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Program for calculation of maximum lift coefficient of plain aerofoils and wings at subsonic speeds

Associated software: ESDUpac A9315

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PROGRAM FOR CALCULATION OF MAXIMUM LIFT COEFFICIENT OF PLAIN AEROFOILS AND WINGS AT SUBSONIC SPEEDS

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PROGRAM FOR CALCULATION OF MAXIMUM LIFT COEFFICIENT OF PLAIN AEROFOILS AND WINGS AT SUBSONIC SPEEDS

The program has been written in “STRICT” Microsoft FORTRAN 77 for use on machines using PC/MS DOS.

1. INTRODUCTION

This Item provides details of a program, called ESDUpac A9315, for the calculation of the maximum lift coefficient of plain aerofoils and wings at subsonic speeds. The methods employed are those given in Item No. 84026 (Derivation 4) for aerofoils and Item No. 89034 (Derivation 5) for wings. Item No. 84026 requires aerofoil lift-curve slope from Item No. Aero W.01.01.05 (Derivation 1) and Item No. 89034 requires data for the spanwise location of wing centre of pressure from Item No. 83040 (Derivation 3).

Section 2 summarises the program and Section 3 describes the input and output data. The input files appropriate to an aerofoil or wing calculation are described in tabular form. Section 4 list the Derivations. Section 5 gives some examples of input and output using the program, including those given in Item Nos 84026 and 89034. The original Items should be referred to for notation and applicability and limitations of the methods.

2. SUMMARY OF THE PROGRAM

The program combines the methods of Item Nos 84026 and 89034 to allow the user to carry out calculations for either aerofoils (2D) or wings (3D) determined by the input of the characters “2D” or “3D” in the input file.

If the calculations are required for an aerofoil the program reads in all the required geometric and flow data from a single input file (Section 3.1.1). For a given aerofoil, which can have either a “smooth” or “rough” leading-edge region as defined in Item No. 84026, calculations can be carried out for a range of Mach numbers and Reynolds numbers within the limits specified in the Item.

The method of Item No. 84026 requires a knowledge of whether the aerofoil is a “conventional” or a “modern” one. With the program the user is given the complete flexibility of a choice between deciding for himself into which category his aerofoil falls or allowing the computer to decide. The computer decision involves a test based on the geometry over the rear 10% of the aerofoil chord. If $[z_u(0.9) - z_l(0.9)]/z_u(0.9) > 0.64$ and $t_b/c > 0.004$ then the assumption is made that the aerofoil is a modern one; it is otherwise assumed to be conventional. If the user elects to decide the category, a warning message is output should the choice be contrary to that which the computer would have made. If the computer is allowed to decide, a warning message is output concerning the choice.

For the case of a wing, which must have a smooth leading edge, it is necessary to divide the run into two parts. The first part, in which the planform geometry and required Mach numbers are input (Section 3.1.2(a)), is necessary to determine η_p , the spanwise location of the peak loading at each Mach number. This information enables the user to establish the section geometry at each value of η_p , if not already known, and is required by the program to carry out the calculation of the maximum lift coefficient for the section at η_p . The input file for the second part, concerning the calculation of C_{Lmax} (Section 3.1.2 (b)), consists of that for the first part plus the now known section geometry at each η_p , together with the geometry required to define the wing camber and twist variation across the span. Non-linear spanwise variations of geometric twist and camber are allowable provided that the twist variation and the resulting spanwise variation of section zero-lift angle due to camber are monotonic and give a modest effective tip twist angle ($|\delta_{et}| \leq 10^\circ$). For such cases geometrical data are required only for the root and 2/3 span sections. Finally, the Reynolds number values are input.

The Figures from the Items are, with one exception, stored within the program in digitised form and the data are extracted using interpolations via low order polynomial fits. The one exception concerns the Figures of Item No. Aero W.01.01.05; in that case the original empirical equations from Derivation 2 were used.

The output is written to a user-specified output file, see Section 3.2. The data given in the input files are checked for validity and appropriate error or warning messages are output if any invalidity is detected. Similarly, allowance is made for error or warning messages to be triggered during the calculation should any parameter be either within an area of uncertainty on the figures or outside specified ranges.

Some of the Figures in the underlying Derivations are limited to non-negative half-chord sweep angles. The program allows limited forward sweep of the half-chord line, provided that the leading-edge is not swept forward and the trailing edge is not swept forward more than 20° .

