140 MPH	118 MPH
Rate of Climb	1750 ft per minute	1000 ft per minute
Maximum Operating Height	14000 ft	14000 ft
Cost	\$31,500 SD	\$209,800 USD

III.II. Problems With Modern Day Autogyro [23]

The major problems with the present day autogyros are the reason why they can't be accepted readily as a PFV. The following are some possible ones:

Inability to hover:

One major disadvantage of an Autogyro and one major advantage that a Helicopter has over an Autogyro is the ability to hover. In order for autorotation to take place and thus in order for lift to be continued, it is absolutely necessary that the Autogyro have some forward motion. Should this forward motion cease, its descent will then begin.

Pilot Induced Oscillations (PIO):

This happens when the pilot tries to adjust the pitch too much too quickly. The pilot will then try to counter the input to bring the pitch back, but what usually happens is that the countering input is overcompensated and the Autogyro begins to jump, similar in effect in the way a leaner driver may bring their car to perform 'Kangaroo-hops'. Should the pilot continue to overcompensate in its input and 'fight' the Autogyro, the rotor is in real danger of slowing down and slumping down to strike the propeller, which in effect destroys both the rotor and propeller and sends the aircraft into a dangerous fall. This happens because of *Pitch Instability*. Negative G forces cause the Autogyro to lose rotor control authority and the flying Autogyro appears to hang from its rotor like an object is hung from a string.

Power-Push over (PPO):

The vertical speed of an Autogyro is directly coupled with its airspeed, if the forward airspeed is increased, then so is the rate of climb. At the high engine throttle settings, if the pilot wants to maintain a level flight, the rotor is then required to be tilted forward thus bringing the rotor in a near horizontal plane. With the rotor in this position, the sensitivity of the control stick becomes a lot greater. Too much forward stick causes the rotor to be aimed toward the ground, when this takes place, negative G's are introduced. The rotor speed is greatly reduced and the rotor is no longer able to provide any lift. The Autogyro is then pitched forward by the propeller thrust and then enters into a somersault. Once in this state, it is very difficult for the pilot to regain total control of the aircraft.

It is for this very reason that the avoidance of PIO and PPOs makes up a large majority of Autogyro pilot training.

Ground Resonance:

This is caused by an interaction of the rotor and the undercarriage. If the rotor is brought out of balance (for instance, because the blades are not properly aligned), and if the undercarriage's natural frequency is close enough to the rotor frequency, the undercarriage will amplify the periodic rotor movement and also aggregate the unbalance of the rotor. Figure 6 shows the condition of ground resonance.

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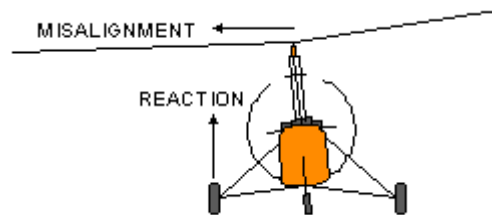


Fig. 6 Ground Resonance

Mast bumping:

If the blade movements are too large, the blades will hit the stops. This is mast bumping. It is also called blade flapping. Normally, the blades are held outward by the centrifugal force acting upon them. They are also held back by the load acting upon the rotor. It is therefore that mast bumping occurs at low rotor speeds and/or unloaded rotor situation (zero-G or negative G maneuvers).

III.III. DESIGN CONSIDERATIONS

Some design parameters have been considered for the designing of PFV for further analysis. These include the shape, Centre of Gravity (C.G) position, dynamics of rotors and powerplant type (pusher or puller). This is done so that the some of the problems listed above can be neutralized or avoided inflight, and also performance and stability could be enhanced within a design of optimized volume. Also few pilot controls and training can offer an aide to the designing amendments and autogyro performance.

Considering conventional and modern day problems along with safety, following observations and conclusions were drawn for further design determination:

Observations:

1. The autogyros cannot hover but simulate hovering by flying at very low speeds. Hovering can also be accomplished when value of head wind is around 15 mph, which can keep the rotor rotating overcoming rotor drag. So the requirement of hovering in an aircraft can be met suitably with a lighter and less complex PFV, with proper controls. There is no license but only training required.
2. Avoiding flight at zero-G and reducing power in situation of PPO, can help deal with it, and also avert mast bumping. Additionally, position of the C.G affects the PPO chances.
3. For dealing with mast bumping, the rotor should be loaded and spinning during the flight, or disc loading should be high enough. If the blades are given enough room for their normal movements, influence of cross winds in unloaded condition becomes less.
4. For avoiding PIO, the fuselage and tail combination should be just stable for banking. Mounting the tail planes in the propeller slipstream, makes them more effective, and sudden movements do not cause much PIO problem. This enables low-speed pitch control for an autogyro.

