International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249-6890; ISSN (E): 2249-8001
Vol. 8, Issue 4, Aug 2018, 475-484

TRANS STELLAR •Journal Publications •Research Consultancy

DESIGN AND FABRICATION OF UNMANNED ARIAL VEHICLE FOR MULTI-MISSION TASKS

SHER AFGHAN KHAN[1], ABDUL AABID[2] & MAUGHAL AHMED ALI BAIG[3]

[1,2]*Department of Mechanical Engineering, Faculty of Engineering, International Islamic University Malaysia, Kuala Lumpur, Malaysia*

[3]*Department of Mechanical Engineering, CMR Technical Campus, Hyderabad, Telangana, India*

ABSTRACT

The design for UAV was planned taking into account the real-life engineering problems such as different phases involved in developing a product. Here the task is to design, create, build and test a remote-control airplane. The planning and designing of an aircraft must start from the scratch, with lots of restrictions and parameters, like a specific motor to be used from the wing profile, dimensions, centre of gravity, materials and other features which are all involved in the process. The main objective of this UAV is to design an aircraft which is efficient during emergency situations and is capable of dropping packages from a minimum height of 100 feet off the ground. A vision-based control strategy is used in this to track and follow objects using an unmanned aerial vehicle (UAV). This unmanned aerial vehicle is created in such a way that it can be used in multi-mission tasks too. The most favorable design must be of one which can perform efficiently, cost-effectively and carry as many payloads as possible, and all these without negotiating on the safety of the aircraft.

KEYWORDS: UAV, Cd & Cl

Received: May 04, 2018; **Accepted**: May 25, 2018; **Published**: Jul 11, 2018; **Paper Id**.: IJMPERDAUG201849

Original Article

1. INTRODUCTION

Most of the Unmanned Aerial Vehicles are used for surveillance and defense activities. UAVs are preferred for missions that are too "dull, dirty or dangerous" for manned aircrafts. The main aim is to design and build a remote piloted heavy-lift aircraft, which can carry payload, maintain aircraft stability, dropping the payload precisely and landing successfully. Challenges involved in designing and building the aircraft include, wing design, stabilizer design, stability, weight reduction and structural integrity. This involves detailed software analysis, experimental data and expert validation to back the optimization. Unmanned Aerial System (UAS) should be capable of accurately dropping humanitarian aid package from a minimum height og 100 feet above the ground. Figure 1 illustrates a common UAS and the various elements are combined to create the system. UAVs are implemented for multiple mission tasks such as; Agriculture, Surveillance, Aerosol Sampling, Detection of Illegal Imports, Electronic Intelligence, Port Protection, Over-Beach Reconnaissance, Forest Fire Detection and Archeology.

Presently UAV is designed and fabricated using various methods of manufacturing taking into consideration lightweight materials mentioned in section three. The major consideration is to design a wing and stabilizer for the purpose of stability in drop-ply mechanism. ANSYS computational has been used for the analysis of fuselage and wing.

