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Design and Computational Analysis of Y-tail Configuration for Maritime Unmanned Aerial Vehicle

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Abstract

This Research article discusses the Tail design of a Maritime Unmanned Aerial Vehicle (UAV). These vehicles are used in marine environment for surveillance and monitoring of ships and coastal areas. The objective is to design a tail with less drag and more stability. The tail components are designed considering the wing, avionics and winglets. The analysis and correlations are made to find the most suitable tail configuration with vertical tail volume of 0.845, with respect to the wing configuration for better results. The Y-tail configuration provides more directional stability at a higher angle of attack with less interference drag. It is concluded that Y-tail provides the C_L range from 0.595 to 1.157 for the conditions raised with different angles of attack and different velocities, and it allows for maximum maneuverability and better aerodynamic characteristics than other tails which are compared here.

Keywords: Y-tail; Maritime UAV; Coefficient of lift; Directional Stability; Interference Drag; Angle of attack

1. Introduction

UAVs (Unmanned Aerial Vehicles) and UASs (Unmanned Aircraft Systems) have been in use for several decades, primarily for military and surveillance purposes. Some early examples of UAVs include the Ryan Firebee, which was used by the US military in the 1950s for reconnaissance missions, and the Teledyne Ryan Model 147, which was used for reconnaissance during the Vietnam War. In the 1980s, UAVs began to be used for civilian applications such as atmospheric research and wildlife tracking. In the 1990s, UAVs were used by various countries for reconnaissance and surveillance operations, and in the 2000s, UAVs began to be used more extensively for military operations. UASs have been used for various purposes such as aerial photography, mapping, and agriculture for several decades. UASs have been used for crop monitoring and crop spraying, and also for search and rescue, and wildlife tracking. Recently, UAVs and UASs have been increasingly used in civilian applications such as package delivery, search and rescue, and inspection of infrastructure such as power lines, pipelines and bridges.

Drones cover a wide variety of aerial vehicles that do not necessarily need a human pilot and include the classifications like unmanned aerial vehicles which are used extensively these days and is possessing more range than the small drones which fly in confined premises [1]. The relevancy of drones comes into the picture in situations where human beings cannot intervene directly, dangerous or inaccessible to reach [2, 3]. The time has changed from where drones were popularly known for spying, surveillance, and military purposes to the usage of drones in civilian purposes like transportation of goods, photography, etc. based upon their capabilities, characteristics, and flight endurance [4]. The foremost function of a drone includes search and rescue which comes under the humanitarian purpose, which includes mapping of cities, surveying, provision of food and non-food items, and delivery of medicines. This function of search and rescue operations transpires in response to the time when wars and spontaneous natural disasters occur and the victims can be located and rescued [5].

Maritime UAVs are used to support a variety of operations in the maritime environment, including maritime surveillance, search and rescue, and maritime security. Maritime surveillance is a critical function in the maritime environment, and UAVs can be used to detect and track ships, monitor illegal activities such as smuggling and piracy, and support search and rescue operations. UAVs can cover large areas of ocean quickly and efficiently, and provide real-time information to maritime operators. Maritime search and rescue is another important application for UAVs. UAVs can be used to quickly locate survivors in the water and provide them with life-saving supplies. They can also be used to search for missing vessels and people, and to provide information to search and rescue teams.

