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Investigation on WIG(Adv. Marine) Craft Aerodynamic Characteristics

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ABSTRACT:

The paper is about the aerodynamic characteristics of the wing-in-ground effect (WIG) craft model that has a noble configuration of a compound wing was experimentally and Theoretical investigated and wind tunnel(TLE-06) with and without endplates. Lift and drag forces, pitching moment coefficients, and the center of pressure were measured with respect to the ground clearance and the wing angle of attack. The ground effect and the existence of the endplates increase the wing lift-to-drag ratio at low ground clearance. The results of this research work show new proposed design of the WIG craft with compound wing and endplates, which can clearly increase the aerodynamic efficiency without compromising the longitudinal stability. The additional lift provided by the ground effect reduces demand on the engines of an aircraft and power needed in order to stay airborne, thus making it more efficient. The knowledge that ground effect flight is more efficient than traditional flight has lead people to develop craft that exploit this benefit by being designed to fly close to the ground. Development of WIG craft spans roughly over the past 60 years, ranging from small scale recreational craft, to large scale military craft, yet such craft have not become successful mainstream products. This is largely due to the limitations present in existing WIG craft designs, such as the high maintenance nature of having exposed engines in close proximity to the sea, which reduces reliability. Such factors have previously lead to a withdrawal of military funding for research and development in this area, across all major countries that were once rigorously involved in this research. Despite this, the potential still exists for WIG craft design to achieve the functionality required to become successful in niche areas such as high speed transport rather than warfare. And, the use of WIG craft is representing an ambitious technology that will help in reducing time, effort, and money of the conventional marine transportation in the future.

Keywords: Aerodynamics, Wind Tunnel (TLE-06), Marine, wig craft, lift-to-drag ratio

1. INTRODUCTION

This report provides the theory of the efficiency of wings operating round effect and the historical back ground to the development of WIG craft. With this back ground it goes onto explore the likely technological hurdles remaining in the development of these craft. It also attempts to out line those areas of technology where relevant advance shave been made since the major development period of these craft through the1960's and 1970's. There port also attempts to outline the performance characteristics of WIG craft and the operational limitations that might be found and eveloped WIG craft. A quantity of experimental and operational data is also provided .This data has been gained primarily from the manufacturers and other supporters of WIG craft and comes primarily from experimental and prototype craft. Little independent data is available for full sized operational craft. Design, regulation, manufacturing requirements and aero-dynamic characteristics are discussed.

2. THEORY

Objects that produce lift in moving air are known as lifting bodies. Whilst many different shaped bodies can produce lift, the most efficient of discovered is the wing. The efficiency of a lifting body is determined by the lift to drag ration (LID) of the body. The body that produces the greatest lift for the least drag is the most efficient.

2.1 Theory of Flight

2.1.1 Lift and Drag

The lift and drag produced by a wing define the performance and general attributes of the craft that it supports. A wing moving through the air produces are sultant force. Lift is defined as the component of there sultant force perpendicular to the velocity vector of the wing. Induced drag is defined as the component of there sultant force parallel to the velocity vector of the wing. There are also other form sof drag, which are collectively referred to a spara site or profile drag, which is the drag created by the friction of the object moving through the air. The total drag of an object moving through the air is the sumo finduced drag and parasite drag. Both lift and drag are functions of a number of variables, the density of the air, the velocity of the object through the air and the geometry of the object.

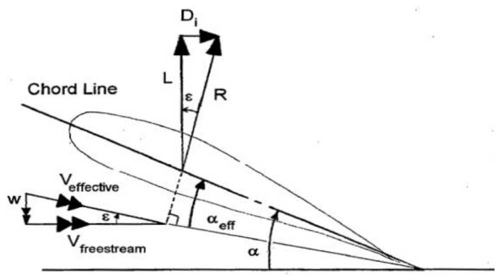

Figure 1: Lift and Drag of a Wing Section

Figure 1: shows the formation of lift (L) and induced drag (D_i) from the resultant force (R) created by the wing's movement through the air. It also demonstrates that the position of the wing as it moves through the air is defined by the geometric angle of incidence (α). The geometric angle of incidence is the angle between the chord line of the wing section and the velocity vector of the wing. Figure 2 demonstrates that the coefficient of lift increases with an increase in angle of incidence until a maximum angle of incidence is reached and the lift abruptly decreases. This point is referred to as the maximum lift coefficient ($C_{L\ Max}$) and is the point at which the wing stalls. The stall occurs because the flow separates from the upper surface of the wing.

