Energy Conversion and Management 98 (2015) 107–114

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Implications of longitude and latitude on the size of solar-powered UAV

Parvathy Rajendran [a,*], Howard Smith [b]

[a] School of Aerospace Engineering, Universiti Sains Malaysia, Engineering Campus, 14300 Nibong Tebal, Pulau Pinang, Malaysia
[b] Cranfield University, Aircraft Design Centre, School of Engineering, MK4 0AL Cranfield, UK

ARTICLE INFO

Article history:
Received 27 November 2014
Accepted 27 March 2015
Available online 10 April 2015

Keywords:
Solar irradiance
Daylight
Uav
Unmanned aircraft
Global aviation
Perpetual flight

ABSTRACT

The implication of solar irradiance and daylight duration on the design of a small solar-powered unmanned aerial vehicle (UAV) that is capable of operating perpetually in various cities around the world was investigated. Solar data in 2013 on 12 cities distributed around the world was collected. The effects of the available solar irradiance and daylight of the city on the maximum take-off weight and wing span of a small solar-powered UAV were studied. The analysis indicates that daylight duration is as important as the available solar irradiance to the performance of the solar-powered UAV. Longitudinal coordinates and elevation have a minor effect on the estimation of daylight duration. Areas considerably high in solar irradiance and daylight duration are more conducive to the effective performance of solar-powered UAVs than other areas. Therefore, cities closer to the equator have an advantage in utilizing solar-powered UAVs; where smaller and lighter solar-powered UAV can be designed.

1. Introduction

Non-renewable energy resources, such as fossil fuels, are likely to be depleted as soon as the rate of global population increases. Renewable energy, such as hydro, tidal, wind, and solar energy, can last permanently and must therefore be harnessed as an alternative to non-renewable energy [1]. Solar energy technology has been well developed because it is applicable in various locations and fields, including aviation.

Unmanned aerial vehicles (UAV) have caught the attention of many researchers around the world because of their potential use in various military and commercial applications. UAVs are cheaper than manned aircrafts; they also eliminate the issue of pilot safety [2,3]. Moreover, the size of a UAV can be customized according to the required maneuverability. As such, UAVs are used in various applications, such as rescue, surveillance, border interdiction, and wild fire suppression [4–6].

The first solar-powered UAV in the world, the Sunrise, was completed in 1974 [7]. Solar-powered UAVs harness solar irradiance through photovoltaic (PV) cells and transform it into electrical energy [8,9]. Most solar-powered UAVs are installed with electric motors driven by PV cells and rechargeable batteries. Any excess energy is stored in secondary batteries that supply the vehicle with energy even at night.

Some studies have measured solar irradiance [9,10]; many other studies have also developed increasingly efficient, long-endurance, and cheap solar-powered UAV [11–17]. Such studies focus on topics, including sizing the solar-powered UAV, optimizing energy management, and analyzing parameters that affect the performance of solar-powered UAVs.

An investigation has been done on the effect of the time of a certain day, the month of a particular year, sun incidence angle, and sun azimuth angle on solar irradiance and the solar power obtained by PV cells [18]. The above-cited work found that the intensity of solar irradiance is the major factor that affects the power production of PV cells. Moreover, the coordinate of a given area on Earth [19] may also have an effect on solar irradiance.

However, a study on the external factors that affect the performance of solar- powered UAV designed for a global-scale operation is yet to be explored. Thus, the present work investigates the impact of the available solar irradiance and daylight on the design of the maximum take-off weight and wing span of a small solar-powered UAV operating in various cities. The optimum area on Earth for solar-powered UAV operation is also identified.

2. Methodology

To identify the effect of coordinates on the sizing of the solar-powered UAVs, 12 cities distributed around the world, from north to south, east to west, and along the equatorial line, were chosen, as shown in Fig. 1. The chosen cities consist of London (United Kingdom), Ottawa (Canada), Tokyo (Japan), Riyadh (Saudi

* Corresponding author.
E-mail addresses: aeparvathy@usm.my (P. Rajendran), howard.smith@cranfield.ac.uk (H. Smith).

http://dx.doi.org/10.1016/j.enconman.2015.03.110
0196-8904/

Nomenclature

P_Solar	solar module system power (W)	*V*	air speed (m/s^2)
Ir_Max	solar irradiance (W/m^2)	*C_Do_W*	zero-lift-drag coefficient
eff_Solar	efficiency of solar module	ε	oswald efficiency
eff_MPPT	efficiency of maximum power point tracker (MPPT)	*AR*	wing aspect ratio
A_Solar	solar module area (m^2)	*b*	wing span (m)
P_Required	UAV power required (W)	*W_Struct*	structure weight (N)
C_L	lift coefficient	*W_Batt*	battery weight (N)
C_D	drag coefficient	*W_Solar*	solar power system weight (N)
W_TOmax	maximum take-off weight (N)	*W_Electric*	propulsion system weight (N)
ρ	air density (kg/m^3)	*W_Ctrl*	control system weight (N)
S	wing area (m^2)	*W_Pay*	payload weight (N)

Arabia), Honolulu (Hawaii), Accra (Ghana), Kuala Lumpur (Malaysia), Quito (Ecuador), Tahiti (French Polynesia), Brasilia (Brazil), Port Louis (Mauritius), and Suva (Fiji).

