Plasma Actuated Unmanned Aerial Vehicle

Aerial roll control using single dielectric barrier discharge devices for efficient aircraft control and maneuvering. CFD and multispecies plasma fluid modeling of SDBD actuators.

Abstract

I investigate the application of solid-state plasma actuators to aerodynamic control surfaces for standard NASA 0010 aircraft and unmanned aerial vehicles (UAVs). These actuators, solid-state dielectrics and conductors are coupled to a 1.0-MHz high voltage (430V pk-pk) pulsed DC generator to create an ionizing electric field, inducing chord-wise ion flow on the surface of an airfoil. The body force exerted by this ion flow strongly influences the boundary layer and is applied to aircraft roll control, replacing the traditional aileron. Using 3D and time-dependent models of the actuator, I will simulate the electrical breakdown of Nitrogen and Oxygen and numerically estimate the body force vector. Wind tunnel measurements will be used to validate these predictions for several plasma-actuated NASA 0010 test sections. Lastly, a three-meter, electric ducted fan UAV will be outfitted with span-wise plasma actuators and flight tested to demonstrate solid-state actuators control under real-world conditions.

Introduction and Motivation

Maneuvering aircrafts above aerodynamic surfaces with low temperature plasma, textured surfaces and compressed air jets has been an area of intense aeronomical research in recent years. Single dielectric barrier discharge (SDBD) plasma actuators, in particular, have been demonstrated as remarkable separation control devices (2007, Carter et al.) effecting self-sustained solutions to bluff body wake control, 3D enhancement and turbulent transition problems. Unrequited, lightweight, reliable solid-state devices, SDBDs have immediate applications to reducing landing aircraft noise through wake control, increasing wind tunnel efficiency and, as I investigate, the possibility for completely flapless controlled flight using electric fields.

Plasma actuator theory

A low temperature plasma can be created at normal atmospheric temperature and pressure by a high electric potential such as the one generated below a high-voltage DC source. A dielectric is placed between the electrodes so as not to prevent breakdown.

Plasma actuators can interact with flow through many mechanisms, by the effect of rapid thermal expansion, by the electric field, by the electro-hydrodynamic effect which accelerates charged particles in an electric field and, similarly, by the magnetohydrodynamic effect which arises for time varying electric fields. However, in the case of plasma actuators that do not generate high temperature plasmas, have negligible gas expansion effects and small magnetic field magnitudes (the SDBD model to the electrohydrodynamic effect). The electron density and mean electron energy are computed by solving a pair of drift-diffusion equations for the positive ions and the electrons; the positive ions and electrons are calculated with the Poisson's equations and reactions (elastic, excitation, superelastic, ionization, metastable quenching) for a number of particle species, so I first limit my model to Nitrogen and Oxygen in 3D and then expand to 2D in phase II.

Plasma actuator modeling

A simple model for calculation of body force due to plasma in fluid flow was used as an initial step. The model involves solving the Poisson equation for electric field assuming Boltzmann distribution for electrons. It successfully captures some of the experimentally observed phenomena including increase in stall angle of wing for flow over a NACA0012. The body force term obtained from this plasma model was added as a momentum source to a RANS fluid solver. The extra momentum imparted to the leading edge boundary layer prevents separation and delays stall. Though the computational results predict delay in stall, the results are off from the experimentally observed values. The physics of plasma is complex making modeling and understanding plasma actuators very challenging. A good numerical scheme must be able to resolve the generation, decay and diffusion of multiple species present in low temperature plasma. Since these processes are many time scales apart at atmospheric density, the time and length scales of the problem are very small. For this reason, all the previous work has been on modeling a simplified version of the governing equations called the Drift Diffusion equation.

In this research, an attempt at solving the full NS equations for multi species plasma, along with simultaneous solution of the Poisson equation has been made. The equations account for thermal and chemical nonequilibrium, viscous phenomena including turbulence, effects of imposed and locally generated electric field and effects of charge separation in the flow. The Lorentz force on charged particles and momentum imparted to neutrals by collision with charged particles will be coupled with a RANS fluid flow solver.

Data Collection

A multiplexed accelerometer is used for measuring the projected plasma actuators induced rolling moments on the flying UAV. Given that the UAV is being controlled remotely GPS, magnetic heading and 3x 6x 9x capabilities are also integrated into the plane’s electronics. These requirements are easily met by the multiplexed 3-axis accelerometer module and a smartphone with the added advantages of high bandwidth digital 3x 6x 9x capabilities, large onboard storage for high rate raw accelerometer data a fast processor for onboard filtering and navigation control, a digital clock and a small, lightweight and low power design. The iPhone 3GS (motherboard shown below) is used with software that collects data at 10-100 Hz in flight. The data stream can be transmitted live and saved on board. We, in addition to this electronic package, an onboard video camera records the flight and is used to independently data represent actual maneuvers.

The first plasma actuated flight

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