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Installed tailplane lift-curve slope at subsonic speeds

Associated software: ESDUpac A8929



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INSTALLED TAILPLANE LIFT-CURVE SLOPE AT SUBSONIC SPEEDS

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INSTALLED TAILPLANE LIFT-CURVE SLOPE AT SUBSONIC SPEEDS

1. NOTATION AND UNITS

Throughout this Item all tailplane quantities relate to the gross planform.

		SI	British
A_T	tailplane aspect ratio, b_T^2/S_T		
A_W	wing aspect ratio, b_W^2/S_W		
a_{1Ti}	lift-curve slope of isolated tailplane	rad ⁻¹	rad ⁻¹
a_{1Ti0}	value of a_{1Ti} at $M \approx 0$	rad ⁻¹	rad ⁻¹
a_{1T}	lift-curve slope of installed tailplane, $dC_{LT}/d\alpha_T$	rad ⁻¹	rad ⁻¹
b_T	tailplane span	m	ft
b_W	wing span	m	ft
C_{LT}	installed tailplane lift coefficient, L_T/qS_T		
$\bar{c}_T$	aerodynamic mean chord of tailplane	m	ft
$\bar{c}_W$	aerodynamic mean chord of wing	m	ft
d_T	body width at longitudinal location of $\bar{c}_T/4$, see Figure 2	m	ft
E_T	tailplane efficiency, a_{1T}/a_{1Ti}		
K_M	secondary Mach number factor		
L_T	installed tailplane lift	N	lbf
l_T	longitudinal distance between moment reference centre and $\bar{c}_T/4$, see Appendix A	m	ft
M	free-stream Mach number		
q	free-stream kinetic pressure, $\frac{1}{2}\rho V^2$	N/m ²	lbf/ft ²
R	Reynolds number based on free-stream flow conditions and $\bar{c}_W$		
S_T	tailplane gross planform area	m ²	ft ²

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S_W	wing gross planform area	m ²	ft ²
s_W	wing semi-span	m	ft
V	free-stream velocity	m/s	ft/s
$\bar{V}'$	modified tail volume ratio, $S_T l_T / S_W \bar{c}_W$		
x_T	distance between quarter-chord points of wing centre-line chord and tailplane aerodynamic mean chord, measured along x-axis in zero-lift plane for flaps-up, tail-off configuration, see Figure 1 (zero-lift plane assumed to pass through quarter-chord point of wing centre-line chord)	m	ft
z_T	height of quarter-chord point of tailplane aerodynamic mean chord above and normal to zero-lift plane for flaps-up, tail-off configuration, see Figure 1	m	ft
α_T	tailplane angle of attack (relative to local velocity at tailplane)	rad	rad
α_W	wing angle of attack (relative to free-stream velocity)	rad	rad
ζ_T	z_T / s_W , see Figure 1		
ξ_T	x_T / s_W see Figure 1		
$\Lambda_{1/4T}$	sweepback of tailplane quarter-chord line	deg	deg
$\Lambda_{1/2T}$	sweepback of tailplane half-chord line	deg	deg
$\Lambda_{1/4W}$	sweepback of wing quarter-chord line	deg	deg
λ_T	ratio of tip chord to centre-line chord for tailplane		
λ_W	ratio of tip chord to centre-line chord for wing		
ρ	free-stream density	kg/m ³	slug/ft ³

Subscripts

()_{expt} denotes experimental value

()_{pred} denotes predicted value

2. INTRODUCTION

The tailplane of an aircraft has to provide the necessary range of pitching moment to control and trim the aircraft longitudinally and to provide a satisfactory degree of longitudinal stability throughout its flight envelope. In order to operate efficiently it is desirable for the tailplane to approach its free-air lift characteristic as closely as possible, consistent with structural and other design considerations.

The amount of lift that a tailplane can generate at a given aircraft angle of attack will obviously depend on the interference effects due to the airframe at the installed location. In this respect tailplane lift is likely to be influenced by

- (i) the local kinetic pressure at the tailplane,
- (ii) the body boundary layer,
- (iii) the interference of the body on the tailplane lift distribution,

and (iv) the downwash field at the tailplane.

