

A SURVEY OF LASER LIGHTNING ROD TECHNIQUES

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ABSTRACT

The concept of using a laser to create an ionized path in the atmosphere to act as a lightning rod is not new. Over the past four decades since the invention of the laser, there have been many documented investigations into the ionization of atmospheric gasses with an eye towards creating a laser lightning rod (LLR). Initial experimental attempts using lasers operating in the IR were not successful. Although some ionization was attained, it was found that the laser beam was self-quenching so that distances of only tens of meters were obtained in the atmosphere near sea level.

With advances in both the power output of lasers and the tunability of the laser frequencies, researchers have been looking for sophisticated ways of avoiding the plasma quenching problem. The direct single photon ionization of atmospheric gasses would require operations in the UV part of the spectrum where there is overwhelming absorption by the atmospheric gasses. This, in concert with the quenching at the longer IR wavelengths, would suggest the use of intermediate wavelengths to produce ionization of atmospheric constituents by multiphoton capture.

This paper briefly reviews the work which has been done in trying to create a laser lightning rod and discusses some ongoing research which has potential for achieving an operational laser lightning rod for use in the protection of missile launch sites, launch vehicles, and other property.

BACKGROUND

Natural lightning occurs with the local breakdown of air inside a cloud which has an electrical field of critical potential. Physical objects, such as the leading edges of aircraft or noses of rockets, may artificially trigger lightning from sub-critical charge centers. From the observed torturous track of

lightning (see the upper portion of the lightning in Figure 1.) and the research into step leaders, it is apparent that lightning is seeking and following the path of least resistance through the atmosphere. Rocket triggered lightning experiments have demonstrated that a conducting wire trailing from a rocket will provide such a path of least resistance as is shown in the lower section of the lightning stroke in Figure 1. If a sufficiently dense ionized column could be created in the atmosphere with a laser beam, such a column would provide a preferred path for lightning [1-3].

The laser evolved on the heels of the development of the maser in the mid 1950's. The intervening years brought investigations in the breakdown of air [4-6] and, more specifically, the possible use of lasers for triggering lightning [7-8]. An attempt was made during the Thunderstorm Research International Program 1978-1979 to trigger lightning using a long-wavelength, CO₂ laser with microsecond pulse where a laser-produced, clear-air breakdown was observed although no lightning could be attributed to the laser firings during thunderstorms. At that time the failure was thought to be the result of the scattering of radiation by raindrops and attenuation of the limited laser energy to below breakdown thresholds [9]. Self quenching of the laser beam is now identified as the major problem.

With advances in both the power output of lasers and the tunability of the laser frequencies, researchers have been looking for sophisticated ways of avoiding this plasma quenching problem. Direct single photon ionization of atmospheric gasses would require operation in the low-wavelength UV part of the spectrum where there is overwhelming absorption by the atmospheric gasses. This suggests the use of an intermediate wavelength between the IR and the UV for multiple photon ionization of air with minimal energy expenditure.

New technology, largely the result of research sponsored by the DoD Strategic Defense Initiative (SDI), has led to the creation of increasingly powerful lasers. Powerful, short pulse lasers have such high densities of photons that multiple photon capture may easily raise electrons to excited states from which ionization readily occurs by absorption of yet another photon. This combined with advances in frequency "shifting" of the lasers output now presents the possibility of laser output being tuned to specific wavelengths so that specific atmospheric constituents may be selected for ionization. These new developments have now dramatically increased the possibility of creating a sufficiently long ionized column which could act as a preferred path for the discharge of electrified clouds, i.e., an LLR.

Another approach would be to choose a laser with a particular wavelength which would not ionize the clear atmosphere but which would ionize cloud droplets thereby leaving an elevated path similar to an exhaust plume from a rocket or to an "altitude" triggered lightning rocket. Recent studies [10] have indicated that absorption of laser beams by cloud droplets cause shattering and vaporization. Increases in the available power might create ionization which could be maintained by a second suitably tuned laser.

POSSIBLE APPLICATIONS

Since a marginally-charged cloud cannot be reliably determined from ground-based electric field measurements because of a possible space-charge screening layer, such a charged cloud presents a hazard to airborne operations.

Because of the ease with which a laser beam can be steered into any cloud overhead, an LLR could be used to ascertain if there exists enough charge in the clouds to discharge to ground as triggered lightning. This holds the possibility of using LLRs to test clouds prior to launching missiles through the clouds or prior to flying aircraft through the clouds. LLRs could also be used to probe and discharge clouds before or during any hazardous ground operations. Thus an operational LLR may be able to both detect such sub-critical electrical fields and effectively neutralize them.

One thing which LLRs probably will not be able to do in the near future is to discharge clouds or cloud systems which are actively producing lightning. In these cases the charges are being built up so rapidly that a single LLR system would not be able to cover the whole sky quickly enough. On the other hand, there is a possibility that as we learn more about the morphology of lightning, a computer controlled bank of LLRs operating on data from ground based field mills, lightning mappers and other data sources might be able to discharge the energy from active thunderstorms and, perhaps, collect the energy for man's use.

CURRENT PROGRAMS

Two promising research efforts are currently being conducted using multiple photon ionization with each proposing vastly different solutions for the creation of an ionized path to trigger lightning.

