Reports

Generation of an Artificial Aurora

Abstract. *On 26 January 1969 an Aerobee 350 rocket was fired from Wallops Island, Virginia, carrying an electron accelerator. Above 230 kilometers the electron guns put out a beam of 0.5 ampere of 10 kev electrons in pulses of 1-second duration aimed downward along the earth's magnetic field lines. The interaction of electron beam with the atmosphere at an altitude of about 100 kilometers generated enough light so that the auroral rays produced could be photographed on the ground by television camera systems.*

Auroras were studied for hundreds of years before it was known that they are caused by energetic particles bombarding the upper atmosphere. In the last 10 years it has been determined that most bright narrow auroral forms are caused by electrons ($E \sim 10$ kev). We still do not know how these particles are energized or from where they come.

The experiment reported here is the first test of the feasibility of using a rocket-borne accelerator to create a small controlled artificial aurora by transmitting an electron beam along the direction of the magnetic field $\overline{B}$ and allowing it to impinge upon the atmosphere (*1*). We hope this technique can be developed to the extent that an electron beam can be transmitted from a vehicle in one hemisphere and made to impinge upon the atmosphere in the other hemisphere, thus allowing determination of conjugate points and their movements, length, and connections of field lines, and electric fields parallel and perpendicular to $\overline{B}$. The purpose of this experiment was to try to demonstrate that the power of the transmitted beam is sufficient to create observable auroras; that plasma instabilities do not excessively dissipate the beam (the distribution function of the beam passing through the ionospheric plasma is quite clearly unstable); that electric fields associated with the beam space charge and the beam return currents do not excessively disturb the beam; and that the potential of the vehicle can be maintained near that of the ambient plasma.

We have demonstrated the technique by directing a pulsed electron beam from a small electron accelerator, which was carried to an altitude of about 270 km by an Aerobee 350 rocket, downward into the atmosphere below. The accelerator consisted of a set of ten electron guns with single-accelerating grids arranged in a circle. It was programmed to put out a sequence of pulses of different voltages and currents. About every 30 seconds a 1-second pulse of full power was emitted. Several of these full-power pulses were detected by ground optics.

The payload also contained an electron-collector screen of aluminized Mylar, 26 m in diameter, which was deployed by inflation into a plane perpendicular to the rocket thrust axis. The screen was of a size such that it could collect a thermal electron current of ionospheric electrons of approximately 1 amp at the F_2 peak. This was done to keep the rocket at roughly the ambient potential. If this had not been done the vehicle could have charged up to the beam voltage and then the electron beam could not have left the rocket. The potential of the rocket with respect to the surrounding plasma was measured by a retarding-potential analyzer (RPA) covering from 0 to 2000 volts. These data have not been analyzed in detail; however, the potential of the vehicle was usually under 2000 volts during the highest current pulses. Ionospheric data were obtained which, in conjunction with the RPA data, should

