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Design Challenges in VTOL Aircraft - A Review

Rekha R, Shahid khan
Student, Acharya institute of technology
VTU University, Bangalore, karnataka -560107, India

Abstract:-

- ***Objective***

To provide comprehensive literature survey on design challenge faced in VTOL.

- ***Statistical Analysis***

For more convenient understanding the various design challenge faced in VTOL is in table format. The table shows the different techniques at different condition to overcome the design challenge fixed in VTOL, finding most studies to overcome this design challenge are swarm optimization in computation techniques, novel hovering is the control strategy applied to PID controller, hybrid automation, Inertial measurement unit(IMU) transition modes in both front transition and back transition.

- ***Application/Importance***

This paper describes the various control strategy and overcome the design challenges and design more efficient VTOL in different conditions.

Keywords:- *VTOL (Vertical takeoff and landing), transition mode, hybrid automation, swarm optimization, novel hovering.*

I. INTRODUCTION

The Design of VTOL is based on the mission profile, size, stability of the aircraft on flight, and also which type of design we are choosing whether it is tilt rotor design, fixed wing design, tilt wing etc. The designing of the VTOL involves mainly the complete design of the model, conceptual design and also based on preliminary design, these are the design considerations while designing any model. Every design model is based on aerodynamics, structural control, stability, electronics, propulsion and also fabrication of the model. Weight estimation plays a major role while designing the aircraft (VTOL) and also sizing of the aircraft is very important to design any aircraft, first it starts with the choosing of wing planform along with the aspect ratio of wing and then comes to the aspect ratio of fuselage and design of fuselage This aspect ratio of wing and shape of wing is determined based on the type of mission.

Once the design is done based on all those parameters mentioned above Analysis of the structure is very important to determine the flow analysis along with the structural analysis of the aircraft. In design of UAV'S, sizing of the UAV and cost of the UAV'S are the major part where the size should be performed as accurately and cost should be minimum .As all the airplane characteristics have to be retained in a small volume there are lot of challenges and complexity in designing the model and also in fabricating the model, Low Reynolds's number which is the result of their small size and also the low speed is the major problem in constructing the model.

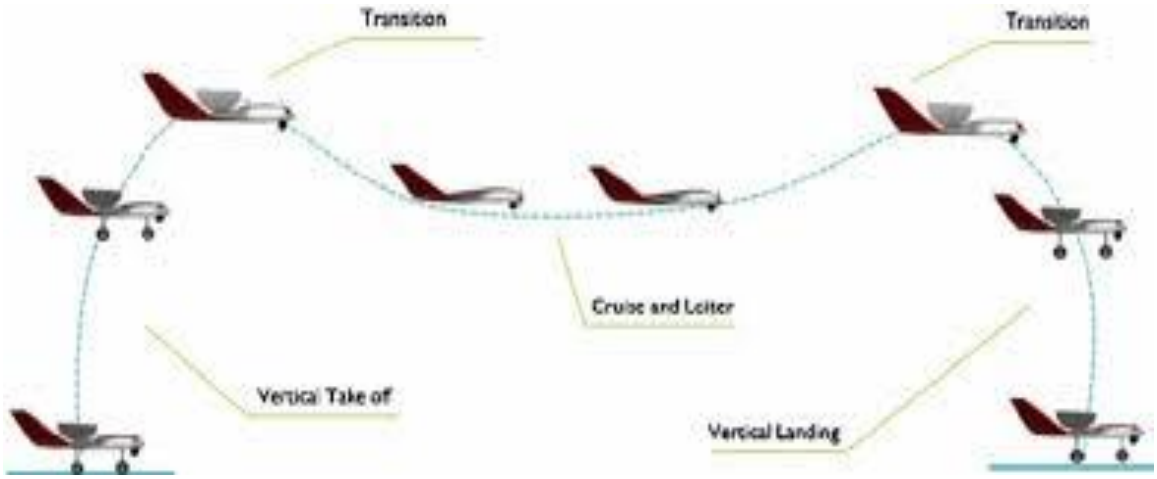

Fig 1:- Mission Profile of VTOL

II. CHALLENGES FACED IN ROTARY-WING-DESIGN

As the size and weight of the aircraft is decreased it becomes one of the major challenges faced by Rotary-wing-design concept[9]. One of the major disadvantages of this concept is power consumption by the motors as it flies in both high speed and low speed and mainly hovering flight is done with this drone[10]. This design is made based on the position of the motors and also based on the number of motors placed these drones perform Vertical takeoff and landing along with hovering design is also based on weight as it is the important criteria and they are maneuverable[11].

