SIMULATION OF THUNDERSTORMS

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INTRODUCTION

Thunderstorm presence is required to fully complement a weather environment simulation. An in-flight aircraft will be subjected to forces in part created by moving air in this environment which can be described by clear air turbulence characteristics.

When the aircraft enters a thunderstorm area, the forces acting on the aircraft due to moving air can undergo a large change.

There are other phenomena related to thunderstorms that also have to be considered:

- o Lightning
- o Thunder
- o Icing
- o Radio Noise
- o Intensity Level Reflectivity

TYPICAL STORM CELL DEFINITION

Reference is made to Figure 1 that illustrates an isometric view of a typical simulated storm cell. The cell is defined as a parallelepiped that encompasses an inner volume containing the simulated storm. The vertical distance, h_S, defines the altitude of the lowest face of the cell. The vertical length of the cell is defined by h_C. Cell coordinates (X_N, Y_N, h_N) define the location of any point internal to the cell. The corner boundaries of the cell are referenced to a prescribed Gaming Area in terms of earth coordinates and altitude (λ, σ, h_S). The volume below the storm plane contains winds consisting of either rising, falling or horizontal drafts. A library of storms can thus be made available described by intensity α_F, or α_R, and an associated height, h_C.

Reference is made to Figure 2 that illustrates a planar view of a typical storm cell model. The storm is contained within a predetermined area bounded by a ½ mile square (by definition). The shaded area represents the storm environment and the remaining area within the square depicts clear air turbulence.

CHARACTERISTICS

Thunderstorms in general can occur individually over relatively small areas or they may exist along a wide front. The individual storms can be described as a "cell" and the frontal area storms can be described as a "storm line."

Throughout most geographic areas, thunderstorms are continuously forming into violent turbulent wind states and decomposing with dissipating winds accompanied by intense rainfall.

During the initial, or cumulous, phase of a thunderstorm, storm intensity increases due to the presence of an unstable, moist air mass that is carried upward by strong drafts. This moist air takes on the form of globules of water which in turn forms into snow and ice pellets as the air stream works further upward.

The initial storm phase is identified by random updrafts whose velocity can vary between 10 and 50 miles per hour at the storm base during periods between two and six seconds. These intensities increase as the updrafts rise in altitude within the thundercloud, or storm cell. During this phase, air is continuously being drawn inward and upward from below the storm base.

As the storm increases in size, the characteristics of the wind currents change. This second, or mature, phase is described as follows:

At some point, the density of water globules and ice pellets cannot be sustained by the upward air thrust and downward wind currents start to form. The proportion of downward air currents continues to increase accompanied by rainfall and possible hail or ice particles. The storm clouds continue to grow and tend to scatter out at the top. In this case, the downward winds increase in intensity as they descend. During this phase, the winds below the cloud base are both flowing outward and inward from the storm cell.

The final, or dissipating phase of the storm consists of intense rainfall with downward winds. The rainfall and winds gradually slacken and the storm is dissipated.

STORM DYNAMICS

The cumulous storm phase consists of wind intensities $\alpha_R = N_1K_1N_2\ (h_s - h_N) + K_2)$ where:

- N_1 is a Gaussian random positive amplitude
- N_2 is a Gaussian random time period
- K_1 is a proportionality constant
- h_s is the storm base altitude
- h_N is an altitude within the storm limits
- K_2 is the storm constant intensity at h_s

The wind intensity below the storm is described as:

$$\alpha_{RB} = N_1N_2(K_3\bar{u} + K\ \bar{z})$$

where:

- K_3, K_4 are constants
- $\bar{u}$ is the unit vector in the storm base plane
- $\bar{z}$ is the unit vertical vector

Falling vertical winds are represented by intensities given by:

$$\alpha_F = -N_1N_2K_1(h_c + h_s - h_N) + K_2)\ \bar{z}$$

where:

- h_c is the storm altitude limit above h_s

STORM LINES

Thunderstorms can occur over a broad front. As a consequence, a storm front can be represented by groups of cells described above within realistic presentation areas of between 10 and 200 square miles. A catalogue of typical storm cells $S_1, S_2, S_3, \ldots S_n$ is to be provided for insertion in the Gaming Area. The location is to be preselected. Reference is made to Figure 3 which illustrates a representative multiple intensity storm front.

