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ESTIMATION OF PITCHING MOMENT OF A HYBRID LIFTING FUSELAGE - DISGUISED AS HULL OF AN AIRSHIP

Anwar Ul Haque[1], Waqar Asrar[1], Ashraf Ali Omar[2], Erwin Sulaeman[1] and JS Mohamed Ali[1]
[1]Department of Mechanical Engineering, International Islamic University Malaysia, Kuala Lumpur, Malaysia
[2]Department of Aeronautical Engineering, University of Tripoli, Libya
E-Mail: waqar@iium.edu.my

ABSTRACT

Munk-Multhop's method is usually used for estimation of pitching moment of fuselage of conventional aircraft but application of the same for hybrid lifting fuselage had not been earlier explored. CFD methods can also be applied for the said purpose but it is difficult to separate out the portion of the moment caused by the fuselage, since the wing and fuselage affect each other. In the present work, a hull disguised as hybrid lifting fuselage of a hybrid buoyant aircraft was taken as a test case. Slope of the pitching moment obtained from the Munk-Multhop's method was further corrected to account for the effect of slenderness ratio. Good agreement of results was found after defining the camber profile of the hybrid lifting fuselage and applying the said correction. The location of the wing relative to the fuselage and lift curve slope of wings has a dominant role in estimation of pitching moment coefficient of the fuselage.

Keywords: munk-multhop's method, zero lift pitching moment coefficient, pitching moment coefficient, hybrid lifting hull.

INTRODUCTION

The concept of hybrid lifting fuselage is derived from lighter than air aircraft (LTA), which get aerostatic lift due to buoyancy effect of lifting gas and aerodynamic lift generated by the aerodynamic profile of fuselage. The static longitudinal stability characteristics of airships is estimated by applying the methods either derived from the wind tunnel testing or by using the potential flow theory. Results of previous work related to stability analysis of airships (Acanfora and Lecce, 2011; Moutinho and Azinheira, 2005; Wang, 2012) have shown that static stability criteria for aircrafts is not applicable for airships. This is perhaps due to the fact that airships donat have a wing attracted to it and that is the reason the airships do not have negative value of slope of the pitching moment coefficient as function of angle of attack, (Carichner and Nicolai, 2013). Due to the absence of a comprehensive databank of (A&S) parameters, advanced design and analysis methods for such aircrafts are not yet fully established. In this regard an analytical effort was done in present research work to use computational fluid dynamics and low fidility tools to evaluate the applicability of Munk-Multhop's method. For hybrid lifting hull with small wings attached to it; analytical relationship of pitching moment coefficient of fuselage at zero lift, and the slope of the pitching moment coefficient as function of angle of attack are shown below as Equation. (1), taken from reference (Gudmundsson, 2013) and Equation. (2), derived from the Munk-Multhop's method to cater the effect of the shape, respectively. These equations contain the constant 36.5, which facilitate the conversion of the angle (α_{ZL_W}, i_f) and slope $C_{L_{\alpha_w}}$ from per radian to per degree, respectively.

$$C_{mo_{fus}} = \frac{k_2 - k_1}{36.5.S_{ref}.C_{ref}} \sum_{x=o}^{x=l_{fus}} w_f^2 (\alpha_{ZL_W} + i_f)\Delta x \quad (1)$$

$$C_{m\alpha_{fus}} = \frac{1}{36.5 S_{ref} C_{MGC}} \left[\frac{C_{L_{\alpha_w}}}{0.0785} \int_0^{l_{f\,front}} w_f^2 \left(\frac{d\beta_{front}}{d\alpha}(x) \right)_{front} dx + \int_{l_{f\,back}+C_R}^{l_{f\,back}} w_f^2 \left(\frac{d\bar{\beta}_{back}}{d\alpha}(x) \right)_{back} dx \right] \quad (2)$$

In Equation. (1-2), terms C_{ref} and S_{ref} are the reference dimensions for the chord length and reference area, respectively. Complete derivation of Equation. 2 is beyond the scope of this work. It is important to note that in Equation. (2) the wing lift curve slope $C_{L_{\alpha_w}}$ is in per degree; allowing the use of $C_{L_{\alpha_w}}$ in per degree. $\left(\frac{d\beta_{front}}{d\alpha}(x) \right)_{front}$ and $\left(\frac{d\bar{\beta}_{back}}{d\alpha}(x) \right)_{back}$ are upwash gradient before the wind and downwash gradient after the wing, respectively. The integrals in Equation (2) can be solved by using Simpson's rule or any other quadrature formula. Equation. (1-2) are now applied on a generic model of hybrid lifting hull of the hybrid buoyant aircraft.

