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Improvement of Scramjet Performance - Experimental Demonstration of MHD Acceleration

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Summary

One of the critical technologies of MHD bypass scramjet propulsion for space launch and cruise vehicles is MHD acceleration. An experiment in a shock tunnel is described in which MHD acceleration is investigated experimentally. The objectives, the methods used and the preliminary results are described in this paper.

Introduction

It is well known that gas flow can be decelerated or accelerated, at least in principle, by the application of a magnetic field and an electric current, thereby generating electrical power or converting electrical power to the kinetic energy of the gas flow. There have been many experiments in which electrical power generation has successfully been achieved by magneto-hydrodynamic (MHD) means. However, relatively few experiments have been made to date for the reverse case of achieving gas acceleration by the MHD means.

MHD acceleration has several potential aerospace applications. The first is to improve the performance of hypersonic scramjet engines for space launch and cruise vehicles (Ref. 1). The second is to improve the performance of a high enthalpy wind tunnel (Ref. 2). The third is to control a hypersonic vehicle (Ref. 3). With such applications in mind, an experiment is being conducted at the NASA Ames Research Center to obtain experimental data on MHD acceleration.

Method

In the experiment, a high temperature air flow is produced by a shock tunnel (see Figure 1). The internal diameter of the driven section of the shock tunnel is 10 cm. The driver gas for the shock tunnel is either hydrogen, helium or a helium-argon mixture. The driver gas is heated by an electric discharge. The driven tube is filled with air or a nitrous oxide - nitrogen mixture which gives the correct mole fractions for air after shock heating. The MHD channel can be operated in the unseeded or seeded mode. Seeding will be done with rubidium, provided in the form of rubidium chloride. The temperatures in the channel will be of the order of 6000 K for unseeded operation and 3500 K for seeded operation. The nominal channel pressure is 1.5 bar and the nominal Mach number is 2.0. The nominal nozzle stagnation pressure is ~12 bar. The test time is estimated to be 800 - 1000 μsec for seeded operation and about 240 μsec for unseeded operation.

The supersonic flow produced by the shock tunnel is made to pass through an MHD accelerator (see Figure 2). The throat of the nozzle is rectangular, 0.57 x 2.03 cm. A supersonic nozzle expands the flow by a ratio of 1.88, providing a 1.07 x 2.03 cm channel at the nozzle exit. After the nozzle exit, the channel diverges continuously to allow for boundary layer growth. The dimensions of the MHD accelerator part of the channel are 1.35 x 2.03 cm at the upstream end and 2.03 x 2.03 cm at the downstream end. The accelerator is 23.7 cm long.

The magnetic field is provided by an air-core coil, powered by a capacitor bank discharge. The initial configuration is designed to produce a field strength of 1.5 - 2 Tesla. Later, it will be upgraded to produce 3.5 - 4 Tesla. The magnet capacitor bank will be able to store about 9 kJ initially, which will later be upgraded to 45 kJ. The magnetic field can be maintained constant to within 10% for ~600 μsec.

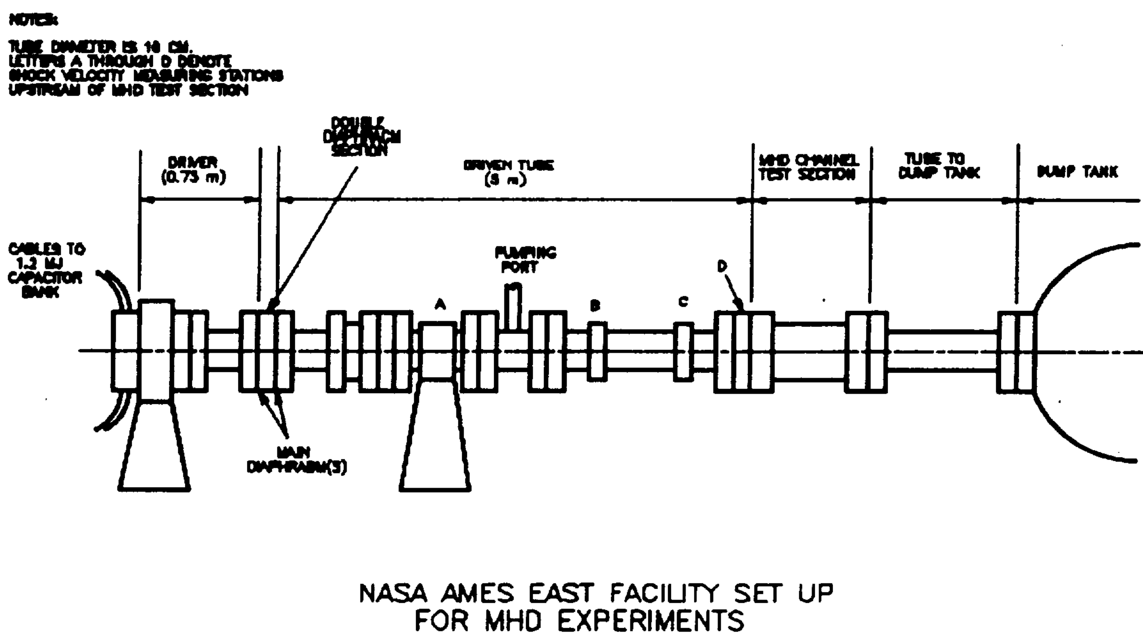

Figure 1. Schematic of the shock tunnel facility.

