UDC 533.693.9 (045)
DOI:10.18372/1990-5548.61.14222

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THE ELEVATOR PARAMETERS STUDY OF JOINED WING CONFIGURATION IN TERM OF LIFT-TO-DRAG RATIO LOSSES DUE TO TRIMMING

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Abstract*—The paper deals with estimation procedure of Lift-to-Drag ratio losses due to longitudinal trimming for several Joined Wing configuration in wide range of lift coefficient. A software for automated calculation of aerodynamic characteristics has been developed, that permit to explore an influence of elevator parameters (elevator span, position and wing configuration) on trimming characteristics of aircraft. The results of calculation for different layouts of Joined Wing are presented, by which it can be concluded that in some combination of the elevator parameters Lift-to-Drag ratio losses take negative values, hence, overall aerodynamic performance of trimmed configuration are better than for wing with zero elevator deflection. The usage of a developed software and proposed methodology make possible rapid evaluation of control surface parameters in wide range of parameters at early design stage.*

Index Terms—joined wing; box wing; elevator; longitudinal trimming; unmanned aerial vehicle; automation.

I. INTRODUCTION

The ecological requirements related to aircraft noise and engine emission become more and more stricter in last years. One way for reduce noise and emission is an reduction of engine thrust, that demand sufficient improvement of aerodynamic performance of aircraft. In case of UAV the key parameter is an endurance, which also demand improvement of aerodynamic performance.

The classical aerodynamic layout is located in the low gradient part of learning curve nowadays, so additional improvements of aerodynamic performance will achieved by large R&D effort in term of time and cost. A significant increase of Lift-to-Drag ratio seems possible with radical change of aerodynamic layouts, underexplored and discarded in previous years. One of this layouts is the joined wing layout, known from early days of aviation, but with very few examples of practical usage.

Using of joined wing layout give several advantages for aircraft in term of low drag due to lift, low weight of load bearing airframe structure, high stiffnes, but some disadvantages related to this layout also known, such as low internal fuel volume in wing, high interference drag, etc. Thoroughful review of joined wing pro et contra has been made by Julian Wolkowith [1], who attracted attention to the study of this configutation.

II. PROBLEM STATEMENT

It is known, that joined wing have a smaller drag due to lift than ideal shaped elliptical wing [2]. But this theoretical result made with elliptical lift distribution at both wing of joined wing system, and can't be expanded at real flight characteristic of typical joined wing UAV because of:

1) Spanwise circulation distribution in real flight often very far from ideal elliptical one due to design and technology restriction imposed on wing shape.

2) Longitudinal trimming of UAV by wing-mounted elevator, additionally change lift distribution away from ideal case as well as from theoretically predicted drag values (Fig. 1).

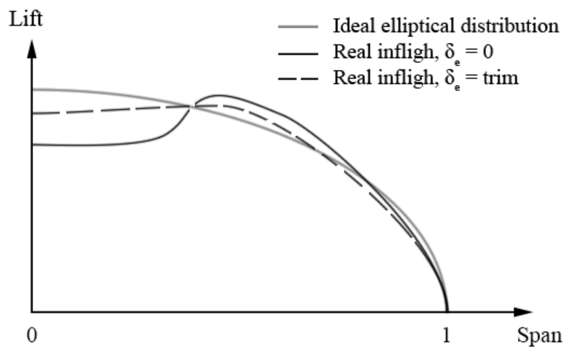


Fig. 1. Spanwise lift distribution in ideal and real case

Therefore, there is a need for method of realistic estimation of aerodynamic characteristic of Joined-Wing UAV with account of abovementioned phenomena. An obtaining of analytical solution is a hard and complex way, but exist different techniques of numerical simulation of flow phenomena, that permit solve this problem in acceptable for initial design phase time span.