MATERIALS AND METHODS

Fuselage used in the present study was taken from a recent work by reference (Haque *et al.* 2014), which has fineness ratio equal to 5.5 and internal volume of 535 m^3. Profile was obtained by using standard airfoils Eppler-1200 and S-1016 till 80 percent of chord length i.e.

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in side view, this lifting hull has a shape of Eppler-1200 airfoil and it is S-1016 as the top/plan view. The extended version of Munk-Multhop's method (Equation. (1-2)) was then applied which accounts for the effect of wing upwash and its downwash effects. Figure-1 shows the major dimensions of the fuselage used in the numerical integration work. The fuselage was divided into 13 planes in lateral direction and slices their mid sections as are shown in the Figure-2.

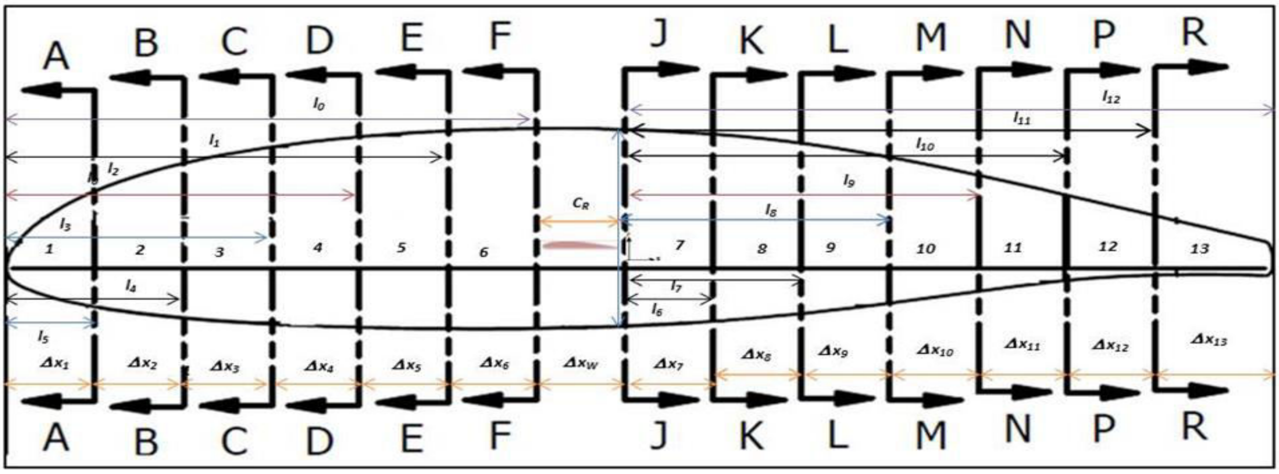

Figure-1. Implementation of Munk-Multhop method for estimating the $C_{mo_{fus}}$ and $C_{m\alpha_{fus}}$.

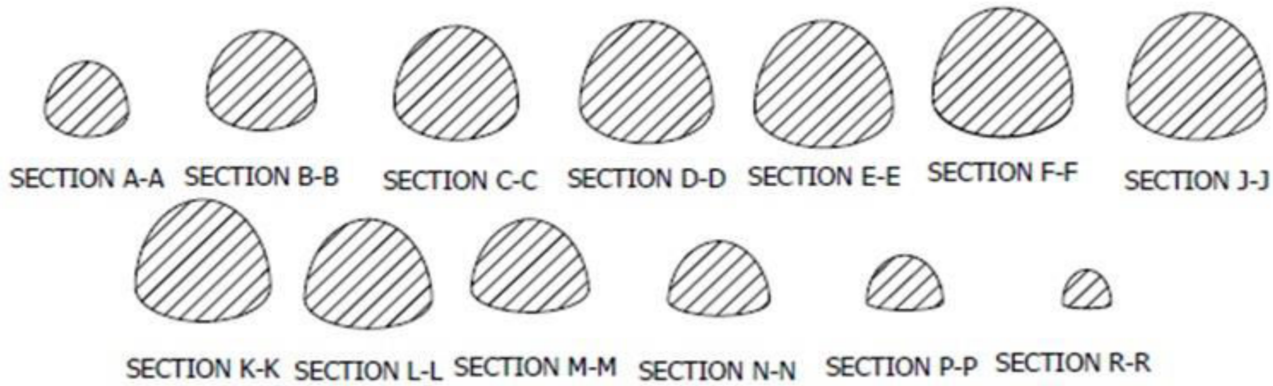

Figure-2. Mid-sectional view of the fuselage of hybrid lifting hull.

