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WYZNACZANIE POŁOŻENIA ŚRODKA AERODYNAMICZNEGO DLA SAMOLOTU ZE SKRZYDŁEM MAJĄCYM ZAŁAMANIE METODĄ ESDU ORAZ PORÓWNANIE Z WYNIKAMI VLM

Streszczenie: W pracy przedstawiono pewną teoretyczno-empiryczną metodę wyznaczania środka aerodynamicznego płata oraz płata z kadłubem i gondolami w opływie poddźwiękowym. Wykonano przykładowe obliczenia dla testowego samolotu i porównano z wynikami otrzymanymi metodą (VLM).

APPLICATION OF AN ESDU METHOD FOR CALCULATING THE AERODYNAMIC CENTRE OF AIRCRAFT WITH CRANKED WINGS AND COMPARISON WITH VORTEX LATTICE METHOD (VLM)

Summary: A semi-empirical method for calculating the aerodynamic centre (AC) of a wing with cranks and a wing-fuselage-nacelle combination in subsonic flow is presented. Numerical calculations are carried out for a test aircraft and the results are compared with the results obtained by a different but well-known VLM.

РАСЩЕТЫ ПОЛОЖЕНИЯ АЭРОДИНАМИЧЕСКОГО ЦЕНТРА САМОЛЕТА С КРЫЛОМ ИМЕЮЩЕИМ ИЗЛОМЫ КРАЕВ С ПРИМЕНЕНИЕМ МЕТОДА ESDU И СРАВНЕНИЕ С МЕТОДОМ VLM

Резюме. В работе представлено теоретическо-эмпирический метод разсщёта положения аэродинамического центра системы крыло-фюзеляж-гондоля обтекаемой невязким газом с дозвуковыми скоростями. Этот метод позваляет определить аэродинамический центр для крыла с изломами на краях. Результаты полученные им для примерного самолёта были сравниены с итогами полученными с помощю другого метода (VLM).

1. INTRODUCTION

Calculation of the AC or neutral point of aircraft should be done with good accuracy even at the priliminary design stage. The AC is an important parameter for trim, stability and control analysis. A designer has a number of options to regulate its position to attain a desired pitching moment derivative value. Exact determination of the AC is difficult without wind tunnel test, which is obviously a costly and time consuming approach. Nevertheless, the semi-empirical method presented in this paper, primarily based upon ref. 3, gives acceptable results. The remarkably small differences between the results of the proposed method and VLM advocate its acceptibility.

The presented algorithm in this paper may be of great interest for wings with cranks in their leading and trailing edges. In such case the real wing will be replaced by an equivalent or reference wing. The fuselage effect, and then the nacelle effect, are calculated separately. The nacelles may be either wing-pylon mounted or rear fuselage-pylon mounted. Attention should be paid to the application range of the proposed method, which is limited to steady, potential and inviscid subsonic flow only. The subsonic region is again limited by excluding the application of this method for super critical profiles. These limitations among others result from the theoretical basis the method is based on and also the statistical data used in empirical equations. This method is built for untwisted wing with flaps and undercarriage undeployed. The power and ground effects are also not taken in to account. To consider these effects ref. 1 can be recomended.

2. MATHEMATICAL MODEL AND GOVERNING EQUATIONS.

2.1. AC for equivalent wing (EQW) geometry

For constructional, aerodynamical and stability reasons a designer may decide to allow for a wing sweep. On the other hand it should be noted that wing sweep together with low aspect ratio may have a strong effect on the induced three dimensional drag due to lift and in some cases on the wing alone undesirable "pitch up" characterstics. For this reason, among others sometimes wings with cranks (two or more sweeps) are also used. A wing with such a geometry can be replaced by a straight tapered wing named as an EQW or a reference wing (Fig.1). The geometric parametrs needed to define and position an EQW planform are calculated from real wing-fuselage planform geometry [ref. 6].

