FINAL REPORT FOR GRANT NGR 05-003-285

National Aeronautics and Space Administration

Washington, D.C. 20546

INVESTIGATION OF RADIATION AND CONDUCTION OF SOLIDS FOR SPACECRAFT HEAT TRANSFER APPLICATIONS

(June 1, 1968-July 31, 1970)

by

C.L. Tien

Professor of Mechanical Engineering

University of California

Berkeley, California

August 31, 1970

INTRODUCTION

The present Research Grant is to investigate certain thermal radiation and conduction phenomena in solids, that are significant in the design and thermal control of spacecrafts. Specific subjects under the present investigation are:

(A) Total emittance of low emittance materials in the temperature range of $300°K > T > 40°K$.

(B) Radiation tunneling effect on heat transfer across two closely spaced metallic surfaces.

(C) Lateral heat transfer characteristics of multilayer insulations with or without spacers.

The earlier progress of this investigation has been reported in the First, Second, and Third Semiannual Status Report (1, 2, 3). The present report summarizes the results of the research accomplished during the entire period of the Grant from June 1, 1968 to July 31, 1970, which includes a two-month no-cost extention as approved.

TOTAL EMITTANCE STUDIES

The total emittance of low emittance materials at cryogenic temperatures is a property of vital practical importance in the design and performance evaluation of multilayer insulations (4). It is the intent of the present investigation to yield quantitative information regarding this property. The present study consists of a combined theoretical and experimental program.

Theoretical results of the total emittance of low emittance materials at cryogenic temperatures have been developed (5). In cryogenic multilayer insulations, however, it is found that the thickness of metal layers on the plastic

film substrate is often in such a range that the emissivity of these metal layers is a function of thickness. This size effect has been under intense investigation and both theoretical and experimental results have been obtained (6, 7). These results clearly indicate the increase of emissivity values with the decrease of metal-film thickness. In addition, the plastic-side emissivity of the singly metallized insulation blanket has also been investigated, resulting in a new method of calculation based on a concept of band-averaged optical constants (8).

RADIATION TUNNELING STUDIES

Radiation tunneling phenomenon could play an important role in the heat transfer behavior normal to a multilayer insulation. An extensive analytical and experimental investigation has been carried out under the support of the present Grant. Results which have been presented in three published papers (9, 10, 11), indicate a significant increase of radiative transfer when the spacing between two layers is comparable to or less than the maximum-intensity wavelength of radiation.

MULTILAYER INSULATION HEAT TRANSFER STUDIES

Successful application of multilayer insulation requires an accurate knowledge of its lateral heat transfer characteristics. The lateral heat transfer along the laminations is governed by the conduction through thin metallized film on the plastic, and the radiation transport along two conducting films. The former contribution has been analyzed in the present investigation, and the analytical results agree favorably with measurements reported earlier (12). The lateral radiation transport along two conducting

films has been analyzed and the predicted results are in good agreement with existing experimental data (13). A more refined experimental study of the lateral conduction and radiation in multilayer insulation has also been carried out under this Grant (14). In order to provide some understanding about the effect of nongray surfaces, a small effort has been made to analyze this effect (15). The calculation of normal heat transfer in multilayer insulation has also been improved by the development of a surprisingly simple but realistic analytical model (16).

SUMMARY

Under the support of this Grant, a significant amount of useful information for the design and performance evaluation of cryogenic multilayer insulation has been obtained and reported in the thirteen publications (4-16). A review and summary of these studies has been presented in a recent international meeting (17). Further investigations of this and other real effects, however, are needed before a good understanding of normal and lateral heat transfer characteristics of multilayer insulations can be achieved.

REFERENCES

1. C. L. Tien, Investigation of Radiation and Conduction of Solids for Spacecraft Heat Transfer Applications," First Semiannual Status Report, NASA Grant NGR-05-003-285, College of Engineering, University of California, Berkeley, California, December, 1968.

2. C. L. Tien, "Investigation of Radiation and Conduction of Solids for Spacecraft Heat Transfer Applications," Second Semiannual Status Report, NASA Grant NGR-05-003-285, College of Engineering, University of California, Berkeley, California, June, 1969.

3. C.L. Tien, "Investigation of Radiation and Conduction of Solids for Spacecraft Heat Transfer Applications," Third Semiannual Status Report, NASA Grant NGR-05-003-285, College of Engineering, University of California, Berkeley, California, December, 1969.

4. C.L. Tien and E.G. Cravalho, "Thermal Radiation of Solids at Cryogenic Temperatures," Advances in Cryogenic Heat Transfer, Chem. Engrg. Prog. Symp. Series, Vol. 64, No. 87, pp. 56-66 (1968).

5. G.A. Domoto, R.F. Boehm, and C.L. Tien, "Predictions of the Total Emissivity of Metals at Cryogenic Temperatures," Advances in Cryogenic Engineering, Vol. 14, pp. 230-239 (1968).

6. B.F. Armaly and C.L. Tien, "Emissivities of Thin Metallic Films at Cryogenic Temperatures," Proceedings of 4th International Heat Transfer Conference, Vol. 3, R1.1 (1970).

7. G.R. Cunnington, G.A. Bell, B.F. Armaly and C.L. Tien, "Total Emittance Measurements of Thin Metallic Films at Cryogenic Temperatures," AIAA Paper No. 70-63 (1970).

8. C.L. Tien, C.K. Chan and G.R. Cunnington, "Infrared Radiation of Thin Plastic Films," to be presented in the ASME Annual Meeting, New York, November, 1970.

9. G.A. Domoto and C.L. Tien, "Thick Film Analysis of Radiative Transfer Between Metals at Cryogenic Temperatures," ASME Paper No. 69-WA/HT-6, to appear in Journal of Heat Transfer.

10. R.F. Boehm and C.L. Tien, "Small Spacing Analysis of Radiative Transfer Between Metals at Cryogenic Temperatures," ASME Paper No. 69-WA/HT-8, to appear in Journal of Heat Transfer.

11. G.A. Domoto, R.F. Boehm, and C.L. Tien, "Experimental Investigation of Radiative Transfer Between Metals at Cryogenic Temperatures," ASME Paper No. 69-WA/HT-7, to appear in Journal of Heat Transfer.

12. C.L. Tien, B.F. Armaly, and P.S. Jagannathan, "Thermal Conductivity of Thin Metallic Films and Wires at Cryogenic Temperatures," Proceedings of Eighth Thermal Conductivity Conference, pp. 13-20, Plenum Press, New York (1969).

13. C.L. Tien, P.S. Jagannathan, and B.F. Armaly, "Analysis of Lateral Conduction and Radiation Along Two Parallel Plates," AIAA Journal, Vol. 7, pp. 1806-1808 (1969).

14. P.S. Jagannathan and C.L. Tien, "Experimental Investigation of Lateral Heat Transfer in Cryogenic Multilayer Insulation, "Paper No. L-6, 1970 Cryogenic Engineering Conference (1970).

15. B.F. Armaly and C.L. Tien, "A Note on the Radiative Interchange Among Non-Gray Surfaces," Journal of Heat Transfer, Vol. 92, pp. 178-179 (1970).

16. G.R. Cunnington and C.L. Tien, "A Study of Heat Transfer Processes in Multilayer Insulations," AIAA Paper No. 69-607 (1970).

17. C.L. Tien, "Fundamental Aspects of Heat Transfer Through Cryogenic Multilayer Insulation," International Symposium on Cryogenics and Cryoengineering, Tokyo, Japan, September, 1970.