III. Review

There are several airplanes and UAVs which use joined wing. The Lockheed Martin corporation incorporate such layout in multiple projects of prospective passenger airliners [3], Boeing used it in carrier-borne AEW project in early 90th [4]. The Innocon company in Israel put small scale UAV with joined wing in mass production [5]. Russia tests VTOL UAV Fregat [6] and China tests HALE UAV Soar Dragon [7]. Some of them proven in flight and one in serial production and market avaliable.

The full scale exploration are costly and dangerous, but in case of small scale vehicle, especially UAV, exist possibility for testing different novelty layouts with small risks and cost. Nowadays Poland and Italy demonstrate significant effort in field of joined wing exploration, implemented in MOSUPS [8] and Prandtl Plane [9] projects.

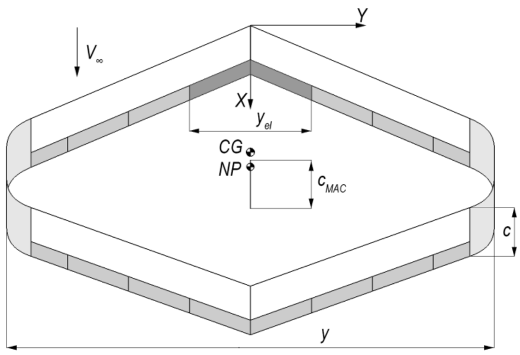
IV. Problem Solution

In present study was considered Lift-to-Drag ratio (LD ratio) loses due to longitudinal trimming by elevator in a wide range of the lift coefficient (CL vary from 0 to 1). Previous papers deals with LD ratio of clean wing (untrimmed condition, zero elevator deflection) [10] and trimming via rear wing angle of incidence for prescribed CL value (demand zero elevator deflection for cruise flight mode) [11].

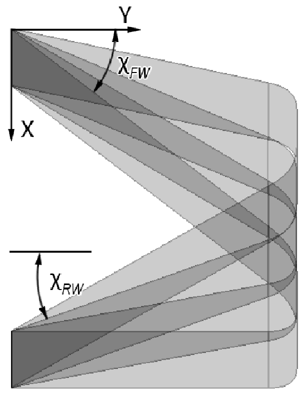
In this paper used Potential Flow Model and Low-Order Panel-Vortex-Method with Symmetry Singularities implemented in PANSYM code [12] developed by TsAGI. Therefore flow separation and skin friction phenomena lays beyond scope of present study and large values of LD ratio was considered.

The system of two sweep wing joined together by vertical endplates was considered in this research, as in two previous publication too. The wingtip, that join wing together, have a fillets with radii of 0.028 of wingspan. The aspect ratio of considered wing system is 10, vertical separation between wing is 0.2 of span. Geometrical parameters of considered layouts shown at Fig. 2 and in Table I.

The parameters that varies between layouts are wing sweep angle and vertical position of wing – front wing below or front wing above rear.



(a)



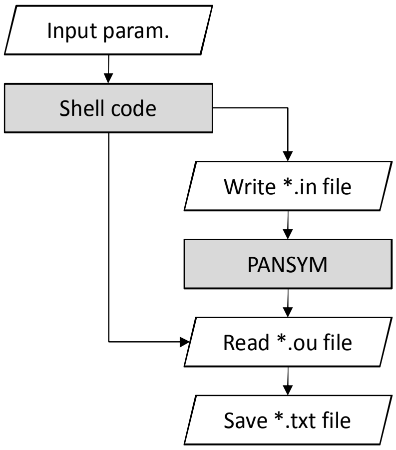
(b)

Fig. 2. Wing planform and elevator position: (a) – R01 layout and different combination of elevator; (b) – wing swept variation

