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Thermally induced vibration of composite solar array with honeycomb panels in low earth orbit

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HIGHLIGHTS

- A method to characterize the thermal response of a rigid solar array is presented.
- Composite material and orbital thermal environments are considered in the model.
- Thermally induced vibration is investigated based on this model.
- The effects of different parameters are discussed.
- Incident angle and parameters of honeycomb composite have significant influence.

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ABSTRACT

Solar arrays are critical appendages that provide primary power sources for spacecrafts. This paper presents a numerical method to characterize the thermal response of a composite solar array subjected to space heat flux. Thermally induced vibration is investigated based on this method. The thermally induced vibrations of a solar array using two commonly used materials are also compared. Thermally induced vibrations in different thermal environments, incident angles of solar radiation, and material properties of honeycomb panel are discussed to reveal the causes of thermally induced vibration. Simulation results reveal the dynamic response of the solar array in low earth orbit under transient temperature, which could provide guidance for designers to optimize the structure utilized in minimizing the influence of the space thermal environment.

1. Introduction

Solar arrays are critical appendages that provide primary power sources for spacecrafts [1,2]. Over the last ten years, Airclaim's Ascend SpaceTrak database has documented 117 solar array anomalies, among which, twelve anomalies directly resulted in total satellite failure [3,4].When the spacecraft is traveling around the Earth, its solar arrays experience periodic heating and cooling in the sunlight and shadow regions of the Earth with the variations of the thermal environment. Dramatic temperature changes occur during day–night and night–day transitions in orbit. Sudden heating changes on the surface of an appendage may induce temperature gradients that generate time-dependent bending moments. These moments induce structure deformations and vibrations of solar arrays, which influence the energy efficiency and reliability of on-orbit spacecraft. In the past few decades, a number of failures of solar arrays that have been investigated were caused by thermal vibrations. For example, the Hubble Space Telescope (HST) [5] have been observed to have vibrations induced by thermally driven bending of the solar arrays when the solar array structure reacts to temperature changes occurring as the spacecraft passes from shadow to sunlight. This 'thermally induced vibration' causes performance degradation of the power subsystem, which may result in total satellite failure.

Generally, temperature variations of solar array under space thermal environment are one of the main inducements of structure vibration. Therefore, temperature analysis is necessary to explore the reasons for structure vibration. The orbiting spacecraft and its solar arrays may be heated by space environment and multiple heat sources [6]. The Sun and Earth are primary heat sources. The solar

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array also emits heat radiation to deep space. When a spacecraft is traveling around the Earth (shown in Fig. 1), the time historical temperature field will be produced throughout its orbital cycle. Dramatic temperature changes are more likely to occur during day–night and night–day transitions in the orbit.

A number of studies have conducted thermal analysis for spacecraft and its appendages [2,7–18]. Foster and Tinker [2] compared the flight data and computer simulation results of a solar array for HST, and found that the source of disturbances was the thermally driven deformation of the solar arrays in conjunction with frictional effects in the array mechanisms. Thornton et al. [7,8] focused on the thermal-structural response of booms on HST solar arrays for a typical night–day transition and presented numerical results of temperature profiles and gradients by using finite element analysis. Ding et al. [9] presented a method for calculating the time-dependent temperature fields for thin-walled beams on the HST solar array that considered nonlinear and time-dependent heat conductions in complex structures. Yang et al. [10] provided a method for calculating the temperature response of folded solar array. Li et al. [11] showed the characteristics of the transient temperature field in the simplified rigid solar array. Gadalla [14] presented a closed-form prediction model for the temperature distribution of a thick-walled cylindrical space vehicle subjected to solar heating in deep space. Kim et al. [15] conducted a thermal analysis of a fixed-type solar array in a low-earth orbit satellite. Foster and Aglietti [16] focused on the thermal environment and the response of the multifunctional structures by analyzing its temperature through a newly developed numerical model. Li et al. [17] developed a thermal analysis model of a composite solar array with complex structure to characterize the thermal response of an entire solar array system subjected to space heat flux. The study also discussed the laws of the transient temperature field of the entire solar array system.

