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FUTURE PROBLEMS OF SANDIA CORPORATION IN THE FIELD OF WEAPON THERMAL PROTECTION

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ABSTRACT

The topics of interest in aerodynamics with emphasis on heat transfer presented in this paper are intended to provide an indication of areas that require immediate study and development if Sandia capabilities in the field of weapon thermal protection are to keep abreast of current advances in missile performance and technology.

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FOREWORD

The mere statement of a problem is, of course, only the beginning of an attack on it. Accordingly, this paper, which states a number of aerodynamic heating problems of interest to Sandia Corporation, is a request for effort rather than a report of work completed. It is hoped that by stating the need for particular data, interest in obtaining them will be stimulated. Suggestions and comments would be welcomed by the author.

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Introduction

In the past, heating of Sandia weapons and related carriers was derived from inputs generated by flight at Mach 5.0 or less. In addition, the studies conducted were limited to reasonably low altitudes where air could safely be regarded as a continuum. While solutions obtained for problems in this regime have been perfectly acceptable from an engineering viewpoint, it is now apparent that the techniques that have been employed are not sufficient to meet future requirements. This paper describes some areas in which study is needed to provide competency in handling the problems presently being dictated by advances in missile performance and technology. The regions of interest are divided into (1) topics related to determination of heating rates; (2) topics related to weapon thermal protection; and (3) topics of general interest.

Topics Related to Determination of Heating Rates

Pressure Distribution

The pressure distribution over slender and blunt bodies must be determined in order to evaluate local flow properties for use in the determination of heat transfer to the body. Since the aerodynamic heating problem arises as a consequence of high-speed flight, the theories employed to predict the pressure distribution may deal with supersonic flow only. For truly slender, pointed bodies the pressure coefficient distribution may be obtained from the linearized theory by allowing a given source distribution to approximate the body contour. Other slender-body theories, applicable to determination of the pressure distribution over a body of revolution, are reported in the literature. When the nose of a body is blunted, the pressure distribution may be determined in the stagnation region by the Newtonian theory. Since this method predicts results as a function of the slope of the body only, some question arises concerning the validity of results when dealing with zero or infinite body slopes. It has been suggested by some investigators that Prandtl Meyer expansion theory be combined with the Newtonian when leaving the stagnation region. Blunt-body theory (Newtonian) also generally accepts the concept of expanding the flow isentropically from conditions behind a normal detached shock wave to local conditions on the body. In this process, no mechanism is provided for recovering pressures and Mach numbers with values approaching that of free stream; hence a greatly reduced local Mach number is predicted over the entire body.

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Studies describing pressure distribution over various body geometrics are presented in References 1 through 5. Since the pressure distribution problem is of prime importance to determination of the heat transfer to the body, it would be desirable to survey existing theories for the purpose of becoming familiar with the state of the art and for becoming adept at applying the best combination of existing theories to Sandia-designed shapes.

Heat Transfer in Dissociated and Ionized Air

For atmospheric flight above Mach numbers of approximately seven, realistic consideration of heat transfer to a body must include the effects of dissociation and, at very high Mach numbers, ionization of the gas surrounding the body. The importance of these considerations is pointed out by the fact that use of the energy equation, neglecting dissociation, predicts a stagnation temperature at reentry velocities of 35,000°K; consideration of a "frozen" boundary layer predicts a stagnation temperature of the order of 7500°K. This large temperature difference is the direct result of employing infinitely fast or infinitely slow recombination rates in the calculations. In actual practice, neither of the above situations exists, and some knowledge of the true recombination rates and dissociation-ionization effects must be obtained. The recombination rates will also be responsible for the mechanism by which heat transfer takes place. For example, Lees has pointed out in Reference 6 that for very fast recombination rates the heat transfer at the wall may be obtained in terms of the surface pressure distribution, while for very slow recombination rates heat transfer from the boundary layer to the body surface is accomplished partly by ordinary heat conduction and partly by the heat released by catalytic recombination of those atoms that manage to penetrate the screen of molecules diffusing away from the surface. At sufficiently high flight speeds diffusion is responsible for practically all of the heat transfer. It is important to notice that these effects exist at altitudes where air may still be considered a continuum. (This implies a knowledge of the various flight regimes, continuum, slip flow, free molecule flow, etc., and the appropriate techniques to be applied in each regime.) As the result of their work on Air Force contracts to study the reentry problem, General Electric, Avco, and Lockheed Missile Systems Division have been the principal generators of knowledge in this area since 1954. It is important to note that the effects of dissociation are not limited to changes in the stagnation temperature but include changes in the gas properties and changes in determination of the heat-transfer coefficient. They hence promote changes in the entire heating problem.

