Advances in Engineering Software 000 (2017) 1–13

Contents lists available at ScienceDirect

Advances in Engineering Software

journal homepage: www.elsevier.com/locate/advengsoft

Development and validation of software for rapid performance estimation of small RPAS[☆]

Hugo Aliaga-Aguilar[*], Cristina Cuerno-Rejado

ETSI Aeronáutica y del Espacio, Polytechnic University of Madrid, Plaza del Cardenal Cisneros, 3, 28040 Madrid, Spain

A R T I C L E I N F O

Article history:
Received 11 October 2016
Revised 19 January 2017
Accepted 19 March 2017
Available online xxx

Keywords:
RPAS
Design
Aerodynamics
Performances
Analysis

A B S T R A C T

There is a high demand for small unmanned aircraft for a wide variety of missions. The relatively limited experience and resources of new commercial companies renders it almost impossible for them to tackle a complete design process with the same quality and results as bigger and more experienced companies. We aim to develop a full rapid design methodology software for such aircraft and present the first step in the process in the form of a performance estimation model. This model is tested with data from ten different commercially available RPAS, as well as two additional RPAS for aerodynamic validation. A comparison between the results obtained by means of this model and the manufacturers' data is presented.

1. Introduction

Remotely Piloted Aircraft Systems (RPAS) are increasingly present in every aspect of society [1]. Their unique suitability for a great number of different tasks and the possibility of being easily designed and manufactured without deploying an extended multidisciplinary team or employing large resources have enabled small businesses and amateurs to build and commercialize a wide range of platforms. This greatly differs from the usual methodology and resources required to build a traditional civil or military transport aircraft.

There is literature that studies the design of RPAS from a broader perspective, such as [2], that discusses the implications of the different subsystems present in the RPAS without elaborating in detail equations or values for parameters that could be found in classical hand-book style publications such as [3,4]. This can be explained by the extraordinary differences in both shape and flight regimes found among the RPAS. The current trend mostly comprises extensive Finite Element Models (FEM) analysis with different degrees of detail for high-end and detailed design, as well as vortex-lattice methods for less complex designs. Additionally, optimization methodologies have also been used for detailed calculation [5]. More recently, mixed approaches employing experimental data have arisen [6]. Code implementations of classical hand-book style methods, such as [7], are less used in favor of more complex and detailed models and environments for designing [8,9] that better utilize Multidisciplinary Design Optimization (MDO). There are additionally a number of works aimed at studying the aerodynamic stability by mixing experimental or precomputed Computational Fluid Dynamics (CFD) data and analytical modeling [10,11].

Our objective in the long run to develop a fully working MDO software environment for RPAS design, principally aimed at low Reynolds number flight conditions. This environment will comprise several disciplinary modules that will be controlled and managed by a main MDO module. One of these models pertains to the aerodynamic analysis and integral performance estimation of RPAS, which is the subject of this paper. We will first introduce the aerodynamic facet of the model, and describe its structure, how the RPAS is defined in order to be studied, and the results of aerodynamic estimations to obtain the lift and drag polar of the aircraft. Then we will address the mathematical model for range and endurance used by the integral performance estimator, to be followed by a detailed aerodynamic analysis of two existing RPAS (the Kahu UAV and a Greek UAV designed for reconnaissance) as well as performance estimations for ten additional UAV for comparison purposes. Finally, conclusions and future work are discussed. Similar works with an emphasis on different subsystems, such as the powertrain, exist in the literature [12].

As mentioned, in order to validate this aerodynamic and integral performance estimation software model, we gathered information about the flight conditions and geometry of ten different RPAS, mostly with low Reynolds numbers flight conditions, as well as the endurance advertised by their manufacturers in order to com-

---

[☆] This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

[*] Corresponding author.
E-mail address: h.aliaga.aguilar@upm.es (H. Aliaga-Aguilar).

http://dx.doi.org/10.1016/j.advengsoft.2017.03.010
0965-9978/© 2017 Elsevier Ltd. All rights reserved.