Once an EQW is defined(eq.1 to eq.7), the lifting force gradient ($a = dc_z/d\alpha$) and relative AC with respect to the mean aerodynamic chord (MAC) leading edge (x/c_a) are found from ESDU 70011 using EQW values of "$A \cdot \tan\Lambda_{1/2}$", "$\beta \cdot A$", and "$\lambda$" where, A- aspect ratio, $\Lambda_{1/2}$- half-chord sweep back angle of EQW planform, β- compressibility factor, $(1 - M^2)^{1/2}$, λ- taper ratio of EQW planform, (c_t / c_0), M- free-stream Mach number, c_t- tip chord of equivalent planform, c_0- centre-line chord of equivalent planform.

$$\tan\Lambda_{1/2} = \sum_{i=1}^{N} (\tan\Lambda_{1,i} - \tan\Lambda_{1,i+1})\left[\frac{s_{1,i} - s_{1,0}}{s - s_{1,0}}\right]^2 + \tan\Lambda_{1,N+1} + \frac{c_t - c_r}{2(s - s_{1,0})} \tag{1}$$

$$c_0 = \frac{s\, c_r - s_{1,0}\, c_t}{s - s_{1,0}} \tag{2}$$

$$c_r = \frac{S_e}{s - s_{1,0}} - c_t \tag{3}$$

$$c_g = c_0 \frac{(1 + \lambda)}{2} \tag{4}$$

$$c_a = 2c_0 \frac{(1 + \lambda + \lambda^2)}{3(1 + \lambda)} \tag{5}$$

$$S = b.c_g \tag{6}$$

$$A = b^2/S \tag{7}$$

where, N- number of cranks in the leading edge, c_g, c_a- geometric and aerodynamic chord of EQW planform respectively, S- area of EQW planform, S_e- area of planform of true wing outside projected fuselage planform.

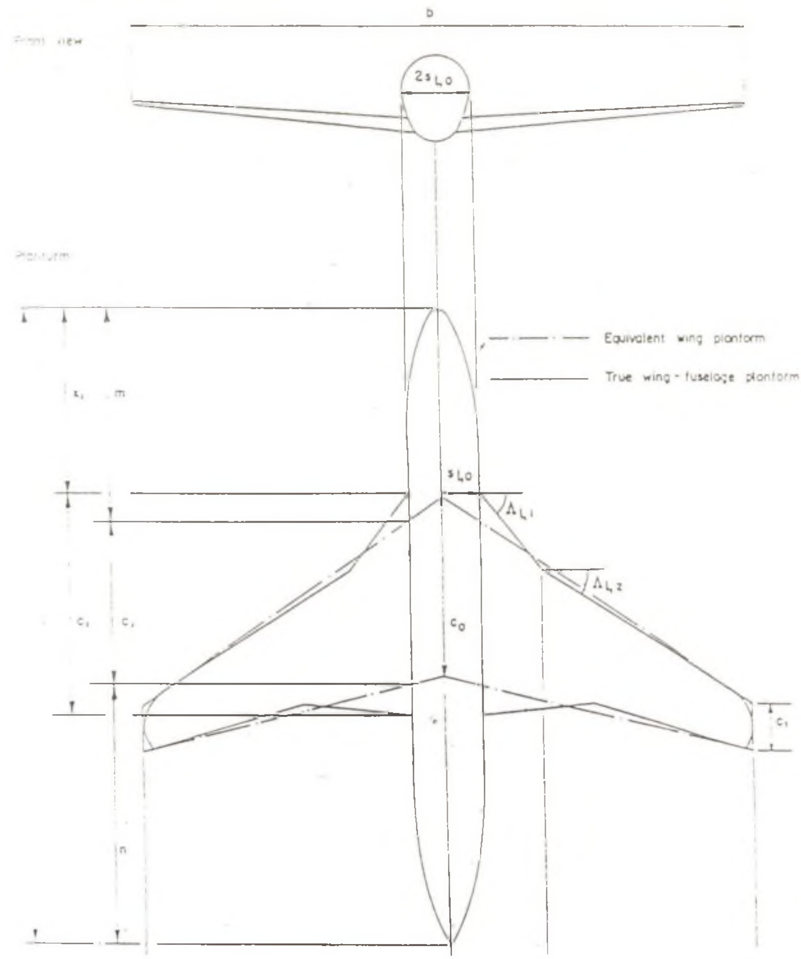

Fig.1. Original and equivalent wing platform
Rys.1. Rzeczywista i zastępcza powierzchnia płata

