APPENDIX C

to the

STRUCTURAL REANALYSIS PROGRAM

For The

R. E. GINNA
NUCLEAR POWER PLANT

March 8, 1983

ARA Report C556
RTI Report 44T-2488-1

UTILITY POLE TORNADO MISSILE TRAJECTORY ANALYSIS

L. A. Twisdale
W. L. Dunn

Applied Research Associates, Inc.
Southeast Division
4917 Professional Court
Raleigh, North Carolina 27609

Prepared for

Research Triangle Institute
P.O. Box 12194
Research Triangle Park, North Carolina 27709

and

Gilbert Associates, Inc.
P.O. Box 1498
Reading, Pennsylvania 19603

Under Purchase Order 201494

TABLE OF CONTENTS

UTILITY POLE TORNADO MISSILE TRAJECTORY ANALYSIS

1. INTRODUCTION

The objective of this study was to perform trajectory calculations of utility pole missiles in tornado windfields. The Nuclear Regulatory Commission (NRC)-defined utility pole [1] was specified as the postulated missile for these analyses. Tornado windfields with peak velocities of 132, 150, and 188 mph were specified. The utility poles were injected at 20 ft above grade, which corresponds approximately to the center of mass of a standing 35 ft pole. Trajectory calculations were made using the random-orientation six-degree-of-freedom (RO6-D) trajectory model [2,3,4], which accounts for drag, lift, and side aerodynamic forces in a time history integration of the equations of motion. The maximum height, range, and speed attained by the missiles were extracted from the time-history flight data. In addition to these numerical calculations, several comparisons of field observations and trajectory predictions of utility pole missiles have been made. This report documents the methods and results of this study.

2. APPROACH

The approach used for the trajectory analyses is based primarily on the models and data reported in Refs. 2-10. A brief summary of the tornado windfield model, trajectory model, missile aerodynamics, and injection model are presented in the following paragraphs.

a. Tornado Windfield

The tornado windfield model used herein is documented in detail in Ref. 4. This synthesized windfield model was developed explicitly for missile transport analysis and includes 5 basic parameters that define the 3-dimensional flow characteristics given the peak speed U_{max} and path width

W_t. These parameters are: translational speed (U_T); the ratio of radial to tangential flow components (γ); the radius to maximum windspeed (ρ_m); core slope (S); and reference boundary larger thickness (δ_0).

A sensitivity analysis was performed [4,6] using a one-at-a-time experimental design and three level input pattern. The basic conclusions of this analysis for tornadoes with U_{max} = 300 mph and two types of missiles were: (1) For given tornado intensity, the number of missiles generated and their transport characteristics are most sensitive to the translational speed (U_T) of the storm. Low values of U_T result in more missile injections and higher missile velocities for specified U_{max}. (2) For given tornado intensity, an increase in the radial inflow component relative to the tangential component increases the number of missiles injected and leads to higher average values of maximum velocities, ranges, and altitudes. (3) Missiles injected and transported by large-core tornadoes generally attain higher maximum velocities but lower peak altitudes than those predicted with smaller ρ_m. The absolute numbers of missiles produced are proportional to the radius of the core. (4) The slope of the core does not have an appreciable effect on missile transport, even for missiles injected at high elevations. (5) Relatively small variations in air density can produce proportional changes in missile range, but the effect of air density (due to entrained dust, etc.) on maximum velocities is heavily dependent on the missile injection height. Hence, from this analysis we have a better understanding of how to characterize the tornado windfield (given the peak windspeed) to maximize missile transport parameters.

A second sensitivity analysis was made to assess the importance of certain unique flow characteristics that exist in several prominent tornado models. To evaluate explicitly the effects of basic differences among windfield definitions, a pairwise comparison study was performed [4,6] with the synthesized model in a series of matched comparisons with other models. From the results of the first phase of the sensitivity analysis, the more important variables in the synthesized windfield were identified as U_T, γ, and ρ_m. In this phase, the pairwise model comparisons were made with the U_T, γ, and ρ_m values in the synthesized model matched to the respective values used in the windfield model selected for comparison. Three models were selected on the basis of their distinguishing features relative to the synthesized model and recentness of development: the Fujita DBT-77 tornado model [11], the Fujita suction vortex DBT-78 [11], and the TRW Phase III model [12].

The results of the comparative missile transport analysis indicate insignificant differences for most of the velocity and range statistics. For the Fujita DBT-77 comparisons, the synthesized model injects more missiles with higher mean values of maximum velocities, whereas the Fujita model predicts slightly higher variances and extreme values. The comparison data exhibit differences that are much less than those obtained from variations in U_T and γ for the synthesized model alone.

