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RADIATIVE HEAT TRANSFER IN MULTILAYER THERMAL INSULATION OF A SPACECRAFT

Abstract

The study is motivated by the need to optimize multilayer vacuum thermal insulation (MLI) of modern high-weight spacecrafts. The present-day computational models for radiative heat transfer in a single layer of the vacuum insulation are insufficient to solve this problem because the experimental data for the wide-range infrared radiative properties of materials are not quite reliable. Moreover, our preliminary estimates showed that the known physical effect of near-field radiative transfer between two closely spaced layers of aluminum foil may lead to a significant increase in the radiative flux. A theoretical prediction of this effect is very sensitive to the distance between the foils, and it is problematic to obtain accurate quantitative results for various flight conditions. In addition, the role of a highly-porous fibrous spacer between the foils has been estimated in our recent papers by neglecting the near-field effect. Obviously, the estimate of the spacer effect should be revised in a general theory taking into account a very small thickness of the gap between the foils. This theoretical study is in the very beginning now. Therefore, the role of the inverse problem solution in obtaining the radiative flux at realistic conditions is considered as a very important stage of the combined experimental and theoretical study. For brevity, we do not give here the complete mathematical problem statement, which can be found in our previous papers. At the same time, it should be noted that we are focused on identification of the conventional effective emissivity, which is the key integral parameter (over the spectrum) used to determine radiative heat transfer in the vacuum insulation of spacecraft. The specimen of real MLI used for BP-Colombo satellite (ESA) was used in our experiments. The previously developed spectral model for radiative transfer in vacuum thermal insulation of space vehicles is generalized to take into account possible thermal contact between a fibrous spacer and one of the neighboring aluminum foil layers. An approximate analytical solution based on slightly modified two-flux approximation for radiative transfer in a semi-transparent fibrous spacer is derived. It was shown that thermal contact between the spacer and adjacent foil may decrease significantly the quality of thermal insulation because of an increase in radiative flux to/from the opposite aluminum foil. Theoretical predictions are confirmed by comparison with new results of laboratory experiments.