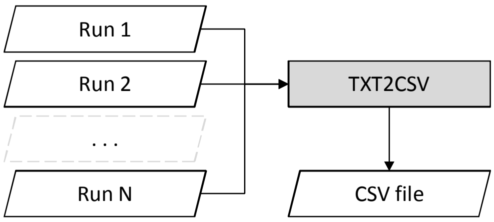
TABLE I. GEOMETRICAL PARAMETERS OF CONSIDERED LAYOUTS

Layout	Geometry					
	χ_{FW},°	χ_{RW}, °	*MAC*	x_A, m	S_Σ, m^2	L_{RW}, m
R01/R05	22.97	-19.71	1 m	0.954	20	3.391
R02/R06	12.00	-29.66		0.478		3.391
R03/R07	30.91	-10.40		1.347		3.391
R04/R08	37.73	0		1.741		3.413

In previous study only one kinematic parameter was varied – rear wing's angle of incidence. The count of result's data point was relatively small, which allowed to use polynomial approximation by 2nd order curve, to determine coefficients of this curve and substitute in resulting formula with "semi-empirical" coefficients. In current paper among varied parameters added span and position of elevator, so in each layout (from 8) are varied 3 parameters in total. In this dimension the previous approach seems impractical, and the following technique is proposed.



(a)



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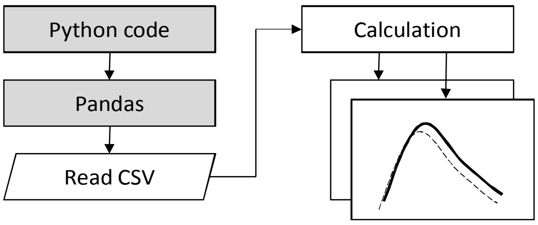

(c)

Fig. 3. Algorithm: (a) is the Single run of PANSYM; (b) is the compile all data in one CSV file; (c) is the data analysis routines

At first stage an aerodynamic characteristics (lift, drag and pitching moment) was calculated by PANSYM with different elevator deflection angle (from –10° to 10° with step of 2°) and elevator parameters (span and position – at front or rear wing). The shell software was developed for automation of this task. This shell take as input the string of numbers (description of layout parameters), generate input file (*.in) for PANSYM, launch PANSYM, extract values of interest from PANSYM output (*.ou) and save this data in text file (*.txt), see Fig. 3a. Multiple text file (704 in total) was combined in single coma separated values (CSV) file with 15488 records at second stage, see Fig. 3b. This file was using as database which contain aerodynamics characteristics of all considered layouts. After that, in Python environments (with using of Pandas, NumPy and SciPy libraries) was calculated points for trimmed aircraft via interpolation, Fig. 3c. The source code of abovementioned programs is available on GitHub [13].

V. Results of Research

Aforementioned algorithm calculate points with zero pitch moments via quadratic interpolation (with extrapolation at ends of range). As result we obtain lift and drag characteristics for trimmed condition in wide range of AoA. Because in this study was considered 8 layouts with 8 variants of span and position of elevator each, so graphical representation of all variants, with regard of limited size of this paper, seems impractical. Hence, for clarity, we will vary only parameter of interest with freezing remaining for each one.

A. Elevator position

At the beginning, consider position of elevator at first or second wing of closed wing system. Let's look at this for the R02 layout with smalles $y_e = 0.25$, so with maximal deflction and trim-related drag. The Lift-to-Drag ratio versus lift coefficient for this two position of elevator shown at Fig. 4, and same data, scaled-up in area of maximal values shown at Fig. 5 for better clarity. LD curves analysis seems impractical, and in next pages we use ΔLD (1) between trimmed and zero elevator deflection case. If ΔLD have negative sign we spoke about LD-losses, conversely, with positive sign we have increment in aerodynamic performance.

$$\Delta LD = \frac{Cl_{trim}}{Cd_{trim}} - \frac{Cl_0}{Cd_0}. \quad (1)$$

Another values used for comparison is an elevator deflection. The ΔLD and elevator deflection angle for this case shown at Figs 6 and 7.