Sudden heating changes on the surface of an appendage may induce temperature gradients that generate time-dependent bending moments. These moments induce structure deformations and vibrations of solar arrays, which influence the energy efficiency and reliability of on-orbit spacecrafts. For orbital spacecrafts, severe changes in the temperature field on the solar array will cause temperature gradients within the structure, which in turn induce thermal vibration and even buckling. Numerous studies on thermally induced vibration of the solar array have been carried out [19–27]. The studies have two kinds of major simplified models based on the diversity of the structure: cantilever beam and rigid/flexible panel. For the space heating cantilever beam, Thornton et al. [19,20] have conducted considerable studies on HST solar array, including coupled and uncoupled thermal-structure analysis of booms and blankets. Song et al. [22] developed a comprehensive structural model of composite spacecraft booms and studied thermally induced flexural oscillations. Xue et al. [22,23] discussed the temperature field of thin-walled tube elements for transient thermal-structural analysis of large-scale space structures based on finite element method, and expounded on the necessary conditions of thermally induced vibration and the criterion of thermal flutter. For the space heating rigid panel, Tauchert [24] and Thornton [25] reviewed the studies on thermally induced bending, buckling, large deformation behaviors, and vibrational characteristics of plates and shells to thermal loadings. Johnston and Thornton [26,27] investigated the thermal-structural performance of rigid panel solar arrays, and the effects of thermally induced structural disturbances of a thin-walled boom with tip mass and a solar panel on the attitude dynamics of a simple spacecraft are investigated.

The previous studies have provided elaborate discussions on the thermal structure issue of simplified beams and panels on solar arrays. However, for the composite solar array with complex structure, these simplified models ignore the interaction among components under thermal load. Thus, the response of the overall structure under space thermal environment in orbit cannot be revealed systematically. Moreover, most of the studies on orbital rigid solar array with composite panels focus on transient thermal analysis, with a limited number of studies on its structure response under transient thermal load being conducted.

The primary purpose of this paper is to conduct a study on a modeling method of composite solar array with honeycomb panels for thermally induced vibration analysis and to explore the characteristics of thermally induced vibration of rigid solar array under transient thermal environment in low earth orbit. The transient temperature field and thermally induced vibration of the solar array are calculated by applying the finite element method.

2. Modeling of thermal-structure analysis

There are 3 steps for modeling: (1) formulate the heat flux in orbital thermal environment, (2) based on the heat flux and the thermal conductivity of honeycomb material, calculate the transient temperature field, (3) taking the temperature field as thermal load, calculate the thermal-structure deformation.

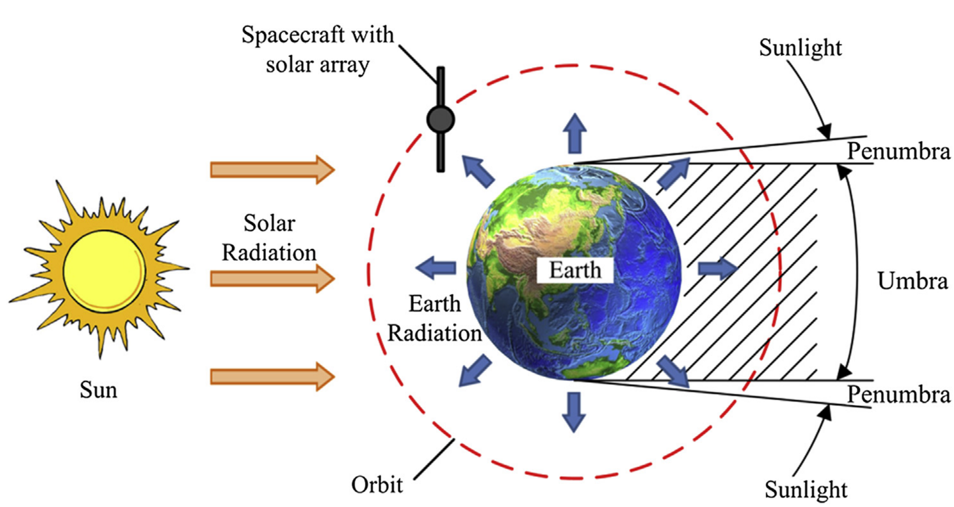

Fig. 1. Thermal environment of orbiting solar array.