2.2. Fuselage effect

The fuselage effect ($\Delta x_h/c_a$) on wing AC (x/c_a) can be obtained from ESDU 76015 by the following equation,

$$\frac{\Delta x_h}{c_a} = \frac{c_r\ a^2\ F\ G}{c_a\ a\ S}\left[1 + 0.15\left(\frac{h}{d} - 1\right)\right] - (k_1 + \lambda\ k_2) \tag{8}$$

where $F(m/c_r, n/c_r)$, $G(\beta d/c_r)$, $k_1(d/b, \lambda, \mathrm{Atan}\Lambda_{1/2})$, $k_2(\beta A, \mathrm{Atan}\Lambda_{1/2})$ are obtained from

ESDU 76015,- "d" and "h" are fuselage width and height respectively at the leading edge of root chord (c_r) of EQW planform and "m" , "n" are found from the following equations:

$$m = x_f + \sum_{i=1}^{N} (\tan\Lambda_{1,i} - \tan\Lambda_{1,i+1}) \frac{(s_{1,i} - s_{1,0})\ (s - s_{1,i})}{(s - s_{1,0})} \quad (9)$$

$$n = 1 - m - c_r \quad (10)$$

As a result the AC for wing-fuselage combination (x_h/c_a) is obtained by the equation 11.

$$\frac{x_h}{c_a} = \frac{x}{c_a} - \frac{\Delta x_h}{c_a} \quad (11)$$

2.3. Nacelle effect

The effect of nacelles on the AC is considered for the two cases: 1) effect of wing-pylon mounted nacelles, 2) effect of rear-fuselage pylon mounted nacelles.
For the first case, the forward shift in AC, Δx_n, is calculated from ESDU 77012 by the following eq.

$$\frac{\Delta x_{hn}}{c_a} = \frac{\Sigma\, a_n\, r\, w\, l}{S\, c_a}\left[\frac{1}{a} + \frac{r'\, c_g}{4\, \pi\, R^2}\right] \quad (12)$$

where:
$R^2 = z_n^{\,2} + r'^2$
a_n - lift curve slope of nacelle based on area "w.l" and obtained from ESDU 77012 as a function of "w/l"
r - chordwise distance of nacelle lip forward of AC of wing-fuselage combination
Σ - represents the summation of contributions from each nacelle.
For the second case the rearward shift of the AC caused

$$\frac{-\Delta x_{hn}}{c_a} = \frac{K[\Sigma(a_n\, w\, l) + 6\, y_p^2]\,(1 - 2\, H\, a/\pi\, A)\, r}{S\, a\, c_a} \quad (13)$$

by the nacelles are estimated from ESDU 78013 by eq. 13.

$$\frac{\partial\epsilon}{\partial\alpha} = \frac{2\, h\, a}{\pi\, A} \quad (14)$$

where, H($\tan\Lambda_{1/4}$, r'/s) is a downwash parameter for calculating rate of change of downwash angle with incidence at nacelle inlet plane and centre of trailing vortex sheet as expressed in eq.14, and can be obtained from ESDU 78013,
y_p- width of pylon-leading edge between nacelle and fuselage side, K- is the ratio of lift on nacelle-pylon-fuselage combination to lift on nacelle and pylon on isolation. Acording to ESDU 78013 the value of K = 2.4 has been found to give satisfactory result for classical airplanes.
Now the AC of wing-feselage-nacelle combination is obtained from the following eq.