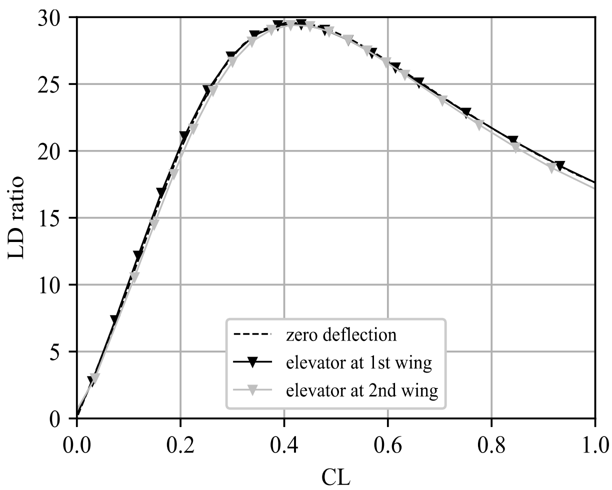

Fig. 4. Lift-to-Drag ratio for R02 layout with different elevator position (R02, wing vary, $y_e = 0.25$)

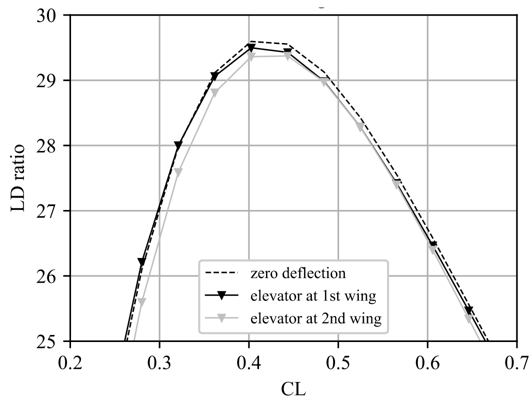

Fig. 5. Close-up of Fig. 4 for clarity (R02, wing vary, $y_e = 0.25$)

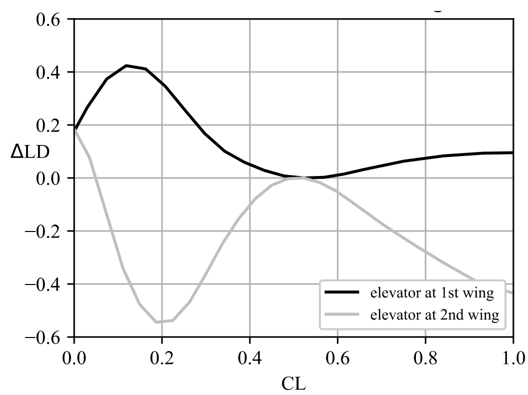

Fig. 6. ΔLD ratio via elevator deflection (R02, wing vary, $y_e = 0.50$)

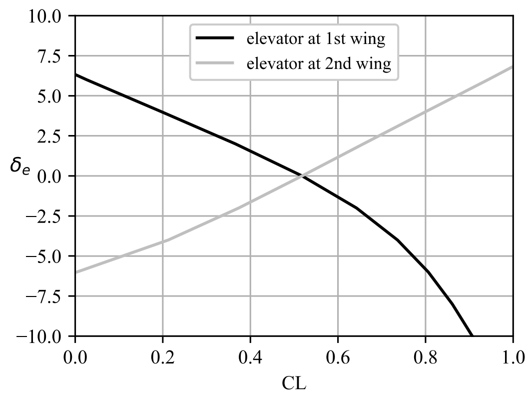

Fig. 7. ΔLD ratio via elevator deflection (R02, wing vary, $y_e = 0.25$)

Analyzing the graph of the dependence at Fig. 6, we clear see, in range of small values of lift coefficient (below CL = 0.5) elevator deflection results in overall increase of LD ratio in case with elevator placed on forward wing. This effect more important for high speed flight, with CL lower than in cruise flight. Zero elevator deflection for CL = 0.5 (see Fig. 7) caused by rear wing angle of incidence, that tailored for cruise flight.