For the present purpose it is useful to define tailplane efficiency, E_T , as the ratio of the installed tailplane lift-curve slope, a_{1T} , to that which would be calculated for the isolated tailplane in free air, a_{1Ti} , obtained from ESDU 70011 (Derivation 13). The lift-curve slope a_{1T} is independent of the downwash field at the tailplane and this Item therefore deals with the effects listed in (i) to (iii). The effect in (iv), *i.e.* the estimation of downwash required for the determination of tailplane local angle of attack, and thence tailplane lift, is given in ESDU 80020 (Reference 19) for a plain wing and ESDU 97021 (Reference 21) for a wing with high-lift devices deployed.

This Item provides simple semi-empirical methods of estimating the lift-curve slope of tailplanes mounted either on the aircraft fin or body. Section 3 outlines the prediction methods while the methods used to analyse test data to extract a_{1T} are given in Appendix A. Section 4 discusses the applicability and accuracy of the prediction methods by comparisons with wind-tunnel data for 40 combat and transport aircraft models with and without high-lift devices. Worked examples illustrating the use of the methods are given in Section 6.

Details of a computer program for the method, ESDUpac A8929, are given in Appendix B.

3. INSTALLED TAILPLANE LIFT-CURVE SLOPE

A large amount of wind-tunnel data (Derivations 1 to 12 and 14 to 18) relating to 40 combat and transport aircraft models with and without high-lift devices was available for analysis. The three basic methods of analysis to extract a_{1T} are outlined in Appendix A. The basic correlation work was undertaken using method (a) of Appendix A applied to the low-speed ($M \leq 0.2$) test data for the models with high-lift devices undeployed. Method (a) provided better consistency than the other two and when accurate data for ranges of small angles of attack of the model ($0 \leq \alpha_w \leq 10^\circ$) and small tailplane setting angles ($-10^\circ \leq \eta_T \leq 10^\circ$) were available it generally gave satisfactory agreement with method (c). The data for a_{1T} thus obtained via Equation (A2.10), were converted to efficiency values for correlation purposes by normalisation with respect to a_{1Ti} , the theoretical lift-curve slope in free air obtained from ESDU 70011.

Following many attempts at correlating the data in terms of various geometry and flow parameters to model the effects listed in (i) to (iii) in Section 2, Figures 1 and 2 were produced for fin-mounted and body-mounted tailplanes, respectively.

Figure 1, for fin-mounted tailplanes, shows the effect on tailplane efficiency of the height of the tailplane above the zero-lift plane (flaps-up, tail-off) in dimensionless form, ζ_T , which was found to be the most significant parameter. The initial slow increase in efficiency with increase in ζ_T reflects the considerable influence of the body for tailplanes mounted low on the fin. For the purposes of this Item a satisfactory approximation to the zero-lift angle (flaps-up, tail-off) required to determine the location of the zero-lift plane, and thence ζ_T , can be obtained from ESDU 87031 (Reference 20) for the wing alone.

Figure 2, for body-mounted tailplanes, shows the primary effect of body width in the region of the tailplane, characterised by the parameter d_T/b_T . A secondary effect of tailplane planform is accounted for in terms of A_T/a_{1Ti0} from ESDU 70011, where a_{1Ti0} is the low-speed value of a_{1Ti} .

Although the basic correlations were for low speeds ($M \leq 0.2$), analysis of a small number of data for the effects of compressibility (Derivations 11, 16 and 17) indicated that the use of the appropriate value of a_{1Ti} from ESDU 70011 allowed a reasonably satisfactory representation of compressibility effects for subcritical Mach numbers. Thus, the installed tailplane lift-curve slope is obtained to a reasonable approximation (see Section 4) from the equation

$$a_{1T} = E_T a_{1Ti}, \quad (3.1)$$

where E_T is obtained from Figure 1 or 2 and a_{1Ti} is obtained from ESDU 70011.

4. APPLICABILITY AND ACCURACY

4.1 Applicability

The methods of this Item apply to straight-tapered tailplanes, either fin- or body-mounted. The ranges of parameters covered by the correlations used to develop Figures 1 and 2 are given in Tables 4.1 and 4.2 respectively.