A thunderstorm area may also consist of a combination of multiple storm lines and individual cells. Reference is made to Figure 4 that illustrates a typical thunderstorm Gaming Area. Storm lines are precatalogued and located as shown by S_{L1}, S_{L2}, S_{L3} etc. Storm front S_{L3} is shown located at Gaming Area coordinates $(\alpha_{L3}, \sigma_{L3}, h_{L3})$. Individual storms S_1, S_2, S_3, etc. are likewise located by Gaming Area coordinates.

An aircraft flight path as shown in Figure 4 may experience a wind intensity profile that is upward, downward, or bi-directional. Figure 5 illustrates three phases of storm dynamics contained in cells S_3, S_4, S_5. A moving aircraft can experience any of these profiles while in the storm area. As the aircraft enters another cell, a typical profile change is illustrated.

LIGHTNING

Thunderclouds contain a heterogenous array of charge formations. Many theories suggest that charge buildup is due to the driving energy, or a wind intensity within the thundercloud. The net effect is that a charge differential builds up both within the storm cell and also between the cell and earth's surface. Our interpretation of this phenomena is that lightning occurs when wind intensity levels or successive intensity level changes exceed a predetermined level.

Reference is made to Figure 6 illustrating the logic that provides a visual lightning cue as well as a radio aural cue. The present wind intensity (α_{t_i}) is compared to the previous intensity $(\alpha_{t_{i-1}})$. If the intensity level difference exceeds a predetermined level reference, then lightning, thunder, and radio noise cues are provided.

ICING

In areas where individual thunderstorms are isolated, or scattered, icing is not considered to be a serious problem. However in areas of numerous thunderstorms, the icing problem can be significant. Therefore, thunderstorm icing discretes for icing simulation should be provided within severe storm line modules for altitudes above the order of 20,000 feet.

CLOUD SIMULATION

When the trainer aircraft enters a storm cell, or storm line, a cloud cover cue is sent to the Visual System. Conversely, when the trainer aircraft leaves the storm cell, or storm line, a clear view cue is sent to the Visual System. The cloud cover cue is associated with the storm intensity.

SIMULATION BLOCK DIAGRAM

Reference is made to Figure 7 which shows a typical Thunderstorm Simulation Block Diagram.

Storm cell and storm line data are instructor furnished. These are generally selected apriori.

Aircraft equations of motion are supplied from another source. The items of interest involve own ship location and altitude. The location defines whether the storm volume has been intercepted. The ship's altitude is required to define wind components.

Two random noise generators are required to provide the storm amplitude and time periods. All cells within the storm front can be activated by the same two random generators. The individual cell characteristics will differ, however, in intensity and polarity.

Data base provides the time references needed for various phases of the program.

The computed functions of the program interface with own ships equations of motion in the case of wind intensity or icing. Visual cues are provided by lightning discretes. Scatter and storm distance information is also provided. Aural cues are provided by thunder and radio noise discretes.

References: "The Flight of the Thunderbolts", Sir Basil Schonland, Second Edition, Clarendon Press, Oxford, 1964.

"The Lightning Book", P. E. Viemeister, Doubleday & Co., 1961.

"Aviation Weather For Pilots and Flight Operation Personnel", FAA, Dept. of Commerce, 1965.