B. Elevator span

The elevator span (y_e) varied from 0.25 to 0.9 of wing span (y_e takes values 0.25, 0.5, 0.75 and 0.9; last values must be 1, but most outboard part of wing span occupied by endplate that join wing together, the endplate occupy 10% of wingspan). Small elevator span required large deflection angle (δ_e) and so large drag and LD ratio losses. Elevator with large span give less losses but in some real-world configuration we need some space for high-lift-device and ailerons too. This parameters show different influence depend from on which wing placed elevator – front or rear, therefore we forced show two set of figures – elevator span influence at front wing, and rear one. Figures 8, 9 present elevator deflection, and Figs 10, 11 present related LD losses.

Analyzing the graph of the dependence at Fig. 7, we clear see very large (compared to imposed limit of 10°) negative elevator deflection with y_e = 0.25 and elevator placed on the front wing. We know, from engineering practice, that this large angle related to flow separation, reduced efficiency of elevator and nonlinear dependency between deflection and lift change. So, our method, that used panel-vortex computation core, don't valid in case, when deflection large than ±10°. Thus, we can't recommend quarter-span elevator at front wing, especially for low-speed vehicle. The half-span elevator show smaller deflection angle and drag rise.

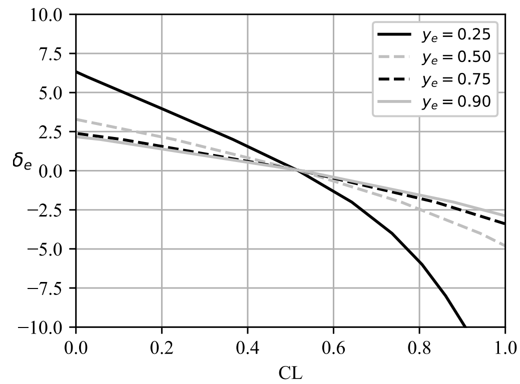

Fig. 8. Elevator deflection for trimming (R02, Front wing, y_e = var)

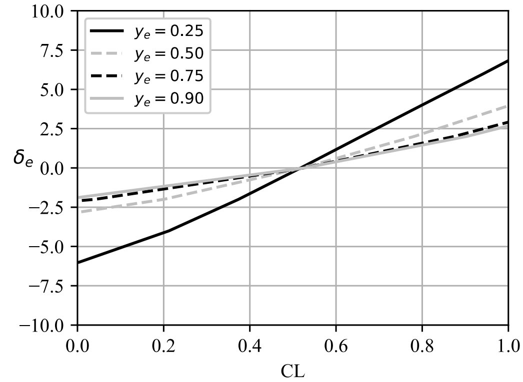

Fig. 9. Elevator deflection for trimming (R02, Rear wing, y_e = var)

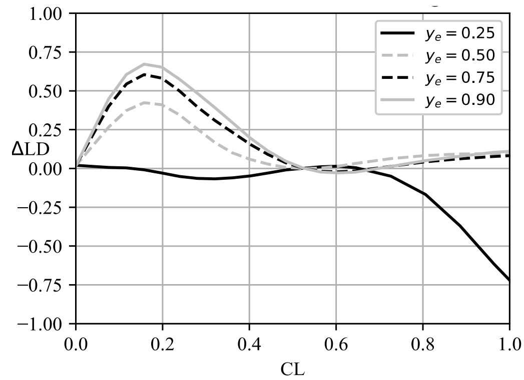

Fig. 10. ΔLD ratio via elevator deflection (R02, Front wing, y_e = var)

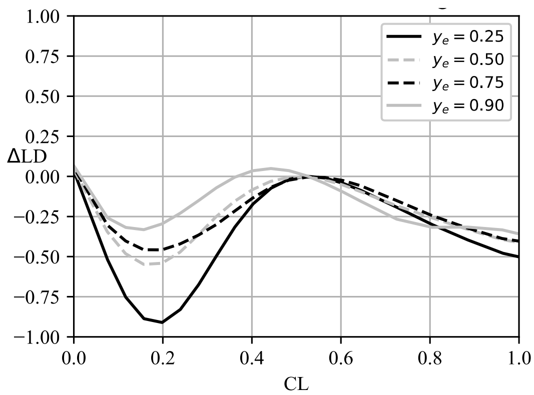

Fig. 11. ΔLD ratio via elevator deflection (R02, Rear wing, y_e = var)