The nominal static pressure and temperature in the MHD accelerator will be about 1.5 atm and 3500 K, respectively (for seeded flow). According to the idealized one-dimensional analysis, the facility is capable of increasing the flow velocity by 20 - 30% at a field of 3.5 - 4 Tesla. It is most important that the temperature rise in the MHD channel be kept to a minimum. Significant temperature rises translate into serious loss of stagnation pressure, which entails serious performance losses in a scramjet engine.

Spectroscopic measurements will be made to determine the temperature of the gas at the diagnostic ports downstream of the MHD accelerator. The luminosity of the D-line of rubidium will be measured. From the luminosity, the static temperature will be determined using the line reversal technique. Velocity will be measured from the Doppler shift of an emission line of rubidium and the Mach number obtained from Mach wave angles. From the measured temperature, velocity, static and impact pressure, the state of the gas downstream of the exit of the MHD accelerator will be determined. The state of the gas so determined will be compared with the theoretical predictions. From pitot rake measurements and temperature profiles, the non-uniformity of the flow downstream of the MHD channel will be investigated.

Results

The shock tunnel facility is in existence, and has been operated for many years. The MHD accelerator is presently being fabricated. The spectroscopic instruments are available, having been used in previous (non-MHD) experiments. By September of 2001 when the conference takes place, we expect to have preliminary results of the experiments. These preliminary results will be reported at the conference.

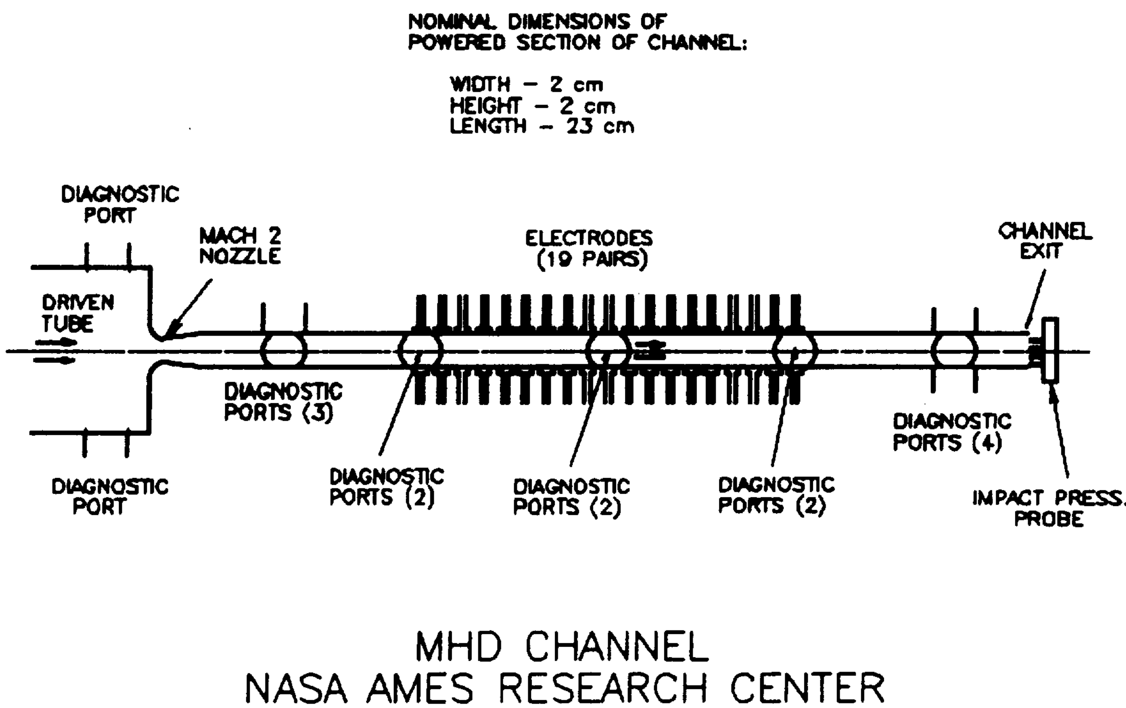

Figure 2. Schematic of the MHD accelerator.

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