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The current paper focuses on the design of a tail for a maritime UAV. The tail or empennage of an aircraft consists of the horizontal stabilizer and the vertical stabilizers, which are in some or other way or present in every aircraft. In the Wright Brother's Wright Flyer I used 3-axis control i.e. pitch, yaw, and roll. The roll was achieved by wing wrapping, which was basically changing the wing configuration to produce varying lifts. The yaw was achieved by the rudder, which was hinged on the vertical stabilizer of the aircraft. It is good against the torque of the engine as it provides lateral stability. The horizontal stabilizer provides longitudinal stability against the moments produced by the difference in the center of pressure and center of gravity of the aircraft as well as provides space to mount the actuation system for altering the pitch of the aircraft i.e. elevator [6]. There are different types of tails that are currently being used such as the conventional tail, T-tail, H-tail, V-tail, and Y-tail. The conventional tail is mostly used because it is easy and economical to manufacture, is very difficult to stall and convenient to perform all the tail functions. But the conventional tail is directly In line with the wing downwash and is affected by it [6]. Spin characteristics can be bad due to the blanketing of the vertical tailplane. And it also has side slip, more drag, and yaw instability [7]. There are only 2 joint surfaces in the V-tail that reduces the drag, and provides the great stability and control with least wetted area, but V-tail loses its aerodynamic performance when the sideslip angle increases, the fuselage must be longer to prevent snaking, and since it does not have a rudder, the directional control will be difficult [8, 9, 10]. H-tail shows more redundancy because of two vertical stabilizers, and it is affected with less downwash from the wing and fuselage. And the turbulent flow from the fuselage is also not affected by the H-tail. But it experiences more drag due to propeller wash as it is behind the propeller wake. And the twin boom that is connected, it will eventually increase the weight [6, 8, 11, 12]. The T-tail is better in aerodynamic performances, but its complexity and cost makes it less adaptable and the condition of deep stall is a giant disadvantage for the T-tail [6, 11, 12, 13, 14, 15]. Because of the mentioned disadvantages of the conventional tail, V-tail, T-tail and H-tail, these tails are not suitable for use.

1.1. Y-tail

A Y-tail is a type of tail design found on some aircraft, where the horizontal stabilizer is split into two separate sections, resembling the letter "Y." The Y-tail design is intended to provide improved stability and control for the aircraft, and can be found on a variety of different types of aircraft, including jets and turboprops. The performance of Y-tails is generally affected by dihedral and vertical stub spans [16]. The rudder allows for more yaw control, reducing the complexity of ruddervators in the V-tail while reducing the interference drag compared to the conventional tail [16]. From the structure of the Y-tail it's lucid that the Y-tail structure is a V-tail attached with a rudder to the rear side. The attachment of the rudder to the V-tail forms the Y-tail which increases the yaw stability. Y-tail limits the drag formation as that of the V-tail.

And this tail is easy to control as it requires the least control power in longitudinal and directional axis and the aerodynamic performances are much superior in Y-tail. Thus, it can be summarized that the Y-tail is the best befitting for the project [17]. For the horizontal stabilizer, NACA 2412 airfoil is used. For the vertical stabilizer, NACA 0024 is used [39].

Figure 1: Y-tail [40]

1.2. Tables

Table 1: Variation of V_{stall} and V_{max} of different aircrafts for V-tail

V-tail

Aircraft	V_{stall} (km/h)	V_{max} (km/h)	Reference
Antonov 181	-	820	[18]
Antonov A-11	60	350	[19]
Antonov A-13	70	350	[20]
Antonov A-15	55	250	[18]
Ameur Altania	65	287	[21]
Beechcraft Bonansa S 35	100	370.77	[22, 23]
Fouge Cm 170 Magister	157	715	[24]

Table 2: Variation of V_{stall} and V_{max} of different aircrafts for Y-tail

Y-tail

Aircraft	V_{stall} (km/h)	V_{max} (km/h)	Reference
Leas Avia Learfan 2100	142	720	[25]
Waiex	64	317	[26]
Xenos B	71	241	[26]
Subsonix	103	463	[26]
Dassault Jet	167	1000	[24]
MQ-9 Reaper	-	482	[27]

Table 3: Variation of V_{max} of different aircrafts for Conventional Tail

Conventional Tail

Aircraft	V_{max} (km/h)	References
Airbus A320	871	-
Airbus A300	833	[36]
Boeing777	945	[37]
Boeing747	939	[38]
Beechcraft A36 Bonanza	360	[24]
Cessna 172	302	[39]

Table 4: Variation of V_{stall} and V_{max} of different aircrafts for T-tail

T-tail

Aircraft	V_{max} (km/h)	V_{stall} (km/h)	References
Dassault Falcon 900	1074.27	158	[32]
Piper Pa-44-180-Seminole	311	109	[32]
Grob G-109	240	73	[24]
BAE 146	912.51	154	[24]
Antonov An-72	700	-	[33]
Antonov An-74	700	-	[33]
Hawker 400	866	171	[34,35]

Table 5: Variation of V_{max} of different aircrafts for H-tail

H-tail

Aircraft	V_{max} (km/h)	References
Consolidated B-24	478	[28]
B-25 Mitchell	438	[29]
Avro Lancaster	454	[30]
Handley Page Halihax	454	[30]
Petlyakov Pe-2	580	[31]