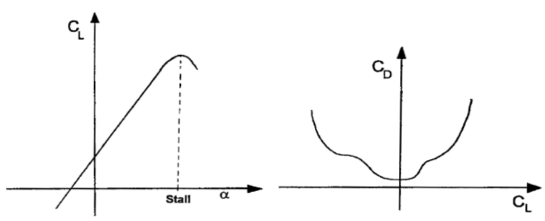

Figure 2: Aerodynamic Relations for Lift and Drag of a Typical Wing

2.2 Ground Effect

Ground effect is the phenomenon caused by the presence of a boundary below and near a wing. The boundary alters the flow of the air around the wing causing an increase in the lift of the wing and are duction in the induced drag of the wing .The effect becomes more pronounced the closer the wing is to the boundary.

Figure3 depicts a wing in ground effect. The boundary creates an alteration of the flow field that is caused by the boundary not allowing the flow under the wing to expand a sit would in free air.

In terms of the total pressure of the flow, the addition all if this due to arise in static pressure under the wing. The total pressure of the flow field can be divided between the static pressure(surface pressure) and dynamic pressure (the pressure associated with velocity.

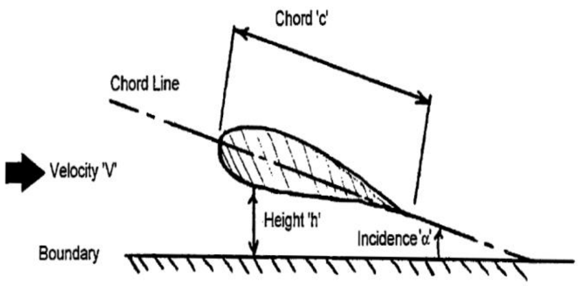

Figure 3: Wings in Ground Effect

Pitching Moment

In addition to creating lift and drag the movement of a wing through the air creates a moment about the aero dynamic center of the wing. This moment is known as the pitching moment and is there sult of the pressure distribution on the wings surface. In a moving craft this pitching moment needs to be balanced in order to keep the craft stable. Air craft designers typically add another lifting surface to over come pitching moment, either at there arof the air craft (tail plane) orat the front of the air craft (canard).

The ram pressure in extreme ground effect causes an ear uniform pressure distribution over the under surface of the wing, while not significantly altering the upper surface pressure distribution.

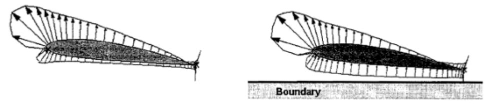

Figure 4: Flow Field In and Out of Ground Effect.

Maximum Lift

The maximum lift coefficient (C_{LMax}) defines the low speed characteristic soft he wing and the take-off and landing speeds .An increase in $C_{L\ Max}$ enable slower take-off and landing speeds and there for reduces the take-off run and lowers landing loads on the structure. The $C_{L\ Max}$ also defines the stall speed of the wing, which defines the slow speed limit of the craft and may affect the stall characteristics of the wing.

Effect of Height above the Ground

Many of the effects of flight IGE are functions of the height above the boundary. These effects are non-linear and are responsible for many of the complications inherent in the development of WIG craft. They have been researched from both an empirical view point and a modeling view point.

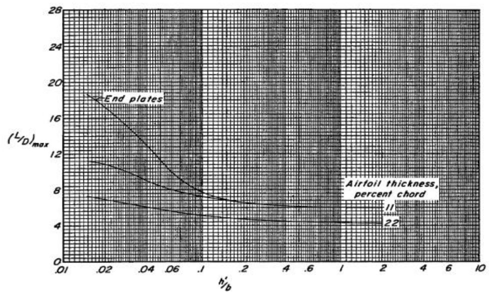

Figure 5:Flow Field In and Out of Ground Effect.

Figure7,also taken from Carter, demonstrates the effects on pitching moment(C_m) with lift(C_L) as a wing moves to and from a boundary.