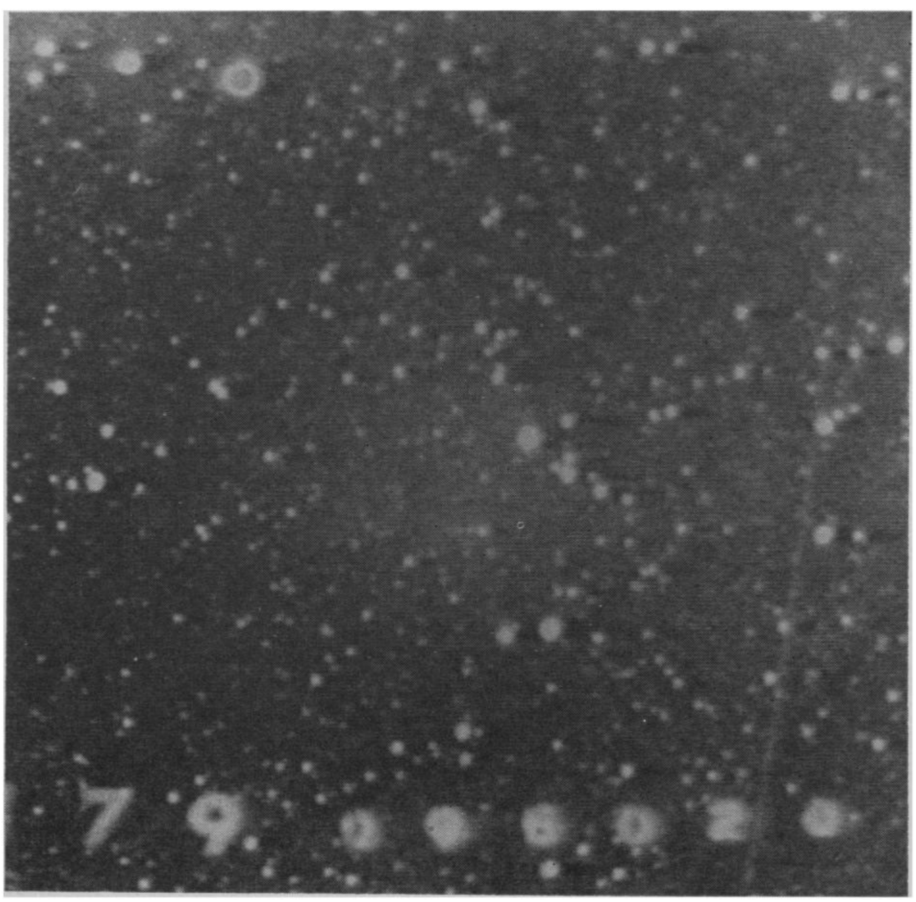

Fig. 1. This photograph of the night sky, made with an image orthicon television camera, shows stars to +9 magnitude. The bright line near the right edge of the picture is an artificial auroral streak about 30 km long and 200 m wide at about 100 km altitude and resulted from transmission of a 0.49-amp, 8.7-kv electron beam of the rocket-borne accelerator.

allow some study of the vehicle voltage versus current characteristics.

A search for optical auroras produced by the beam pulses was conducted with image-orthicon and image-intensifier cameras, Super-Schmidt meteor cameras, visual observers, photometers, and ballistic cameras located on the ground near Wallops Island and near Washington, D.C. These stations were provided with plots of look angles versus flight time for several possible rocket trajectories; the real trajectory was to be determined from radar data following burnout of the vehicle.

A search for electromagnetic radiation from the electron beam was conducted using two ground-based VLF stations, covering together the frequency range 500 hz to 12 khz, and narrow bands at 500 khz, 1.75 Mhz, and 2.9 Mhz. No positive results have been obtained to date from this search for electromagnetic radiation from the beam, indicating that lIttle energy was emitted as waves.

The Aerobee 350 rocket carrying the accelerator experiment was launched from Wallops Island at 09:45 G.M.T. 26 January 1969. After burnout, the spinning of the rocket was stopped, and the rocket was reoriented with the electron guns pointing downward along $\overline{B}$. The nose cone was jettisoned and the electron collector screen deployed. Then the sealed electron guns were opened and electron beam pulsing began at approximately 235 km, continued through apogee at about 268 km, and was terminated by program at about 105 km. The maximum distance traversed by the beam was approximately 170 km. Reception was good, and all systems worked as intended.

The trajectory actually flown by the rocket was outside the anticipated path. As a result, no precalculated look angles were available, and the auroras were farther from the magnetic zenith of the prime optical observing station than had been intended. Nevertheless, auroras corresponding to the first four full-power pulses (490 ma at 8.7 kv for 1 second) were observed by two orthicon cameras. The auroras observed were long slender rays with a length (along $\overline{B}$) of 30 to 40 km and a width of 250 ± 50 m (Fig. 1). The pulse location, size, shape, and intensity are all roughly as expected. However, the spot width seems somewhat wider than calculated by Coulomb scattering stopping the beam. The intensity of auroral rays is close enough to the expected intensity that we are sure a substantial fraction of the electron beam power penetrated to about the 100 km level in the atmosphere. The experiment shows that beam propagation and stability problems were not too serious, and that producing auroras with electron beams is apparently feasible.