For the suction vortex model, a number of simulations were made with single and multiple suction vortices with both the pipe and auto missiles. The results indicate that the missile generation and impact positions are influenced by embedded vortices. However, for the same reference windspeed intensity, a tornado with no suction vortices yields higher missile transport characteristics when compared to a system in which the same maximum winds occur in the fast-moving embedded vortices. Thus, for conservative

predictions of missile transport, there is no need to model suction vortices for missile trajectory analysis.

For the TRW model, more injections result for the pipe missile, but the synthesized model predicts higher velocity and range statistics. In general, the data suggest that the transport differences in the models, with the same U_{max}, ρ_m, and γ, are limited primarily to low injection heights. The TRW model generally dominates at z = 10 ft, and the synthesized model at 33 ft with similar transport statistics over the combined elevations.

On the basis of these sensitivity studies and the resulting updating of the U_T, γ, and ρ_m parameters in Ref. 4, the synthesized wind model provides a tested windfield model for utility pole transport calculations.

b. Trajectory Model

Trajectory models that have been used in tornado missile trajectory analyses include: (1) the ballistic 3-D model, which assumes a constant drag force and neglects lift and side forces; (2) the random orientation, 6-D (RO6-D) model, in which aerodynamic drag, lift, and side forces are dependent on missile orientation, which is periodically updated; and (3) the conventional 6-D model, which tracks missile translation and rotation using a system of 6 coupled differential equations. Detailed discussion and comparisons of these models are presented in Ref. 4. Trajectory comparisons of these models have been made using utility pole missiles [2], 12-in pipe and automobile missiles [4]. On the basis of these comparisons, the ballistic 3-D model has been shown to underpredict velocity, lift, and range characteristics. The RO6-D model provides predictions that tend to bound those of the 6-D model and it is considerably more computationally efficient.

c. Missile Aerodynamics

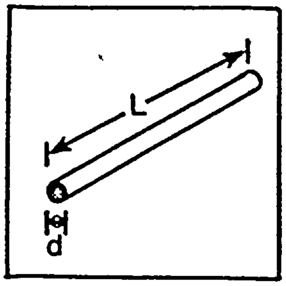
A model of the aerodynamic coefficients for a general class of missiles was developed in Ref. 2 and later updated [4] to reflect new aerodynamic data based on full and subscale tests [12,13]. A modified cross flow technique has been developed to predict drag, lift, and side force coefficients as a function of angle of attack and roll angle, given the drag force coefficients for the object in flow normal to the major body axes. Table 1 summarizes the model for cylindral missiles such as the utility pole. A plot of the model predicted vs. utility pole wind tunnel data [13] for 3 different R_e numbers is shown in Figure 1. These results indicate close agreement between the aerodynamic model and measured coefficients.

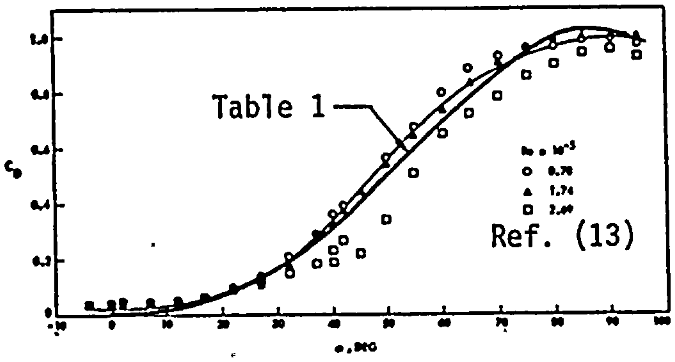
d. Injection Model

As the tornado windfield passes over an object, the dynamic pressure induces aerodynamic forces that are dependent on the missile shape, orientation, surface roughness, and proximity to other objects and surfaces. If these aerodynamic forces are greater than the restraining forces, such as gravity, sliding friction, and foundation embedment, the object will be displaced by the windfield. In general, these aerodynamic forces will not act through the center of mass of the body and the missile tumbles and interacts with the ground and other objects during this injection phase. Hence, detailed modeling of injection requires information on restraining force time histories and interaction models to simulate missile collisions.