Conclusions:

- a) Position of C.G:

The design of this PFV which can sustain the aerodynamics of an airplane fuselage, and also benefits with rotary advantages depends primarily on the C.G. The important parameter for stability is the position of C.G. of the PFV. For

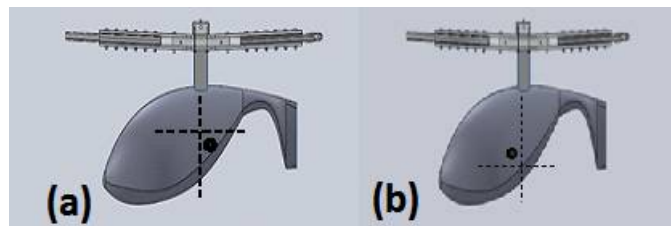
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PFV to be stable, 2 configurations are found suitable and these are explained as follows using side view of 3-D model in figure 7:



(a) C.G. behind Rotor lift line and below propeller thrust line

(b) C.G. in front of lift line and above the thrust line

Fig. 7 Configuration comparison for location of C.G.

After taking into account a suitable seating arrangement and positioning of various components and power plant, configuration in Figure 7 (b) was selected. In this configuration as C.G. is in front of lift line so it will have a nose down tendency. Similarly due to positioning of C.G. above thrust line it has an opposite nose up tendency. Thus, the moments due to thrust line and lift line cancel each other.

If the CG is behind the thrust line of the rotor, the pitching moment induced by the rotor is positive (nose up). An increase of the thrust line will increase the moment. The rotor thrust is, at first order, perpendicular to the tip path plane, and then an increase of the flapping angle will rock the thrust behind. This will increase the cross arm of the moment and then will also increase the moment. Therefore, the derivative of the moment relative to the angle of attack is positive. This is an unstable condition.

Now if CG is in front of the thrust line of the rotor. This time the rotor induces a negative pitching moment (nose down). When a gust increases the angle of attack the rotor reacts the same way as before. We have an increase of the thrust and the flapping angle. An increase of thrust will increase the absolute value of the moment (more nose down moment). As the moment is negative, this will lower the moment. The flapping angle will reduce the cross arm and then decrease the absolute value of the moment. This time, the two phenomena don't act in the same way but it can be demonstrated that it is the variation of thrust which is most important. So we are in stable condition [24].

Also, the problems of Power Pushover can be dealt with by keeping the C.G. above thrust line. Thus, this configuration solves the problem of stability and PPO.

A mechanism of transfer of fuel from one pump to another can be installed with booster pump to relocate fuel between differently located fuel tanks to maintain C.G. in second quadrant. It is necessary because during different prevailing wind conditions pilot may have to permanently set the angle of the plane of rotation of rotors by column stick. So, to balance the moment generated due to thrust line, relocating of fuel becomes necessary.

b) Unarticulated Flexible/ Articulated Rotors:

To counter de-symmetry of lift caused by difference in relative velocity of air speed over forward moving and backward moving blade, flexible unarticulated blades would be used as articulated blades require special training of individuals and would defeat the sole purpose of designing an easy to fly PFV.

c) 3-way clutch:

For VTOL, an autogyro requires tip jets and pre-rotators. The pre-rotators are mechanical means of spinning the rotors. The aircraft is taxied with the rotor disc tilted aft, allowing airflow through the system to accelerate it to flight r.p.m. Many pre-rotators are capable of only achieving a portion of the speed necessary for flight; the remainder is gained by taxiing or during the takeoff roll [25]. These can be made functional by using a 3-way clutch mechanism. This can deliver the power from the engine to the propellers, the rotors, and the wheels when required.

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When needed, this autogyro can also be used as roadable vehicle. For this purpose, the rotors need to be folded for packing them in along the shape of the autogyro. Thus it can be driven on the roads like an ordinary car. With this feature, it becomes a roadable autogyro. A 3-way clutch can help in motoring the vehicle on roads and also in folding in and folding out the rotors.

d) Pusher/Puller Configuration:

As an autogyro is a very light machine, so even placement of payloads like pilot or co-pilot have huge impact over the position of C.G. So to balance the weight of passengers which are kept in front portion of fuselage for better visibility, engine should be kept behind the lift line (lift line is behind passengers) in an effort to bring C.G. closer to lift line. Thus, a pusher configuration is advantageous in many ways as discussed below.

