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The Future of Hypersonics Research

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Abstract

In this paper, the current status of the hypersonic research is reviewed, and the areas needing further work are proposed.

***Keyword**: hypersonic*

1. Low Hypersonic Regime

In the low hypersonic regime, i.e., the Mach number range from about 4 to 8, where air behaves as a perfect gas, a great deal of advancement has been made in recent years through experimentation in shock tunnels, mostly by CALSPAN in Buffalo, New York. This is the speed range where scramjet propulsion system has been shown to be effective. Many practical problems of scramjet propulsion have been studied with fairly high degree of precision. These include the problem of scramjet inlets, control surface effectiveness, turbulent transition, shock-to-shock interaction, and shock-to-boundary layer interaction. The areas not yet fully studied are the nonequilibrium phenomena in the expanding nozzles, mixing combustion in the exhaust plumes, in the ejector engines, and in the base of rocket engines. The existing CFD methods seem to capture most of the problems, except those of nozzle flows and mixing combustion.

2. Intermediate Hypersonic Regime

In the intermediate hypersonic regime, i.e., the Mach number range from about 8 to 15, there is a weak real gas effect because of the vibrational excitation and oxygen dissociation, In some cases, the weak real gas effects occurring in this speed range can be neglected, or may be accounted for by using an effective gamma. All those problems existing in the low hypersonic regime become more intense in this flight regime, and are affected substantially by the nonequilibrium effects. There exist a small number of experimental data taken in shock tunnels in this speed range. But their accuracy becomes suspect because of the nonequilibrium phenomena, not only in the flow phenomenon itself but also in the nozzle producing the test flow. For air, the thermo-chemical nonequilibrium phenomenon is complex because of the existence of all three molecules, oxygen, nitrogen, and nitric oxide. The accuracy of the CFD calculations suffer mostly from not knowing the nonequilibrium effects well.

3. High Hypersonic Regime

In the high hypersonic regime, i.e. at Mach numbers above 15, the nonequilibrium real gas effects become dominant. All problems occurring at lower Mach number regimes become more difficult to understand because of the real gas effects. For air, the dissociation phenomenon becomes simpler because of the rapid disappearance of molecular oxygen. However, the emergence of electronic excitation and ionization brings complications. Shock tunnel flows suffer from the nonequilibrium effects to such a large extent that their test results become quite doubtful. Ballistic ranges should be able to produce useful results at least for simple geometries, but their potentials have not yet been fully exploited. Because of the very high heating rates, material ablation becomes a prominent phenomenon. Describing the phenomenon occurring inside the ablating material becomes a new addition to the traditional hypersonics. In the very high Mach number flight regime, radiative heating becomes important. Interaction of radiation with the ablation phenomenon leads to a new class of problems, such as radiation absorption, massive blowing, solid particle ejection, and turbulence. These phenomena can be studied experimentally only in an arc-heated wind tunnel. The flows in arc-heated wind tunnels are not yet fully understood. Advancement in these areas are hampered by the lack of data on the state parameters, chemical-kinetic parameters, transport properties, and radiative properties. Quantum mechanical solution of the Schroedinger equation offers the best means of obtaining those parameters. But this technique has not been fully exploited.

4. Needed Future Research Areas

From the foregoing observations, one can reason that further work is needed for the following areas:

1. *Continuation and extension of CALSPAN experiment.* The experiments in the shock tunnels at CALSPAN on control surface effectiveness, turbulent transition, shock-shock and shock-boundary layer interaction should be continued and extended to higher Mach numbers, perhaps outside of CALSPAN as well as inside. Efforts should be made to numerically reproduce those experimental results.
2. *Nozzle flow properties.* The thermo-chemical state of the flows in a shock tunnel nozzle in the intermediate and high hypersonic speed ranges should be studied both experimentally and theoretically, to interpret the experimental data taken in the shock tunnels in those speed ranges.
3. *Ballistic range experiment.* For certain simple geometries, ballistic range experiments should be carried out to compare with the results of the shock tunnel experiments and possible flight experiments. Efforts should be made to reproduce those results by CFD.
4. *Flight experiment.* Flight experiments on simple geometries should be carried out and the results should be compared with those obtained in the shock tunnels and ballistic ranges.
5. *Base/mixing combustion.* Experiments in a shock tube or shock tunnel reproducing the base combustion or mixing combustion should be carried out. Efforts should be made to numerically reproduce those results.
6. *Quantum mechanics.* The state parameters, chemical-kinetic parameters, transport properties, and radiative properties should be determined by solving the Schroedinger equation.
7. *Planetary entry problems.* The thermo-chemical nonequilibrium, radiation, turbulence, solid particle injection, and ablation phenomena occurring during planetary entry flights need much future work.
8. *Arc-jet flows.* The flows in the arc-jet wind tunnels need to be studied both experimentally and theoretically not only in the nozzle but also in the region upstream of the nozzle throat.