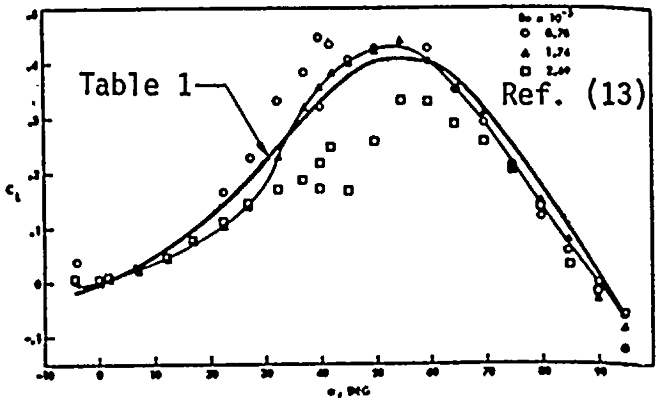
In view of the complexities of missile injection, tornado missile trajectory analyses generally treat injection parametrically through the specification of the initial conditions of the missile at the instant it is released to the tornado. Once released, the missile is assumed to be acted on

TABLE 1. AERODYNAMIC COEFFICIENTS FOR CYLINDRICAL MISSILES

Geometrical shape	Right circular cylinder 
Missile type	Rods, pipes, poles
Missile set numbers [2]	1, 2, 3, 4
Axial drag coefficient, C_{Da}	1.16 Solid (rods, poles) 0.812 Hollow (pipes)
Skin friction correction, f	1, $L/d < 1$ $0.724 + 0.276\,e^{-2(L/d-1)}$, $1<L/d<4$ $0.681 + 0.0108\,L/d$, $L/d>4$
Cross-flow coefficient, C_{Dc}	1.25, (subcritical) $0.85\,[1.9 - \frac{1.8}{\pi}\alpha]$, (supercritical)
Aspect-ratio correction, k	$1 - 8\,(d/L)$, $d/L<0.02$ $0.58 + 0.42e^{-[0.51 + 5.6\,(d/L - 0.02)]}$, $d/L>0.02$
Drag coefficient, C_D	$\frac{\pi}{4}\frac{d}{L} C_{Da}\, f\, \lvert\cos^3\alpha\rvert + C_{Dc}\, k \sin^3\alpha$
Lift coefficient, C_L	$-\frac{\pi}{4}\frac{d}{L} C_{Da}\, f \cos\alpha\, \lvert\cos\alpha\rvert \sin\alpha +$ $C_{Dc}\, k \cos\alpha \sin^2\alpha$
Side coefficient, C_S	0
Ref. area, A	Ld



(a) Drag Coefficient



(b) Lift Coefficient

Figure 1. Aerodynamic Coefficients for Utility Pole Missile

only by gravity and aerodynamic forces. A missile injection methodology was developed in Ref. [2] and subsequently refined [4] to conservatively account for the complexities and uncertainties in a parametric injection model. The approach involves a two-step procedure: (1) the vertical and horizontal aerodynamic force time histories on the missile are calculated as function of tornado position, and (2) the position of the tornado corresponding to peak aerodynamic forces are then determined. This position defines the time of release of the missile with respect to the moving windfield. Injection studies have shown that this method provides for optimum missile transport and tends to result in missile trajectories that bound those documented in field observations. This optimum release criterion is used herein in the utility pole trajectory analysis.

3. TRAJECTORY SIMULATION RESULTS

Using the models previously described, trajectory calculations have been made for the utility pole missle [1]. The postulated missile is 35 ft long with a diameter of 13.5 inches and weight of 1,122 lbs. The center of mass of the missile is positioned at 20 ft above grade. Peak U_{max} windspeeds of 132, 150, and 188 mph are considered. Given these peak windspeeds, the remaining tornado parameters have been defined from the information in Ref. 4. A median case windfield, corresponding to the means of the distributions on U_T, γ, ρ_m, S, and δ for the respective intensity level has been specified, as noted in Table 2. For example, for a 150 mph tornado, the distribution on tranlational speed is assumed in Ref. 4 to be truncated normal, ranging from 5 to 55 mph with a mean of 35 mph and a standard deviation of 11 mph. Hence, for the median case, U_T is assigned a value of 35 mph. In addition, a more severe set of parameters has been defined using the results of the previously reported