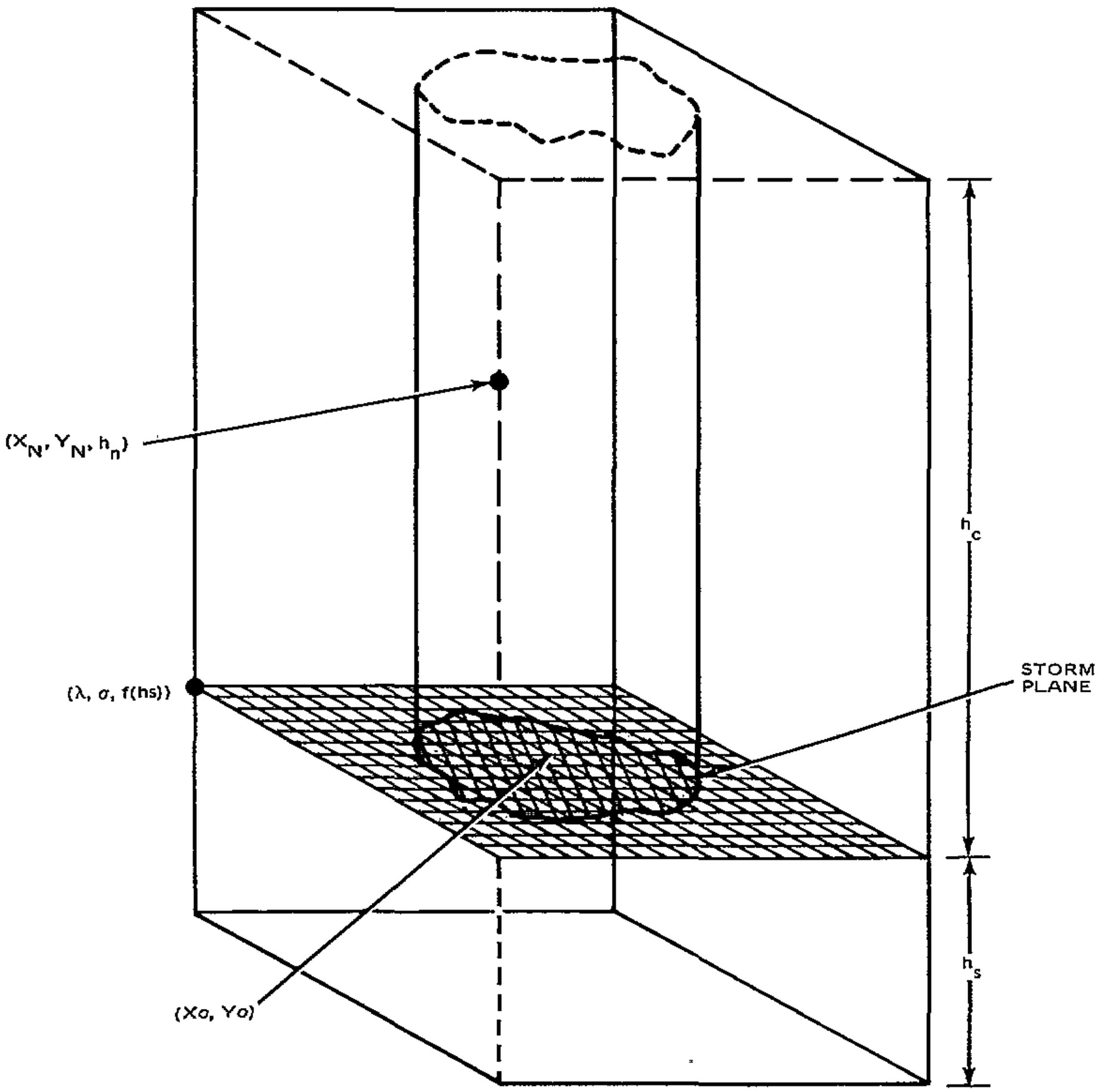

Figure 1 Geometric Presentation of a Storm Cell

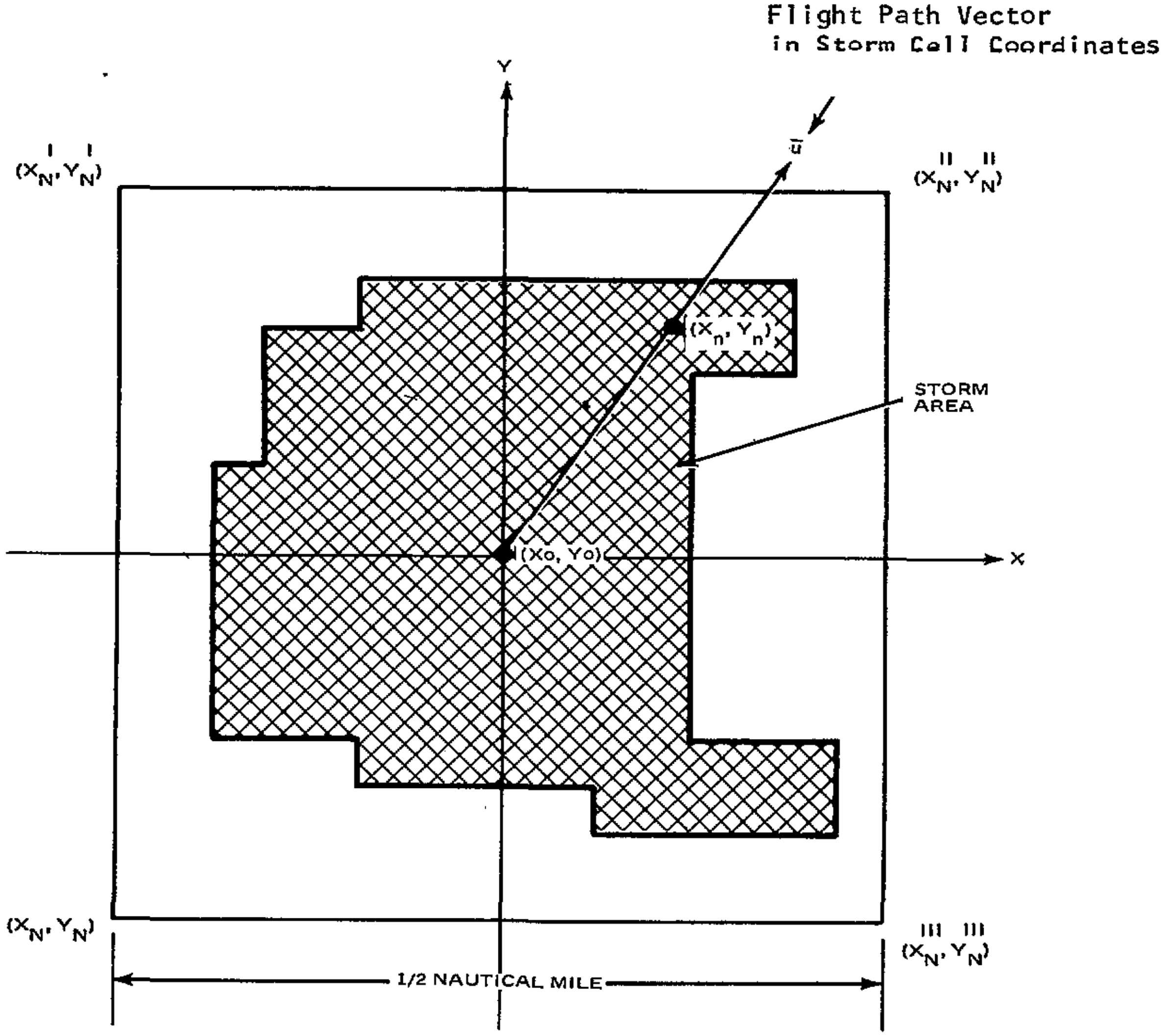

Figure 2 Planar View of Typical Storm Cell

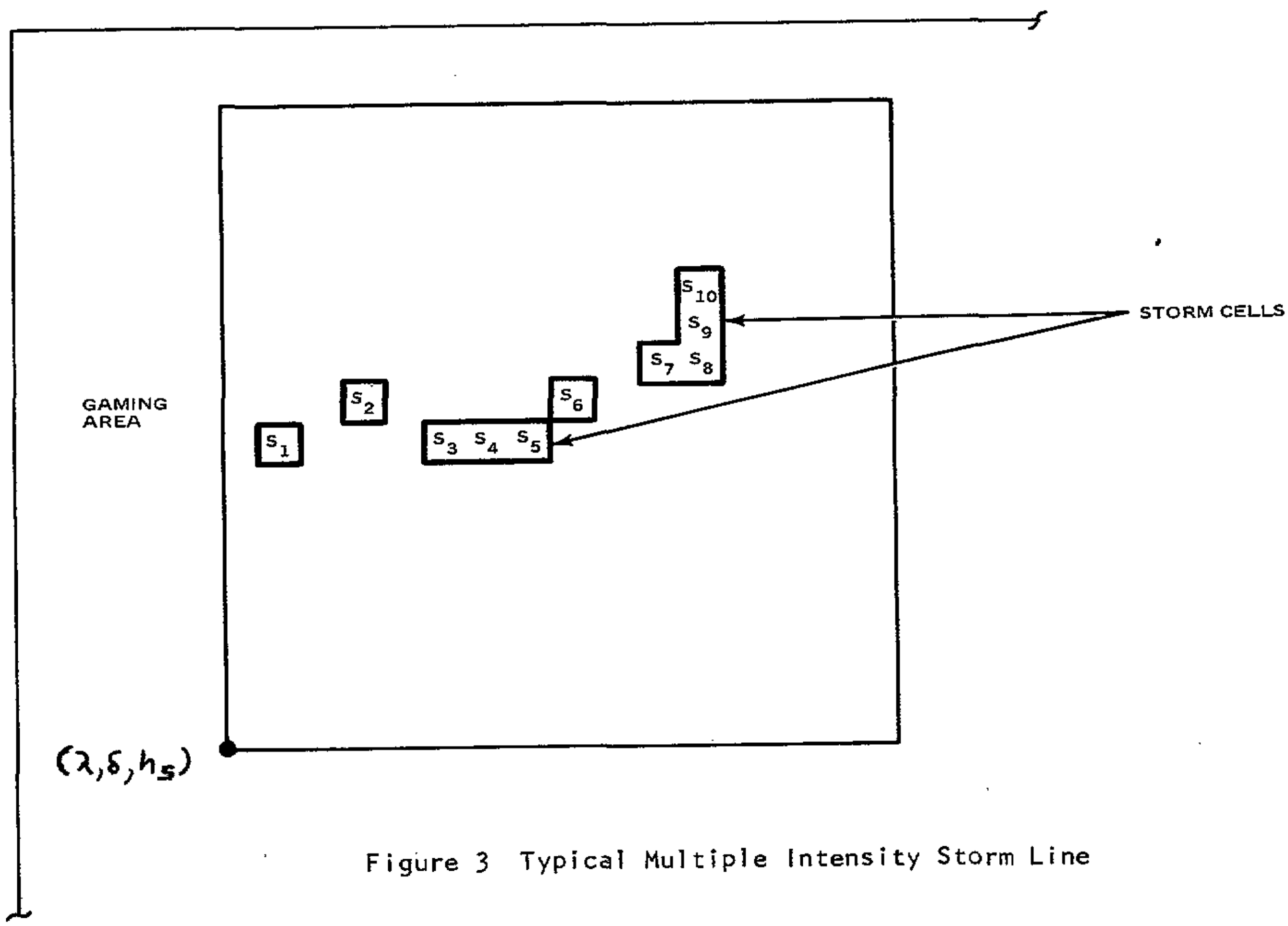

