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Estimation of the unsteady lift coefficient of subsonic propeller blades in non-axial inflow

Associated software: ESDUpac A9627

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THE PREPARATION OF THIS DATA ITEM

The work on this particular Data Item was monitored and guided by the following Propeller Noise Working Party on behalf of the Aircraft Noise Committee:

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ESTIMATION OF THE UNSTEADY LIFT COEFFICIENT OF SUBSONIC PROPELLER BLADES IN NON-AXIAL INFLOW

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ESTIMATION OF THE UNSTEADY LIFT COEFFICIENT OF SUBSONIC PROPELLER BLADES IN NON-AXIAL INFLOW

1. NOTATION

		Units	
		SI	*British*
a_2	upwash component of velocity on blade section	m/s	ft/s
$C_L(k)$	unsteady lift coefficient at k^{th} load harmonic		
c	local chord	m	ft
c_0	speed of sound	m/s	ft/s
F	force per unit span	N/m	pdl/ft*
$\mathscr{F}(t)$	complex Fresnel integral		
$J_n(X)$	Bessel function of order n and argument X		
k	loading harmonic		
M	Mach number in flight path direction		
M_r	section relative Mach number [$= (M^2 + r_0^2 M_t^2)^{1/2}$]		
M_t	tip rotational Mach number [$= \Omega r_t / c_0$]		
r_t	radius of propeller	m	ft
r_0	radial coordinate normalised by r_t		
S	Sears function		
$S_c^h(\sigma, M_r)$	high frequency compressible Sears function		
$S_c^l(\sigma, M_r)$	low frequency compressible Sears function		
S_c	compressible Sears function		
S_{ic}	incompressible Sears function		
t	argument of complex Fresnel integral		

For footnotes see end of Notation section

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x, y, z	flight Cartesian coordinates (see Sketch 3.1)		
α_p	angle of pitch of propeller axis relative to flight axis (see Sketch 3.1)	deg	deg
α_y	angle of yaw of propeller axis relative to flight axis (see Sketch 3.1)	deg	deg
ζ	variable of integration		
λ	compressibility factor $[= \sigma M_r / (1 - M_r^2)]$	rad	rad
ρ_0	ambient air density	kg/m^3	lb/ft^3
σ	reduced frequency $[= k(\Omega c / (2c_0 M_r))]$	rad	rad
Ω	rotational speed of propeller	rad/s†	rad/s†

* 1 lbf is approximately equal to 32.2 pdl (poundals).

† For the user's convenience, the rotational speed of the propeller is input to the program in revolutions/minute.

2. INTRODUCTION

This Item permits the user to calculate the unsteady local lift coefficient of a blade aerofoil section of a subsonic propeller with non-axial inflow. This forms part of the data input required by the propeller noise program in ESDU 11005 (Reference 5). The analysis is a three-dimensional one; it permits the orientation of the propeller axis to be described by the angles of yaw and pitch relative to the flight axis. These are Euler angles and are defined in Section 3. This Item is applicable to an aircraft on a steady straight line flight path which need not be horizontal.

With axial inflow into a propeller, each blade aerofoil section has a constant angle of incidence to the airflow and therefore a constant or steady load. With non-axial inflow each aerofoil section has a changing angle of incidence to the airflow during a single rotation and therefore an unsteady load on it. An unsteady lift coefficient is therefore associated with each section.

The loading waveform, *i.e.* the variation of the load at any fixed point on the blade as a function of time, has a period that is equal to the time taken for one rotation of the blade. In general, many data points may be required to describe the lift coefficient as a function of time. It is much easier to describe the waveform in terms of loading harmonics. Then, only a few complex harmonic coefficients are needed to represent the waveform. This is also the required form of unsteady load coefficient input to the propeller noise prediction program in ESDU 11005.

3. THEORY

In ESDU 11005 non-axial inflow is described by the Euler* angles of yaw, pitch and roll defining the orientation of the propeller axis relative to the flight axis. That convention is preserved in this Item, but with the angular inflow being described by just the angles of yaw and pitch. Sketch 3.1 shows how these

* The Euler angular coordinate system has become a standard in aerodynamics (Reference 4). The final position is obtained by, or described by, consecutive rotations in the order of yaw, pitch and roll. Prior to any subsequent rotation each axis occupies the position into which it was carried by the earlier rotation.

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