Theoretical Benefits of Ground Effect

The theoretical efficiencies of air borne craft can be expressed in terms of their ability to carry a given pay load over a given distance. This efficiency is directly related to the crafts lift to drag ratio. WIG craft shigher lift to drag ratio provide them with the potential for greater efficiencies than aircraft.

There sulting increase in the lift to drag ratio of a WIG craft results in an increase in the craft efficiency. One measure of efficiency is to consider the distance a specific pay load can be transported. Air borne craft are governed by the Bregue trange equation, for which the representation for propeller driven craft is shown below:

Range=η_p

$$\text{Range} = \frac{\eta_p}{C_p} \cdot \frac{L}{D} \cdot \log_e\left(\frac{W_i}{W_i - W_f}\right)$$

- η_p – propeller efficiency
- C_p--specific fuel consumption
- L/D --lift to drag ratio
- W_i --initial weight
- W_f --fuel weight

From the range equation, it is clear that an increase in the lift to drag ratio will have a direct effect on increasing the available range with a given payload.

Stability and Controlling GroundEffect

Due to the aero dynamic influences of ground effect there is a corresponding change to the dynamics response of the craft. Stability and control have been the greatest hurdles in the early development of WIG craft due to the non linear dependence of aero dynamic characteristics with height. Might be over come by the use of a vertical in.

3. HISTORICALPERSPECTIVES

The development of ground effect craft stems from observations made in the 1920's on the landing performance of aircraft. Soon after, in 1921, a theoretical understanding of ground effect was achieved. Later a number of countries, namely the USA and the USSR, became interested in attempting to exploit the potential benefits of ground effect. Early developments in the 1960's awa number of experimental craft designed by these countries. The USA abandoned efforts to produce ground effect craft in the mid 1960's in favour of Surface Effect Ship development. Germany began work in the late1960's using the designs of Alexander Lippisch. How ever the undisputed leader, in research and development up to thelate1980'swastheUSSR.

4. Wind Tunnel

The aero dynamic characteristics, specifically the ground effect of the WIG craft with a compound wing were investigate dina low speed wind tunnel. This wind tunnel was able to deliver a maximum air speed of 30m/s (160knotsor288km/hr) inside the test section. The size of test section was2.0 meters wide,1.5 meters height, and 5.5meterslong.The flow inside the wind tunnel was of good quality, with a flow uniformity<0.15%, temperature uniformity<0.2, flow angularity uniformity<0.15, and turbulence<0.06%. TLE-06 had high-quality facilities that allow for accuracy and repeatability of experiment results.

The wind tunnel is equipped with a6-component balance for load measurements. The balance is a pyramidal type with virtual balance moment at the centre of the test section. The balance has acapability to measure aero dynamic forces and moment in the3-dimensional.The aero dynamic load scan be tested at various wind direction by rotating them odel via turntable. The accuracy of the balance is within 0.04% based on standard deviation. The maximum load rangeis±1200N for axial and side loads.

WIG Craft Model

The experiments were carried out on a WIG craft model that used anew compound wing configuration as shown in Figures 6and 7.The compound wing was composed of three parts: a rectangular wing in the middle and two reverse taper wings with a hedralangle at the sides. The NACA 6409 air foil section was selected as a section of the compound wings. The principal dimensions of the WIG craft.

Figure 6: WIG craft model with endplates

Figure 4: New compound wing configuration.

Scale factor	1 : 6
Wing span	83.4 cm
Wing root chord	66.7 cm
Middle wing span	41.4 cm
Aspect ratio	1.25
Anhedral angle	13^0
Length ofWIG craft	1.2m
Breadth ofWIG craft	0.13m
Tail wing span	0.78m
Tail wing chord	0.15m

Table: Principle dimensions of WIG craft

I. EXPERIMENTAL PROCEDURES AND SET-UP

In the wind tunnel, aerodynamic force measurements were carried out for a range of ground clearances (h/c) and different angles of attacks (α), from h/c = 0.18 to h/c = 0.25 and from α= $4^0$to α=6^0. Ground clearance (h/c) was defined as the distance ratio between the wing trailing edge centre and ground surface (h) to root chord length (c) of the wing. In this study, the floor of wind tunnel was used as a fixed flat ground as shown in Figure 4. The WIG craft model was mounted on the test section of the wind tunnel with a strut as shown in Figure 5.The position of the strut was at the 40%ofchord length from the leading edge of the compound wing. The strut was adjustable and then was fixed at any height. The WIG craft model could be rotated about an axis at the strut position. The frontal area ratio of the WIG craft model and the test section was small; therefore, the blockage ratio for the wings related to side and roof walls of the wind tunnel can be neglected. In this study, all experiments were performed with free stream velocity of 5m/s.