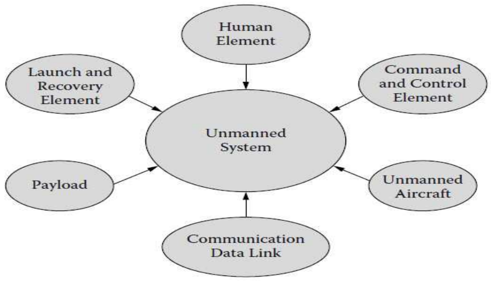

Figure 1: Elements of an Unmanned Aircraft System

2. LITERATURE SURVEY

In earlier attempts, for path control and online optimization to track the UAVs investigated the feasibility of a non-linear model predictive tracking control (NMPTC)and formulated a NMPTC algorithm using gradient-descent method (kim et al., 2002). Flight control system has been designed to control and navigate small, unmanned, jet-turbine powered fixed-wing aircraft and to allow the aircraft to maintain controlled flight, and return to its original position, without any operator involvement (Mcbride, 2010). Initially the concept of air-drop of payload was developed for delivering half pound of medical supplies to a known location. A dropping algorithm has been developed taking into account the speed, wind direction, altitude and other factors to facilitate a very accurate drop at a target (Boura et al., 2011). UAVs swarm systems were investigated to achieve time varying formation and analyze design problem by formation control analysis. Then, consensus-based approaches were applied to deal with the time-varying formation control problems for UAV swarm systems(Dong et al., 2015). Physics based analysis to generate feasible aircraft models has been designed using CAD model bases of optimal design for a mission(Locascio et al., 2016). Well-thought-of demonstrated flight handling qualities, practical and affordable manufacturing requirements providing a high vehicle performance has been studied and the requirement of ferry flight mission was to fly as many laps as possible within 4 minutes has been observed(Khan et al., 2016). For such application presented a conceptual design of a UAV with a battery powered propulsion system. Relate to the take-off mass with the wing-span, chord-length and fuselage-length. Such equations are based on a designed take-off mass, there exist several variants of the aircraft concept by varying wing-span, chord-length and fuselage-length of the UAV(Osheku, 2017). A multipurpose UAV for mountain rescue operations has also been designed. The multi-rotors is design based on flying plat-form and its embedded avionics to meet environmental requirements for mountainous terrain such as high altitude, low temperatures, and high wind affects, assuring the capability of carrying different payloads (separately or together) (Silvagni et al., 2017). The impact of manufacturing techniques based on aerodynamics, structures and materials for UAV is also explored. In this review present technologies used in UAV through innovations in materials and structures, and their advantages and disadvantages were discussed(Goh et al., 2017). Hybrid VTOL UAV which has the advantage of a multi-rotor UAV that has the ability to travel fast was implemented. Fabrication and methodology methods were discussed followed by several flight tests to prove the concept. The UAV is equipped with quad-copter motors, and a horizontal thrust motor for vertical and horizontal modes of flying respectively(Ashraf et al., 2018). To improve the performance of the airplane an high-lift airfoil has been designed and experimentally certified by subsonic and supersonic wind tunnel tests. Therefore, at low Reynolds number these type of airfoilscan also be designed for UAVs (Selig et al., 1997).

3. DESIGN PROCESS

First step is to come out with designing solutions (i.e. selection of appropriate parameters) to suit the mission requirements and justification in using computational analysis. Then second step is fabrication to develop a CNC solution to enable the production of 3D wings rapidly. Next is to verify the equipment reliability and worthiness. And finally the flight testing, demonstration of airworthiness and evaluation of actual flight data. The methodology shown in figure 2

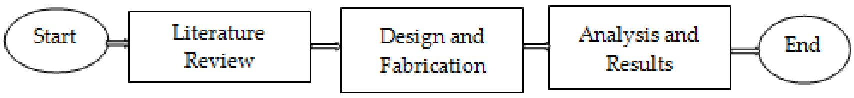

Figure 2: Methodology

3.1. Wing Design

One of the main characteristics that affects the chosen aircraft is the airfoil. In each category experimental aerodynamic data is compiled for a selected number of airfoils. In this study, CH10 (smoothed) a cambered airfoil has been selected for the main plane as shown in figure 3. It has a thickness of 12.75%, a cambered of 10.20%, chord of 30.8%, low Reynolds number, high lift and a value of$C_m = -0.92$. The maximum coefficient of lift value for CH10 (smoothed) was found to be $C_{l,max} = 1.95$ from equation (1);

$$C_{l,max} = \frac{M}{qSc} \quad (1)$$

3.2. Vertical Stabilizer Design

The UAV has a vertical stabilizer which consists of NACA 0012airfoil, a symmetrical airfoil is shown in figure 4. NACA 0012 airfoil has a thickness of 12% of the chord length and has no camber. It propagates a beteer yaw movement and gives a good stability. There is a horizontal stabilizer AG36, a flat bottom airfoil which fits the design requirements. AG36 has a maximum thickness 8.2% at 27.9% chord and a maximum camber of 2.3% at 37% chord.