C. The vertical position of first wing

The R01…04 layouts differ from the R05…08 only by the vertical position of first wing – a front wing is below rear one or above. The effect of the vertical position of a front wing on trim characteristics in case with $y_e = 0.5$ and equal sweep angle (R01 and R05 have front wing sweep of 22.97°) shown at Fig. 12.

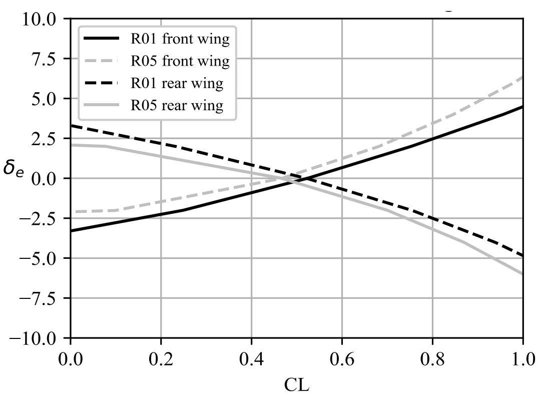

Fig. 12. Elevator deflection for trimming (χ_{FW} = 22.97°, wing vary, y_e = 0.5)

It is clear that in both cases (elevator at a front wing and rear one) the R01 layout (with front wing below) requires large elevator deflection angles for trim, than the R05. In other words, in case of front wing placement below rear one, the elevator efficiency lower regardless of position (at front wing or rear one). But overall performance of wing system in terms of LD ratio shown more complex dependencies, see Fig. 13.

The elevator deflection causes a change of spanwise circulation distribution not only at wing with elevator, but at another wing too, by changing of downwash. Hence overall effect on aerodynamic characteristics of wing system depends on more parameters and it wrong to say that "more deflection = more drag".

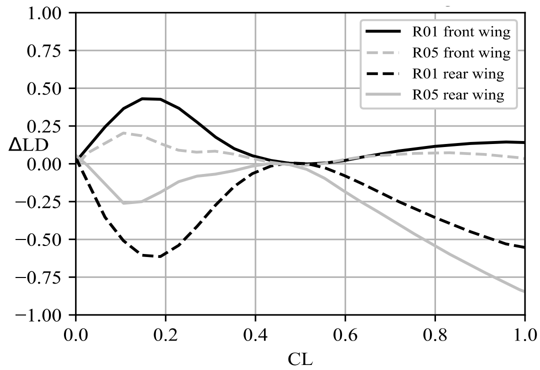

Fig. 13. ΔLD=f(CL) (χ_{FW} = 22.97°, wing vary, y_e=0.5)

The ΔLD for the R01 significantly larger than for the R05, but in range of small lift coefficient values with elevator at front wing this deviation have a positive sign, that mean overall increase of LD ratio due to downwash effect or spanwise circulation improvement.

D. The wing sweep angle variation

In present study the wing sweep angle was change for both wing, but it is assumed that only wing sweep for with elevator effect on trim characteristics.

The sweep angle for wing with elevator vary from χ_{FW} = 12° to 37.73°. The case with $y_e = 0.5$ with elevator at first wing, and front wing above rear one (i.e. R05…06 layouts) was taken for demonstration. The elevator deflection for trimming for these layouts shown at Fig. 14. It is clear that elevator deflection curve shifted down with increase of wing sweep angle.

