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A REVİSİT TO MUNK-MULTHOPP'S METHOD FOR ESTİMATİNG THE PİTCHİNG MOMENT OF A FUSELAGE İMMERSED İN A HİGH WİNG FLOW

Anwar ul Haque[1]
Center of Excellences in Sciences and Applied Technologies (CESAT), Islamabad, Pakistan

Waqar Asrar[2], Erwin Sulaeman[2]
International Islamic University Malaysia (IIUM), Kuala Lumpur, Malaysia

ABSTRACT

Munk-Multhopp's method; an existing handbook method, derived from the hull of conventional airship of body of revolution is revisited for the estimation of the contribution of fuselage towards the pitching moment for a high wing-fuselage configuration. Due to the absence of full derivation of its analytical relationship of slope of pitching moment coefficient, the correction to account shape effects is uncertain. Aircraft DATCOM is used to obtain the analytical results of the said method on a generic model of wing-fuselage configuration. These results were further correlated with wind tunnel testing of complete configuration along with the individual testing of fuselage and half model of wing. Based on the wind tunnel results and its comparison with Munk-Multhopp's Method; a correction for the slope of the pitching moment is suggested to account for the effect of the slenderness ratio. In order to apply this extended version of Munk-Multhopp's method, the effect of wing upwash and its downwash effects can be obtained by extracting the individual contribution of the wings towards pitching moment from the results of wing-fuselage configuration. Offset in experimental and DATCOM results for zero-lift pitching moment coefficient is observed and most probably it is due to the additional lift generated by the aerodynamic contour of the fuselage.

Keyword: Munk-Multhopp's method, zero lift pitching moment coefficient, slenderness ratio, slope of pitching moment coefficient, wind tunnel testing

[1] Email: ulhaque.anwar@gmail.com

[2] Email: waqar@iium.edu.my

[3] Email: esulaeman@iium.edu.my

NOMENCLATURE

A_R	aspect ratio
Al	aluminum
BMC	balance moment center, *m*
b	wing span, m
c	chord length, m
C_L	coefficient of lift
C_{L_o}	lift coefficient at zero angle of attack
$C_{L_{\alpha_w}}$	lift curve slope of the wing, *(/degree)*
C_D	coefficient of drag
C_{DO}	zero lift drag coefficient
$C_{m\alpha}$	slope of pitching moment of complete aircraft, *(/degree)*
$C_{mo_{fus}}$	value of pitching moment of fuselage corresponding to zero lift condition, *(/degree)*
$C_{m\alpha_{fus}}$	slope of pitching moment of fuselage, *(/degree)*
$C_{m\alpha_w}$	slope of pitching moment of wing, (/degree)
d_{fus}	fuselage diameter
F	fuselage alone case
f	fineness ratio
$LSWT$	Low speed wind tunnel
R_e	Reynolds number
S_{ref}	reference area, m^2
S_w	reference area of wing, m^2
V	velocity, m/s
W	wing alone case
WF	wing fuselage case
w_f	average width of fuselage section
α_{OL}	angle of attack corresponding to zero- lift condition, *degree*

α_{ZLW}	wing zero-lift angle relative to the fuselage reference line, *degree*
λ	fineness ratio
$k_2 - k_1$	correction factor to account for the fuselage slenderness ratio