TABLE 2. TORNADO WINDFIELD PARAMETERS

Parameter	Case	Parameter Values For Each Windfield		
		U_m = 132 mph	U_m = 150 mph	U_m = 188 mph
Translational Speed, U_T (mph)	Median	30	35	45
	2σ	5	13	20
Radial Inflow, γ	Median	0.7	0.7	0.7
	2σ	1.1	1.1	1.1
R_{max} (ft)	Median	375	375	500
	2σ	200	200	300
S	Median	0.15	0.15	0.15
	2σ	0	0	0
δ (ft)	Median	450	450	450
	2σ	500	500	500

sensitivity analysis [4,6]. This set is denoted as the 2σ case in Table 2 since each parameter has been set at its $\mu + 2\sigma$ (or $\mu - 2\sigma$ depending on the sign that maximizes missile transport). Thus, since low U_T, high γ, are low ρ_m maximize missile transport (given U_{max}), these parameters are set respectively at $\mu - 2\sigma$, $\mu + 2\sigma$, and $\mu - 2\sigma$, respectively. This 2σ case was included to study the influence of variations in the three dimensional windfield on the trajectory of the utility pole missile. They correspond to about the 95th percentile of each respective distribution.

The tornado is positioned(see Fig. 2) relative to the missile at that offset position that corresponds to the peak winds within the tornado. As noted in Refs. [3,4], this offset position is given by $\rho_m \cos(\tan^{-1}\gamma)$. The missile is released to the moving tornado at peak aerodynamic force and the equations of motion are numerically integrated to track the motion time history of the missile. Drag and lift forces (the radially symmetric utility pole has no side force) are calculated using the cross-flow equations in Table 1. The missile is tracked until the center of mass of the pole reaches ground elevation ($z = 0$). The horizontal distance traveled until the center of mass of the pole falls from $z = 20$ ft to $z = 0$ is defined as the range of the trajectory.

Table 3 summarizes the results of these transport simulations for both the median and 2σ windfields. For the 132 mph tornado, the utility pole does not lift for any of the orientations considered. The peak aerodynamic force at injection is about 1,800 lbs and is directed horizontally for the vertical and horizontal pole orientations. When the pole is pitched into wind (orientations 3 and 4), the peak vertical injection force is about 700 lbs. Hence, the pole drops as soon as it is released. For the 132 mph tornado, we estimate a peak range of about 34 ft and a peak velocity of 37 mph.