3. INPUT AND OUTPUT

3.1 Input

Tables 3.1 and 3.2 respectively list, in order, the parameters required in the input files for an aerofoil and wing calculation and, where appropriate, their notation in the relevant Item. Examples of typical input files which were constructed by reference to the tables are given in Section 5.

3.1.1 Aerofoils (2D)

TABLE 3.1 Input file for aerofoils

<i>Variable name in program</i>	<i>Notation in Item</i>	<i>Comments</i>
CHARR(1) CHARR(2) CHARR(3)	— — —	The first three lines of the input data file are read as text and are written to the output file to enable the user to describe the run. Each line may contain 72 characters and must end with a carriage return. In each case a blank line must be entered if no text is available.
FYLNAM	—	Name of file (up to 12 characters) to which output file is to be directed.
ID	—	Indicator for aerofoil or wing. For aerofoil ID = 2D or 2d.
MODERN	—	Variable used to describe aerofoil category. MODERN = Y or y; user has decided aerofoil is “modern”, see Section 6 of Item No. 84026. MODERN = N or n; user has decided aerofoil is “conventional”, see Section 6 of Item No. 84026. MODERN = ?; computer to decide aerofoil category, see Section 2 of this Item.
RORS	—	Indicator for rough (RORS = R or r) or smooth (RORS = S or s) leading-edge region, see Section 2.2 of Item No. 84026.
TBYC	t/c	Aerofoil thickness to chord ratio ($0.06 \leq TBYC \leq 0.24$).
XTRBYC	x_{tr}/c	Dimensionless location of boundary layer transition ($0 \leq XTRBYC \leq 1$).
XUMBYC, ZUMBYC	$x_{um}/c, z_{um}/c$	Dimensionless location and value of maximum upper-surface ordinate.
TAUDEG	τ	Trailing-edge angle, degrees.
XBYC(1), ZUBYC(1), ZLBYC(1) : XBYC(J), ZUBYC(J), ZLBYC(J) : XBYC(17), ZUBYC(17), ZLBYC(17)	$x/c, z_u/c, z_l/c$	Aerofoil dimensionless upper-surface and lower-surface coordinates at each of $J = 1$ to 17 standard values of $XBYC(J) = 0, 0.01, 0.0125, 0.025, 0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.95, 0.99, 1.0$.
NMG	—	Number of Mach number values to be given ($1 \leq NMG \leq 10$).
EMS(1),..., EMS(J),..., EMS(NEMS)	M	Values of Mach number; on one line ($0 < EMS(J) \leq 0.4$, $1 \leq NEMS \equiv NMG \leq 10$).
NRG	—	Number of Reynolds number values to be given ($1 \leq NRG \leq 10$).

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TABLE 3.1 Input file for aerofoils

Variable name in program	Notation in Item	Comments
RCS(1),..., RCS(J),..., RCS(NRCS)	R_c	Values of Reynolds number; on one line $(0.7 \times 10^6 \leq RCS(J) \leq 9 \times 10^6$ for RORS = S or s, $0.7 \times 10^6 \leq RCS(J) \leq 6 \times 10^6$ for RORS = R or r, and ZUBYC(3) ≥ 0.017 , $RCS(J) = 6 \times 10^6$ for RORS = R or r, and ZUBYC(3) < 0.017 . $1 \leq NRCS \equiv NRG \leq 10$).

3.1.2 Wings (3D)

For a given Mach number appropriate section geometry (at η_p) for a wing calculation can in general only be established when the value of η_p has been determined and so for a wing the run is split into two parts. Part I determines η_p and Part II is the full calculation for maximum lift coefficient. Obviously, if η_p , or the section geometry at η_p , is already known then only Part II is required.

(a) Part I: Determination of η_p

TABLE 3.2 (a) Input file for wings – Part I

Variable name in program	Notation in Item	Comments
CHARR(1) CHARR(2) CHARR(3)	– – –	The first three lines of the input data file are read as text and are written to the output file to enable the user to describe the run. Each line may contain 72 characters and must end with a carriage return. In each case a blank line must be entered if no text is available.
FYLNAM	–	Name of file (up to 12 characters) to which output file is to be directed.
ID	–	Indicator for aerofoil or wing. For aerofoil ID = 3D or 3d.
MODERN	–	Variable used to describe category of wing section at η_p . MODERN = Y or y; user has decided aerofoil is “modern”, see Section 6 of Item No. 84026. MODERN = N or n; user has decided aerofoil is “conventional”, see Section 6 of Item No. 84026. MODERN = ?; computer to decide aerofoil category, see Section 2 of this Item. NOTE: although this information is not actually required for a Part I run it is included to simplify the editing required to construct the input file for Part II, see Table 3.2(b).
ASP	A	Aspect ratio ($2 \leq ASP \leq 12$).