- On later stages, autogyro if used as air taxi or as an emergency ambulance or for agriculture could host various types of instruments in its nose like radar, UV cameras, and pesticides for spraying, etc.
- It also helps to minimize the danger to the passengers and other payloads.
- No slipstreams are formed so there is less skin friction effect over the fuselage as the turbulence if produced would only be after the propeller and not over fuselage or other lift producing surfaces like wings if used.
- No Prop-wash over any section of lifting surfaces like wing would reduce their form drag.
- Form Drag of fuselage is reduced as flow is attached to the fuselage and there is no flow separation.
- Surface area of the rudder could be kept less as velocity across vertical stabilizer would be high so small deflection would give the desired yaw [26].
- Weathercock effect would be reduced. Since in case of a pusher configuration, the airflow over the vertical stabilizer is increased, and so the effective area causes the moment to increase and give directional stability to the autogyro [27].
- Any fire in any system of aircraft will be directed backwards so it will increase safety of passengers.
- Leaks of fuel, oil or coolant from engine will be thrown away from aircraft so it will also help to curb or reduce fire.

e) Nose cone:

To obtain low drag of fuselage a straight forward method of taking 2/3rd of tabulated low drag airfoil ordinates was used. It has been shown that parabolic elongated bodies of revolution have less drag than an elliptic body of revolution [28]. Our nose cone of PFV has been designed on the same and such fuselage fore body shapes will favor laminar flow by creating favorable negative pressure gradients. So pointed shaped bodies with hyperbolic or parabolic noses may give less drag than rounded or elliptic-nosed shapes.

f) Tail plane:

The rotors of an autogyro can provide both roll and pitch movements. Thus, the need of a horizontal stabilizer in the tail plane can be eliminated. This in addition to lesser control mechanism also reduces the empty weight of the PFV. Also in our proposed design the advantage of structure joining the fuselage and vertical tail i.e. tail boom (unlike that in conventional design) is to prevent the slip stream effects of propeller reaching the rotor when rotor is at high pitch. To compensate for increase in negative lift of modified fuselage design (as was obtained during CFD analysis) the upper surface of structure joining fuselage and vertical tail can be modeled to give it camber so as to produce some lift. Alternatively that structure can be modeled to provide longitudinal stability up to some extent.

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g) Rotors:

It has been found out that a reduction in parasitic drag leads to higher cruising speed, higher endurance, and in general higher efficiency for an autogyro. Thus, in any case more than two blades seem to reduce parasitic drag which is favorable in order to maintain flight comfort [29].

h) Wing design:

A design of a PFV with wings can also be considered. Wherein, both the rotors and the wing surface will generate lift, thereby, increasing the efficiency. Wings can also improve the glide ratio. In case where, the autogyro is to be convertible into a car running on city roads, the wings can also be folded. For this case, Shape Memory Alloys can be used as the construction material for wings.

This design was however rejected due to increase in complexity due to inclusion of wing folding mechanism to keep the wing inside fuselage while on road. This concept will also decrease the space available inside the fuselage and may result increase in dimensions which will ultimately result in increased drag, increased power required, better engine specifications and hence more weight so, increasing the cost and driving this design towards economic unfeasibility.

III.IV. Designs

The designs that have been developed after considering the parameters discussed above are:

1. Puller configuration PFV:
2. Pusher configuration PFV:
 - i. Pusher configuration with wing design.
 - ii. Pusher configuration with tail connected to fuselage from below the propeller (Conventional Design).
 - iii. Pusher configuration with tail connected to fuselage from above the propeller.

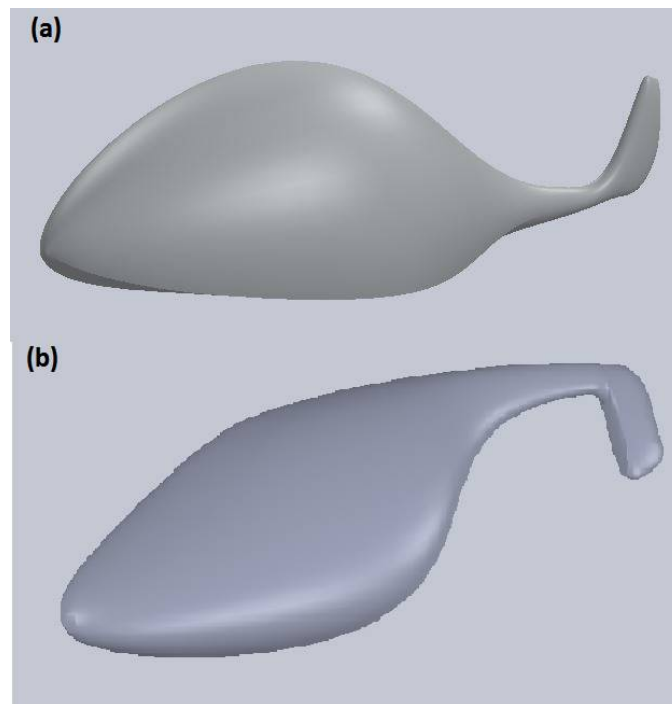
Again based on the discussion in section 3.3 and results of analysis obtained in section 4 configuration 2.(iii) was chosen as final (proposed) design. CAD models of both the conventional and proposed design as shown in figure 8 were made.

