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The optimal design of space structures considering the criterion of thermal flutter

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ABSTRACT

Thermally-induced vibrations typically occur when flexible appendages are subject to rapidly developing or decaying temperature differences when satellites undergo orbital eclipse transitions [1]. Since the 1960s, it becomes a typical failure of spacecrafts [2]. The most severe case is the unstable thermally-induced vibration, called thermal flutter, which is due to the coupling effect between structural deformations and thermal loadings.

Thermally-induced vibration of thin beams was firstly predicted by Boley [3, 4], who introduced a Boley factor to describe the necessary condition of the occurance of this phenomenon. This prediction was soon confirmed by a series of accidents and many researches have been conducted in this field [2]. For example, Thornton and Kim analysed the thermally-induced vibration of deployable space structures of the Hubble sapace telescope by a simplified beam model. Both uncoupled and coupled thermal-structural analyses and the stability criterion of the dynamic response were presented in their paper [5]. However, although the fundamental theory has been laid on, many literatures present only simple beam examples. Li et al., who used finite elemnt method to analyze the non-linear vibration of practical large-scale thin-walled space structures subjected to suddenly applied thermal loading [2]. In their study, the coupling effect between structural deformations and the incident solar heat flux is considered, and the criterion of thermal flutter is established.

Since thermal flutter is a typical failure of spacecrafts, what interested to a desinger is how to avoid it. This could be achieved by an optimal design method presented in this paper. In this optimization method, the objective function is the total weight of the structure; the design variables are dimensional parameters, material properties and structural damping ratio; and the constraint functions are the lower and upper bounds of the design variables and the stability criterion of thermal flutter presented in [2].

Because the damping is always exited in structures, the thermally-induced vibration is attenuable. The real danger comes from the coupling between structural deformations and the thermal loading. When the structure continuously absorbs thermal energy from environment, the thermal flutter could happen. Therefore, the heat conduction equation and the structural dynamic equation of this system contain the coupling term that

bridges the temperature field and the displacement field. After transforming these governing equations into state space, the stability criterion of thermal flutter is constructed from the sign of the eigenvalues of their coefficient matrix according to *Liapunov*'s stability theory [6]. Based on this criterion, one of the constraint functions in the proposed optimal design method is requiring the real parts of all eigenvalues be negative.

This optimal design problem can be efficiently solved with gradient-based algorithms. All sensitivities needed are calculated through the analytical formulation of the derivative of eigenvalues with respect to design variables by the methods presented in [7-9]. Finally, the validity of this optimal design method is illustrated by numerical examples.

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