Figure 3 Typical Multiple Intensity Storm Line

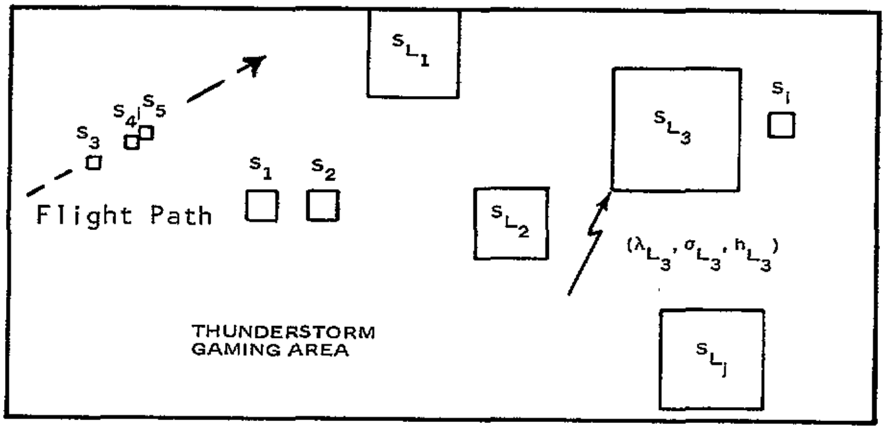

Figure 4 Typical Thunderstorm Gaming Area

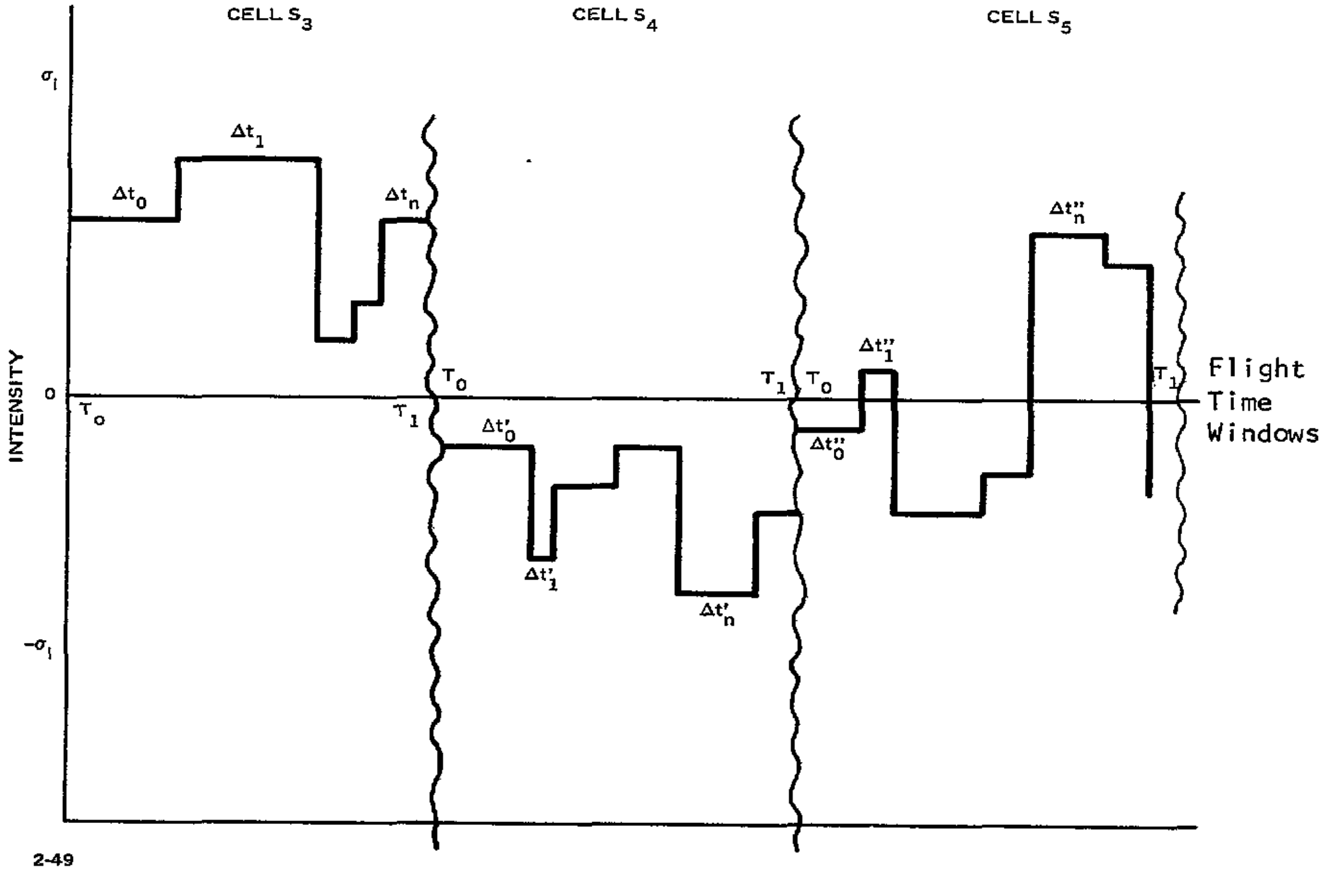