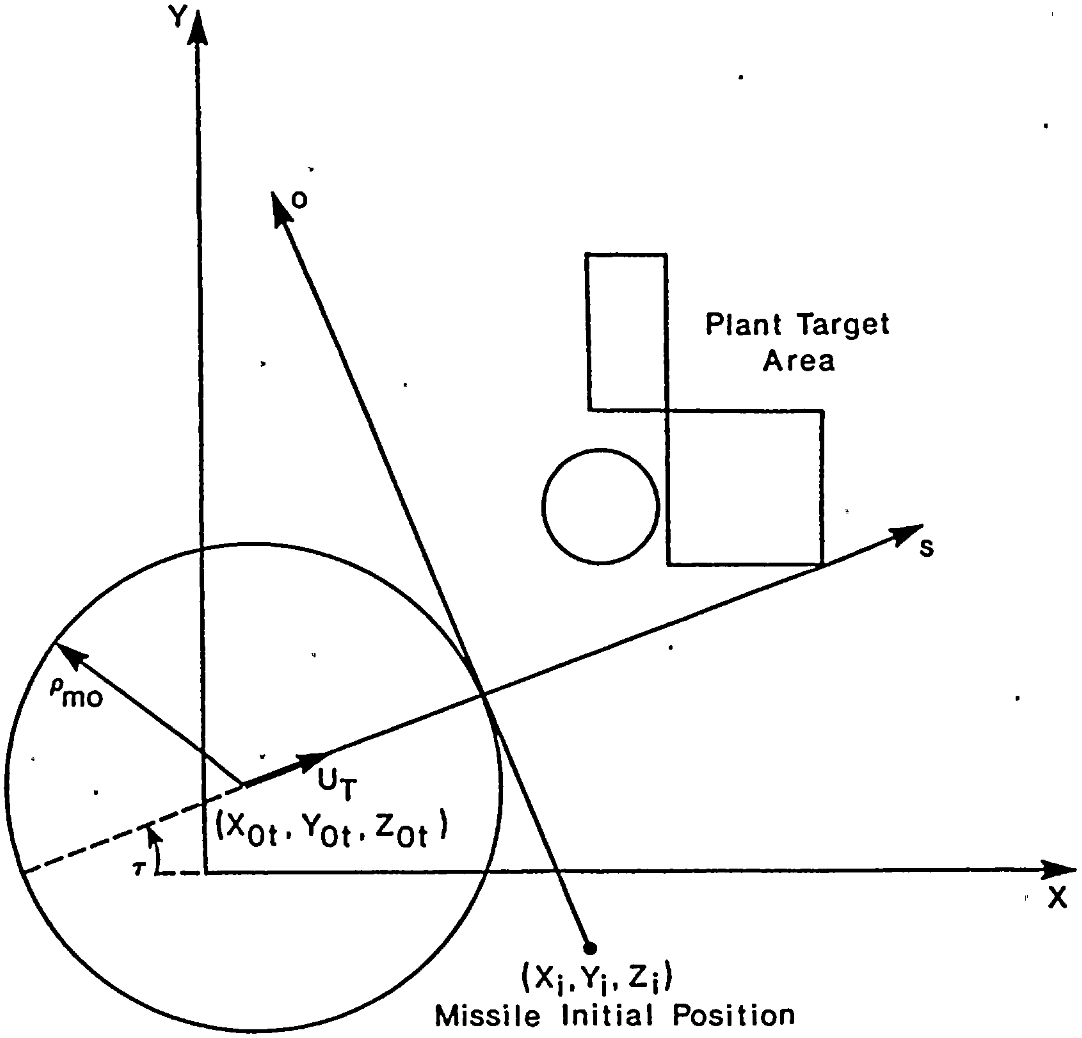


Figure 2. Track Length and Offset Coordinate System for Missile Injection Model

TABLE 3. TRANSPORT CHARACTERISTICS OF UTILITY POLE MISSILE

Simulation Parameters		Transport Characteristics By Peak Windspeed (mph)								
	Missile Orientation	Maximum Height[1] (ft)			Maximum Range[2] (ft)			Maximum Velocity[3] (mph)		
Case Description	$(\hat{x},\hat{y},\hat{z})$	$U_m = 132$	$U_m = 150$	$U_m = 188$	$U_m = 132$	$U_m = 150$	$U_m = 188$	$U_m = 132$	$U_m = 150$	$U_m = 188$
Median Windfield: (U_T, γ, ρ_m, δ_0, S at mid value)	Vertical (0,0,1)	20	20	20	27	35	49	24	40	50
	Horizontal (0,1,0)	20	20	20	26	34	54	33	40	53
	45° X(-0.71,0,0.71)	20	20	20.1	23	29	111	30	32	64
	45° XY(-0.5,-0.5,0.71)	20	20	20	27	41	88	30	36	57
Median + 2σ Windfield: (U_T, γ, ρ, δ_0, s at $\mu+2\sigma$)	Vertical (0,0,1)	20	20	20	27	36	54	35	43	55
	Horizontal (0,1,0)	20	20	20	31	41	57	35	38	57
	45° X(-0.71,0,0.71)	20	20	22	27	34	154	37	35	76
	45° XY(-0.5,-0.5,0.71)	20	20	21	34	58	94	36	45	58

[1] Height above grade; missile injected at 20 ft.
[2] Range in X-Y plane until ground impact.
[3] Usually occurs at ground impact.

The results for the 150 mph tornado are similar to those for the 132 mph tornado in that the aerodynamic forces are not sufficient to lift the pole. The peak aerodynamic force at injection is about 2,200 lbs, of which about 900 lbs act vertically for the favorable orientations. Since the pole weighs 1,122 lbs, it accelerates downward upon release. Maximum predicted range and speed are 41 ft and 45 mph, respectively.

For the 188 mph tornado, the windspeeds produce vertical aerodynamic forces that exceed the weight of the missile (for orientations 3 and 4), which produces lift at injection. The maximum lift is about 2 ft (from 20 to 22 ft above grade), a modest amount that is consistent with the peak vertical aerodynamic force of about 1,400 lbs. This lift results in a much longer range (up to 154 ft), and impact velocity (76 mph) since the object is sustained in the winds about twice as long as before (2 sec vs 1 sec).

A few additional simulations were made with the pole positioned at zero offset for the cases given in Table 3. The results show reduced transport characteristics when compared to the values in Table 3. It is noted that other offsets might result in transport that could approach or slightly exceed those in Table 3. However, previous studies with rather dense injection grids have shown that the offset $\rho_m \cos(\tan^{-1}\gamma)$ generally provides accurate estimates of peak transport parameters.

