Generation of Ultra-High Total Entalpy Gases through Multicomponent Flow Techniques

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Theme

IN spite of several decades of research, hypervelocity flight environments cannot be reproduced adequately in a ground test facility. While many experimental techniques have been proposed, none of these concepts resulted in a facility having a true flight duplication capability.

Some of the major deficiencies of contemporary facilities are: a) In shock tubes test times are too short for many types of investigations. b) In electrically heated facilities the testing medium may not be sufficiently representative of true atmospheric conditions due to contaminations caused by the heating or acceleration processes; i.e., residual dissociation or ionization of the test gas, or vaporization of electrodes, or other foreign materials. c) Inability to simultaneously produce the total enthalpies and pressures, as well as the associated real gas effects which are experienced by re-entering vehicles, especially in the very important altitude regime from as low as 100,000 to approximately 200,000 ft altitude.

Contents

The process described in this paper has the objective of producing air flows which can be used in duplicating re-entry conditions without first going through phases of high static temperatures and pressures; the process differs in approach, however, from previous concepts. Instead of using rotating machinery, or magnetohydrodynamic acceleration, a multicomponent flow process is employed in which kinetic energy is transferred from a low molecular weight working gas, e.g., hydrogen or helium, to a much higher molecular weight gas such as air. Two types of multicomponent flow energy transfer processes will be discussed in this paper: 1) the direct energy transfer process in which an expanding low-molecular weight working gas accelerates air in the form of liquid or frozen particles; and 2) the intermediate process, in which an expanding low molecular weight working gas accelerates high refractory particles, which in turn accelerate an air stream to desired high speeds. Performance potentialities and critical research areas for both processes will be identified.

The direct energy transfer process is illustrated schematically in Fig. 1. By this process a high-molecular weight working medium in the form of small particles or droplets (e.g., liquid air) is sprayed 1 into a carrier gas flow 2 of low-molecular weight, e.g., hydrogen or helium, at a sufficiently low temperature to avoid air particle vaporization. The air particles are accelerated gradually through the curved expansion nozzle 3. Methods of influencing the size of liquid droplets and of determining optimum nozzle shapes and their performance characteristics have been investigated theoretically and experimentally. During the expansion process through the nozzle 3 the droplets may be frozen, thus maintaining their size during subsequent acceleration. In the curved nozzle 3 the larger particles drift further away from the center of nozzle curvature than the smaller particles. Therefore, by means of the splitter plate, the small particles can be screened out so that droplets of relatively uniform size are obtained for the subsequent acceleration by the carrier gas which is admitted through inlet nozzles 5–8. The total temperature of the carrier gas admitted through these nozzles increases with each nozzle (as indicated) while the static temperature of the expanded carrier gas remains below air particle vaporization temperature. Thus, particle temperature and static gas temperature are nearly the same throughout the acceleration process.

The air particles follow a curved flow path from a radially inward flow direction to a nearly axial flow direction. The resulting inertial forces cause the air particles to be concentrated ultimately at the mid-plane or axis of symmetry in case of a two-dimensional or axisymmetrical configuration, respectively. After the hydrogen flow passes through the particle stream it is discharged to ambient atmosphere through the curved vanes indicated in Fig. 1.

Relatively thick boundary layers are formed on the walls of the injection nozzles. It is necessary to prevent the air particles from entering these boundary layers in order to prevent particle deceleration or premature vaporization. These conditions are most critical in the last two hydrogen injection nozzles 7 and 8. For this reason the boundary layers are removed as indicated schematically by 9. It is important that the particle stream, for a given configuration of injection nozzles, be adjusted in such a manner that the particles pass the nozzle edges without impacting them. This can be achieved by throttling, which will influence the total pressure at the entrance to each injection nozzle.

At region 10 the air particles are vaporized by energy addition. Also, the static temperature of the resulting air flow is raised from 100° R to approximately 400° R (corresponding to the air temperature prevailing in an altitude regime between 10^5 and 2.10^5 ft).