Figure 5 Three Simultaneous Representations of Storm Cell Intensities

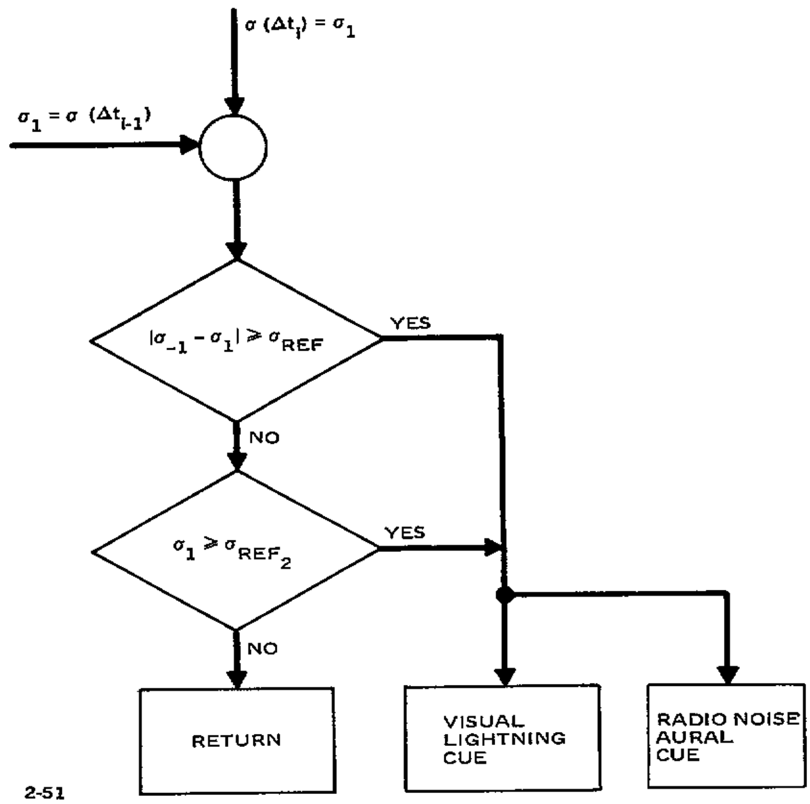

Figure 6 Lightning and Aural Cue Simulation

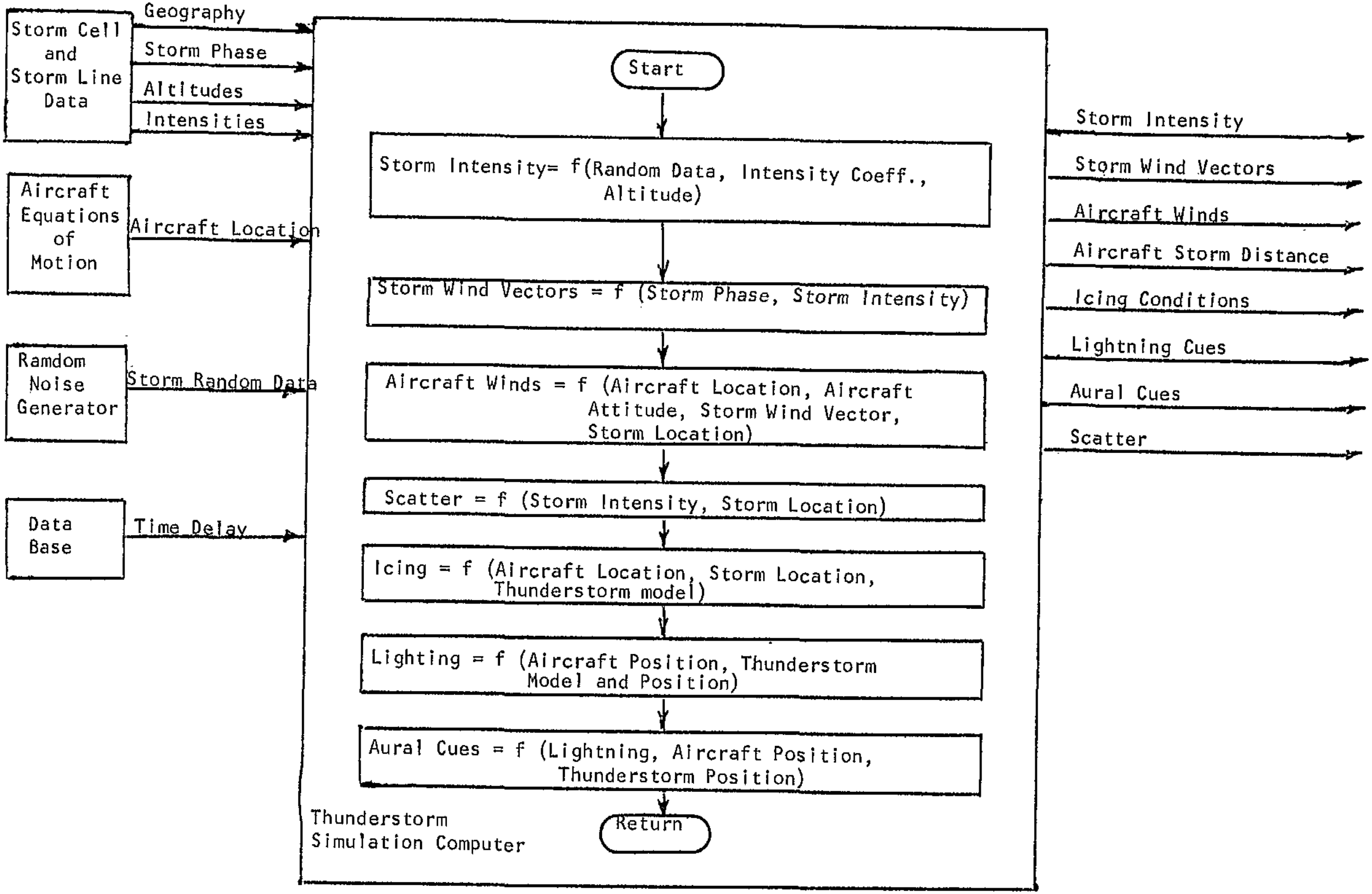

Figure 7

Thunderstorm Simulation Block Diagram

ABOUT THE AUTHOR

MR. MELVIN PAIKEN is a Senior Engineer at Grumman Aerospace Corporation. His primary responsibility is math model development of aircraft systems for the A-6E Weapons System Trainer. Previous experience includes: system simulation of E-2C trainer, F-14 maintenance trainer, trainer proposals, development of computer programs for automatic checkout equipment, and dynamic analysis of aircraft and spacecraft control systems. Mr. Paiken holds a B.E.E. degree from the College of New York and an M.E.E. degree from Polytec Institute of Brooklyn.