4. COMPARISONS TO OTHER WORK AND FIELD OBSERVATIONS

The previous results indicate very little lift and transport less than 200 ft for utility pole type missiles injected in tornadoes with peak windspeeds up to 188 mph. These predictions can be compared to other calculations and field observations. The available comparisons generally correspond to higher windspeeds, but will nevertheless provide some basis for judging these results.

a. 6-D Trajectory Model Predictions

Redmann et al. [13] simulated the trajectories of utility pole missiles in 255 mph tornadoes. With the utility pole at 20 ft elevation pitched into the wind at a 45 degree angle, the missile lifted to a maximum height of 40 ft during a 339 ft flight and impacted the ground at 113 mph. For an initial angular velocity of 10 rpm, which is a more realistic injection condition, the pole lifted only 4 ft to an elevation of 24 ft and landed at 91 mph with a 140 ft range.

These results tend to support the trend established in Table 3. At 188 mph, we noted that the vertical aerodynamic forces were beginning to exceed missile weight and some lift was noted. At 255 mph, one would expect the missile to lift substantially higher since the aerodynamic forces would be about $(255/188)^2 = 1.8$ times greater. As a further test of the R06-D model used in the development of Table 3, 10 simulations were made using a 255 mph tornado with initial orientation 3, similar to that reported in Ref. 13. The R06-D model predicts an average maximum height of 43 feet with ranges up to about 500 ft and impact speeds up to 133 mph. These results tend to bound the 6-D model predictions, and are similar to previous comparisons of the 6-D and R06-D models [2,4].

b. 3-D Ballistic Model

Simiu and Cordes [14] used the simplified ballistic 3-D model for calculation of maximum horizontal missile speeds. For the 35 ft utility pole, they predict peak horizontal speed of 60 mph in a 240 mph tornado when the utility pole is injected at 131 ft elevation. These results are clearly

unconservative when compared to the 6-D and R06-D model predictions (for z_0 = 20 ft) presented previously and raise questions regarding the adequacy of the 3-D ballistic model for slender body shapes.

c. Utility Pole Transport: Xenia, Ohio Tornado

McDonald [15] and Mehta et al. [16] report the transport of a utility pole in the Xenia, Ohio, tornado of April 3, 1974. The pole failed 2 ft above the ground and was transported a total distance of 160 ft by F5 tornado winds estimated at about 250 mph. The pole was 10 in. in diameter and 25.5 ft in length. Mehta et al. [16] note that the other utility poles that had failed at this location in the tornado path were found within 10 to 15 ft of their original positions.

The R06-D trajectory model and peak aerodynamic force injection model has been tested against these field observations [4]. To similate the F5 tornado windspeeds, a 250 mph tornado with ρ_m = 500 ft, γ = 0.7, and U_T = 40 mph was used as the input to the transport model. The 250-mph intensity at 33 ft is based upon Twisdale's [2,8] estimated midrange of F'5 storms. The utility pole was positioned at z_0 = 15 ft to correspond to the initial height of the center of mass above the ground plane. Simulations with an initial vertical orientation of the pole result in maximum predicted transport ranges less than 53 ft. Using favorable orientations to account for initial repositioning after the pole fails, maximum transport ranges of 283, 651, and 161 ft are predicted for missile offsets on the right side of the tornado center. A maximum impact velocity of about 140 mph is predicted. For a 200-mph tornado with ρ_{mo} = 300 ft, the predicted ranges are 62, 121, and 91 ft for offsets of 100, 150, and 200 ft, and the maximum impact velocity is 63 mph. The results suggest that, with a favorable initial missile orientation, windspeeds in the

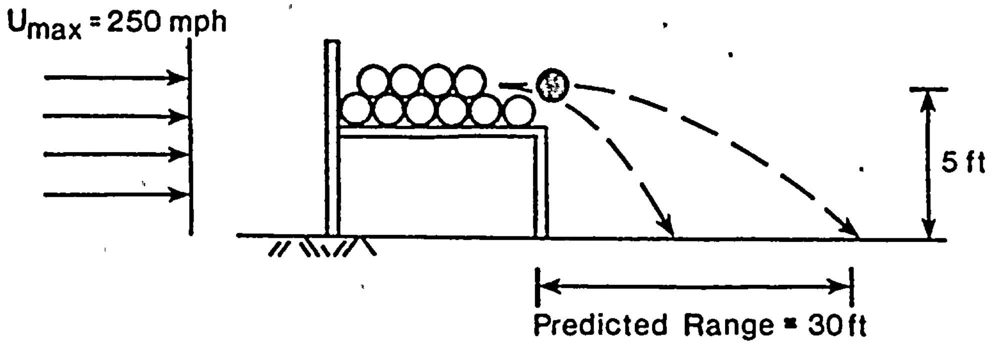
200 to 250 mph interval could have produced the observed 160-ft transport range. The fact that many of the failed poles were not significantly displaced confirms the predictions of the R06-D trajectory analysis with unfavorable initial orientations and tends to support the use of the R06-D transport model.