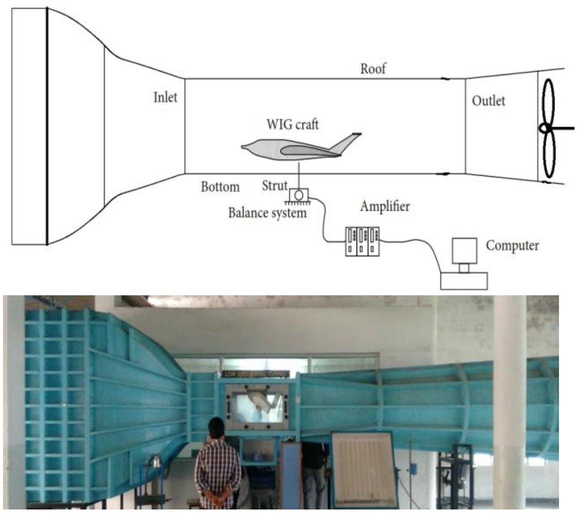

Figure 8: TLE-06 Wind Tunnel

7. Results and Comparisons

The WIG craft model aerodynamic coefficients and centre of pressure were obtained in this study sing the following formulas:

$$C_L = \frac{L}{0.5\rho U^2 S}$$

$$C_D = \frac{L}{0.5\rho U^2 S}$$

$$C_M = \frac{M}{0.5\rho U^2 S}$$

$$X_{CP} = 0.4 + \frac{C_M}{C_L \, Cos\alpha + C_D \, Sin\alpha}$$

The lift coefficients of the WIG craft model with and without endplates are shown in Figure 9. As expected the lift coefficient of the WIG craft model with endplates was higher than the lift coefficient of the WIG craft model without endplates. The lift coefficients of the WIG craft model increase up to 42% and 50% for angles of attack of 4∘and 6∘, respectively. From the previous figure, it is clear for higher angle of attack and lower ground clearance endplates significantly enhanced the lift coefficient. Figure 10 depicts the drag coefficient (C_D) of the WIG craft model with and without endplates. The drag coefficients of the WIG craft model with and without endplates do not show high discrepancy for each angle of attack, probably because of reduction of induced drag due to the effect of endplates. Thus, the increment of drag can be related only to angle of attack and ground clearance. For higher angle of attack and ground clearance drag coefficient increases up to 11% and 5%, respectively, as shown in the figure.

The performance of an aircraft is defined by its lift to drag ratio (L/D).The comparison of lift to drag ratio between the WIG craft model with and without endplates is shown in Figure 11. For lower ground clearance endplates enhance the lift-to-drag ratio up to 45%; the lift-to-drag ratio of WIG craft model with endplates decreases sharply compared to the model without endplates as the ground clearance increases. Augmentation of lift to drag ratio can also be attributed to the angle of attack, where larger angle of attack amplifies the lift to drag ratio. In addition, L/D decreased when the ground clearance was smaller. The moment coefficients (C_M) of the WIG craft model with and with out end plates are shown in Figure 12. The pitching moments were measured about the point which was 40% of the chord length from the leading edge. The CM_Z being positive for the wing with end plates is consistent with the prior discussion about stability for a WIG.

The second parameter that has main effect on the stability of WIG craft is its center of pressure. The distance between the leading edge and center of pressure on the wing is defined as Xcp. Figure 13shows the center of pressure for the WIG craft model with and without endplates. In general, the position of center of pressure of the WIG craft model shifted towards leading edge due to effect of endplates. This effect is expected as pitching moment reduced due to endplates. As discussed earlier, static stability depends on the rate of change of moment and lift coefficient with respect to angle of attack and ground clearance. The height of aerodynamic center (X_h) and pitch aerodynamic center (X_α) of the WIG craft model with endplates were upstream than that of the WIG craft model without endplates as depicted in Figures 14 and 15. The height of static stability (HS) of the WIG craft model for both with and without endplates was negative with respect to ground clearance (Figure 16) that makes the craft statically stable for both cases [15].