Please cite this article as: H. Aliaga-Aguilar, C. Cuerno-Rejado, Development and validation of software for rapid performance estimation of small RPAS, Advances in Engineering Software (2017), http://dx.doi.org/10.1016/j.advengsoft.2017.03.010

Nomenclature

A	Aspect ratio
b	Wingspan
C	Coefficient
c	Chord
Cap	Battery capacity (Ampere hours)
Cci	Circumferential length of the wing-fuselage intersection
C_1–C_4	Diederitch's method coefficients
D	Drag
di	Diameter
E	Endurance
Err	Error
f	Diederitch's lift distribution function
h	Height
HTP	Horizontal tailplane
i	Discharge current (Amperes)
in	Angle of incidence
K	Factor for calculating the lift on the wing plus body
k	Ratio of βCl_α to 2π
l	Length
L	Lift
MAC	Mean aerodynamic chord
max	Maximum
min	Minimum
N	Number
n	Discharge parameter
P	Power
q	Dynamic pressure
R	Range
Re	Reynolds number
Rt	Battery hour rating (hours)
SMC	Standard mean chord
S	Surface
sc	Specific consumption
t	Time
V,v	Flight speed
Vol.	Volume
Volt	Output voltage of the battery
VTP	Vertical tailplane
W	Weight
$W_{\frac{1}{2}p}$	Half wing perimeter
x	Coordinate measure from the MAC leading edge
y	Spanwise coordinate from the airplane centerline
α	Angle of attack
α_{0l}	Zero-lift angle per unit of twist
δ	Increment of wing vortex-induced drag from additional lift
β	Prandtl's compressibility correction
Δ	Increment
ε	Twist
η	Non-dimensional length
ηtot	Total efficiency
Λ	Sweepback angle
λ	Slenderness
ν	Kinematic viscosity of air
ρ	Density of air
ϕ	Shape factor

Subscripts

a	Additional lift distribution
ac	Aerodynamic center
airf	airfoil
att	Attached
b	Basic lift distribution
cg	Center of gravity
char	Characteristic
corr	Correction
cp	Center of pressure
cr	Cruise
det	Detachment
del	Delivered
D	Drag
eff	Effective
f	Fuselage
fi	Final
fn	Fuselage nose
F	Friction
h	Horizontal stabilizer
i	Initial
int	Interference
j	Number index
lam	laminar
L,l	Lift
loit	Loiter
m	Moment
man	Manufacturer
max	Maximum
min	Minutes
mod	Model
n	Nacelle
p	Point
prof	Profile
r	Root
req	Required
t	Tip
tot	Total
tur	Turbulent
u	Undercarriage
V	Vertical stabilizer
vor	Vortex
W	Wing
wf	Wing-fuselage
x	Axis parallel to the chord of the airfoil
α	lift-curve
0,l0, L0	Zero lift
$\frac{1}{2}$	Point $\frac{1}{2}$ of the chord
$\frac{1}{4}$	Point $\frac{1}{4}$ of the chord

pare them with values obtained from our model. The Kahu and Greek RPAS have been studied previously by Shafer et al. [10], and Spyridon et al. [13]. The results presented regarding the behavior of their drag polar, aerodynamic efficiency, pitching moment and lift coefficient will be used as a baseline to compare and validate our results, which will ultimately validate the aerodynamic and integral performance estimation model presented here.

2. Aerodynamic model

In order to study and develop new methods for RPAS rapid sizing, we present here a first step towards a fully working MDO methodology: a new performance estimation model that implements the philosophy of hand-book style methods and adapts it to micro and small RPAS flight regimes by integrating surrogate models of the behavior of the wings based on experimental data [14,15]. This model enables the designer to estimate the lift, drag polar and performance of a given model from the flight conditions

Please cite this article as: H. Aliaga-Aguilar, C. Cuerno-Rejado, Development and validation of software for rapid performance estimation of small RPAS, Advances in Engineering Software (2017), http://dx.doi.org/10.1016/j.advengsoft.2017.03.010