Modeling Crossflow-induced Propeller Autorotation  
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***Abstract*—The design of aircraft, particularly eVTOL aircraft, commonly converges on the use of multiple electrically powered, thrust-vectoring propellers to meet the high thrust requirements of vertical flight. Many configurations employ aft-mounted propellers fixed in a vertical orientation, dedicated exclusively to providing extra lift during vertical take-off and landing. At cruise, these propellers, left unpowered, experience crossflow—air moving parallel to the plane of rotation—which in turn induces autorotation. Modeling the aerodynamic behavior resulting from this crossflow-induced autorotation requires a modified mathematical framework—an adaptation of blade element theory—formulated specifically for crossflow conditions. This report presents a formulation of such a model and details the development of software that solves the model numerically, yielding both transient and steady-state solutions for the propeller’s angular position, angular velocity, angular acceleration, lift, drag, side-force, torque, and regenerated power, given propeller geometry and initial crossflow conditions.**

***Nomenclature***cBlade chord length (m)  
CdSection drag coefficient  
CℓSection lift coefficient  
DTotal propeller drag (N)  
DhPropeller hub drag (N)  
DnDrag from the nth propeller blade (N)  
hPropeller hub height (m)  
IzMoment of inertia about the z-axis (kgm2)  
KvMotor velocity constant ((rads/s)/V)  
KtMotor torque constant (Nm/A)  
LTotal propeller lift (N)  
LnLift from the nth propeller blade (N)  
NNumber of blades  
RMotor resistance (Ω)  
rRadius (m)  
RpPropeller radius (m)  
RhPropeller hub radius (m)  
tTime (s)  
Local velocity vector (m/s)  
VℓLongitudinal velocity (m/s)  
VtTransverse velocity (m/s)  
Freestream velocity vector (m/s)  
Angular acceleration vector (rads/s2)  
βSection blade pitch (rads)  
θPropeller angular position (rads)  
Freestream air density (kg/m3)  
Net torque (Nm)  
Total Aerodynamic Torque (Nm)  
Aerodynamic Torque on the nth blade (Nm)  
Motor torque (Nm)  
Angular velocity vector (rads/s)

***Abbreviations***EMFElectromotive force  
GUI Graphical user interface  
RK4 Fourth-order Runge-Kutta  
SIMDSingle instruction, multiple data  
VTOLVertical take-off and landing  
eVTOLElectric vertical take-off and landing

1. INTRODUCTION

The aerodynamic analysis of unpowered, vertically oriented propellers downstream of a lifting surface poses an unconventional and intricate challenge in aerodynamic design

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