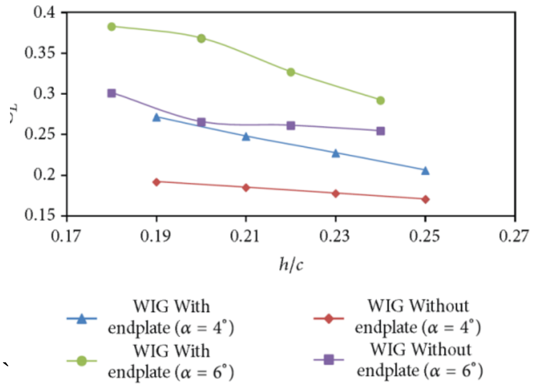

Figure 9: Lift coefficient (C_L) of WIG craft model with and without endplates versus ground clearance (h/c) at different angles of attack.

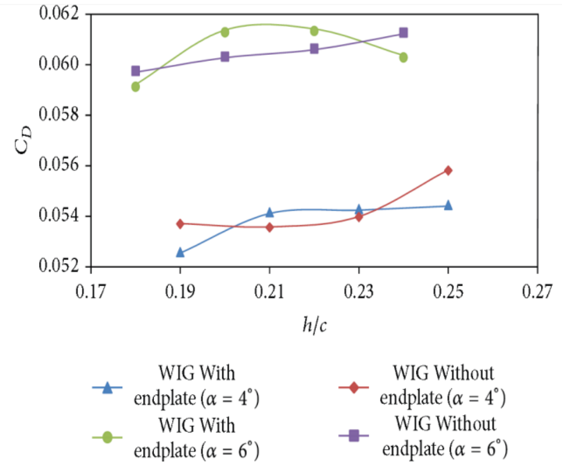

Figure 50: Drag coefficient (C_D) of WIG craft model with and without endplates versus ground clearance (h/c) at different angles of attack.

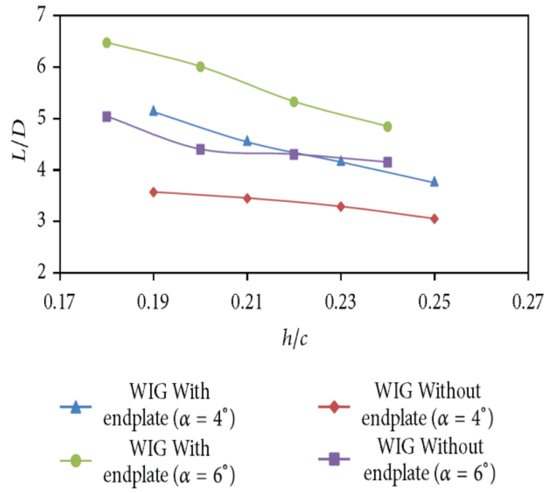

Figure 61: Lift-to-drag ratio (L/D) of WIG craft model with and without endplates versus ground clearance (h/c) at different angles of attack.

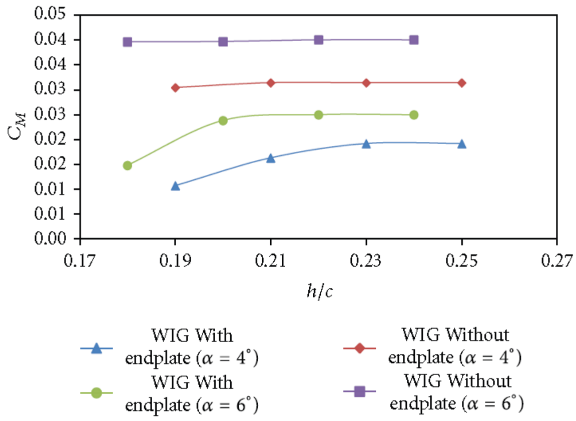

Figure 7: Moment coefficient (C_M) of WIG craft model with and without endplates versus ground clearance (h/c) at different angles of attack.