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(a) Conventional design (b) Proposed design

Fig. 8 Comparison of conventional design and proposed design

IV. RESULT AND DISSCUSSION

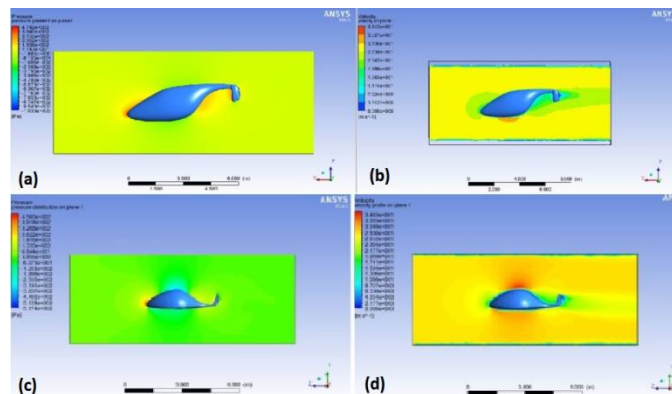
3-D model of design devised on the basis of C.G and performance calculations was made using Catia V5 and was analyzed under Computational Fluid Dynamics simulations using *Fluent* as shown in Figure 9. The boundary conditions for preliminary analyses were steady state analysis, fluid was air at 25⁰C, and Reference Pressure of 1atm, Domain motion was taken as stationary, turbulence model was taken as K-Epsilon. Turbulence at inlet was taken at 5% of velocity. Outlet was at static pressure at relative pressure of 0 Pa. Turbulence numeric was taken as high resolution. Residual type was RMS with target of 1e-4. Figure 9 shows the pressure and velocity distribution on the proposed and the conventional design at a velocity of 30 m/s.

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(a) Pressure Distribution over the Proposed Autogyro Design (b) Velocity Distribution over the Proposed Autogyro Design (c) Pressure Distribution over conventional Autogyro Design (d) Velocity Distribution over conventional Autogyro Design

Fig. 9 Pressure and velocity distribution over the Proposed and conventional Autogyro Design

After analyzing the conventional design and our modified design as shown in figure 9 for speeds from 1m/s to 30m/s it was found that our modified design adds only 7.4 N drag at 30m/s as shown in Fig 10, but this small increase in drag is outweighed by increased stability, reduced possibility of PIO's and PPO's and most importantly increase in usable volume and ability to accommodate 4 persons as shown in Fig. 12 in which pilot sits in front, behind it 2 passengers sit in side-by-side configuration and one person at back; instead of 2 as in conventional design. Also, as is visible from figure 9 our proposed design does not affect the velocity above the fuselage which would be beneficial for rotor aerodynamics where as conventional fuselage designs had a very high velocity as compared to the surroundings just above its upper surface.