Continuing

TABLE 3.2 (a) Input file for wings – Part I

Variable name in program	Notation in Item	Comments
ELMDA	λ	Taper ratio ($0 \leq \text{ELMDA} \leq 1$).
EN	n	Chord line parameter ($0 \leq \text{EN} \leq 1$).
ELMDAN	Λ_n	Sweepback of n 'th chord line . $0 \leq \Lambda_0 \leq 50^\circ$, $\tan^{-1} \left[-\frac{2(1-\lambda)}{A(1+\lambda)} \right] \leq \Lambda_{1/2} \leq 50^\circ$, $-20^\circ \leq \Lambda_1 \leq 50^\circ$.
NMG	–	Number of Mach number values to be given ($1 \leq \text{NMG} \leq 10$).
EMS(1),..., EMS(J),..., EMS(NEMS)	M	Values of Mach number; on one line ($0 < \text{EMS}(J) \leq 0.8$, $1 \leq \text{NEMS} = \text{NMG} \leq 10$) .

(b) **Part II: Determination of C_{Lmax}**

TABLE 3.2 (b) Input file for wings – Part II

Variable name in program	Notation in Item	Comments
CHARR(1) CHARR(2) CHARR(3)	– – –	The first three lines of the input data file are read as text and are written to the output file to enable the user to describe the run. Each line may contain 72 characters and must end with a carriage return. In each case a blank line must be entered if no text is available.
FYLNAM	–	Name of file (up to 12 characters) to which output file is to be directed.
ID	–	Indicator for aerofoil or wing. For aerofoil ID = 3D or 3d.
MODERN	–	Variable used to describe aerofoil category of wing section at η_p . MODERN = Y or y; user has decided aerofoil is “modern”, see Section 6 of Item No. 84026. MODERN = N or n; user has decided aerofoil is “conventional”, see Section 6 of Item No. 84026. MODERN = ?; computer to decide aerofoil category, see Section 2 of this Item.
ASP	A	Aspect ratio ($2 \leq \text{ASP} \leq 12$).
ELMDA	λ	Taper ratio ($0 \leq \text{ELMDA} \leq 1$).

Continuing

TABLE 3.2 (b) Input file for wings – Part II

Variable name in program	Notation in Item	Comments
EN	n	Chord line parameter ($0 \leq EN \leq 1$).
ELMDAN	Λ_n	Sweepback of n'th chord line $0 \leq \Lambda_0 \leq 50^\circ$, $\tan^{-1} \left[-\frac{2(1-\lambda)}{A(1+\lambda)} \right] \leq \Lambda_{1/2} \leq 50^\circ$, $-20^\circ \leq \Lambda_1 \leq 50^\circ$.
NMG	–	Number of Mach number values to be given ($1 \leq NMG \leq 10$).
EMS(1),..., EMS(J),..., EMS(NEMS)	M	Values of Mach number; on one line $(0 < EMS(J) \leq 0.8$, $1 \leq NEMS \equiv NMG \leq 10)$.
For each value of EMS(J), i.e. for $M = 1$ to NEMS, the following data concerning the section geometry at η_p are required to determine $(C_{Lm})_p$ at low speeds via Item No. 84026.		
TBYC(M)	$(t/c)_p$	Section thickness to chord ratio $(0.06 \leq TBYC(M) \leq 0.24)$.
XTRBYC(M)	$(x_{tr}/c)_p$	Dimensionless location of boundary layer transition ($0 \leq XTRBYC(M) \leq 1$).
XUMBYC(M), ZUMBYC(M)	$(x_{um}/c)_p$, $(z_{um}/c)_p$	Dimensionless location and value of maximum upper-surface ordinate.
TAUDEG(M)	$(\tau)_p$	Trailing-edge angle, degrees.
XBYC(1), ZUBYC(1,M), ZLBYC(1,M) : : : XBYC(J), ZUBYC(J,M), ZLBYC(J,M) : : : XBYC(17), ZUBYC(17,M), ZLBYC(17,M)	$(x/c)_p$, $(z_u/c)_p$, $(z_l/c)_p$	Section dimensionless upper-surface and lower-surface coordinates at each of $J = 1$ to 17 standard values of XBYC(J) = 0, 0.01, 0.0125, 0.025, 0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.95, 0.99, 1.0.
Wing twist and camber data:		
TI, CI	–	Twist and camber indicators: TI = 0 for no geometrical twist TI = T for geometrical twist, linear or non-linear (but monotonic) CI = U for uniform (constant) camber across span CI = V for camber varying across span giving either linear or non-linear (but monotonic) variation of section zero-lift angle.