Nose of the fuselage was defined as the datum/reference point. Sign convention used to define i_f is the same as that used in reference (Gudmundsson, 2013), Figure-3. Effect of $C_{L_{\alpha_w}}$ was included by estimating its valve using XFLR software. Although the geometry of the fuselage was also modeled alongwith with that of the wing; but due to known constrains of modeling, this analytical tool could not predict the aerodynamic forces acting on the voluminous fuselage. Therefore, only the wing was considered here for the analysis work and for cruise flight condition; $C_{L_{\alpha_w}}$ was estimated to be equal to 0.093 (/degree) and is shown here as Figure-4. *ANSYS-FLUENT*, a commercial CFD analysis software was used to obtain the aerodynamic properties of the fuselage. Numerical simulations were run by employing the Menter Shear Stress Transport (MSST) turbulence model for cruise velocity, V_{cruise} equal to 100 km/hr. No-slip wall condition is employed at the surface of the fuselage.

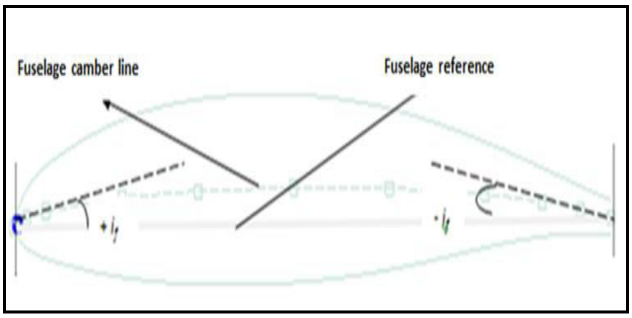

Figure-3. Fuselage camber incidence angle, i_f .

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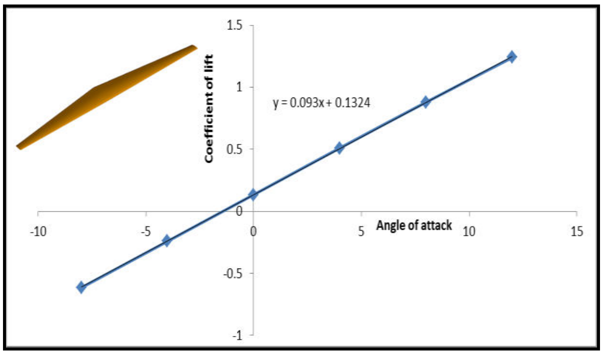
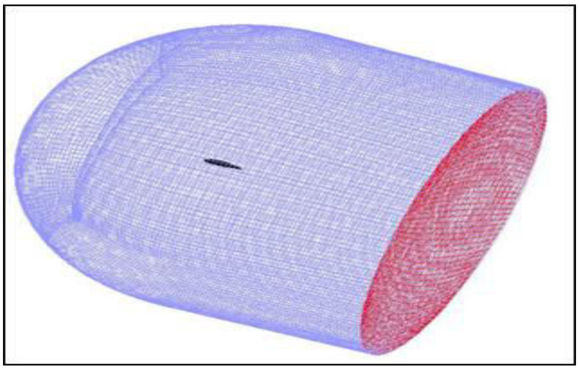
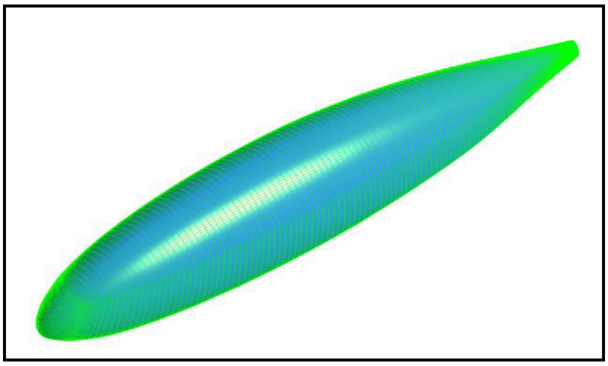