Radiation Heat Transfer

In past Sandia Corporation work, heating problems related to nuclear weapons were generally associated with the Mach range 2.0 to 5.0. In addition, flight times were usually short - of the order of 15 minutes or less. In view of these conditions, it was acceptable to neglect radiation heat transfer on the basis that it contributed less than 10 percent to the total

heat-transfer process. With the advent of high-altitude, long-duration internal carriage (B-70), radiation has become the primary mode of heat transfer to the body. In addition, the reentry heating problem is greatly alleviated by radiation from the high-temperature outer skin of the body. Keck, Kivel, and Wentink (Reference 7) have studied properties of high-temperature air in the wake of a reentry body as a possible radiative heat source to the body. In any event, it appears that radiation heat transfer must be studied and included in future heating work, either as the primary heating mode or as part of the heat balance in problems arising from hypersonic flight.

Two-Phase Boundary Layers

The rate of energy transfer to the surface of a hypersonic vehicle may be sufficiently great to melt the surface of the vehicle. In some short-time applications, melting may present no adverse effects. However, in general, melting may affect the body aerodynamics by changing the external shape appreciably. In addition, surface melting may be responsible for loss of pressure ports on the vehicle surface and lead directly to a loss of other desired events. Change in body contour resulting from surface melting has been approached by generally assuming that the "melt" is removed from the surface as soon as it appears. A more realistic approach to the problem allows the existence of a two-phase boundary layer. The rate at which a surface recedes (melting rate) is not only a function of the external environment but also a function of the liquid hydrodynamics and heat capacity. In the event that detailed knowledge of the change in body contour with flight time be required in a given problem, the theory applied should include the existence of a two-phase boundary layer. A detailed analysis of the two-phase boundary layer by Scala and Sutton of the General Electric Company is presented in Reference 8.

Stagnation Point Heating

Heat transfer to the stagnation point of a blunt body has been studied by many investigators, as in References 9, 10, and 11. In general, the theories have been restricted to hemisphere-cylinders, spheres, or other well behaved geometric shapes. An effort should be exerted here to survey the existing theories (Van Driest, Fay and Riddell, Stine and Wanlass, etc.) in order to determine the theory or combination of theories that best agree with experiment. Also, the work should be extended to include stagnation point heating of various hemisphere-flat, scant-flat, and other nose shapes which are more frequently employed in actual weapon aerodynamic designs.

Heat Transfer in the Region of a Protuberance

Some recent work conducted at Brooklyn Polytechnic Institute has shown that the heat-transfer rates may increase over the local flat plate value by a factor of two to five in a region near a protuberance. In problems

where the local skin temperature has approached very closely the maximum allowable, the increased input generated by a protuberance and the resultant local "hot spot" may be of considerable importance. This problem is of particular interest to Sandia Corporation as the result of the unique aerodynamic designs generated in nuclear weaponry. The effects of a protuberance on heat transfer in high-speed flows are described in Reference 12.

Topics Related to Weapon Thermal Protection

Ablation

The study of ablation as a reentry vehicle thermal protection scheme appears as one of the prime problems in the heating field. With the advent of the second generation of reentry vehicles the heat sink type protective device has virtually been eliminated. Present plans call for ablating heat shields on all (known) existing generation II nose cones. It seems reasonable that generation III reentry vehicles will be subject to ablation as the result of their performance whether this phenomenon has been incorporated in design or not. The ablation problem presents a broad scope of work including many of the topics in the field of aerodynamic heating. Material studies are required to determine the best protective coating for specific applications. For example, in the lower Mach range, Teflon, a subliming material, proves adequate. In the higher performance application, quartz or resin-impregnated fiberglass and plastic materials may be required. In general, one should consider the ablation process primarily as a thermal protection device which requires knowledge of two-phase boundary-layer theory, cooling by mass transfer to the boundary layer, material properties, material behavior in a high enthalpy-high velocity environment, and the resultant changes in h, taw, heat of sublimation, etc. The process appears to hold such promise for the immediate future that it is considered of sufficient importance to be listed as a separate field of work.

Mass Transfer and Transpiration Cooling

Mass transfer to the boundary layer and transpiration cooling should also be included as protective schemes against the thermal environment arising from high-speed flight. In this application, the material injected into the boundary layer may be liquid, solid, or gas, and may be supplied through small holes in the vehicle outer skin or from a source located near the stagnation point of the vehicle. The presence of proper foreign particles in the gas flow results in a reduction of boundary-layer temperature and heat transfer to the body. A detailed knowledge of these processes would be beneficial especially when applied to the design of a high-speed, short-duration missile flight in which the transpiration cooling system could be supplied by a simple reservoir of compressed gas. Results of recent investigations of this subject are presented in References 14 through 16.

