25 Years of Ionospheric Modification with Space Shuttle OMS Burns

Paul A. Bernhardt
Plasma Physics Division, Naval Research Laboratory
Washington, DC 20375

The Space Shuttle Orbital Maneuver Subsystem (OMS) is the largest engine to be fired in the F-region ionosphere. The OMS thruster provides 10 kg/s of exhaust materials exiting at a speed of 3 km/s. The OMS nozzle can be pointed in the ram, wake or out-of-plane relative to the Space Shuttle orbit. The vector addition of the exhaust velocity and the orbit velocity provides possible injections speeds of between 4.7 and 10.7 km/s. When the exhaust impacts the ionosphere, neutral-ion collisions and ion-molecule charge exchange yields ions moving at hyper-acoustic speeds. A ten second burn of two OMS engines deposits over 1 Giga-Joule of energy into the upper atmosphere. The ionosphere reacts to an OMS burn by exciting a large number of plasma wave modes including the whistler, fast and slow MHD, Alfven, ion acoustic, lower hybrid, and ion Bernstein waves. These waves have been detected by both radar scatter and in situ electric field plasma probes. Field aligned irregularities are produced by the exhaust interactions.
The exhaust pickup ions eventually thermalize with the background atmosphere and they recombine with ambient electrons leaving an electron hole. All these phenomena were obtained first in July 1985 during STS-51F and were detected for the next 25 years through STS-129 with 18 flights of the Space Shuttle. These experiments have demonstrated the (1) Space Shuttle OMS burns can change the HF radio propagation characteristics of the F-layer, (2) artificial ionospheric holes may be used to trigger plasma instabilities that scatter radar and possibly affect GPS propagation, (3) space-based electric field sensors can detect OMS burns in the ionosphere for ranges over 400 km, and (4) optical emissions are produced as the pickup ions recombine with F-region electrons. This type of ionospheric modification has been studied with computer models that employ direct simulation Monte Carlo (DSMC) techniques for the neutral exhaust expansion, plasma fluid theory for the plasma density effects and kinetic theory with Maxwell's equations for the plasma wave generation.

An extensive theory has been developed to explain the observations of plasma waves excited Space Shuttle OMS burns in the ionosphere. The first evidence of plasma waves were detected by radar scatter from the exhaust region for the series of experiments called Shuttle Ionospheric Modifications with Pulsed Localized Exhaust (SIMPLEX). Lately, in situ measurements of artificial plasma turbulence were obtained during two Shuttle Exhaust Ionospheric Turbulence Experiments (SEITE) conducted during the flights of the Space Shuttle (STS-127 and STS-129). Motivated by computer modeling at the NRL Plasma Physics Division and Laboratory for Computational Physics & Fluid Dynamics (LCP), two dedicated burns of the Space Shuttle Orbital Maneuver Subsystem (OMS) engines were scheduled to produce 200 to 240 kg exhaust clouds that passed over the Air Force Research Laboratory (AFRL) Communications, Navigation, and Outage Forecast System (C/NOFS) satellite. This operation required the coordination by the DoD Space Test Program (STP), the NASA Flight Dynamics Officer (FDO), the C/NOFS payload operations and the C/NOFS instrument principal investigators. The first SEITE mission

used exhaust from a 12 Second OMS burn to deposit 1 Giga-Joules of energy into the upper atmosphere at a range of 230 km from C/NOFS. The burn was timed so C/NOFS could fly though the center of the exhaust cloud at a range of 87 km above the orbit of the Space Shuttle. The first SEITE experiment is important because is provided plume detection by ionospheric plasma and electric field probes for direct sampling of irregularities that can scatter radar signals. Three types of waves were detected by C/NOFS during and after the first SEITE burn. With the ignition and termination of the pair of OMS engines, whistler mode signals were recorded at C/NOFS. Six seconds after ignition, a large amplitude electromagnetic pulse reached the satellite. This has been identified as a fast magnetosonic wave propagating across magnetic field lines to reach the electric field (VEFI) sensors on the satellite. Thirty seconds after the burn, the exhaust cloud reach C/NOFS and engulfed the satellite providing very strong electric field turbulence along with enhancements in electron and ion densities. Kinetic modeling has been used to track the electric field turbulence to an unstable velocity distribution produced after the supersonic exhaust molecules charge exchanged with ambient oxygen ions. Based on the success of the first SEITE mission, a second dedicated burn of the OMS engine was scheduled to intercept the C/NOFS satellite, this time at an initial range of 430 km. The trajectory of this exhaust cloud was not centered on the satellite so the turbulent edge was sampled by the C/NOFS instruments. The electromagnetic pulse and the in situ plasma turbulence were recorded during the second SEITE experiment. A comparison of the data from the two OMS burns shows that a wide range of plasma waves are consistently produced with rocket engines are fired in the ionosphere.

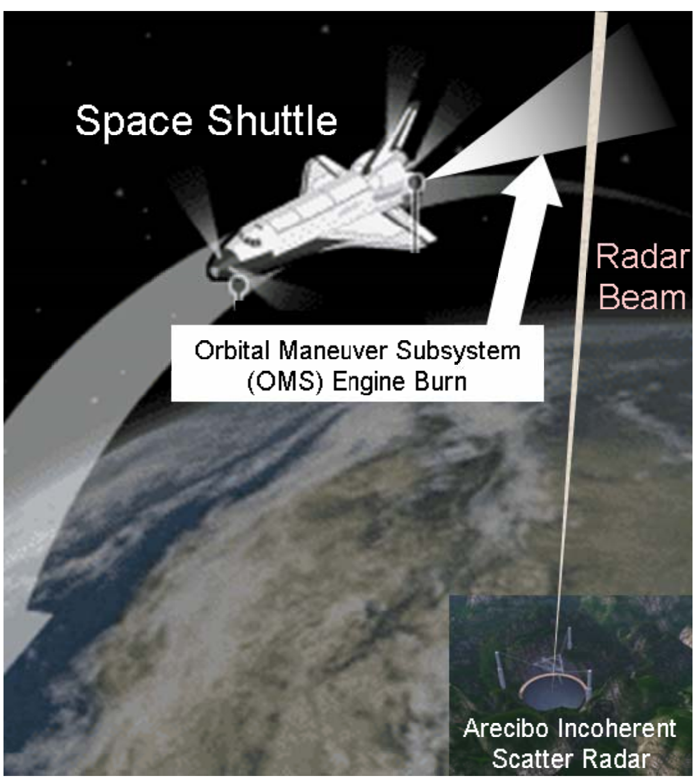

Figure 1. Geometry for the radar observations of the OMS burns during SIMPLEX.