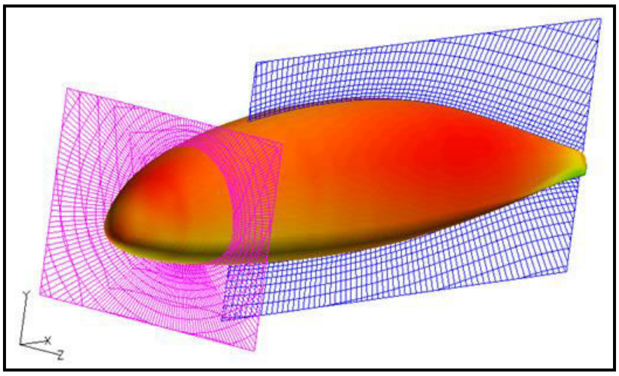
Figure-4. Plot to get the slope of $C_{L_{\alpha_w}}$.



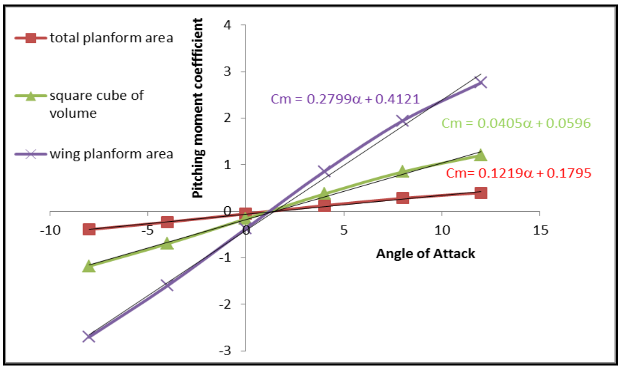
(a) Computational Grid.



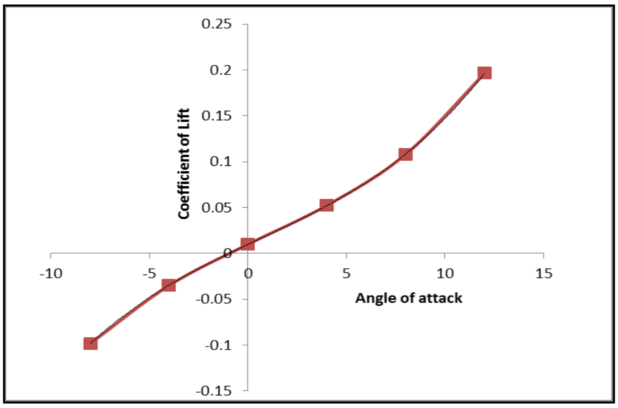
(b)Surface Grid.



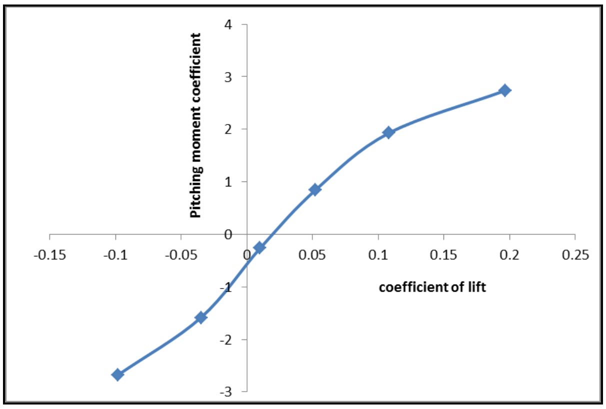
(c) Sectional view of the grid and contours of total prssure on the surface of fuselage.



(d) Variation in pitching moment coefficient of fuselage with different reference areas.



(e) Trendline of lift produced by the lifting fuselage.



(f) Plot used to find the $C_{m_{o\,fus}}$ (/degree).

Figure-5. CFD results of fuselage alone case at V=100 km/hr (Haque *et al.* 2015).

