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Research on optimal solar array layout for near-space airship with thermal effect

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ABSTRACT

The output performance of solar array on near-space airship can be effectively improved by the layout optimization of solar array. This paper studied the effect of layout parameters on output energy of solar array on the airship with and without thermal effect, and particularly the optimization of solar array layout under the thermal effect. Based on the thermal model of solar array and the layout optimization model, a Matlab numerical program is adopted to calculate the output power or energy of solar array and latitudes and the change trend of optimum layout parameters for whole year and different latitude. The theoretical model is clearly verified comparing with the experimental result of temperature distribution of solar array. The effect of layout parameter on the thermal performance of airship was then analyzed by CFD simulation. The results show that the output performance of solar array is significantly improved through optimized layout and the output power or energy is decreased when considering thermal effect. The optimization of layout parameter may increase average temperature of airship and the velocity of internal helium of airship. Therefore, it is valuable to investigate the thermal effect of solar array in practical engineering of solar power system.

1. Introduction

With the great potential in the areas of telecommunications, Earth observation science and other services, the near-space airship has received increasing attention in many countries and regions in recent decades (Ilcev, 2011; Tozer and Grace, 2001). The energy resource of near-space airship includes solar energy, fuel cell and others. Solar array is recognized as the ideal energy resource of near-space airship to ensure its normal operation by virtue of renewability and light-weight (Dolce et al., 2003). But due to the problem of low photoelectric conversion efficiency of solar array (Ito et al., 2008; Jiang et al., 2017), its extensive application is limited. Consequently, the researches of solar array are worthwhile to improve the energy management of near-space airship.

To the feasibility of solar energy powering the near-space airship, several scholars conducted detailed analysis in the past decades. The feasibility of realization about integrating a solar-electrical propulsion system in such a small airship was early demonstrated based on the design of solar powered and radio-controlled airships (Kroeplin and Schaefer, 1995). The power system requirements of high-altitude airship and the feasibility of the solar power system of the airship were also studied, the results show that the designed solar power system is adequate to meet the high-altitude airship system's requirements (Naito et al., 1999). The works of Colozza (2003) also show the feasibility of a long-endurance near-space airship and the numerous factors which can influence the energy balance of solar-powered near-space airship were identified.

Based on the foregoing researches of scholars, it is certain that solar array being the main energy resource to power airship is feasible. Therefore, many researches about the output performance of solar array of near-space airship have been published in the recent years (Li et al., 2011; Sun et al., 2012; Zhang et al., 2016). Wang et al. (2007) presented a computation method for solar radiation on solar array of high-altitude airship, and clarified that the effect of the airship's attitude on the performance of its energy system cannot be neglected. In addition to the research about the output performance of solar panel of near-space airship, the thermal performance of solar powered airship were also investigated based on a simplified numerical model by Li et al. (2012). The results indicated that the operation latitude, date and wind speed are significant factors to the output performance of photovoltaic array, and that the solar array can change the thermal performance of the airship. To further compare the output performance of solar array on near-space airship with or without thermal effect, Li et al. (2016a) developed the effects of the transmittance of solar array encapsulant