2. Calculations

Optimum tail arm length $l = l_{\mathrm{opt}} = K_c\sqrt{\frac{4\overline{C}S\overline{V}_{\mathrm{H}}}{\pi D_f}}$

Horizontal tail volume coefficient: $\overline{V}_{\mathrm{H}} = \frac{l}{\overline{C}}\frac{S_{\mathrm{h}}}{S}$

Aspect ratio of horizontal tail: $\mathrm{AR}_{\mathrm{h}} = \frac{2}{3}\mathrm{AR}_{\mathrm{w}}$

Taper ratio of horizontal tail: $\lambda_{\mathrm{h}} = \frac{C_{\mathrm{h_{tip}}}}{C_{\mathrm{h_{root}}}}$

Vertical tail volume coefficient: $\overline{V}_{\mathrm{v}} = \frac{l_{\mathrm{v}}S_{\mathrm{v}}}{bS}$

Vertical tail area: $S_{\mathrm{v}} = \frac{b \cdot S \cdot \overline{V}_{\mathrm{v}}}{l_{\mathrm{v}}}$

Optimum Tail moment arm: $l_{\mathrm{opt}} = K_c\sqrt{\frac{4\overline{C}S\overline{V}_{\mathrm{H}}}{\pi D_f}}$

Table 6: The values of different parameters are provided after calculations from the given formulas. Here, vertical tail volume coefficient ($\bar{v}_v$), reference area (S), optimum tail moment arm ($lopt$), mean aerodynamic chord ($\bar{C}$), fuselage diameter (D_f), length of the fuselage (L_f), tail arm (L_t), aspect ratio (A_R), height (H), vertical tail sweep angle (Λ_V), aerodynamic pitching moment coefficient (C_M), and vertical tail dihedral angle (Γ_v) are given.

$\bar{v}_v$	0.4	L_f	165cm
S	0.549 m^2	L_t	105 cm
Kc	1	A_R	2
S_v	0.1568 m^2	**H**	56 cm
$lopt$	0.4804 m	Λ_V	6.11
$\bar{C}$	12.21 cm	C_M	0.4957
D_f	16cm	Γ_v	45

3. Computational Analysis

With a reference area of 0.549 m^2, the vertical tail volume coefficient is 0.4. According to calculations, the vertical tail area is 0.1568 m^2, the optimum tail moment arm is 0.4804 m, the mean aerodynamic chord is 12.21 cm, the fuselage diameter is 16 cm, the length of the fuselage is 165 cm, the tail arm is 105 cm, the aspect ratio is 2, the height is 56 cm, the vertical tail sweep angle is 6.11, the aerodynamic pitching moment coefficient is 0.4957, and the vertical tail dihedral angle is 45 cm. The NACA2412 airfoil is chosen which gives C_{Lmax} of 1.3 at 12° angle of attach at Reynolds number 10^5. The analysis is done with velocity of 10m/s and angle of attack of 0°, 3° and 5°. It is done with the wing attached to get the accurate result. The ANSYS Fluent solver is used with k-epsilon omega 2 model.

