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Influences of initial launch conditions on flight performance of high altitude balloon ascending process

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Abstract

Influences of initial launch conditions on flight performance are addressed for the high altitude balloon ascending process. A novel dynamic model was established to describe thermodynamic and kinetic characteristics of balloon which consists of atmospheric, thermal and dynamic submodels. Based on the model, ascending processes of a high altitude balloon under different initial launch conditions were simulated. The initial launch conditions were classified into three types: inflating quantity, launch time and launch position. The ascending velocity and the differential pressure were defined and used as evaluation parameters of flight performance. Results showed that the inflating quantity is the most effective factor for ascending process, and the upper and lower limits were also proposed separately from safety and performance perspectives. For both launch time and launch location conditions, different solar radiation is the main effect approach during ascending process. Specifically, the influence mechanism of launch time in one day and launch longitude are completely identical due to the Earth's rotation. Results also showed that the sunset process is the optimal selection for safety of balloon and efficient utilization of solar energy. Due to the Earth's revolution, the influence mechanism of launch date and launch latitude are identical and the effects are more seasonal and less effective. Launch time and location should be considered comprehensively in practical operation of ballooning.

Keywords: High-altitude balloon; Flight performance; Launch conditions; Ascending process

1. Introduction

The high altitude balloon is a class of Lighter-than-air vehicle with application potential in communication, investigation, science exploration and other fields. Stratosphere is the most suitable space for the balloon because of year-long steady wind field in specific altitude (Schmidt et al., 2007). Therefore study in stratospheric balloon becomes the focus in many counties in recent years (Smith, 2004; Makino, 2002; Agrawal et al., 2002). In order to fulfill the tasks of a high altitude balloon, ascending process is an essential part of ballooning. During ascending, the lifting force is very sensitive to thermal effect (Palumbo et al., 2007). Both the balloon itself and the environment conditions affect ascending process (Guo and Zhu, 2013). Among those factors, launch conditions are of vital importance due to their controllability. To achieve better ascent performance, proper choices of launch conditions are required in the balloon mission preparation. On the other hand, poor launch conditions will cause potential safety risks and lead to the mission failure, especially for super-pressure balloons.

In the past decades, many important models of the performance of high altitude balloons have been developed. Kreith and Kreider (1974) provided an efficient and

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calibrated computer program to predict balloon ascent rates, ceiling, and behavior at float altitude which is considered as the starting point of the balloon modeling research. Carlson and Horn (1983) established a new thermal and trajectory model for high-altitude balloons, and the model predicted the temperature difference between gas and film which was observed in several test flights. The importance of thermal effect on balloon performance was revealed and more studies on radiative properties and thermal effect were completed (Cathey, 1996, 1997; Franco and Cathey, 2004) . Pankine et al. (2003) developed an advanced balloon performance and analysis tool called Navajo which can provide high-accuracy vertical and horizontal trajectory predictions. Farley (2005) built a new user-friendly software tool, in which adaptable formulations were generalized to allow balloon flight simulations in extraterrestrial atmospheres. Palumbo et al. (2007) constructed analysis code for high-altitude balloons including more features such as ballasting and valving, but is applied only to zero pressure balloons. The drag coefficient in the analysis code is presented as a function of the Reynolds number, the Froude number and another dimensionless parameter and it is quite suitable to fit the flight data. And based on the analysis code, a methodology was proposed for the prediction and optimization of the ascent trajectory (Morani et al., 2009; Palumbo et al., 2010). Conner and Arena (2010) discussed the development of a performance predictor for near space balloon systems and the balloon's volume and drag coefficient were established as a function of altitude. Dai et al. (2012) investigated the influence of film radiation properties and clouds on balloon thermal behaviors at float condition but the influence on ascending process was not discussed. Liu et al. (2014) proposed a novel model to investigate the thermal-dynamic performance of scientific balloon and the balloon film temperature distribution was discussed.

The foregoing articles mainly focused on the accuracy and correctness of the model to make the prediction more accurate. The effects of launch conditions on balloon flight performances have not been given much attention. The primary purpose of this study is to reveal the influence mechanism of launch conditions on flight performance through modeling of high altitude super-pressure balloon. The remainder of this paper is organized as follows. In Section 2, features and hypothesis of high altitude balloon are introduced firstly to build a balloon flight simulation model. Then, submodels of atmosphere, thermal effect and dynamics are established and governing equations are presented. Section 3 describes the simulation method which includes simulation environment, initial launch conditions and evaluation parameters. Finally, the accuracy of the model is verified by comparing the simulation data to the measured data. After validation the numerical solution is given under different launch conditions. Based on the simulation results, influence of launch conditions are discussed.

2. High altitude balloon model

The object of the model is a super-pressure balloon made of a composite fabric that is filled with helium. The pressure inside the envelop is maintained above the ambient pressure at all times to keep the balloon afloat at a constant altitude. Based on the general model of fixed-wing aircraft, some specific features were introduced into the high altitude balloon model. These features include high-altitude thermal radiation environment, buoyancy, virtual mass and the coupling relation between kinetics and thermodynamics. And in order to simplify the model, some reasonable hypothesis are made:

- The system of high altitude balloon is treated as rigid body in kinetic equations.
- In the ascent phase, the shape of the balloon is always assumed to be spherical.
- The temperature of balloon film and helium inside are both represented as arithmetic average value.

2.1. Atmospheric model

The atmosphere model in this paper consist of atmospheric parameters which are only related to geopotential altitude. The model implements the mathematical representation of the 1976 Committee on Extension to the Standard Atmosphere (COESA) United States standard lower atmospheric values for absolute temperature, pressure and density for the input geopotential altitude.

2.2. Thermal model

Stratospheric balloon thermodynamic models are used to calculate the temperature both of the balloon film and the internal helium. Factors that affect the temperature variations include environmental radiation, thermal characteristics of the balloon film, convective heat transfer, and the expansion and compression of balloon as a result of the state change of helium. Fig. 1 describes the components of thermal behaviors. These factors vary with time, location, altitude, weather, the amount of helium gas and the parameters of balloon. Therefore, a thermodynamic model which can adapt to complex flight state is necessary for evaluating the influence of launch conditions on the flight performance of stratospheric balloon.

2.2.1. Environment radiation

Environment radiation in flight includes direct solar radiation, solar scattering radiation, planet albedo radiation, cloud layer albedo radiation and planet infrared radiation.

2.2.1.1. Direct solar radiation. Of all the sources of radiation received by a balloon, the direct solar radiation is the most critical. There are many factors that affect the direct