INTRODUCTION

It is well known that stability and maneuverability of an aircraft are inversely proportional to each other. Low speed aircraft are usually more stable than high speed aircraft but the c.g position has a major influence on the stability and, for instance, the B747 has much greater stability than a Cessna 172. It is well known that the analytical formulations for estimation of static longitudinal stability of aircraft are derived from airships. But they have different criteria and sign conventions. For airships, all moments are referred about the center of volume and in the case of aircraft; it is the center of gravity, [Anderson, 1999]. As per [Carichner and Nicolai, 2013] airships are directionally unstable but aircraft are stable in yaw. Except aerostats, which remain at a fixed location in air, static longitudinal stability criteria applicable for aircraft cannot be used to evaluate the stability responses of airships. This is because an airship's stability is only affected by aerodynamic damping effects and aerostatic lift [Nahon and Sharf, 2011]. Stability of airships can only be analyzed by investigating the dynamic responses about the buoyancy center, [Liu, Hu, and Wu, 2007]. Such analysis work is constrained to small perturbation about the equilibrium flight condition, [Abdul, Arshad and Husaini, (2012), Xi, Xin, Fang, and Kai, (2011), Schmidt and Corporation, (2011), Stockbridge, Ceruti and Marzocca, (2012)]. This also requires non-linear aerodynamics characteristics over a large range of angle of attack and additional acceleration derivatives, [Acanfora and Lecce (2011), Ashraf and Choudhry, (2013), Asrar, Omar, Suleiman and Ali, (2014), Mueller, Paluszek, Zhao, (2004)]. Airships have positive C_{m_α} for moderate angle of attack and its sign changes to negative for very large angle of attack . Therefore, in comparison with low speed aircraft, airship's stability cannot be evaluated by sign conventions of stability derivatives which are applicable for aircraft, [Roskam, 1990].

Based on the experimental findings; [Multhop, 1941] was the first to establish the analytical relationships $C_{m\propto_{fus}}$ and $C_{mo_{fus}}$ from the Munk method of airships. To the authors best knowledge, complete details of the geometric parameters of the model used in his experimental work and accuracy of his results is missing in open literature. Moreover, for the estimation of pitching moment of a high wing-fuselage *(WF)* configuration, no such studies exist and there is a gap of fundamental research in this area. Since the validity or veracity of analytical method under discussion is questionable, then the proper engineering parameters that govern the sizing and stability analysis cannot be reliably executed in any detail conceptual design work. Munk-Multhop's method can be applied in future for its application for un-conventional configurations like hybrid lifting fuselage of hybrid buoyant aircraft. In the present study, wind tunnel tests were carried out on high wing-fuselage configuration and results obtained are compared with Munk-Multhopp's technique employed in Aircraft DATCOM by Galbraith, (2010). This software is part of other analysis software like MATLAB and without validation work; any simulation work related to aircraft's longitudinal stability and control for a high wing-fuselage (*WF*) configuration might be inadequate.

METHOD

Fuselage used in the present experimental work is for a generic model of a transport aircraft; which has fineness ratio equal to 7.7, Fig. 1(a). were conducted in IIUM-LSWT; a closed-loop wind tunnel with a test section of dimensions 1.5m × 2.3*m* × 6*m* and maximum speed of 50 *m/s*.

Wing is having chord of length 114 mm and maximum diameter of the fuselage is 130 mm, Fig. 1(b). The span of the wing (*b*) and length of the fuselage (l_{fus}) are equal to 1000 mm. Material used for model manufacturing is *Al* 5054 and unpainted gloss surface finish is obtained by adopting the lapping procedure. The model is supplied to incorporate two-point tunnel interface scheme with main strut and pitching strut that has provisions for mounting at forward or aft body of the fuselage. The whole assembly is rested on tunnel turntable that capable of rotating at 180 degree range. All the moments are referred at the aerodynamic center position of the wing by defining the offset values i.e. shifting the moments from the balance moment centre (BMC) of the tunnel. Data logging system will capture all related parameters including model's six component forces and moments; drag, lift, side force, pitching moment, rolling moment and yawing moment. For the purpose of consistency in the results; all the moment are referred to aerodynamic center of the wing i.e. the quarter chord of the wing whose location is at 435.25 mm from the nose of the apex of the fuselage. For the present study, similar to conventional aircraft S_{ref} is defined here as the total planform area of wing, equal to 0.125 m^2.