TABLE 4.1 Parameter ranges for fin-mounted tailplanes

A_W	λ_W	$\Lambda_{1/4W}$	A_T	λ_T	$\Lambda_{1/4T}$
2 to 12	0 to 0.8	0 to 45°	2.4 to 5.5	0.4 to 0.7	0 to 43°

$\bar{V}'$	ξ_T	ζ_T	$R \times 10^{-6}$	M
0.2 to 1.6	0.7 to 2.0	0 to 0.6	0.5 to 15	0 to 0.2

TABLE 4.2 Parameter ranges for body-mounted tailplanes

A_W	λ_W	$\Lambda_{1/4W}$	A_T	λ_T	$\Lambda_{1/4T}$
2 to 12	0 to 0.8	0 to 45°	2.8 to 5.7	0.2 to 0.7	0 to 45°

$\bar{V}'$	ξ_T	ζ_T	d_T/b_T	$R \times 10^{-6}$	M
0.2 to 1.4	0.7 to 2.0	0 to 0.26	0.1 to 0.3	0.5 to 15	0 to 0.2

The prediction methods would be expected to apply to any configuration within these ranges with certain exceptions, as follows.

For fin-mounted tailplanes on close-coupled configurations with $\xi_T < 0.9$, Figure 1 was found consistently to overestimate tailplane efficiency (see Section 4.2) and caution should be exercised for such configurations. Otherwise, for $0.9 \leq \xi_T < 2.0$, no systematic effect of ξ_T was found. A considerable overestimate (see Section 4.2) was obtained using Figure 2 for one extreme case of a relatively close coupled tailplane mounted on the highly upswept afterbody of a low-wing aircraft. In order to identify such cases it is suggested that caution be exercised for body-mounted configurations with $\zeta_T/\xi_T > 0.25$.

High-lift devices

The basic correlations were for configurations with high-lift devices undeployed. However, it was found in the analysis of the test data that deployment of high-lift devices (Derivations 1, 2, 4, 5, 10, 12 and 16) generally had a minor effect on tailplane efficiency. The methods of this Item can therefore be assumed to apply to configurations with high-lift devices deployed, provided that for fin-mounted tailplanes ζ_T is based on the flaps-up configuration.

Flow conditions

Although the predictions for compressible flow on the basis of Equation (3.1) were within the basic accuracy of the method for low speeds (see Section 4.2) there was a consistent trend towards overestimation by up to 5 or 6% at the higher Mach numbers. On the basis of the small number of test data for five transport aircraft and three combat aircraft a tentative correction factor K_M , shown in Figure 3, was derived which can, if desired, be applied to the value of a_{1T} derived from Equation (3.1) to offset the minor overestimations. Thus, Equation (3.1) can be modified to become

$$a_{1T} = K_M E_T a_{1Ti}. \quad (4.1)$$

No attempt should be made to extrapolate Figure 3 to higher Mach numbers.

There was no indication in the analysis that Reynolds number had any significance, even at the lower end of the ranges in Tables 4.1 and 4.2, provided that the flow was fully attached.

Kinetic pressure at the tailplane

The installed lift-curve slope, a_{1T} , is defined in terms of the free-stream kinetic pressure, q . Ideally, had it been based on a value more closely representative of the tailplane location, it is conceivable that better correlation might have been achieved. Indeed, the generally poor correlation for some close-coupled configurations might have been symptomatic of this problem. However, since in the majority of tests no data were given for kinetic pressure at the tailplane and since no simple prediction method is available, this course was not feasible.

4.2 Accuracy

Sketch 4.1 illustrates the accuracy of the methods incorporating Figures 1 and 2 for aircraft without deployment of high-lift devices. On the basis of this sketch it is suggested that an accuracy of about $\pm 6\%$ on a_{1T} be taken for the prediction methods, excluding the extreme cases noted in Section 4.1. In the worst of such cases the methods overpredict a_{1T} by about 20%. It is worth noting that the accuracy on a_{1Ti} itself is about $\pm 5\%$ using ESDU 70011. For transport aircraft with body-mounted tailplanes, values greater than 0.4 for the ratio of maximum body width to tailplane span or, particularly, maximum body height to tailplane span, can lead to prediction errors greater than $\pm 6\%$.