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EMPIRICAL UNCERTAINTIES IN PREDICTING
PARTICLE TRAJECTORIES

by

T.E. VanZandt and J.W. Reed

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June 1958

WORK PERFORMED UNDER AEC CONTRACT AT-(29-1)-789

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ABSTRACT

Project Rawijet, conducted by Sandia Corporation and the Air Weather Service, provided detailed observations of time and space variability of rawinsonde runs. Sequences of these balloon runs have been examined to determine the uncertainty of predicting the ground trajectory of airborne parcels or particles. A separation of the two contributing variables, time of flight and the length of time over which persistence is forecast, has been attempted. The relation of the results to existing turbulence theory is discussed.

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On Project Rawijet balloons were released from the same point at one-hour intervals for 10 hours and tracked by radar for about 50 minutes, by which time their altitude was about 60,000 feet. This was done on three days. The experiment on any one day can be schematized as in Slide 1.

We have analyzed the data obtained in two ways. First, to obtain the standard deviation of the position errors relative to the position predicted by persistent winds, as a function of time of flight and time after prediction of release. Second, to obtain the standard deviation of the wind errors as a function of the layer thickness as well as of the time of flight and prediction time.

The equation for the position standard deviation σ_p is on Slide 1. On Slide 2 σ_p is plotted vs prediction time T , and on Slide 3 vs time of flight t . On Slide 4 we have plotted contours of constant σ_p together with the lines of best fit:

$$\sigma_p(t, T) = 0.076 t^{1.3} T^{0.85} \text{ kft}$$

Here t is in minutes and T in hours.

These results apply only to the particular conditions under which the experiment was done. A result of perhaps more importance is illustrated in Slide 5 where we have plotted the errors on normal paper. The straightness of the curves shows that a normal distribution of errors would be a reasonable approximation. Unlike our numbers this qualitative result should be valid over a wider range than that of the experiment.

A major application of such data might be to fallout problems. But let us see how our range of t and T compares with those of interest to fallout (Slide 6).

On Project Rawijet balloons were released also at 15-minute intervals. And using synoptic observations our range of T can be extended indefinitely. But to increase the time of flight t would require slower rising balloons, which would result in long ranges and necessitate an array of radars for tracking instead of a single set. Another expedient would be to let balloons rise to altitude and then fall slowly, noting their position errors only on the ground. By either technique it seems that extension of the data to large t is likely to be expensive.

It has been suggested that more representative wind observations would be obtained from averaging balloon motion through thicker layers. Especially fallout patterns, which are a result of integration through thick layers, could be more adequately constructed. In the extreme it is obvious that time variations of wind averaged throughout the depth of the atmosphere should be small.

Rawijet data for balloons released one hour apart, and with positions recorded every eight seconds, furnished statistics to show the effect of varied time of flight increments, proportional to layer thickness, on periodic variability. Data from observation sets for three days, averaged for all levels to 60,000 feet, are shown in Slide 7, for a single component direction. A total vector standard deviation is $\sqrt{2}$ times as large as the component sigmas.

The six-hour interval data show that regular synoptic schedule observations are not improved in representativeness by reasonable variation from the WBAN SOP interval of one minute. Also since the details observed in measuring over smaller layers are lost in the six-hour period variability, reporting winds at frequent SOP intervals seems unnecessary.

An empirical pattern fitting the data for $t \geq 32$ seconds is shown, and may also be expressed as a function of thickness. Thus the error in predicting fallout particle trajectories may be deduced from this data. A particle which falls from some altitude in a given time is expected to be displaced by an average wind observed for entire height range, at the time it is dropped. Up to the time it lands it will actually have experienced a mean wind which will be different by an amount nearly equal to the change of the layer wind for one-half the fall time. The expression for error in the mean layer wind, assuming a correction for aerodynamic fall, for a particular particle is shown in Slide 8. Since position error on landing is the mean wind error multiplied by flight time, the curve of position circular error vs flight time is also shown.

This shows essential agreement with the turbulence theory of Richardson, as the position error follows $t^{1/2}$ for short times and small-scale eddy effects, and becomes more nearly proportional to $t^{3/2}$ as larger scale motions are encountered.

STANDARD DEVIATION OF POSITION ERRORS, X COMPONENT:

$$\sigma_x(t, T)^2 = \frac{\sum_{n=T}^{n_{\max}} [X_n(t) - X_{n-T}(t)]^2}{(n_{\max} - T)}$$

BALLOON RUNS

Slide 1

STANDARD DEVIATION OF POSITION ERRORS VS
PREDICTION TIME

Slide 2

STANDARD DEVIATION OF POSITION ERRORS VS
TIME OF FLIGHT

Slide 3

Slide 4

033 008

POSITION ERRORS: TEST FOR NORMALITY

Slide 5

TIME RANGES OF POSITION σ 'S

Slide 6

r 33 110

STANDARD DEVIATION OF COMPONENT WIND SPEED VS BALLOON FLIGHT TIME AVERAGED FOR WIND
(TIME BETWEEN BALLOONS INDICATED FOR EACH CURVE)

WIND AND TRAJECTORY ERRORS FOR PARTICLE FALL TIMES

Slide 8

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