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Magnetohydrodynamics

Heat transfer to a body is, among other things, dependent upon the viscous boundary layer over the body and the outer inviscid flow. At extreme hypersonic Mach numbers, the stagnation temperature of air renders the gas sufficiently ionized so that it may be considered an electrically conducting fluid. The mutual interaction of a magnetic field and the flow of an electrically conducting fluid may be used to advantage in aerodynamic problems. Recent studies (Reference 17) have indicated that the primary mechanism which serves to reduce the heat transfer to a body is an alteration of the inviscid flow external to the boundary layer. At very high speeds, a magnetic field of sufficient strength will affect both the inviscid flow and the boundary layer, and a complete heat-transfer analysis must therefore account for both these effects.

Aerodynamic Heating in Separated Flows

It has been demonstrated by Bogdonoff and Vas (Reference 18) that heat transfer may be reduced in a region of separated flow over a body. The mechanism by which the heat transfer reduction is accomplished is related to the separated flow remaining laminar thereby reducing the heat transfer to a fraction of the turbulent value. Also, use of a spike protruding forward of a blunt body may produce separated flow over the entire body. This situation produces pressure fields similar to those existing over slender bodies. The reduced pressure fields provide attendant reductions in the heat-transfer process. Separated flow may occur in presently considered reentry designs over surfaces forward of the aft, stabilizing, conical flare. Since, in some applications, the reduced heat transfer in regions of separated flow may be important to Sandia applications, it is desirable to have a working knowledge of this phase of the work.

Boundary-Layer Transition

Boundary-layer transition has been studied by many investigators and reported throughout the literature. Since transition from laminar to turbulent flow results in significant increases in heat transfer to a body, the location of the transition region may directly influence a given design. Work in this field should include survey studies of existing data and the generation of original theoretical and experimental data. Investigation of boundary-layer transition would also include methods of delaying transition as well as those factors which cause transition.

Topics of General Interest

Scaling Laws

Since it is not always possible to conduct a full scale experimental aerodynamic heating test, scaling laws should be developed that would relate the temperature-time response of model internal components to that of the full scale item. Scaling laws would be dependent on such quantities as: heat transfer to the model surface, material thermal properties, time, and model dimension. Although the task of deriving such scaling laws would be a formidable one, the advantages resulting from the ability to obtain transient heating data for full scale items from wind tunnel models warrant investigation of this area. Scaling considerations should be extended to include results from tests conducted in non-air media such as rocket exhaust, water vapor tunnel, etc.

Effect of Neglecting Longitudinal Conduction on Temperature Predictions

In heating problems that do not require a high degree of accuracy, the temperature gradient along the body is usually neglected. This assumption results in theoretical temperatures higher than those actually present in the heated skin. It would be of academic interest to test experimentally a thin-skinned model (a) of all-metal construction, and (b) of alternate rings of metal and insulating material, in an attempt to evaluate the effects of the longitudinal temperature gradient and to determine the agreement between theory and experiment.

Means of Solving Transient Heating Problems

The most satisfying method of solving any scientific problem is to obtain the analytical closed solution to that problem. Unfortunately, nature provides real problems that are not amenable to solution by pure mathematical treatment. In the case of aerodynamic heating problems, machine solution has been employed for the problems encountered to date. Serious limitations exist in most equipment since, in programming a heating problem, the study is limited to: (a) one-dimensional heat flow, (b) fixed number of layers for use in the finite difference equations, and (c) heat inputs at one body station only. The DDA and REAC are subject to limitations (a) and (b), while the electrical analog (of Organization 1261) is subject to limitation (c). The general solution of a heating problem would call for removal of these limitations. The electrical analog could fulfill this requirement with slight expansion of the existing equipment plus addition of components to allow for heat input from more than one body station. The use of the step function in the present system to account for changes in time would also be required for spatial changes in heating inputs. In summary, it would be desirable to devise a method of solving heating problems which would include variable heat inputs over the body and three-dimensional heat flow within the body, all as a function of time.

Miscellaneous

In the field of aerodynamic heating many methods exist for formulating and evaluating specific problems. For example, the heat-transfer coefficient may be presented in a number of nondimensional forms, or it may be evaluated explicitly from several equations. These equations have generally been derived for use in specific geometric problems and are different for laminar and turbulent flow. The value of the adiabatic wall temperature which must be evaluated in solving a problem is related to the recovery factor, which has been shown to be related to Prandtl number. In general, Prandtl number is computed locally at the outer edge of the boundary layer, and the question arises as to what temperature should be used in evaluating local flow properties. The T', T*, T_∞ concepts have all been used in previous work. In addition, Van Driest has presented theories based on free-stream-to-wall-temperature ratios which relate the skin friction coefficient to a nondimensional heat transfer coefficient (N_{St}) through the Reynolds analogy. (The modified Reynolds analogy has also been suggested.) Many of the ideas presented above are presented in Reference 19. Since there are many theories, modifications, and techniques for formulating and evaluating problems of this nature, many pitfalls are present in the sense that one could conceivably apply an incorrect approach to a given problem. In order to avoid such pitfalls, the existing methods should be reviewed and understood, and evaluated as to which are best for certain applications. The purpose of the above paragraph has been to point out that a host of supporting problems is present in the over-all attempt to formulate and evaluate, in a detailed, refined manner, aerodynamic heating problems covering a wide range of geometric shapes.