In the simulation work, steady-state condition is considered and a pressure-based solver; SIMPLEC was used. The C-O computational grid type used in this numerical work is shown in Figure-5(a) and surface grid is given in Figure-5(b). Fully structured grid is generated so that the flow is aligned with the grid. Sectional views of the grid are shown in Figure-5(c). Grid independence study was also carried out by changing the number of grid points in the circumferential and axial direction. Grid

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skewness was also checked before defining the properties of the boundary conditions. $C_{m_{\alpha\,fus}}$ was estimated for different available options of reference area (S_{ref}) and it was found that slope of $C_{m_{\alpha\,fus}}$ decreases with increase in its value, Figure-5(d). For the present study, similar to conventional aircraft (S_{ref}) was taken equal to the total platform area of wing, equal to 27.75 m^2. $C_{L_{\alpha\,fus}}$ was also plotted as Figure-5(e) which was further utilized to get the plot of C_m vs C_L . Plot shown in Figure-5(f) had provided the value of $C_{m_{o\,fus}}$ equal to -0.6, where lift becomes equal to zero. Moreover, it can be observed from Table-3 that without correction for slenderness ratio $(k_2 - k_1)$, in comparison with CFD result; the values of $C_{m_{\alpha\,fus}}$ was over predicted by the Munk-Multhop's method. It can be observed from this table that although the CFD work did not include the upwash and downwash effects due to the wing, but overall the results are quite in agreement with those obtained from extended version of Munk-Multhop's method. It is cited in reference that the pitching moment contribution of the fuselage can also be approximated by Equation. (3), taken from a NACA Reprt (Gilruth and White, 1941). In this relationship; W_f is the maximum width of the fuselage and L_f is the length. Figure (16.14) of reference (Raymer, 2012) provides the empirical pitching moment factor K_f.

$$C_{m_{\alpha_{fus}}} = \frac{K_f W^2{}_f L_f}{C S_w}, per\,deg \tag{3}$$

$C_{m_{\alpha\,fus}}$ value obtained by using Equation. (2) for lifting fuselage under study was almost double than that predicted by CFD and Munk-Multhop's method and its value is equal to 0.47.

Table-1. Implemntation of Munk's Multhop matrix to find $C_{m_{\alpha\,fus}}$ and $C_{m_{o\,fus}}$ for wing location at 18.72 m, including the sensitivity analysis for α_{ZL_W} .

	ID	li	Δx	x_c	w_i	w_{fi}	$\frac{x}{C_{MGC}}$	x	dβ/dα	$w_f^2 \Delta x$	$w_f^2 \frac{\partial\beta}{\partial\alpha}\Delta x$
FRONT FUSLEAGE	0	16.72	1.01	14.95	2.026	1.013	0.225	0.68	1.389	1.03951	1.4440345
	1	14.44	1.52	12.34	3.032	2.529	0.524	1.58	1.289	9.69609	12.4953928
	2	11.58	2.14	7.071	4.284	3.658	1.17	3.53	1.127	28.662	32.2937861
	3	6	2.54	4.799	5.076	4.68	1.989	6	1.031	55.5883	57.3015614
	4	3.53	2.96	3.059	5.916	5.496	3.859	11.64	1.27	89.3494	113.456897
	5	1.58	2.93	1.465	5.858	5.887	5.272	15.9	0.861	101.51	87.3881026
WING	W	0	2.7	2.11	5.4	5.629	6.205	18.72			
BACK FUSELAGE	6	0.76	2.58	-4.5	5.154	5.277	7.46	22.5	0.777	71.761	55.7776023
	7	-5.79	1.53	-6.8	3.056	4.105	8.05	24.28	0.899	25.7484	23.1473148
	8	-7.56	1.08	-9.29	2.16	2.608	8.802	26.55	0.945	7.3458	6.9423461
	9	-9.83	0.74	-11.1	1.48	1.82	9.35	28.2	0.968	2.45118	2.37221595
	10	-11.5	0.48	-12.6	0.962	1.221	9.8	29.56	0.981	0.71709	0.7036661
	11	-12.8	0.39	-13.9	0.778	0.87	10.21	30.78	0.986	0.29443	0.29036247
	12	-14.1	0.26	-14.7	0.52	0.649	10.44	31.5	0.991	0.10951	0.10854935
	13	-14.8						32.5			