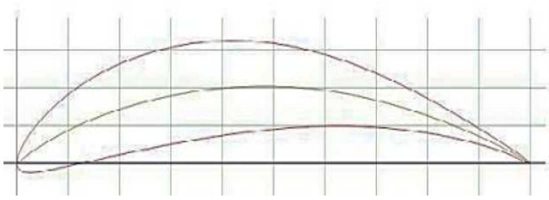

Figure 3: Plot of CH10 (Smoothed)

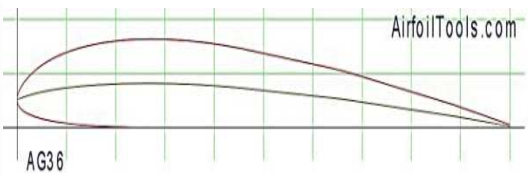

Figure 4: Plot of AG36 Airfoil

3.3. Fuselage Design

The fuselage design is of great importance as it is constructed in such a way so that it can carry heavy payloads. There is a box type fuselage in UAV that can carry large payloads with low weight factor. The expellable cargo is released by servo actuation. It incorporated the three components of the flight score (FS) into three primary design criteria: precise flight control (S1), minimized aircraft weight (S2), andlifting capability of maximum takeoff load W_{TO} = 26lbs (S3). These criteria focuses on UAV stability and control. The specification of the scoring system is that if the package is dropped precisely within 50 feet drop target, will get a non-zero flight score FS. In order to achieve non-zero FS, the worked-on weight reduction should not exceed 12pounds.

3.4. Avionic Selection

Data Acquisition System (DAS) functions were considered and made sure that it is able to display the altitude of the plane in real time and log the altitude when the payloads are dropped. Recording of GPS and airspeed data as well as provide a real-time span of a camera to assist the payload dropping and its measurement i feet with the precise of at least 1 feet, these were all the additional goals of DAS. To read-out and visibility from a ground station and having an arming/reset switch. In the case of manual switch it is located externally and is at least 12 inches away from the propeller. So wireless arming/reset switch is considered. Same frequency cannot be used as the flight control system in the case of DAS systems. How the data transits shown in figure 5.

Figure 5: Data Transmission

Interfaces

- 5x UART (serial ports), one high-power capable, 2x with HW flow control
- Spectrum DSM / DSM2 / DSM-X® Satellite compatible input up to DX8 (DX9 and above not supported)
- Futaba S. BUS® compatible input and output
- PPM sum signal
- RSSI (PWM or voltage) input
- 3.3 and 6.6V ADC inputs
- External micro USB port

Weight and Dimensions

- Weight: 38g (1.31oz)
- Width: 50mm (1.96")
- Thickness: 15.5mm (.613")
- Length: 81.5mm (3.21")

3.5. Engine Selection

A UAV is powered by a internal-combustion engine and is likely to have superior range, because of the energy density advantages of the fossil fuels and the range can be extended by adding fuel tanks. The results derived in this case by testing propellers of various configurations at the maximum safe revolution per minute attainable by the engine and recording static thrust mounted on the test bench. The resulting maximum thrust measurement allowed us to predict takeoff equilibrium conditions and the specification shown in table 1.

Table 1: Engine Specification

Displacement	Bore	Stroke	Practical Rpm	Output	Weight	Recommended Props
0.467 cu in (7.5 cc)	0.906 in (23.0 mm)	0.724 in (18.4 mm)	2,000-16,000	1.18 hp @ 16,000 rpm	9.6 oz (270 g)	11x6, 11x7

4. FABRICATION OF UAV

Construction is also a vital part, since there are restrictions of the empty weight to 8lbs. There are many factors which has to be taken into consideration while designing a RC airplane.

4.1. Implementing CNC Solution

Computer Numerical Control (CNC) method has to be involved to meet out the fabrication requirements. Despite the uncertainties in reliability, the design of 3D foam cutter is proposed, instead of adopting the 2D precision cuts into wingspan, because it offers precision and accuracy in shaping complex geometries compared to manual means of arranging 2D sections and DIY machine costs only a fraction (<10%) of those available commercially.

4.2. Main Plane

Figure 6 shows the main plain of the UAV is made from balsa wood. The reason for choosing balsa wood is its high strength to weight ratio. The wing ribs, spars and control surfaces are all made from balsa of different thickness according to their use. Spars which provides support to the ribs were made from spruce wood. Spruce wood has an elastic modulus of 11.03 GPa and a rupture modulus of 70 GPa which highly suits our design. The power plant is restricted for cambered airfoil with huge wing span which can carry heavy payloads. Thus, a wing spanof 10 feet was chosen. Each section of the wing is attached using carbon fiber tubes and bolted at the sections. Carbon-fiber-reinforced polymers are composite materials. The properties of CFRP depend on the layouts and the proportion of the carbon fibers relative to the polymer. Young's modulus of a standard carbon fiber rod is 70GPa.