(a) Fuselage *(F)* alone testing

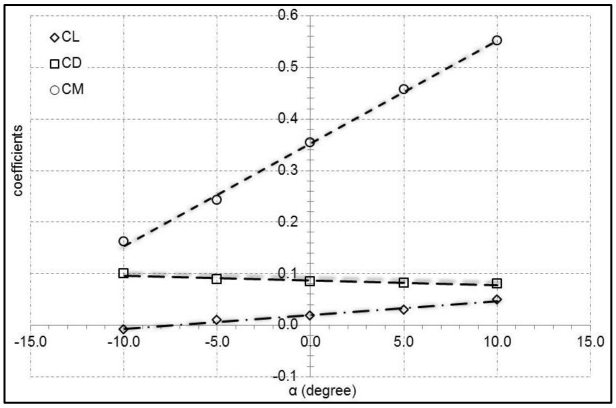
(b) Wing-fuselage *(WF)* testing

Figure 1. Wind tunnel models tested in IIUM wind tunnel

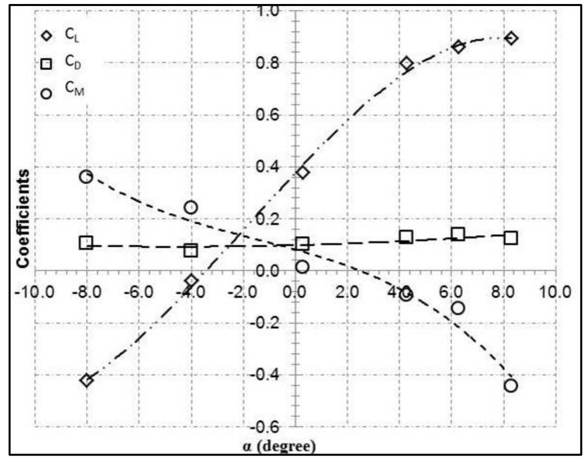
RESULTS

Contribution towards lift and pitching moment of fuselage are estimated by conducting the wind tunnel testing in fuselage alone model, Fig 2(a) and with the wing, Fig 2(b). Results of C_m are further utilized to get the plot of $C_m$vs C_L, which provided a value of $C_{mo_{fus}}$ equal to 0.23 for (*F*) and 0.185 for (*WF*) cases at α_{OL} equal to 6^o and -3.5^o respectively. This shows that the forces and moments due to upwash and down effects of the presented wing have significant influence on the value of $C_{mo_{fus}}$.

The wing alone model tested in IIUM-LSWT is shown in Fig. 3(a) and the results of aerodynamic coefficients are shown in Fig. 3(b). It can be observed that $C_{L_{\alpha_w}}$ obtained from the wind tunnel tests is 3.83 (/rad). A value of 3.9 is typical of tapered wings and 4.2 of elliptical wings for a wing of A_R equal to 4 and $C_{L_{\alpha_w}}$ mentioned in the referred work by Multhopp is 4.5 (/rad) which is quite low for a wing of A_R equal to 8. Due to the manufacturing constraints, effects of variation in $C_{L_{\alpha_w}}$ was not studied.



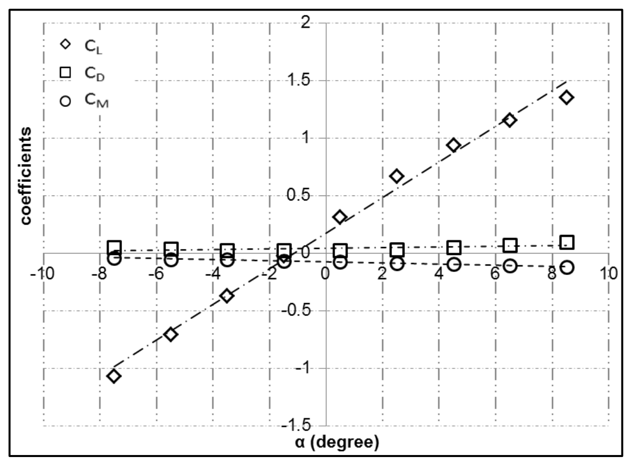
(c) C_L, C_D *and* C_M plots for *(F)* case



(d) C_L, C_D *and* C_M plots for *(WF)* case

Figure 2. Wind Tunnel results of fuselage alone (F) and (WF) cases at V=30 m/s

(a) Half model tested for Wing alone (*W*)