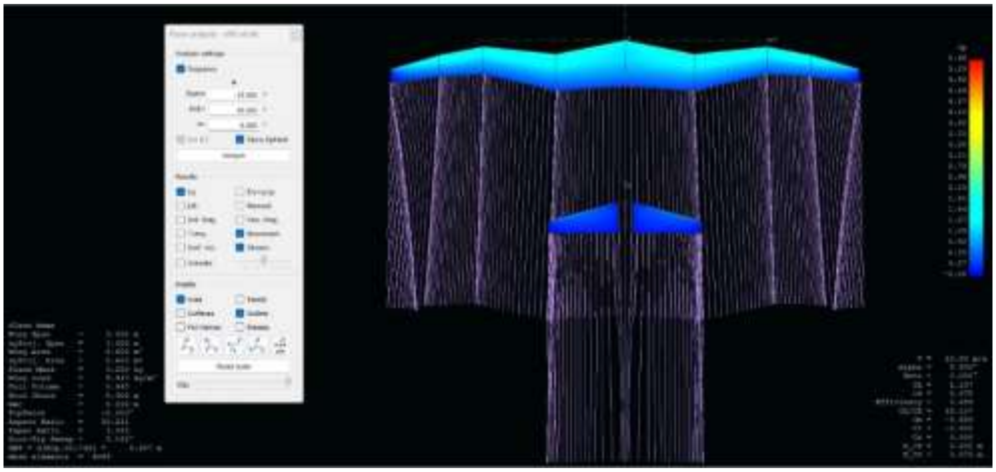

Figure 2: Depicts the coefficient of pressure for the particular tail with the volume of 0.845 and angle of attack given is 5.5 degree with a coefficient of lift and drag to be 1.157 and 0.07 respectively with a velocity of 10.00m/s. So here the C_p value as per the analysis comes out to be in between -0.00 and 0.27 throughout the tail part. The tip, the leading edges and the edges of the tail showcase the C_p value of -0.00 as per the diagram shown above. The equi distance between leading edge and the tip exhibit the C_P value of 0.27. In closing the tail depicted here manifest more directional stability and less interference drag.

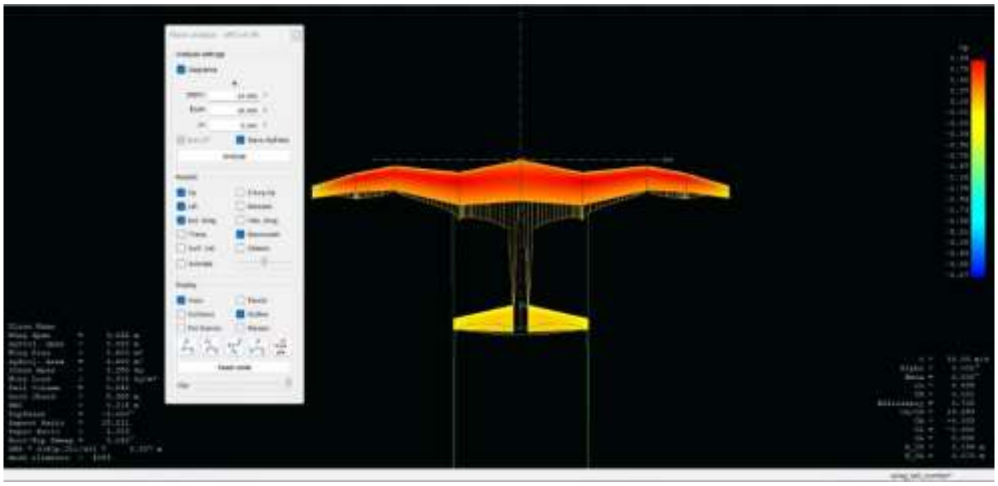

Figure 3: Figure shows that, as the boundary layer over the stabilizer continues to thicken due to the increasing unfavourable pressure gradient, flow separation over the rudder may happen. When sideslip angles are greater, separation increases in front of the rudder hinge, which contrasts with the supplied picture's constant slope and decreases side force versus incidence.