The University of New Mexico's concept (Geophysics Directorate contract) will use a femtosecond pulsed KrF laser at 248 nm for ionization of oxygen by multiphoton absorption. To compensate for loss of energy in the beam, the laser pulse will be frequency swept which will produce pulse compression as the pulse propagates through the atmosphere. A second Nd:YAG laser at 1.06um will be used to maintain a conductive path by preventing the attachment of the multiphoton-absorption generated electrons to oxygen. Inter-cloud discharge triggering is separately addressed by using a third cloud clearing and waveguiding CO₂ laser at 10.6 um.

The Ophir Corporation [11] proposes a more energy efficient approach (NASA SBIR contracts) using a single laser to excite a minor atmospheric constituent. In this concept, it is proposed that a smaller number of photons at 314.5 nm will produce sufficient ionization of Argon. A tunable dye laser will be used in the laboratory feasibility experiments although atmospheric testing will require the further development of Raman excimer technology to shift the 308 nm wavelength of a XeCl laser.

CONCLUSIONS

The advantages of an efficient, reliable LLR are many. In the immediate future an LLR could be used to signify the presence of atmospheric electric fields that would be hazardous to rocket or shuttle launches and aircraft operations. Further into the future, banks of LLRs could be used to neutralize atmospheric corridors for airborne operations and also be utilized as a protective screen for sensitive ground facilities against lightning strikes. One might even peer into the distant future and envision a world-wide harvesting of atmospheric electricity for use by man as a power source.

The success of either or both of these studies will enhance the prospects of an operational LLR in the very near future. The failure of both on the other hand, would generate new ideas and alternate approaches through lessons learned and would not necessarily prove the impossibility of the LLR concept.

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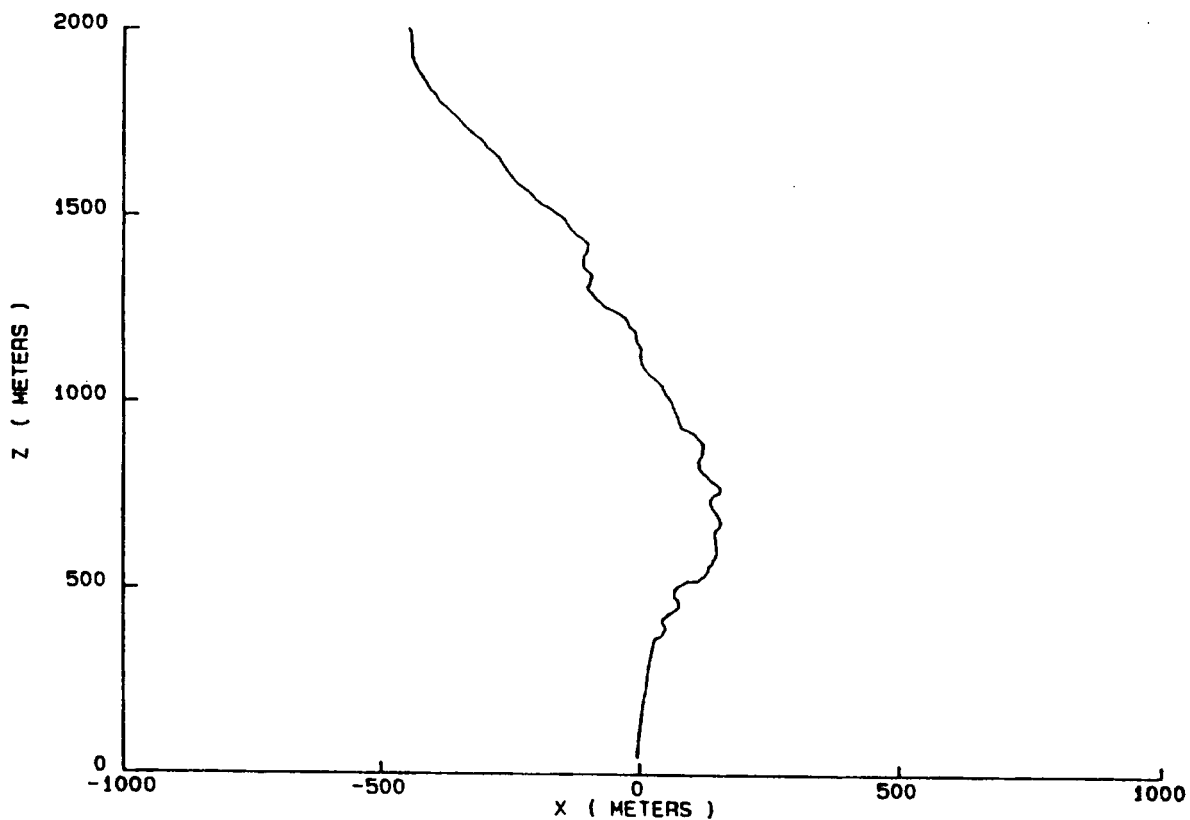


FIGURE 1. Computer reconstructed X-Z projection of a triggered lightning stroke. The straight channel from the ground is typical of "classical" triggering when the copper wire attached to the rocket is also electrically attached to the ground. The torturous path of the lightning channel higher up is typical of natural lightning.