d. Stored Utility Poles: Brandenburg, Kentucky

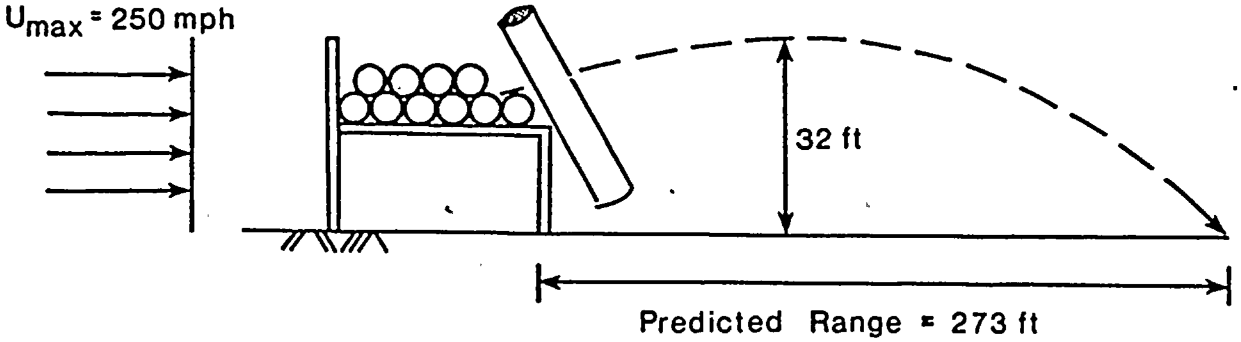
The Brandenburg tornado of April 3, 1974, with a rated intensity of F5 passed directly through the storage yard of the Rural Electric Cooperative. McDonald [15] and Mehta et al. [16] present photographs that document the effects of the storm on various objects in its path. Of particular interest is a number of 8-in.-diameter by 20-ft-long utility poles that were stored horizontally on a rack about 5 ft above the ground elevation. The poles were displaced from the rack, but none were transported significantly.

The effects of an F'5 tornado on these objects has been simulated [4] with the use of both the initial horizontal storage conditions of the missiles and a favorable initial orientation. A 250-mph tornado was assumed in both cases. For the horizontal injection mode, the model predicts that the poles may experience total forces that approach 1,400 lb, but only a small fraction of this is directed vertically. Hence, the predicted trajectories are parabolic, and the poles drop to the ground within 30 ft of the rack, as indicated in Figure 3. This transport compares closely to the post-tornado observations of the majority of the poles.

Favorable initial missile orientations were also simulated that could have resulted for several missiles in the stack as they interacted during their initial response to the tornadic winds. Transport ranges between 50 and 273 ft resulted for these simulations, depending upon the exact orientation



(a) Horizontal Initial Orientation



(b) Favorable Random Initial Orientation

Figure 3. Predicted Ranges for Brandenburg Utility Poles

and the offset from the tornado center. The maximum height and range predicted are 32 feet and 273 ft, respectively, as noted in Figure 2. The peak velocity attained by the pole was 95 mph.

It is noted that simulations with U_{max} = 200 mph predict ranges of 13 ft and 100 ft, respectively, for the horizontal and random initial orientations. The Brandenburg poles are significant in the sense that the objects responded to the windfield, but few, if any, aligned favorably to be lifted by the winds and hence to be transported the distance that was predicted for favorable initial orientation.

5. CONCLUSIONS

On the basis of this brief study, the following conclusions are made:

1. Tornadoes with peak windspeeds of 132 and 150 mph generate aerodynamic lift forces that are less than the weight of the postulated utility pole missile. Estimates of the peak range for an injection height (height above grade of pole center of mass) of 20 ft are 27 ft and 41 ft, respectively, for the 132 and 150 mph windfields. Range is defined as the horizontal distance traveled as the pole center of mass falls from z = 20 ft to z = 0. Maximum velocities are estimates at about 37 and 45 mph, respectively, for the 132 and 150 mph tornadoes.

2. Tornadoes with peak windspeeds of 188 mph can produce about a 2 ft lift (from 20 ft initial elevation), a range up to 154 ft, and a peak velocity of about 76 mph for the utility pole missile. These conditions occur when the pole is pitched into the wind at about a 45 degree angle and released at peak aerodynamic force. These are idealized and very conservative release conditions that would be difficult to duplicate in an actual tornado strike.

