Experimental and theoretical study of the bi-leader process
Part II : Theoretical study

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1. Introduction

The main purpose of this paper is to describe a self consistent model of the bi-leader process. This model has been designed to determine the external threshold conditions for aircraft or space launcher striking, and to calculate the current and electromagnetic fields associated with the bi-leader development. Experimental studies (see part I of the present paper) were first used to understand the basic physical processes involved to define the main features of the model, and finally to validate the model results under a wide range of experimental conditions; both laboratory and triggered lightning electrical and optical measurements were used.

2. General principles of modelling

The model is self consistent and is based on a time dependent solution of the basic transport and thermodynamic equations of the discharge process [1],[2]: the input data are only the inital field distribution around an electrically floating object, and the different phases of the bi-leader inception and development are numerically simulated in a sequential way. The simulation code is made of three coupled routines which calculate at each time step:

(1) the inception and propagation parameters of the positive discharge (inception time, charge, current, propagation velocity, conductivity, etc...) as functions of the local electric field;

(2) the inception and propagation parameters of the negative discharge;

(3) the field distribution and the object floating potential distorded by the presence of discharge channels and corona space charges.

The positive and negative discharge models have been separately tested and validated under laboratory conditions [1],[2],[3]. The specific processes involved in atmospheric discharges were investigated though the study of triggered lightning data [4]. The E-field calculation uses an extended version of the classical "Charge Simulation Method".

3. Results

3. 1. Laboratory bi-leader

The input data are the electrodes geometries and the voltage waveform. The calculation provides the simulation of the space time developement of the bi-leader (as given in figure 1), the calculation of currents, electric field, etc...These results are found to be in excellent agreement with experimental data.

3.2. Bi-leader phase of a triggered flash in altitude

The input data are the ambient vertical E-field profile and the rocket and wire geometry . The simulation code is used to find the altitude of the discharge initiation and to calculate all the bi-leader development parameters. Figure 2 gives the calculated space time development of both leaders and provides various parameters which can be compared to optical and electrical data (leaders velocities, step length and period). The results are very consistent with experimental data.

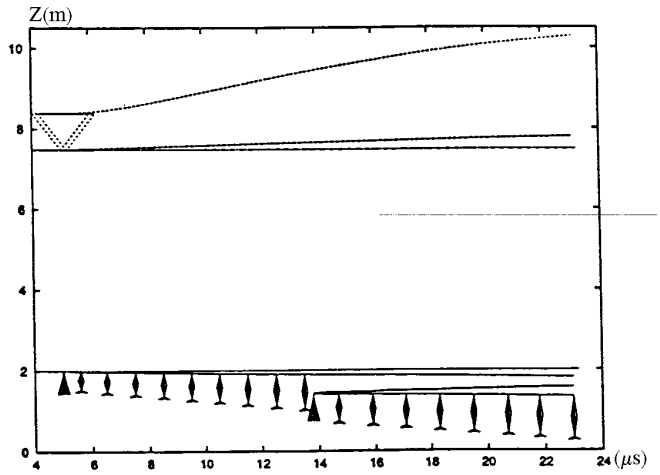

Fig. 1 -Numerical simulation of the laboratory bi-leader

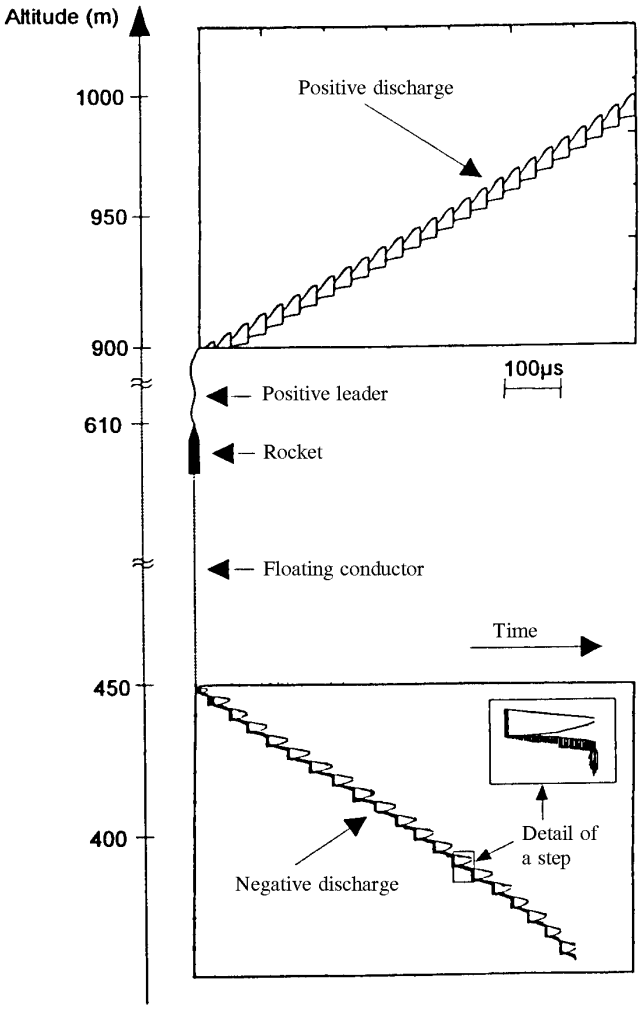

Fig. 2 -Numerical simulation of the bi-leader process in an altitude triggered flash: simulation of the space time developement of the bi-leader during the first milisecond after the negative stepped-leader onset.

3.3. Application : determination of striking criteria

One of the main practical applications of this model is to calculate the triggering conditions on aircrafts or launchers, on the basis of a complete physical model which determines the threshold conditions for the stable propagation of leader channels over long distances. The geometry of the aircraft (or space launcher) is used as input data, together with the ambient field distribution and the net charge carried by the aircraft.

The calculation is performed in the case of a Transall aircraft (see fig. 3) in order to compare the calculated triggering conditions with data obtained during in-flight experiments.

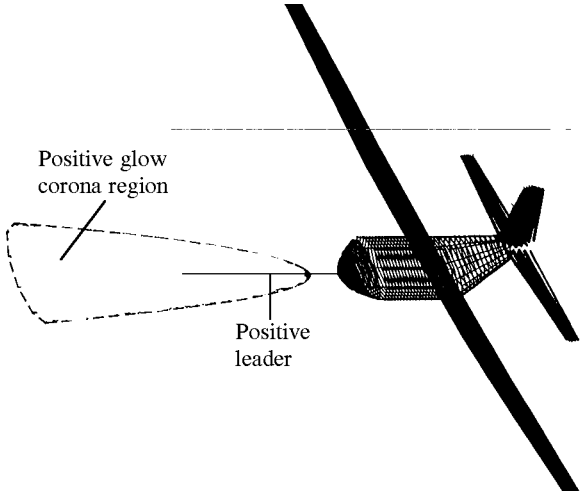

Fig. 3 - Numerical simulation of the positive discharge onset on a Transall aircraft

4. Conclusion

The presented model appears a valuable tool for analysis of the bi-leader process over a very large set of experimental conditions, and provides accurate evaluations of the striking threshold of aircrafts in given ambiant electric field conditions.

References

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