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Note

1. This experiment was performed through the joint efforts of many people from several organizations. I acknowledge the cooperation and support of the following groups: NASA Goddard Space Flight Center; NASA Wallops Station; Ion Physics Corporation; Geophysical Institute, University of Alaska; Smithsonian Astrophysical Observatory; Radioscience Laboratory, Stanford University; Stanford Research Institute; U.S. Naval Research Laboratory; U.S. National Security Agency; School of Physics and Astronomy, University of Minnesota; Lockheed Palo Alto Research Laboratories; The Johns Hopkins University.

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Waterfall-Generated Earth Vibrations

Abstract. *Waterfalls generate periodic earth vibrations whose frequencies are inversely proportional to the height of the waterfall. Action of turbulent eddies is a probable explanation.*

Typically, a waterfall produces continuous earth vibration with one frequency predominating; this frequency is inversely proportional to the height of the waterfall. Frequency data for nine waterfalls in Iceland, Alaska, and continental United States, ranging in height from 5 to 93 m, were obtained with an HS-10 geophone, whose position, whether at the brink or the base of the fall, was immaterial (Fig. 1).

Waterfalls in which the flow is thoroughly broken up by ramps and ledges, such as a "horsetail" fall, have high background noise with no characteristic predominant frequency. While wide waterfalls—such as the Canadian and American Niagaras, also have high background noise—their predominate frequencies are discernible. Generally the data are not as consistent for low waterfalls as they are for high ones. A multiple-level fall, such as Gullfoss, a wide two-stage Icelandic waterfall, has as many characteristic frequencies as it has levels. Fourier analysis of the vibration frequencies of Gullfoss shows the two frequencies of 6 and 40 hz, which correspond, respectively, to drops of 7.5 and 27 m (Fig. 2).

While vibration set up in the earth must result from the water impinging

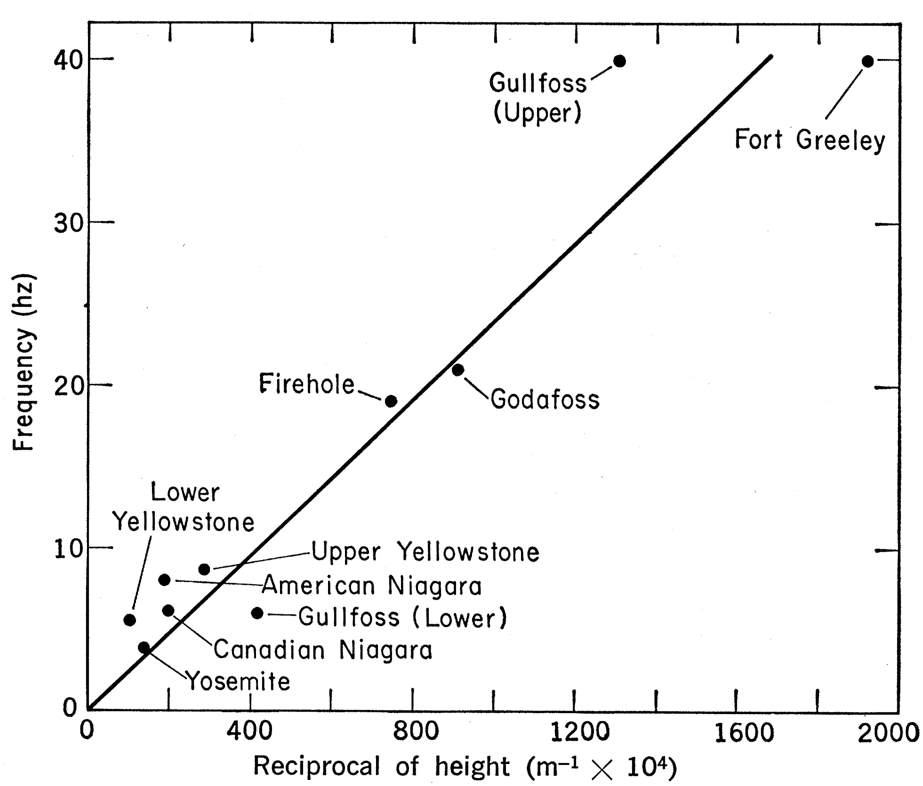

Fig. 1. Predominant vibrational frequency as a function of reciprocal of waterfall height.