4.3. Tail Plane

The tail plane reduces the empennage weight of the UAV and it is connected to the fuselage using a carbon fiber of 25mm diameter. Due to its high stiffness it is resistant to bending while traveling at high velocity. The tailplane consists of the vertical and horizontal stabilizer. The horizontal stabilizer is made from a flat bottom airfoil AG36 while the vertical stabilizer or the rudder is made from NACA 0012. The ribs and spars for these are made from balsa wood as well. The carbon fiber boom is angled, and it can sustain the amount of torsion produced. It is angled to show the difference in height between the main wing and tail wing and it is shown in figure 7.

Figure 6: Wing Covered with Film Cover

Figure 7: Horizontal Stabilizer

4.4. Fuselage

Figure 8 shows the UAV with a box type fuselage. The firewalls are comparatively thicker than the bulkheads. For the purpose of weight reduction, the bulkheads are cut everywhere except in the joints. In order to carry heavy payloads and bear the impact while landing, the spars are made out of spruce so that it gives good support and strength. A complete truss structure which was initiated was later avoided for weight reduction reason. Hence the tailplane was connected to the fuselage using a carbon fiber rod of 25mm diameter. And the fuselage was made spacious enough to occupy all the systems of the aircraft.

Figure 8: Side View of Fuselage with Engine Mount

4.5. Landing Gear

The landing gear is designed considering the weight, the longitude, and the width of the entire UAV. The main base upper part of the landing gear will be attached to the fuselage and supports the UAV. The nose wheel tricycle landing gear has been the preferred configuration for the UAV. Improved stability during braking and ground maneuvers is the most attractive feature of this type of undercarriages. Present study reveals that landing gear stability could be improved by longer wheel axle, stiffer damping mechanism and smaller wheel mass and lower aircraft sinking velocity.

4.6. Weight Breakdown

The empty weight of the aircraft is chosen to be 8 Lbs. The construction ofeach part of the aircraft wieght is done consciously. The weight breakdown was done as per the tabulated below table 2. Weight reduction is made by making holes in ribs, replacing the truss structure by a carbon fiber rod and holes in the fuselage walls .

Table 2: Weight Breakdown

Parts	Fuselage	Main Plane	Tail Plane	Tail Boom	Flight System	Total Weight
Weight (Lbs)	2.2	2.86	0.98	0.338	1.32	7.698

5. RESULTS AND DISCUSSIONS

5.1. Airfoil Analysis

The main plane of the aircraft plays a important role in producing maximum lift. After continuous tests and experiments a prototype of the wing was made with a change in chord length and thickness, optimized the wing. The C_l versusC_d graph was also plotted. The $C_{l,max}$value from the graph was found to be 1.95 for the given airfoil. Tested this airfoil in the selected angle of attacks were the maximum coefficient of the lift and maximum C_l/C_d can be obtained whichin turn will increase the wing performance. The selected angle of attacks is α=3.25,4.25, 2.75. In these, α =4.25° angle of attack delivered the high C_l/C_d ratio in therange of 300,000 to 500,000 Reynolds number that is 39 km/hr to 65 km/ hr, so this gives cruising speed which is between this range and more preferably 45 km/hr. The theoretically calculated graphs shown in figure 9.

versus graph was also plotted. The value from the graph was found to be 1.95 for the given airfoil.

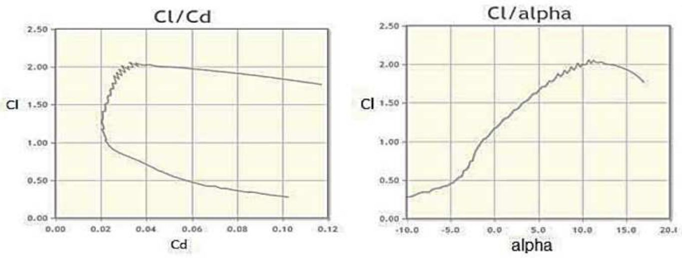

Figure 9: Cl Versus Cd (b) Cl Versus α

5.2. Main Wing Analysis

With the help of proven analysis software and conventional workshop methods the aircraft was tested to determine its performance. ANSYS (ANSYS Inc, 2016) is the software used for the computational analysis purpose, which enabled us to define the flow property over the airfoil in the UAV. Therefore, for two-dimensional analysis considered CH10 (smoothed) airfoil. Similarly, for three-dimensional analysis considered wing of the designed UAV as shown in figure 10.