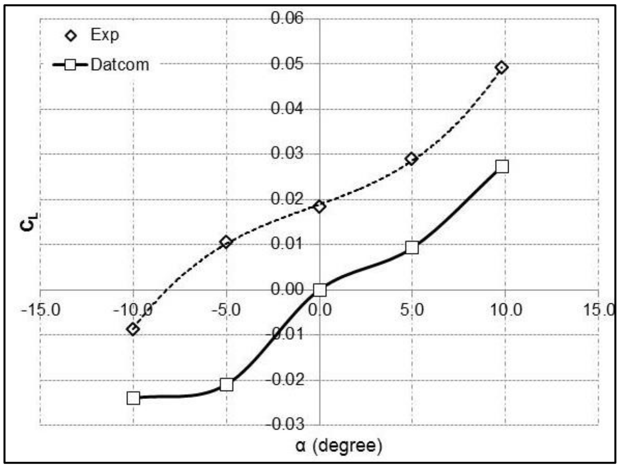


(b) C_L, C_D and C_M plots

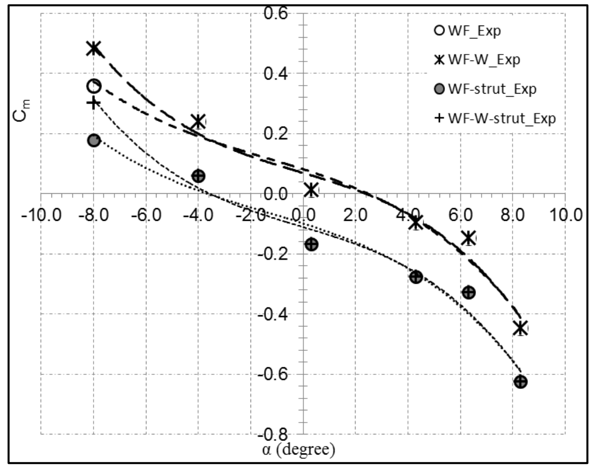
Figure 3. Experimental results obtained from wing (alone) testing at V=30 m/s

Aircraft DATCOM is run to find the contribution of the lift of the fuselage. In comparison with the held experimental data, this standard prediction method of stability for characteristics has under-predicted the lift coefficient, especially at angle of attack equal to zero. It is quite obvious from the general trend from Fig. 4(a) that lift of the fuselage linearly increases. Auxiliary strut for changing angle of attack alongwith main strut is then mounted at a certain distance from the main strut Influence of the main strut on the actual force and moments were measured in IIUM-LSWT at fixed velocity and without giving any α. The obtained from wind tunnel testing is of considerable magnitude and is employed for data correction for C_m, Fig. 4(b). $C_{mo_{fus}}$ value drops from 0.185 to 0.07 after subtracting the effect of the strut (*WF-strut*). Also, the contribution of C_{mo_w} towards $C_{mo_{fus}}$ is also high, Fig. 4(b).

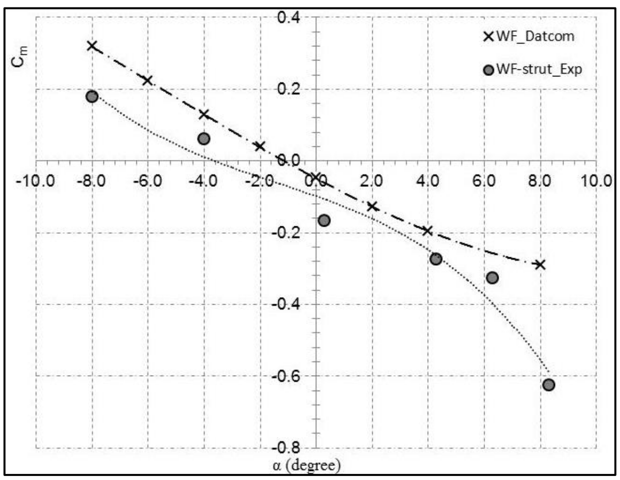
For the purpose of comparison with analytical results; plot of C_m vs α is compared with experimental results. Munk-Multhop's method over predicted the $C_{mo_{fus}}$ as its value is 0.093 as compared with the experimental value of -0.02, Fig. 4(c).