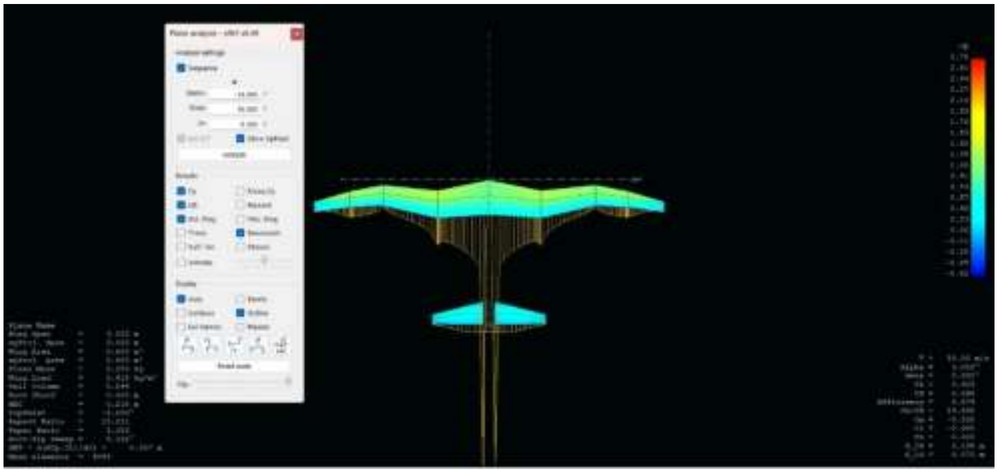

Figure 4: Delineate the coefficient of pressure value between 0.06 and 0.4 with the input concerns of velocity 10 m/s ,angle of attack 3°,and the coefficient of lift and drag feed in is 0.903 and 0.046 respectively with the efficiency of 0.674. Here, the axis x, y and z convey the paddock encircling the design. Indubitably the Y-tail configuration debuted over here satisfied all the objective that has been stated so far.

4. Result and Discussion

Table 7: The coefficient of lift (C_L), coefficient of drag (C_D), coefficient of induced drag (C_{Di}), and moment coefficient (C_M) is measured for the Y-tail discussed here with respect to changing angle of attack (α).

α	C_L	C_{Di}	C_{Dv}	C_D	C_M
-7	-0.13004	0.001722	0.066246	0.067968	0.11458
-6.5	-0.07826	0.001149	0.06005	0.061199	0.083516
-6	-0.02644	0.000759	0.053998	0.054757	0.051948
-5.5	0.025404	0.000553	0.049134	0.049687	0.02021
-5	0.077277	0.000531	0.045099	0.045631	-0.01152
-4.5	0.129165	0.000695	0.041152	0.041847	-0.04348
-4	0.181059	0.001043	0.037443	0.038486	-0.07549
-3.5	0.23295	0.001578	0.034013	0.035591	-0.10752
-3	0.28483	0.002298	0.0307	0.032998	-0.13961
-2.5	0.33669	0.003205	0.028049	0.031254	-0.17178
-2	0.388521	0.004297	0.025643	0.02994	-0.20399
-1.5	0.440314	0.005575	0.023348	0.028923	-0.23626
-1	0.492061	0.007039	0.022023	0.029062	-0.26856
-0.5	0.543752	0.008687	0.021	0.029687	-0.3009
0	0.595379	0.01052	0.020403	0.030923	-0.33324
0.5	0.646933	0.012535	0.020123	0.032659	-0.36561
1	0.698406	0.014734	0.019937	0.034671	-0.398
1.5	0.749788	0.017113	0.020023	0.037137	-0.4304
2	0.80107	0.019673	0.02023	0.039904	-0.46279
2.5	0.852246	0.022412	0.020535	0.042947	-0.49516
3	0.903304	0.025328	0.021001	0.046329	-0.52751
3.5	0.954238	0.028419	0.021539	0.049958	-0.55982
4	1.005039	0.031685	0.022131	0.053816	-0.59209
4.5	1.055698	0.035122	0.023869	0.058991	-0.62433
5	1.106206	0.038729	0.02539	0.064119	-0.65651
5.5	1.156556	0.042505	0.029301	0.071806	-0.68871

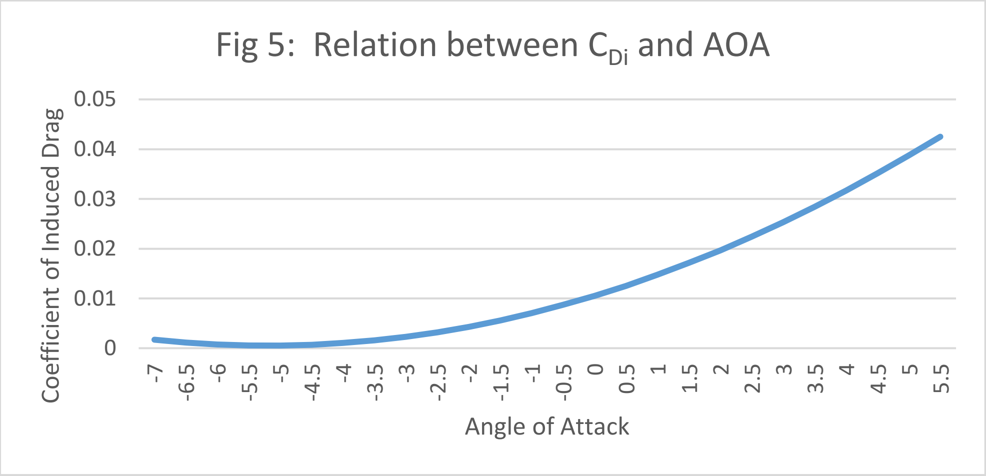

Figure 5: The relation between coefficient of induced drag and angle of attack is found through analysis at 300K and 1.225 kg/m^3. It is found that the C_{Di} is twice at 5 AoA when compared to 2 AoA