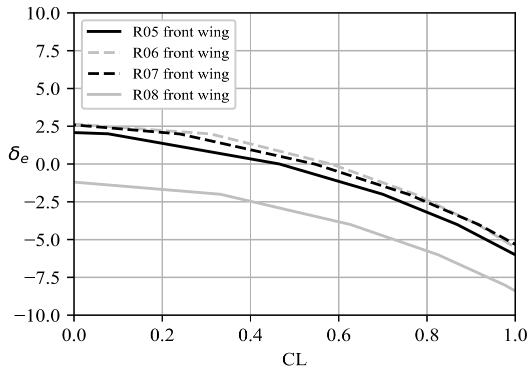

Fig. 14. Elevator deflection for trimming (χ_{FW} = var, front wing, y_e = 0.5)

VI. CONCLUSIONS

The method for joined wing's trim characteristics calculation was demonstrated. 15488 data points has been explored with using of specially developed software.

In present paper we not intended to build a mathematical model of the phenomenon, instead PANSYM solver was taken as "black-box", and input geometry parameters was varied with subsequential analysis of output aerodynamics characteristics. This approach intended for optimization and search of best combination of geometry parameters. In other words for using as design tool. Obtained instruments with small modifications will be embedded into optimization loop and used at early design stage of joined wing aircraft.

The obtained result show best combination of geometry parameters in term of LD ratio and elevator efficiency. This combination have front wing placed elevator with minimum sweep angle and front wing above rear one. The elevator efficiency increase with span, but for ΔLD this is not so clear due to downwash effect. Recommend to take elevator span as a half of forward wing span from practical consideration.

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Received September 03, 2019

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Предаченко, К. О. Лемко, О. Л. Дослідження параметрів руля висоти компонувальної схеми з замкненим крилом з точки зору втрат аеродинамічної якості на балансування

В статті розглянута процедура оцінки втрат аеродинамічної якості на балансування для декількох компонувань замкнутого крила в широкому діапазоні коефіцієнтів підйомної сили. Розроблено програмне забезпечення для автоматизованого розрахунку аеродинамічних характеристик, що дозволило дослідити вплив параметрів руля висоти (відносний розмах, положення та вплив компонування крила) на балансувальні характеристики літального апарату. Продемонстровані результати розрахунків для різних компонувань із замкнутим крилом дозволяють зробити висновок, що при деякому сполученні параметрів руля висоти втрати аеродинамічної якості збалансованого компонування вище, ніж для крила з нульовим відхиленням руля висоти. Використання розробленого програмного забезпечення та запропонованої методології дозволяє швидко оцінити параметри керуючих поверхонь в широкому діапазоні на ранніх стадіях проектування.

Ключові слова: замкнене крило; коробчасте крило; руль висоти; повздовжнє балансування; безпілотний літальний апарат; автоматизація.

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Напрямок наукової діяльності: аеродинаміка, літаюче крило, безпілотні літальні апарати, експериментальна гідрогазодинаміка.
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Предаченко, К. О. Лемко, О. Л. Исследование параметров руля высоты компоновочной схемы с сочлененным крылом с точки зрения потерь аэродинамического качества на балансировку

В статье рассмотрена процедура оценки потерь аэродинамического качества на балансировку для нескольких компоновок сочлененного крыла в широком диапазоне коэффициентов подъемной силы. Разработано программное обеспечение для автоматизированного расчета аэродинамических характеристики, что позволило исследовать влияние параметров руля высоты (относительный размах, положение и влияние компоновки крыла) на балансировочные характеристики летательного аппарата. Продемонстрированные результаты расчетов для различных компоновок с сочлененным крылом позволяют сделать вывод, что при некотором сочетании параметров руля высоты потери аэродинамического качества принимают негативные значения, то есть аэродинамическое качество сбалансированной компоновки выше, чем для крыла с не отклоненным рулем высоты. Использование разработанного программного обеспечения и предложенной методологии позволяет быстро оценить параметры поверхностей управления в широком диапазоне на ранних стадиях проектирования.

Ключевые слова: сочлененное крыло; коробчатое крыло; руль высоты; продольная балансировка; беспилотный летательный аппарат; автоматизация.

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