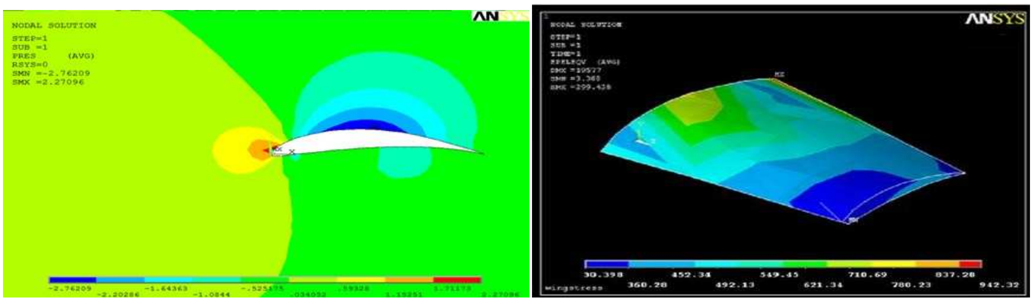

Figure 10: (a) CH10 (Smoothed) Airfoil Analysis (b) Wing Analysis

5.3. Weight Distribution Analysis

5.3.1. Payload Prediction

The payload of an aircraft includes frame weight, fuel weight, expellable cargo and other systems of the aircraft. Of these, the fuel weight keeps decreasing proportionally to the throttle inputs. Static cargo-bay is fully enclosed and it has no restriction on size or shape. Expellable cargo-bay cannot occupy the same space as the static cargo-bay area as it is used to carry 3-lb humanitarian package. The requirement of expellable cargo, sand enclosed by a sewn fabric material, weighs between 1.36kg and 1.47kg. The figure 11 illustrated in detail about the payload variation with respect to the altitude. The equation used to plot the graph is mentioned in the graph.

5.3.2. Drop Mechanism

Accuracy in dropping is the most competitive part. Expellable cargo is dropped from the aircraft by projectile drop mechanism. The velocity of expellable cargo when released from the aircraft will be equal to that of the velocity of the aircraft. Opted for Ardupilot 2.6 Mega (Ardupilot APM 2.6: User guide, 2017) for the telemetry system. The UAV will lose its stability once the expellable cargo is dropped. The Ardupilot board contains gyro assistance and hence it is taken care off. The UAV can maintain a stable flight even after the cargo is dropped, because the Ardupilot is gyro assisted.

5.3.3. MATLAB Simulation

We have adopted projectile drop mechanism to drop the expellable cargo from the aircraft. MATLAB software (MATLAB Inc, 2017) was used for simulation purpose to determine the trajectory of the payload that is to be dropped. The assumption made for this, the target and the UAV are placed along the same plane. UAV speed and the forward speed of the expellable payload is maintained constant. Using the equation of motion, the values are initialized, and the program is done in MATLAB software and required trajectory is determined in figure 12.

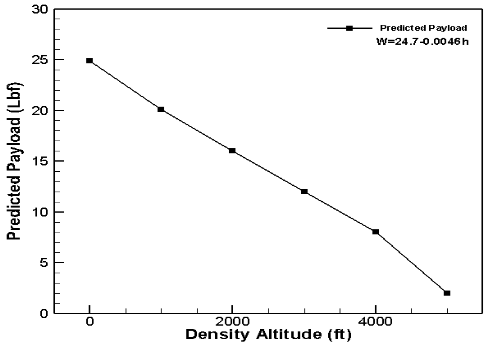

Figure 11: Payload Prediction Graph

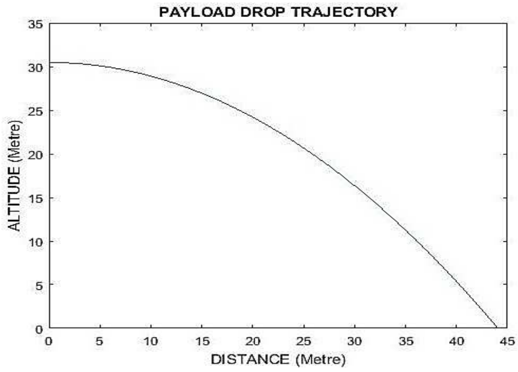

Figure 12: Payload Drop Trajectory

5.4. Force Analysis

In order to have a stable flight, force analysis plays an important role, all the loads must be balanced to its center of gravity, which should always be located between both the wings. In the selected monoplane configuration, the distance between the leading edge of the top wing and the trailing edge of the bottom wing was of fifteen inches, so the location of the center of gravity must be within this region.