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Nomenclature

A	the area, m^2
c_s	specific heat capacity of solar array
E_{ele}	the total energy output of solar array per day, J
E_{loss}	the equivalent input energy of a solar cell without thermal effect, J
E_{in}	the energy loss of solar array after considering thermal effect, J
$\vec{G}$	the vector of gravity direction
$\vec{n}_e$	the normal vector of a cell unit
$\vec{S}$	the vector of solar irradiation
h_{free}	free convection heat transfer coefficient
h_{force}	force convection heat transfer coefficient
I_d	the direct solar irradiance, W/m^2
I_{di}	diffuse solar radiation, W/m^2
kij	thermal conductivity of solar array
ke	thermal conductivity of airship envelope
$kair$	thermal conductivity of atmospheric
L	total length of the airship, m
L_0	characteristic length, m
m_{ij}	the mass of a cell unit, kg
Nu_{air}	the free convection Nusselt number
Q_{ele}	the output power of solar array, W
Q_T	the heat power of solar array, W
Q_R	the reflection radiation from the earth, W
Q_{inf}	infrared radiation heat loss, W
Q_{SC}	convection heat loss to sky, W
Q_{AC}	conductive heat loss to airship envelope, W
Q_d	solar direct radiation, W
Q_{di}	diffuse radiation, W
r	the equivalent rotary radius of airship, m
R	the radius of maximum cross section of airship, m
r_e	the solar reflectivity
t_{ij}	the thickness of solar array, m
t_e	the thickness of airship envelope, m
τ	time, s
T_{ij}	the temperature of cell element, K
T_{atm}	the temperature of atmosphere, K
T_{GP}	the temperature of ground plane, K
μ_{air}	atmospheric kinematic viscosity, m/s
y_0	the leading edge of solar array, m
y	the axial coordinate of the profile of airship, m
ν_w	the relative velocity between the airship and the flowing air, m/s
α	the solar absorptivity of solar array
α_R	the absorptivity of solar array to reflected radiation
θ	the central angle of solar array, degrees
θ_{ij}	the included angle between the cell unit normal and gravity direction, degrees
θ_{ele}	solar elevation angle, degrees
β_{ij}	the included angle between the normal vector of the element and the vector of solar irradiation, degrees
ε	the infrared emissivity of solar array
σ	Stefan–Boltzmann constant value, $\sigma = 5.67e-8\ W/(m^2 K^4)$
η	conversion efficiency of solar cell
δ	the transmittance of solar array encapsulant material

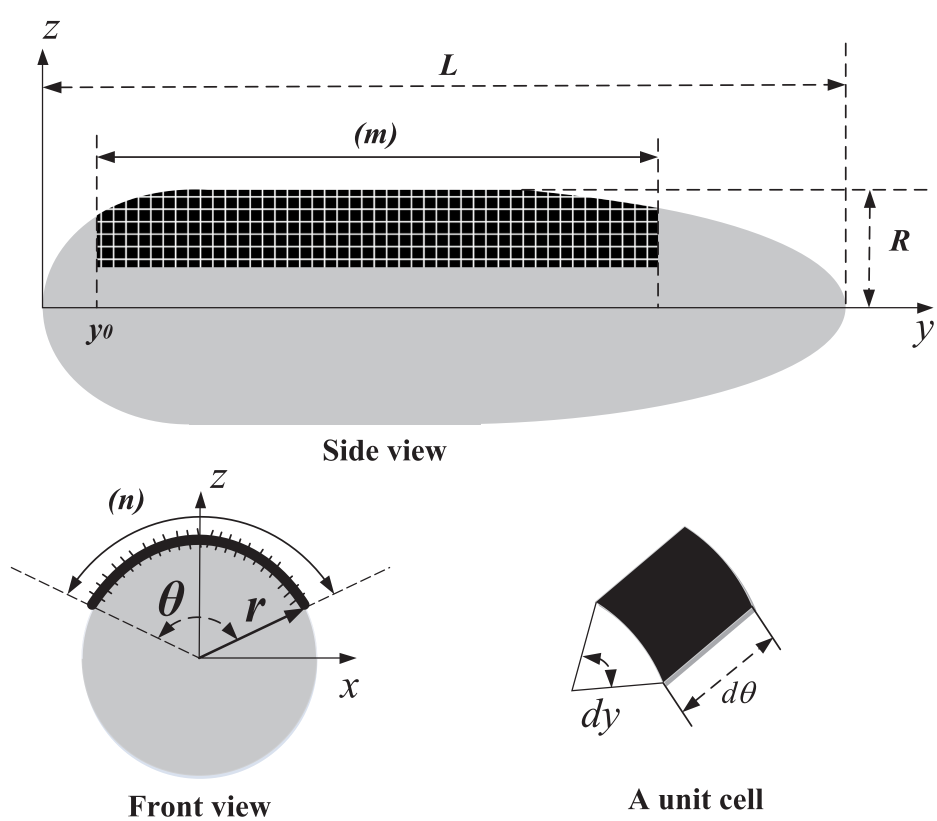

Fig. 1. Schematic of the near-space airship and solar array.