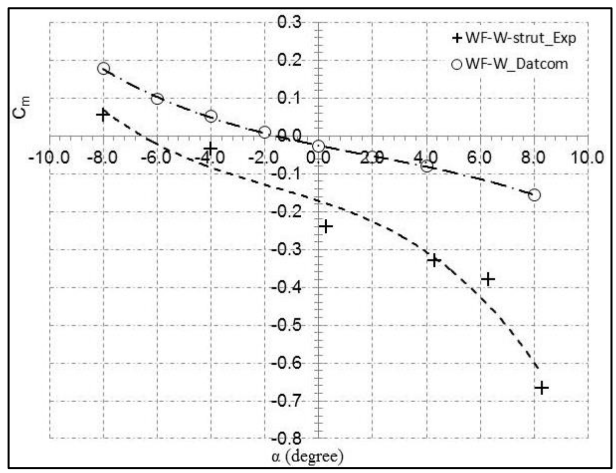
(a) contribution of lift generated by the fuselage



(b) Effect of wing and strut on overall trend of C_m



(c) Comparison of analytical and experimental results for of the fuselage in the presence of wing



(d) Comparison of analytical and experimental results for of the fuselage in the absence of wing

Figure 4. Analytical Results and its Comparison with the experimental results of fuselage alone, wing fuselage and wing fuselage case after subtracting the individual contribution of the wing

In comparison with the experimental results, one of the possible reason of deviation is results is due to the additional lift generated by the aerodynamic profile of the fuselage. Boundary layer profile, specially at the aft body of fuselage can also be the potential reasons of the difference between the results for $C_{mo_{fus}}$. But the analytical method under discussion under predict the slope of the $C_{m\propto_{fus}}$ and its value is equal to -0.023 *(/degree)* against the experimental one of -0.0387, Fig. 4(d). For the experimental data, contribution of C_{m_W} is subtracted from the results of wing fuselage case (*WF-W-strut*). C_{m_W} is estimated by using wind tunnel data of wing alone testing. Analytical results for $C_{m\alpha_{fus}}$ are further corrected to account the effect of fineness ratio by employing the Munk's correction factor of 1.57; calculated against the *f* equal to 7.7. After applying the said correction; $C_{m\propto_{fus}}$ is found to be consistent with the experimental data; value equal to -0.036 *(/degree)*.

Based on the comparison of analytical and computational results, a correction to account for the effect of the slenderness ratio is suggested for its existing form for fuselage of a conventional aircraft with a high wing attached to its upper surface. Since the validity or veracity of analytical method under discussion is questionable, then the proper engineering parameters that govern the sizing and stability analysis cannot be reliably executed in any detail conceptual design work. Therefore, there is a need to rederive the analytical relationships of the slope of pitching moment of fuselage and the corresponding of it at zero lift condition to rule out the possible reason of the absence of shape effects. Furthermore, Munk-Multhop's method can be applied in future for its application for un-conventional configurations like hybrid lifting fuselage of hybrid buoyant aircraft.

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Conclusion

Munk-Multhop's method do includes the effect of a finite fuselage length on the slope of the pitching moment and is based on the assumption that the fuselage is sufficiently long. A correction that accounts for the effect of fineness ratio is incorporated in the analytical formulation for $C_{mo_{fus}}$ On the other side, its absence in the analytical relationship of $C_{m\propto_{fus}}$is due to the negligible effect observed by Multhopp in experiments for mid wing configuration only.Moreover, the sign convention used in Munk-Multhopp's method applies to airships only and the negative sign has to be removed for the equation to be applicable for aircraft. However, if the correction to account the shape/slenderness ratio effects is not included, then in comparison with experimental results, the existing Munk-Multhopp's method for conventional aircraft under-predicts the slope of the pitching moment coefficient of fuselage. Results of $C_{mo_{fus}}$ is also less than the experimental value at the defined flow conditions

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