	ID	(i_f)	α_{ZL_W}				$(\alpha_{ZL_W} + i_f)$				$w_f^2(\alpha_{ZL_W} + i_f)\Delta x$				$w_f^2(i_f)\Delta x$
			i	ii	iii	iv	i	ii	iii	iv	i	ii	iii	iv	
FRONT FUSLEAGE	0	37	-1.24	-1.9	0.7	0.2	35.76	35.1	37.7	37.2	37.17	36.49	39.2	38.7	38.46184
	1	24	-1.24	-1.9	0.7	0.2	22.76	22.1	24.7	24.2	220.7	214.3	239	235	232.70628
	2	14	-1.24	-1.9	0.7	0.2	12.76	12.1	14.7	14.2	365.7	346.8	421	407	401.26835
	3	6	-1.24	-1.9	0.7	0.2	4.76	4.1	6.7	6.2	264.6	227.9	372	345	333.52975
	4	0.8	-1.24	-1.9	0.7	0.2	-0.44	-1.1	1.5	1	-39.3	-98.3	134	89.3	71.479516
	5	-2.4	-1.24	-1.9	0.7	0.2	-3.64	-4.3	-1.7	-2.2	-369	-436	-173	-223	-243.6232
WING	W	-7.24	-1.24	-1.9	0.7	0.2	-8.48	-9.14	-6.54	-7.04	-725	-782	-560	-602	-619.3909
BACK FUSELAGE	6	-12.7	-1.24	-1.9	0.7	0.2	-13.9	-14.6	-12	-12.5	-1000	-1048	-861	-897	-911.365
	7	-14.6	-1.24	-1.9	0.7	0.2	-15.8	-16.5	-13.9	-14.4	-408	-425	-358	-371	-375.9261
	8	-15	-1.24	-1.9	0.7	0.2	-16.2	-16.9	-14.3	-14.8	-119	-124	-105	-109	-110.187
	9														
	10														
	11														
	12														
	13														

Table-2. $C_{m_{\alpha\,fus}}$ and $C_{m_{o\,fus}}$ for wing at 18.72 m.

	ID	*li*	*Δx*	x_c	w_i	w_{fi}	$\frac{x}{C_{MGC}}$	*x*	dβ/dα	$w_f^2 \Delta x$	$w_f^2 \frac{\partial\beta}{\partial\alpha}\Delta x$
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	5	1.58	2.93	2.145	5.858	5.887	5.272	15.9	0.861	101.51	87.3881026
	6	0.68	2.7	1.35	5.4	5.629	6.205	18.72	0.803	85.5512	68.7156898
WING	W	0	2.58	-4.5	5.154	5.277	7.46	22.5			
BACK FUSELAGE	7	-5.79	1.53	-6.8	3.056	4.105	8.05	24.28	0.899	25.7484	23.1473148
	8	-7.56	1.08	-9.29	2.16	2.608	8.802	26.55	0.945	7.3458	6.9423461
	9	-9.83	0.74	-11.1	1.48	1.82	9.35	28.2	0.968	2.45118	2.37221595
	10	-11.5	0.48	-12.6	0.962	1.221	9.8	29.56	0.981	0.71709	0.7036661
	11	-12.8	0.39	-13.9	0.778	0.87	10.21	30.78	0.986	0.29443	0.29036247
	12	-14.1	0.26	-14.7	0.52	0.649	10.44	31.5	0.991	0.10951	0.10854935
	13	-14.8						32.5			

Table-3. Comparison of results.

wing location	$C_{m_{\alpha\,fus}}$		$C_{m_{o\,fus}}$	
	with correction	without correction	with correction	without correctio n
15.9	0.298	0.247	-0.597	-0.723
22.5	0.3153	0.261		
CFD	0.27		-0.6	

The difference between the CFD and analytical results may not be treated as error because (Multhop. H., 1936) mentioned that "so far based on the comparison study, the Munk's correction for slenderness ratio had little effect on longitudinal motion of fuselage".

But when his theory is applied for the lift producing fuselage than a need is perceived to cater the effect of the slendernss ratio.

The forces and moments due to upwash and down effects of the presented wing have a small influence on the values of $Cm_{o_{fus}}$ and $Cm_{\alpha_{fus}}$, but may have a much greater effect on very large fuselages. Boundary layer separation and vortex flow at aft body are the potential reasons of small difference between the results for $Cm_{o_{fus}}$. For accurate estimation of $Cm_{o_{fus}}$, value of α_{ZL_w} should be defined with accuracy for known value of zero lift angle attack of wing. Based on the comparison of analytical and computational results, correction to account the effect of the slenderness ratio is suggested.

CONCLUSIONS

In this analytical and numerical study, Multhop's method which is based on Munk's work on the pitching moment of airships was evaluated for its potential usage for hybrid lifting fuselage. Correction had been applied in $Cm_{o_{fus}}$ and $Cm_{\alpha_{fus}}$ to account for the effects of fineness ratio. If the correction to account the shape/slenderness ratio effects is not included, then in comparison with CFD results, existing Munk-Multhop's method for conventional aircraft has over-predicted the slope of pitching moment coefficient for a hybrid lifting fuselage.

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