The particle cloud moving over the nozzles exhibits an undesirable spread as illustrated. Studying the causes for particle spreading, it appears that all of them can be eliminated by alternating the hydrogen admission side relative to the particle stream. (The slower moving inner particle layer of one nozzle becomes the faster moving outer particle layer of the subsequent nozzle. The particle flow follows an *S* shape path.)

The most severe conditions are those occurring in the last hydrogen admission nozzle 8 for the following reasons: the stagnation temperature should be as high as possible for obtaining realistic simulation performance while the static temperature must be low (90° R) to avoid air particle vaporization. Therefore, the conditions in this nozzle determine the performance limit. Analysis results in the following potential performance values at a simulated flight altitude of 100,000 ft: air stagnation pressure, 5000 atm; air stagnation temperature, 17,000° R; air stagnation enthalpy, 4000 Btu/lb; Mach number, 14.

In contrast to the direct energy transfer process, which utilizes liquid or frozen air particles, the intermediate process employs particles of high refractory materials. After the particle accelera-

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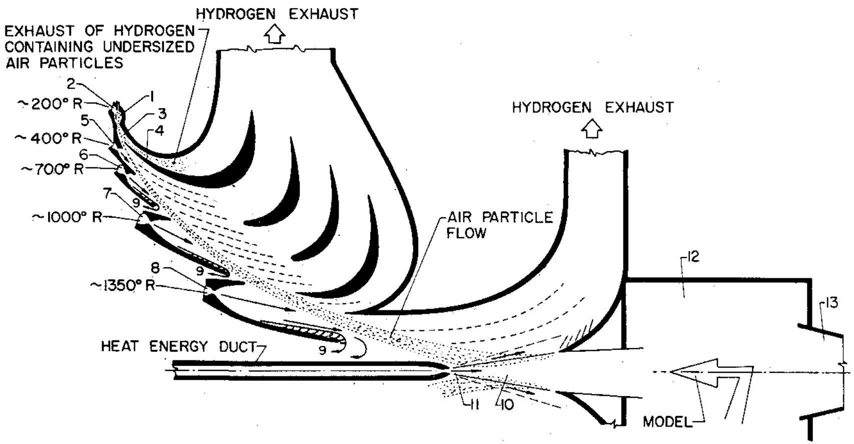

Fig. 1 Schematic of direct energy transfer process; (direct kinetic Energy exchanger from hydrogen to air).

tion and separation process is completed, the stream of closely spaced particles enters an airflow which is expanded to a static pressure equal to that of the expanded hydrogen. By momentum exchange between the particles and the air, the velocity of the air is greatly increased. Also, during the momentum exchange process the entropy is increased which causes a temperature increase of both the particles and the air. Subsequently, the air is separated from the particles by Prandtl-Meyer expansion to the static conditions in the test section.

Because of the use of high refractory particles, much higher stagnation temperatures of the low-molecular weight working gas can be employed than in the direct process. Also, the requirement of extremely low-static temperatures to prevent air particle vaporization is abolished. The total enthalpy values of the air in the test section may range from 5000 to 9000 Btu/lb based on static conditions corresponding to altitudes from approximately 150,000 to 200,000 ft. The fact that the low-molecular weight working gas is expanded to a pressure far above test section conditions results in relatively small dimensions of the accelerator in contrast to those of the direct process.

Critical areas requiring further investigation and research are the following: 1) achievement of high particle concentration, 2) methods to avoid particle wall interactions to prevent erosion and particle deceleration, 3) research on transient particle temperature and particle-air heat-transfer phenomena during the momentum exchange process, and 4) investigation of air acceleration by lower speed particles prior to entering the main momentum exchange section (semistaging). In this way excessively high transient peak temperatures of the particles would be avoided.

Conclusion

The concept of multicomponent flow can be employed to produce high Mach number and high enthalpy flows corresponding to altitudes from as low as 100,000 ft to approximately 200,000 ft if the critical problem areas associated with particle acceleration, separation and vaporization can be solved through research. The multicomponent flow method offers the unique possibility of studying and testing important individual components at small scale. Also, a small scale pilot facility can be employed to prove concept feasibility since in the regime of small geometric dimensions the multicomponent scaling laws given in the analysis are quite accurate.