Continuing

TABLE 3.2 (b) Input file for wings – Part II

Variable name in program	Notation in Item	Comments
Wing twist and camber data:		
If CI = V:		
Two sets of aerofoil coordinates are required, for the root (K = 1) and 2/3 span (K = 2) sections to calculate α_{0r} and $\alpha_{02/3}$ from Equation (5.1) of Item No. 84026.		
XBYCT(1), ZUBYCT(1, K), ZLBYCT(1, K) . . . XBYCT(J), ZUBYCT(J, K), ZLBYCT(J, K) . . . XBYCT(14), ZUBYCT(14, K), ZLBYCT(14, K)	$(x/c)_r$, $(z_u/c)_r$, $(z_l/c)_r$, $(x/c)_{2/3}$, $(z_u/c)_{2/3}$, $(z_l/c)_{2/3}$	Section dimensionless upper-surface and lower-surface coordinates at each of J = 1 to 14 standard values of XBYCT(J) = 0, 0.025, 0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.95 and 1.0.
If TI = T:		
DELT23	$\delta_{2/3}$	Geometrical twist at 2/3 span (degrees).
NRG	–	Number of Reynolds number values to be given ($1 \leq \text{NRG} \leq 10$).
RCS(1),..., RCS(J),..., RCS(NRCS)	$R_{\bar{c}}$	Values of Reynolds number; on one line ($0.7 \times 10^6 \leq \text{RCS}(J) \leq 12 \times 10^6$ $1 \leq \text{NRCS} \equiv \text{NRG} \leq 10$).

3.2 Output

The output begins with a standard header. Three lines of user-defined text, describing the run for example, then follow together with the chosen output file name. Should any errors be detected while reading in the input data, appropriate messages are output at this stage. Details of the input data then follow to act as a record and a check, preceded by a general heading to indicate whether the calculations are for an aerofoil or a wing.

The results of the calculations then follow, with general section or planform data preceding tabulated calculations for each requested Mach number.

Table 3.3 translates the output parameters into the notation of the relevant Items.

TABLE 3.3 Program output parameters

Output parameter	Notation in Item	Output parameter	Notation in Item
A	A	Lambda	λ
(a1)0	$(a_1)_0$	Lamdan	Λ_n
Alpha0	α_0	Lambda0	Λ_0
Alpha0r	α_{0r}	Lambda1/4	$\Lambda_{1/4}$
Alpha02/3	$\alpha_{02/3}$	Lambda1/2	$\Lambda_{1/2}$
		Lambda1	Λ_1
Beta	β	M	M
		Mup	μ_p
CLm	C_{Lm}	n	n
CLmax	C_{Lmax}		
CL0	C_{L0}	Rc	R_c
c	$\bar{c}$	Rcbb	$R_{\bar{c}}$
cbb	$\bar{c}$	Rcp	R_{cp}
cp	c_p		
DeltaCL	ΔC_L	Tau	τ
DeltaCLLambda	$\Delta C_{L\Lambda}$	Taua	τ_a
DeltaCLM	ΔC_{LM}	Tauu	τ_u
DeltaCLR	ΔC_{LR}	t	t
DeltaCLT	ΔC_{LT}	tb	t_b
Deltaet	δ_{et}		
Delta2/3	$\delta_{2/3}$	xtr	x_{tr}
		xum	x_{um}
Etab	η		
Etap	η_p	Zetap	ζ_p
FM	F_M	zl	z_l
FS	F_S	zu	z_u
		zum	z_{um}
Kappa	κ		

WARNING AND ERROR MESSAGES

Provision is made within the program for a number of warning and error messages to be output when triggered. Warnings are associated with successful runs and are cautionary. Error messages are associated with a failed or terminated run and are intended to help in pin-pointing any error or inconsistency in the input data.