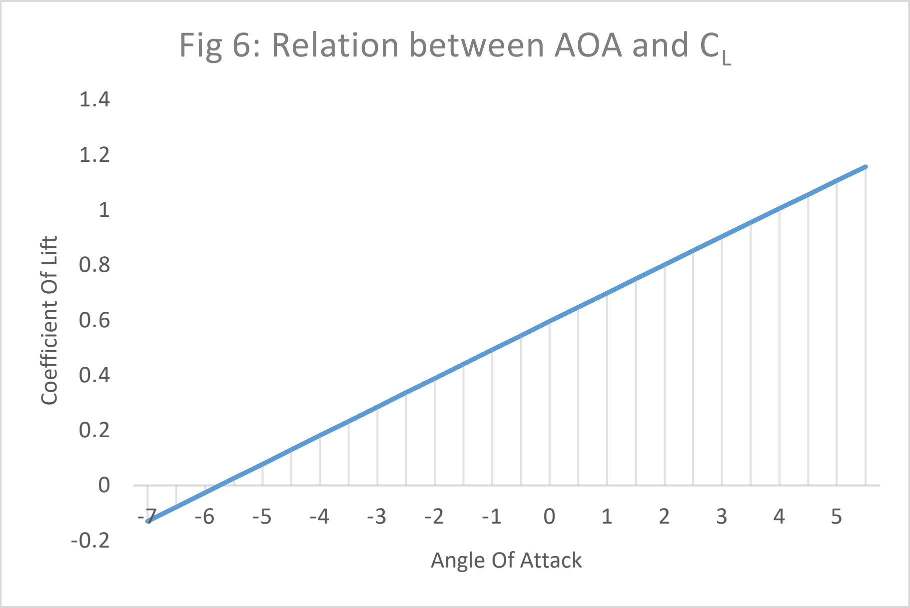

Figure 6: The relationship between angle of attack and coefficient of lift is plotted from the analysis results at 300 K and 1.225 kg/m^3. It is shown that the coefficient of lift increases uniformly with increase in angle of attack.

Conclusion

The tail that is analyzed and created here is a Y-tail having aforementioned specifications. The comparisons are carried out considering the vehicle as a whole by taking references from different articles and books. The tail sections which are compared are V-tail, Y-tail, H-tail, T-tail, and conventional tail. NACA2412 is used for the horizontal stabilizer. The reason of choosing NACA2412 airfoil is that it helps in more lift generation then other airfoils series which are compared in the experimental studies. It causes the reduction of the movement of control surfaces and the considerable advantage of this airfoil selection is that, this airfoil generates lift even at negative angle of attack and this increases the aerodynamic characteristics. NACA 0024 is used for the vertical stabilizer. Here no lift is produced and for the vertical stabilizer being an important consideration as Y-tail configuration is taken which resembles a V-tail fixed with a rudder. So it's important to control the motion of the vertical stabilizer, and it's accomplished by NACA 0024 as it is a symmetric airfoil. It is easy to manufacture and able to withstand the environment of the sea. The finding here are that the V-tail and Y-tail are the best possible options available. But when the sideslip angle increases for the V-tail it makes it less adaptable i.e. the aerodynamic performances of the V-tail gets reduced in this scenario. But the Y-tail improves the yaw stability and provides better maneuverability. The design of the Y-tail is made by doing the calculations and found the parameters needed for the manufacturing of the tail. Analysis is carried out with angles of attack from 0° to 5° and velocity 10 m/s satisfying the requirements and validating the comparisons. The exact dimensions of the Y-tail are found from the formulas taken from different books and papers. With the advancements in technology, maritime UAVs are becoming increasingly autonomous and able to operate in harsh weather conditions, making them a valuable tool for maritime operations. The results obtained are completely novel and work of the mentioned authors.

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