Electrofluid Dynamic Augmented Wind Tunnel

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Theme

THE process described in this paper, has the objective of adding energy to test air flows to help simulate re-entry and space shuttle conditions without exceeding pressure and temperature limitations of the air supply. Electrofluid dynamic (EFD) acceleration is involved, whereby kinetic energy is added to the flow by the volume forces resulting from interaction between a strong electrostatic field and small charged particles imbedded in the flow. The charged particles are removed before the test section is reached so that the test flow is not contaminated. This process is described in more detail in the revised version of the AIAA paper. The objective is to present generalized analyses of EFD augmentation for facilities applications in order to show promising areas for exploratory research.

Contents

A schematic diagram of the electrofluid dynamic augmented wind-tunnel (EFDAWT) system as a whole is shown in Fig. 1, with the following principal parts: a) high pressure air supply, b–d) high-voltage EFD power supply, e) EFD acceleration section whereby unipolar charges are strongly accelerated by a high-voltage electrostatic field, f) final expansion nozzle which expands the flow to the desired test section conditions, also collecting and neutralizing the charges, g) test section, and h) exhaust section.

The EFD generator, Sec. d is being developed by the Energy Conversion Laboratory of the Aerospace Research Laboratories, which has been active for a number of years in the direct conversion of heat into electrical energy by the EFD process. References are given in the AIAA paper, as revised.

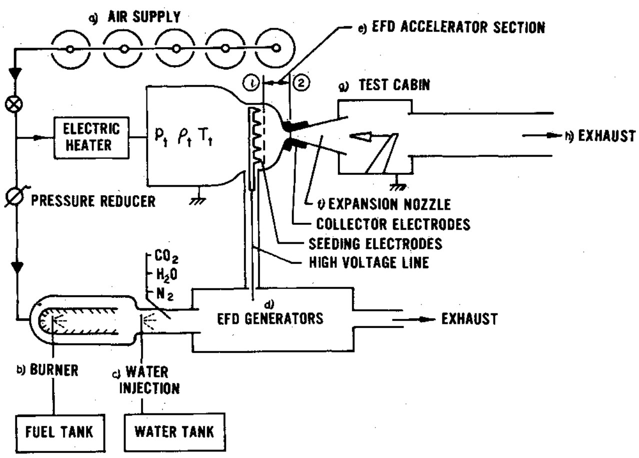

Fig. 1 Schematic of EFD augmented wind tunnel system.

In Fig. 1, the fluid under storage conditions expands isentropically according to channel geometry and gas laws. Without the addition of external energy, the velocity at any point relates directly to the drop in enthalpy. The addition of electrical energy between two points, say point 1 and point 2, will result in a supplementary increase in enthalpy or velocity. Throughout the EFD acceleration process, the motion of the gas is under the

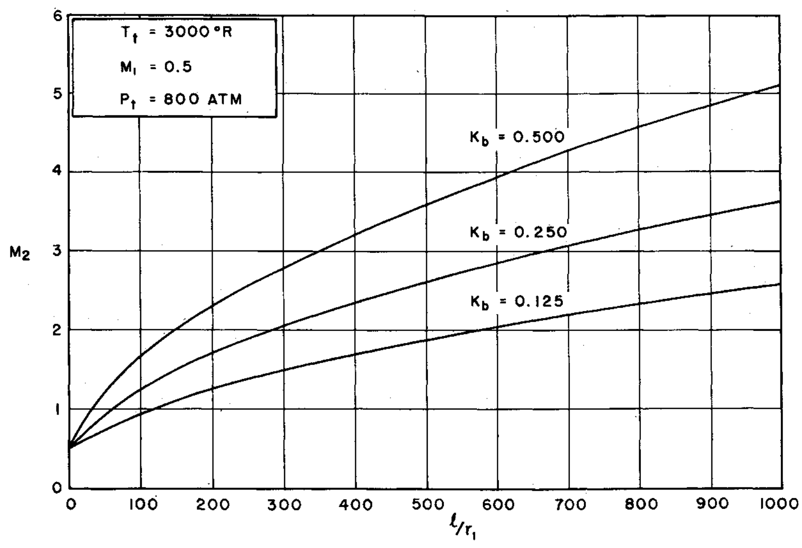

Fig. 2 EFD Mach number augmentation for M_1 = 0.5, P_t = 800 atm and T_{t_1} = 3000°R.

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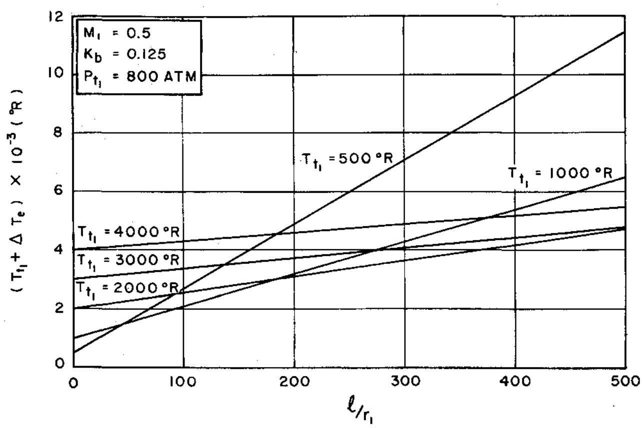

Fig. 3 Plot of $(T_{t1} + \Delta T_e) \times 10^{-3}$ (°R) vs l/r_1 for $M_1 = 0.5$, $P_{t_1} =$ 800 atm and $K_r = 0.125$.

influence of volume forces, and the flow boundaries are free, so that walls are not required during this process.

For the conceptual purpose of this paper, it is assumed that the entire cross section at point 1 is seeded uniformly with unipolar charged particles which are accelerated in a constant density flow from velocity V_1 to V_2 by a high-voltage electrostatic field between points 1 and 2; it is further assumed that all the electrical power goes into change of flow speed, and that the slip between charge velocity and flow velocity is negligible.

The relationship between charge density and radial field strength (E_r) is assumed to be that given by Gauss's law. With the assumption that the axial field strength (E_x) is constant, the ratio of the product $E_r E_x$ to the square of the breakdown field strength E_b^2 is a factor K_b whose theoretical maximum value is 0.5. For the analysis, the breakdown strength E_b is assumed proportional to the local fluid density.

The equations developed in the basic paper provide the background for parametric studies of electrofluid dynamic acceleration for fluid dynamic facilities applications. They show several factors which have a major effect: a) fluid density (should be as high as feasible), b) the value of the velocity at Sec. 1 (should be low); Fig. 2 shows the augmented Mach number as a function of l/r_1 and of K_b for $M_1 = 0.5$, c) the attained value of K_b (should be high), d) the breakdown strength of the fluid under normal conditions (should be high), and e) the value of the length-to-radius ratio of the charge cloud l/r_1 (should be high).

A simplified way of showing the relationship between the expansion process and EFD augmentation is to consider the total stagnation temperature T_{t1} of the gas the total temperature augmentation due to EFD action ΔT_e, which is given by the formula

$$Jg\, c_p\, \Delta T_e = (1/2)(V_2^2 - V_1^2)$$

Figure 3 shows $T_{t1} + \Delta T_e$ as a function of l/r_1 for assumed constant conditions of pressure K_b and several values of stagnation temperature T_{t1}. It is seen that at low values of l/r_1, the stagnation temperature dominates; at higher values, EFD augmentation has a much greater influence.

It is concluded that the acceleration process presented in this paper might lead to better simulation of high-speed flight phenomena in ground test facilities if the state-of-the-art of EFD were considerably advanced by research.