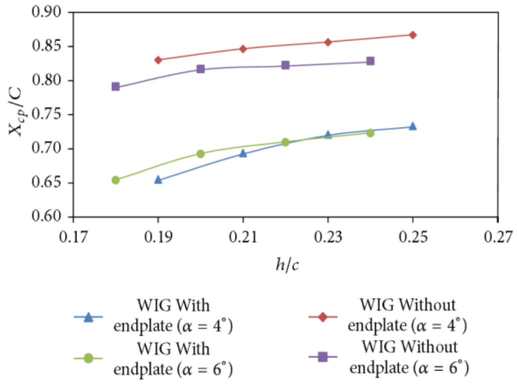

Figure 13: The position of the center of pressure (Xcp/C)of WIG craft model with and without endplates versus ground clearance (h/c) at different angles of attack.

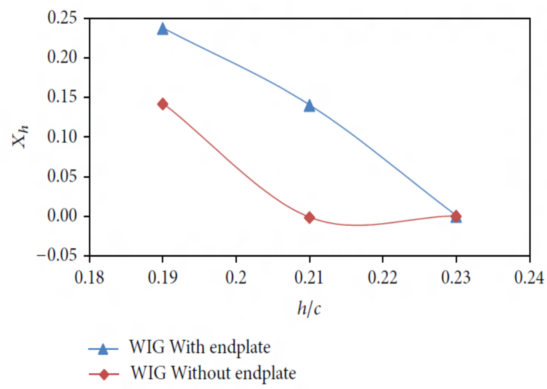

Figure 14: Height of aerodynamic center (X_h) of WIG craft model with and without endplates versus ground clearance (h/c) at angle of attack of 4°.

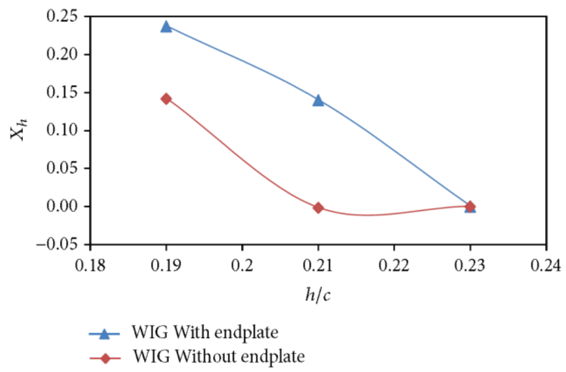

Figure 15: Pitch aerodynamic center (Xα) of WIG craft model with and without endplates versus ground clearance (h/c) at angle of attack of 4^0

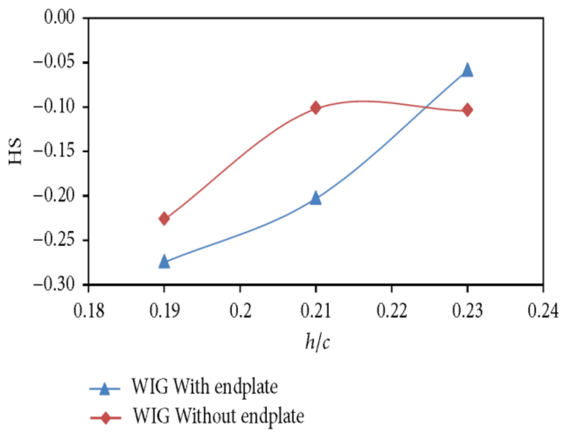

Figure 16: Height of static stability (HS) of WIG craft model with and without endplates versus ground clearance (h/c) at angle of attack of 4^0.

5. Conclusion

This study experimentally investigated the aerodynamic characteristics of a WIG craft model with a new configuration of a compound wing. Effect of endplates on the craft aerodynamic characteristics was studied and it was found that endplates increase the lift and drag ratio of the WIG craft model. Finally, The aerodynamic performance of the new design was investigated by wind tunnel tests and aerodynamic coefficients are presented for the new design.

(iii) The static stability of the new design was investigated and it was found that the new design is statically stable enough.

6. Nomenclature

c: Chordlength

C_L: Lift coefficient

C_D: Drag coefficient

C_M: Momentcoefficient

D: Drag force

h: Height of trailing edge above the ground

h/c: Ground clearance

HS: Height of static actability

L: Liftforce

L/D: Lift-to-drag ratio

S: Planformareaofwing

Xcp: Center of pressure

U: Freestreamvelocity

α: Angle of attack, geometric angle of incidence

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