Summary

The great majority of heating work considered by Sandia Corporation to the present time has been limited to Mach 5.0 or less. While solutions obtained for past problems have been perfectly acceptable from an engineering viewpoint, refinements of solutions for this type of problem could be made by taking full advantage of the state of the art. The important point at this time is to consider that the theories applied in past problems represent one phase of the heating field and that this work is not adequate for future requirements. In order to advance in the heating field, along with current missile performance advances, it is necessary to consider topics similar to these mentioned above. It would also be well to consider such topics in advance of project developments that require use of these topics and their underlying theories.

[redacted]

REFERENCES

1. Ferri, Antonio, Elements of Aerodynamics of Supersonic Flows, The Macmillan Company, New York, 1949.

2. Frankl-Karpovich, Gas Dynamics of Thin Bodies, Interscience Publishers Ltd., London, and Interscience Publishers, Inc., New York.

3. Van Dyke, M. D., Second-Order Slender-Body Theory - Axisymmetric Flow, NACA TN 4281, 1958.

4. Adams, Mac C., and Sears, W. R., "Slender-Body Theory - Review and Extension," Journal of Aeronautical Sciences, Volume 20, No. 2, February, 1953, pp. 85-98.

5. Langelo, V. A., Pressure Distribution About Six Blunt Bodies at Several High Mach Numbers and Gammas, Aerodynamics Fundamental Memorandum No. 46, General Electric Company, Philadelphia, Penn.

6. Lees, Lester, "Laminar Heat Transfer Over Blunt Bodies at Hypersonic Flight Speeds," Jet Propulsion, April, 1956.

7. Keck, James; Kivel, Bennett; and Wentink, Tunis, Jr., Emissivity of High Temperature Air, 1957 Heat Transfer and Fluid Mechanics Institute, Reprints of Papers, Stanford University Press, Stanford, California.

8. Scala, S. M., and Sutton, G. W., The Two-Phase Hypersonic Laminar Boundary Layer - A Study of Surface Melting, 1958 Heat Transfer and Fluid Mechanics Institute, Preprints of Papers, Stanford University Press, Stanford, California.

9. Van Driest, E. R., On the Aerodynamic Heating of Blunt Bodies, TN-57-732, AD 136-716, North American Aviation, Inc., Missile Development Division, 1957.

10. Fay, J. A., and Riddell, F. R., "Theory of Stagnation Point Heat-Transfer in Dissociated Air," Journal of Aeronautical Sciences, Volume 25, No. 2, February, 1958, pp. 73-85.

11. Stine, H. A., and Wanlass, K., Theoretical and Experimental Investigation of Aerodynamic Heating and Isothermal Heat-Transfer Parameters on a Hemispherical Nose with Laminar Boundary Layer at Supersonic Mach numbers, NACA TN-3344.

12. Bloom, M. H., and Pallone, A., Heat Transfer to Surfaces in the Neighborhood of Protuberances in Hypersonic Flow, 1957 Heat Transfer and Fluid Mechanics Institute. Preprints of Papers, Stanford University Press, Stanford, California.

13. Roberts, Leonard, Mass Transfer Cooling Near the Stagnation Point, NACA TN 4391, 1958.

14. Rott, Nicholas, On the Transfer of Heat and Mass in the Turbulent Boundary Layer, Report No. GM-TR-211, the Guided Missile Research Division, The Ramo-Wooldridge Corporation, 1957.

15. Van Driest, E. R., On Mass Transfer Near the Stagnation Point, AFOSR-TN-57-458, North American Aviation, Inc., Missile Development Division, 1957.

16. Low, G. M., The Compressible Laminar Boundary Layer With Fluid Injection, NACA TN-3404, 1955.

17. Meyer, Rudolph C., On Reducing Aerodynamic Heat Transfer Rates by Megnetohydrodynamic Techniques, Institute of the Aeronautical Sciences, Preprint No. 816, January, 1958.

18. Bogdonoff, S. M., and Vas, I. E., Exploratory Studies of a Spiked Body for Hypersonic Flight, 1958 Heat Transfer and Fluid Mechanics Institute, Preprints of Papers, Stanford University Press, Stanford, California.

19. Eckert, E. R. G., Survey on Heat Transfer at High Speeds, WADC Technical Report 54-70, April, 1954.