This center of gravity does not account the weight of the payload that ultimately will come into the airplane. For this reason, the center of gravity should be close to the middle of the payload bay so that it is does not shift while more weight is added to the airplane. Even though this is a crucial part of our design, it can be further modified after the final construction of the airplane by effectively arranging the added weight in the payload. The CG of the wing is calculated using Win Laengs V 2.7 software (Reichertshofen, 2018). The figure 13 shows the complete CG of the aircraft which was also theoretically determined by the same software.

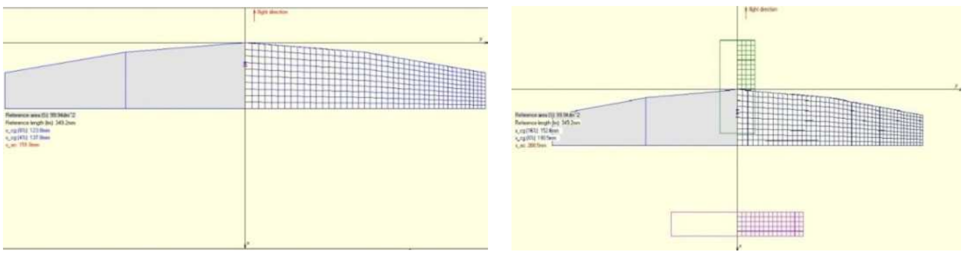

Figure 13: (a) CG of the Wing (b) CG of the Aircraft

5.5. Overall Configuration

Another important feature of this mission is the overall configuration. As per this assignment, the aircraft must have enough space for the bay to carry the static cargo, telemetry system and other basic systems required for operating the UAV. In accordance with these, the aircraft was sized as mentioned in the table 3 and 4.

Table 3: Dimensions of the Aircraft

Parts	Length (ft)	Area(ft^2)
Main Plane	9.68	11.312
Tail Plane	3.445	4.111814
Fuselage	2.41	3.76

Table 4: Aircraft Performance at Take-off and Cruise Stages

	Velocity(ft/s)	Thrust(lbf)	Lift (lbf)	L/D	Induced Drag(lbf)
Take off	33	5.25	24.6	8.1	2.3
Cruise	58	2.56	26.5	9.2	1.0

The induced drag is 130% more during takeoff than a cruise. The aircraft needs more thrust toovercome the drag, at cruise condition. The aircraft travels with almost twice the velocity than takeoff condition. At cruise condition, the thrust produced will be equal to the drag produced, which is not the case during takeoff. Then calculated the drag coefficients for each part which is the sum of zero lift drag (C_{D_o}) and Lift-induced drag (C_{D_i}). The total drag is the sum of C_{D_o} and C_{D_i} for the fuselage, main wing, and tail wing separately.

$$C_D = C_{D_o} + \frac{C_L^2}{\pi\, eAR} \tag{2}$$

where

$$L = \frac{1}{2}\rho V^2 S C_L \text{ and } D = \frac{1}{2}\rho V^2 S C_D$$

Finally, the designed model shown in figure 14.

Figure 14: Unmanned Arial Vehicle

6. CONCLUSIONS

The UAV was designed in such a manner, that with very slight modifications it can be used in various fields. The weight of the aircraft, stability and precision dropping were given extreme importance. This project is also aimed at transforming the various ways of operations carried out by inculcating the use of UAVs inorder to reduce manpower and also to increase efficiency. With several flight tests the UAV is successfully tested for the stability and payload drop. The team hopes these UAVs will be used to serve the nation very soon. One of the major challenges in payload drop is restricting the movement of CG to prevent a change in stability of aircraft. The UAV demonstrated a stable flight even after the payload drop, which makes it suitable for dropping the payload of specified mass

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