- *Challenges in Tilt wing and Rotor design*

This is the combination of rotary wing design and fixed wing design concept, they have similar challenges, but the main challenge in this design is the transition mode that is from multicopter, there is both front transition and back transition which requires different control strategy in order to fly this type of aircraft[12,13]. Firefly 6 and E-Flite convergence are some of the tilt rotors design which are newly made, some of the other aircraft are Bell eagle-eye and Birutan these all have tilt rotor mechanism which give excellent performance and have capability to carry out vertical flight capabilities and also have the potential to alter the air transportation by vertical takeoff and landing performance (capability)[14].

These are used in military aircraft as it has a tilt rotor mechanism, these are usually found at high speed in airplane mode and low speed in multicopter mode, Different methods offered to perform some autonomous transition maneuvers in which E-Flite and firefly have fixed autonomously and is been successful[15].

Author,[refs]	PUBLICATION YEAR	RESEARCH AND CONCLUSION
Jang-Ho Lee , Byoung-MunMin and Eung-Tai Kim[1]	2007	An autopilot design of tilt rotor which is being developed as a UAV development program using swarm optimization method, UAV is considered in this paper has 5 modes of control in the stability and control augmentation system. It is very time consuming to design autopilot of a tilt rotor UAV which has various dynamic characteristics nonlinearity and uncertainty along control techniques, as there are many design points and operating conditions throughout the flight envelope so to solve this particle swarm optimization method was developed which is a computation technique which helps in finding the solution faster and main advantage of this approach is handling nonlinear dynamics and changing the structure of autopilot system and meets all design requirements.
Takaaki Matsumoto, Atsushi Konno, Atsushi oosedo[2]	2010	Novel hovering control strategy was presented and was applied to a PID controller to realize robust UAV hovering. Simulation and experiments was conducted which resulted in attitude errors. This strategy was based on the analogy of an inverted pendulum model, 2D simulator was developed to evaluate this strategy, superior stability and control was achieved by the resolved tilt twist angle and this was not limited in hovering motion and doesn't depend on the aircraft current attitude and this can be used for different aircraft maneuvers which shift altitude dynamically with stall condition and not only normal motion as level flight.
P.Casau, D.Cabecinhas, C.Silvestre[3]	2011	The problem of autonomous transition between the hover and level flight for fixed wing UAV was addressed in this paper, for this different reference maneuvers are generated to provide robustness with respect to disturbance and uncertainty when performing transition maneuvers. A solution for this problem was presented where the flight envelope was partitioned in different regions with respect to hover, transition and level flight and also they designed a hybrid automation model for the overall system where the models of operation were correspond to the different flight envelope regions. Controllers which provide closed loop system, input to state stable with restrictions were for all the modes of operation for practical tracking of reference maneuvers with small tracking errors. This