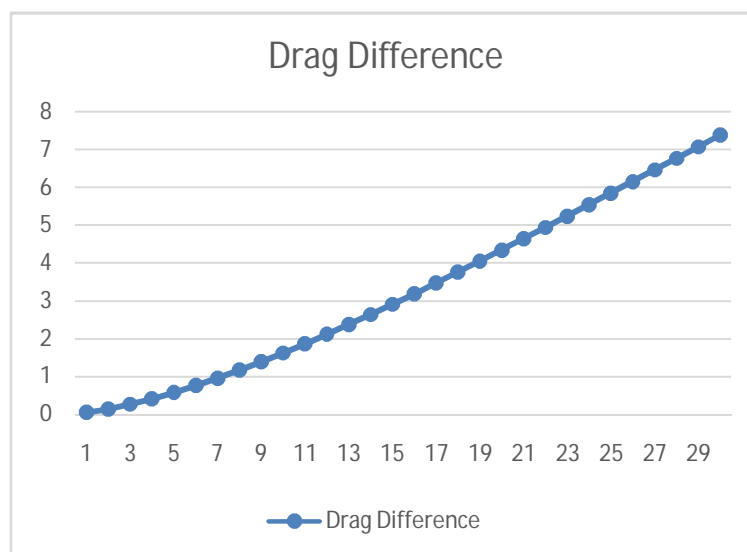


Fig. 10 Drag difference of both designs Vs Velocity

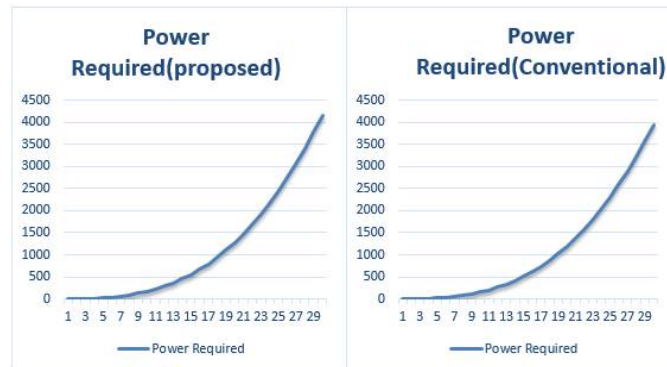
After the CFD analysis results obtained, the graphs, as shown in figure 11 are plotted between the Power required and Velocity for the conventional and the proposed design.

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a) Power Required Vs. Velocity for Proposed Design b) Power Required Vs. Velocity for Conventional Design
Fig. 11 Power Required Vs. Velocity Curve

This plot is very important in identifying the flight performance of any aircraft. As can be observed, there is difference of only 221.73 W in the power required for the two designs. So we can conclude that this proposed design, with very less additional power requirement than the conventional design is best suited because of its advantages as discussed above.

Now Table 3 below, shows the approximate weight of some of the major components of the PFV

Table 3. Mass of some of the Major Components

Mass of Major Components	
Components	Mass
Powerplant	56.7 Kg
1 Person	75 Kg (approx.)
Fuel	67.62 Kg (approx.) (density=690Kg/m ³) (volume=0.0984m ³)
Cargo	10 Kg (approx.)
Avionics bay and Cockpit	15 Kg (approx.)

Considering the solutions given to the problem and weight of major components, figure 14 shows the cutout section of design obtained where center seat is a side-by-side seat for 2 persons so that the design accommodates 4 persons.

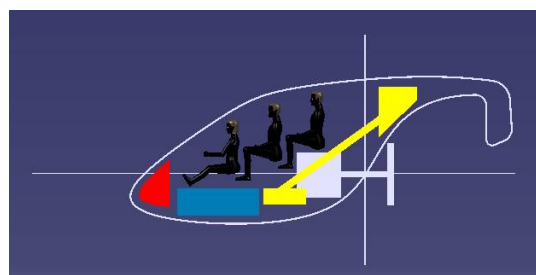


Fig.12Cutout Section of volume optimized proposed design with major components highlighted.

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In the above figure 12, different colors means the following

Red – Avionics bay, radome and backside of cockpit

Blue – Cargo bay

Yellow – Fuel tanks with booster pumps between them to control location of C.G. w.r.t. Lift line during various flying conditions.

Grey – Powerplant

The research is to aide beginning of a new era of aviation technology. The need of a personal flying vehicle is expanding boundlessly due to increasing population; traffic on roads; expenses of commercial flights; emergency in medical society in remote areas; disaster management and easy evacuation; necessity to protect the wildlife and vegetation in efficient ways. Along with all the requirements a PFV will emerge with giving a reality to the ancient fascinations of mankind and serve recreational purposes. This can be an economic side of transport. The research and amendments in design and stability of autogyros brought us a step closer to realizing the dream of PFV. This is a preliminary paper work. With further improvements in propulsion and structures there is wide scope for turning it into a fully functional element of air transport.

As by 2030 individually preferred means of transport will shift from road transport to air transport even for short distance travels (2014 Thomson Reuters), PFV can certainly adapt to this role.

V. CONCLUSION

So, it can be concluded from the results of CFD analysis on the proposed and conventional designs that the fuselage design proposed in the paper is aerodynamically improved. It can be inferred from the results that this design has an optimized volume with negligible increase in drag and 5.54% increase in power required as compared to the conventional design. The stability characteristics have also been postulated to improve by applying the concept of C.G positioning with respect to lift line and thrust line. The positioning of tail boom and its shape will also help in avoiding the wake of propellers from affecting the rotors during high pitch and also in longitudinal stability. In addition to this, suggestions for dealing with current problems with autogyro have also been mentioned.

So, through this research, we have tried to introduce the idea of a PFV which would be inevitably important in future as the cars are today. This idea would be further strengthened by follow up research on stability, propulsion and structural study of the design.

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