3. Maximum height attained during a tumbling wind-borne transport for $U_{max} \leq$ 188 mph by any part of a 35 ft utility pole would probably not exceed 35 to 40 ft. Other injection modes, such as a ramp-type injection could produce upward ricochet of a horizontally-translating pole. However, this injection mode would require "ideal" missile origin position, terrain, and target configuration in order to pose a realistic threat to elevated targets.

These results are conservative in the missile injection release criterion, definition of range and peak velocity, positioning of the missile relative to the windfield, and the windfield flow characteristics. For example, the tip of the pole will strike the ground as the pole begins to drop and this interaction will reduce the horizontal momentum. Hence, the estimates of peak range and horizontal velocity are very conservative. In addition, the weight of the pole is less than the 1,490 lbs used in some tornado missile calculations [e.g., 17]. Using the 1,490 lb weight, the maximum 154 ft range in the $\mu + 2\sigma$ 188 mph tornado (see Table 3) reduces to less than 100 ft.

In general, field observations do not confirm significant utility pole transport for the windspeeds considered herein. Our best estimate of typical utility pole response for $U_{max} \leq 188$ mph would be a trajectory range from 0 to 50 ft with horizontal missile speeds approaching 50-60 mph.

REFERENCES

1. U.S. Nuclear Regulatory Commission, Standard Review Plan, "Missiles Generated by Natural Phenomena," Section 3.5.1.4, Washington, D.C., November 1975.

2. Twisdale, L. A., et al., "Tornado Missile Risk Analysis," Electric Power Research Institute, Palo Alto, California, NP-768 and NP-769, May 1978.

3. Twisdale, L. A., Dunn. W. L., and Davis, T. L., "Tornado Missile Transport Analysis," Nuclear Engineering and Design, 52, 1979, pp. 296-308.

4. Twisdale, L. A., and Dunn, W. L., "Tornado Missile Simulation on Design Methodology," EPRI NP-2005, Electric Power Research Institute, Palo Alto, California, August 1981.

5. Dunn, W. L., and Twisdale, L. A., "A Synthesized Windfield Model for Tornado Missile Transport," Nuclear Engineering and Design, 52, 1979, pp 134-144.

6. Twisdale, L. A., "An Assessment of Tornado Windfield Characteristics for Missile Loading Prediction," Proceedings, Fourth U.S. National Conference on Wind Engineering Research, University of Washington, Seattle, Washington, July 1981.

7. Twisdale, L. A., "A Risk-Based Design Against Tornado Missiles," Proceedings of the Third ASCE Specialty Conference on Structural Design of Nuclear Plant Facilities, Boston, Massachusetts, April 1979.

8. Twisdale, L. A., "Tornado Data Characterization and Windspeed Risk," Journal of the Structural Division, Proceedings ASCE, Vol. 104, No. ST10, October 1978.

9. Twisdale, L. A., "Regional Tornado Data Base and Error Analysis," Preprints, AMS 12th Conference on Severe Local Storms, San Antonio, Texas, January 1982.

10. Twisdale, L. A., and Dunn, W. L., "Probabilistic Analysis of Tornado Wind Risks," Journal of Structural Engineering, Vol. 109, No. 2, February 1983.

11. Fujita, T. T., "Workbook of Tornadoes and High Winds," SMRP 165, University of Chicago, Chicago, Illinois, September 1978.

12. Redmann, G. H., et al., "Wind Field and Trajectory Models for Tornado-Propelled Objects," Electric Power Research Institute, Palo Alto, California, Draft, 1980.

13. Redmann, G. H., et al., "Wind Field and Trajectory Models for Tornado-Propelled Objects," EPRI NP-748, Electric Power Research Institute, Palo Alto, California, May 1978.

14. Simiu, E., and Cordes, M., "Tornado Borne Missile Speeds," NBSIR-76-10-50, National Bureau of Standards, Washington, D.C., April 1976.

15. McDonald, J. R., "Tornado-Generated Missiles and Their Effects," Proceedings of the Symposium on Tornadoes, Texas, Tech University, Lubbock, Texas, June 1976.

16. Mehta, K. C., et al., "Engineering Aspects of the Tornadoes of April 3-4, 1974," Committee on National Disasters, National Academy of sciences, 1976.

17. "Safety Related Site Parameters for Nuclear Power Plants," WASH-1361, U.S. Atomic Energy Commission, Directorate of Licensing, Office of Safety, Washington, D.C., January 1975.