2.1. Solar irradiance model

A comprehensive model was developed to study on how the sun movement affects the solar module system's performance as shown in Fig. 2. The parametric considerations done in this model includes the time and day of the year, the longitude and latitude coordinates of the flight location, and the orientation of the sun and solar cell. These parameter values are used in determining the sun's altitude, declination and azimuth, the tilt angle of earth axis and tilt angle of solar cells. This modeling and simulation has enabled a precise solar irradiance and daylight duration prediction.

In this study, the modeling framework for the movement of the sun (Fig. 2) was adopted from the work of Muneer [20], where the input parameters i.e. information regarding the date, time, green meridian time, latitude, longitude, and altitude of the UAV operation are defined. The modeling then determines if the given date falls on a leap year to ensure that the next parameter (i.e. day number or the number of days in a given year) is correctly determined.

Once the relevant date parameters are defined, the solar time functions can be determined. These functions include the equation of time, universal time, radius (distance between the given location and the sun) and apparent solar time. The equation of time and apparent solar time are the times used in all calculations

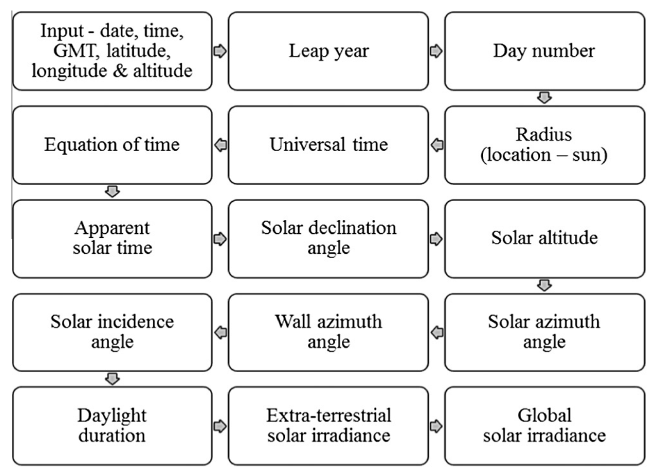

Fig. 2. The framework of solar irradiance and daylight duration modeling.

pertaining to solar geometry. These parameters apply the corrections caused by the difference between the longitude of a given locality and the longitude of the standard time meridian.

In addition to the solar time parameters, solar declination, solar altitude, solar azimuth, and solar incidence angle must be determined. Solar declination is the angle between the earth–sun vector and the equatorial plane. This parameter is considered positive when the earth–sun angle vector lies northward of the equatorial plane (Fig. 3).

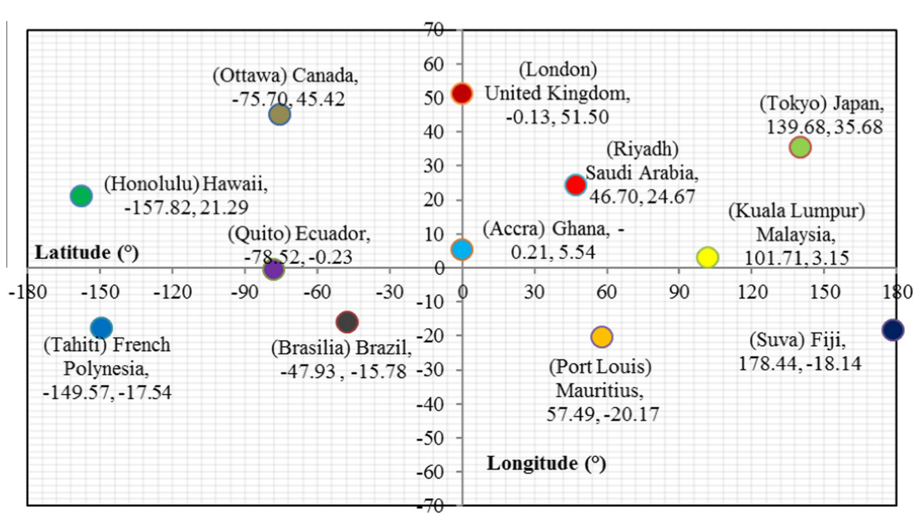

Fig. 1. Latitude and longitude of 12 selected cities around the world.