$$\frac{x_{hn}}{c_a} = \frac{x_h}{c_a} - \frac{\Delta x_{hn}}{c_a} \quad (15)$$

3. AC CALCULATION FOR A TEST AIRCRAFT

A numerical program "NEUTRAL" is worked out for calculating the AC on the basis of the presented algorithm. As an example, calculations were carried out for a test aircraft presented in [ref.4]. The results obtained by this method is presented in tab.1. Also in this table are placed the results obtained by a different but well known Vortex lattice method for comparison. To have a better understanding of this method ref.4 and ref.5 is recomended. The AC by VLM was obtained using the program "VORTR" [ref.4]. The AC by this method was obtained by the following eq.

$$x_{ac} = \frac{x_2\ c_{z2} - x_1\ c_{z1}}{c_{z2} - c_{z1}} \tag{16}$$

where, x- indicates centre of pressure, c_z- lift coefficient and prefixes 1,2 indicate two different incidence angles.

By applying VLM it was possible to calculate the AC for the real wing and also for the real wing-fuselage combination. This was especially interesting to see the penalty received by replacing the real wing with an EQW that was proposed in this paper for the cranked wings.

Tab.1. Results for the test aircraft obtained by the proposed and Vortex lattice method.

Tab.1. Wyniki obliczeń dla testowego samolotu proponowaną metodą oraz VLM.

Method and result	x/c_a	x_h/c_a	$\Delta x_h/c_a$	x_{hn}/c_a	$\Delta x_{hn}/c_a$	"a" wing	"a" wing-fuselage
Proposed method	.243	.116	.127	.096	.020	.085	.085
VLM real wing	.221	.117	.104	-	-	.079	.083
Difference	.022	.001	.023	-	-	.006	.002

4. DISCUSSION AND FINAL REMARKS

The AC of aircraft plays an important role in triming, stability and control analysis. The proposed semi-empirical method in this paper for calculating the AC of wing-fuselage-nacelle combination is very simple, cost and time effective in comparison to other (eg. wind tunnel or computational aerodynamics) methods. The proposed algorithm allows to see the change of the AC, in a very short time, of any geometric change or different combinations in conceptual design. It also may be combined with experimental results, for example, the calculation of fuselage effect on experimentally obtained data for the AC of the wing alone. To verify the accuracy of the proposed method, results of an arbitrarily choosen test aircraft obtained by this method are compared with results from VLM (Tab.1), where it is seen that the difference between the two methods are remarkably small. But it can not be concluded at this stage of work which one of these methods gives more accurate results, because both have shortcomings of different types. The proposed method, which uses some statistical data, for example can be used for simple planforms but it does not take into consideration the thickness, cambering or twisting of the wing. On the other hand, program "VORTR" at this stage does not consider the fuselage as a closed solid body. Rather it was modelled as a flat plate like it appears on the planform, thus not considering wing-fuselage interference. This is one of the reasons the nacelle effect is not calculated by the VLM (Tab.1). Nevertheless, the small differences between the results obtained by the two methods may advocate their acceptibility. The method proposed in this paper can well be preferred for its simplicity, low cost and time consumption which is very important at the primary design stage. Of course the results should be revised in the later stage by more convincing methods such as wind tunnel tests.

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Strszczenie

W pracy zaproponowano pewną teoretyczno-empiryczną metodę obliczania położenia środka aerodynamicznego układu skrzydło-kadłub-gondola dla opływu nielepkiego i poddźwiękowego. Metoda ta pozwala określić środek aerodynamiczny dla konstrukcji skrzydła z załamaniem krawędzi natarcia lub/i spływu (rys. 1). Wyniki otrzymane dla samolotu sportowo-turystycznego [4] były porównane z wynikami otrzymanymi inną znaną metodą (VLM). Różnice w wynikach były znikomo małe (tab.1), ale na obecnym etapie nie można stwierdzić, która z tych metod daje dokładniejsze wyniki dla omawianego celu, bo każda z tych metod ma różne uproszczenia. Natomiast na etapie projektowania wstępnego stosowanie proponowanej metody jest uzasadnione ze względu na jej prostotę, mały koszt oraz szybkość. Wyniki oczywiście należy weryfikować w późniejszym etapie analizy stateczności dynamicznej przy użyciu bardziej zaawansowanych modeli obliczeniowych lub w tunelu aerodynamicznym.

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