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		provided a novel way to control transition for a VTOL aircraft but time taken was more and also the control effort.
J. Escareno, R.H.Stone, A.Sanchez and R. Lozano[4]	-	Problem of transition between rotary wing and fixed wing flight of a tail sitter UAV been addressed in this paper, where a nonlinear control design is presented to regulate the vertical flight dynamics of a vehicle, here IMU(Inertial measurement unit) is used to perform autonomous altitude stabilized flight in vertical mode. During the transition and after the transition dynamic and aerodynamic equations of that model are presented and also behavior of vehicle is described. An embedded control system is described to perform an autonomous flight and control algorithm has been derived for vertical flight mode, which is based on the back stepping and it was robust enough to manage with considerable aerodynamic perturbations and this was successfully tested for stabilization of attitude in vertical flight.
Liu Zhong , He Yuqing , Yang Liying and Han Jianda[5]	2016	As varying dynamics and aerodynamic interference is the main technical challenge faced by the tilt rotors, here mainly they have focused on the control techniques where dynamics modeling, control methods and structural features are discussed and major challenge such as safe transition between flight modes, reasonable aircraft dynamic modeling have been discussed and mentioned in this paper. Tilt rotors have been developed for certain mission requirement relying on its varying structure, hence new ideas are developed to overcome these challenges by path planning algorithm in different environments and flight mode of this aircraft has been improved.
Aswini kumar patra,Kandarp patel,Gourav singh and Vinay[6]	2017	UAV is becoming versatile where fixed wing have high endurance and range and multicopter has hovering and various terrain operation, combination of both gives the idea of autonomous transition hence a conceptual design was made of VTOL capability which is the combination of fixed wing aircraft and multicopter for the mode of operation, which is suitable for hover as well as cruise mode operation and here the CG was fixed such a way to maintain hover, cruise along with transition, hence autopilot was developed for smooth transition.
Chao Chen, Jiyang Zhang, Daibing Zhang and Lincheng Shen[7]	2017	Tilt rotor has ability to perform VTOL operation as well as fixed wing operation this paper presents a tilt rotor vehicle with all modes of operation from rotor to fixed wing and fixed wing to rotor for these characteristics a control allocation method was designed to make controller adaptive to all modes of flight and to reduce cost, accurate dynamic model of tilt rotor UAV is not obtained so gull mode flight strategy was designed in view of this situation and autonomous flight was conducted and results gave satisfactory performance for this method.
WinKoKoOo, HlaMyoTun, Zaw Min Naing and Win Khine Moe[8]	2017	This paper presented the design of VTOL with aircraft mode and tricopter mode, where first VTOL design was considered and mathematical mode of VTOL is applied to test the stability here KK2.1 flight controller was used for both the modes of aircraft. In this paper the vision based control system used Raspberry Pi 3, Raspberry Pi camera, 443 MH3 RC module (Transmitter and Receiver) and arduino board for operation of VTOL. This paper gives advantages to various type of tricopter system and evaluates their configuration.

Table 1

➢ *Challenges in fixed wing drone design*

The main challenges faced by these drones are selection of wing shape, sizing of the aircraft, aspect ratio for maximum endurance and weight estimation[16,17]. Here the thrust to weight ratio should be more, these drones cannot fly slowly and cannot hover these are the easiest ones developed to design and fabricate. Depending on the mission drones have different altitude, endurance and flight speed[17]. These drones fly with high speed as it flies over water and also around forests. Lift over drag ratio is more and there is decrease in Reynolds number, due to the decrease in velocity and dimensions there is decrease in Reynolds number and also decrease in efficiency. Many researchers have used trial and error method in designing this type of drones but their design is not considered as optimized due to size, weight etc[17].

III. MATERIALS AND METHODS

A search was made on the Google Scholar database on 3rd July, using specific keywords (Design challenges faced in VTOL). The keyword "Vertical Take Off and Landing (VTOL)" generated about more than 100 results. The results generated included all other publications that had the words. Searches were also made on other databases such as Scopus Indexed Journals. Other key words, such as 'PID Tuning' or 'Transition mode in VTOL', were also used.The search and re-search in all database yielded near-similar results. Selection criteria for inclusion were made to eliminate all non-related or irrelevant publications.

IV. RESULTS AND DISCUSSION

➢ *Relevant Studies*

The background knowledge was taken from a review of chapters in relevant textbooks in the field of Aerodynamics. For the foreground knowledge, a total of 101 articles were found from the online database (Google Scholar); 92 articles were excluded because their titles, abstracts, or contents were not related to the aims of this article (Figure 2). Finally, 9 articles were considered as relevant studies (Table 1). Table 1 shows a critical review of the studies that fulfilled all the criteria mentioned above are presented as follows.

V. PROPOSED SOLUTION FOR DESIGN CHALLENGES

To overcome these challenges the design process of drones should be based on the configuration and design methodology. For all the drawbacks of previous methods, we can find solutions by using statistical, theoretical, bio-inspirational and comprehensive methodology, they should be considered for design of light weight, deployable, easily operable, low storagewings for all UAV's during designing of any model. Recently there are many design challenges which have overcome due to the inspiration from nature, marine organisms etc.

VI. CONCLUSION

Recent researches and studies in the field of flying drones including Fixed wing,Tilt wing and Rotor design. These flying drones can be used to carry out various civil and military missions. The used design methods and their challenges were also consolidated for all types of drones. Possible solutions for the design challenges were proposed and discussed.

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