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GREAT BEND TORNADOES OF AUGUST 30, 1974

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with

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1. INTRODUCTION

Late in the afternoon of August 30, 1974, six tornadoes touched down in open fields north through southwest of Great Bend, Kansas. The touchdown locations moved progressively from northeast to southwest taking one hour and 30 minutes. Nonetheless, these tornadoes were not family tornadoes, because the NWS radar at Garden City revealed that they were spawned by different thunderstorm cells which moved toward the easterly direction.

In view of the evidence that they were not spawned as family tornadoes, we may call them "the Great Bend tornado series" (see Fig. 1).

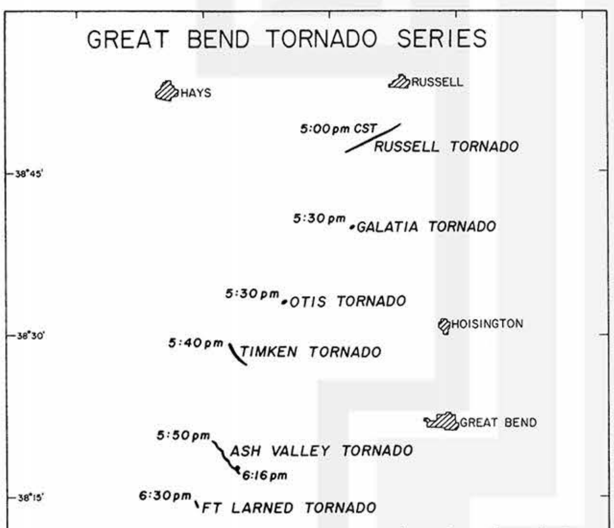

Fig. 1. Six tornadoes on August 30, 1974 in the vicinity of Great Bend, Kansas. This series of tornado outbreak is identified as the "Great Bend Tornado Series".

These tornadoes, except the Russell tornado, were filmed by Robert Dundas, a newsman from Great Bend, Kansas who literally chased them successively. The most spectacular storm filmed by him was the Ash Valley tornado which left behind a 5.8-mile long swath near the Ash Valley community, 25 miles west of Great Bend. This tornado was studied by Golden and Purcell (1977), who referred to it as the Great Bend tornado.

To obtain meteorological parameters of design-basis tornado for Nuclear Regulatory Commission, the authors visited the photographic sites of the Dundas and Haas movies, as well as those of still pictures taken by others.

Presented in this paper are the results of photogrammetric analyses of these movies and pictures. During the course of this research, however, the authors recognized that the data collected contain much more scientific information than those presented in this paper. Further research is being conducted in order to publish a comprehensive result at a later date.

2. RADAR AND SMS PICTURES

During the period of the Great Bend tornadoes, there was a line of echoes extending from south of Garden City to the northwest corner of Missouri (see Fig. 2). The surface map at 6:00 pm CST showed a distinct wind-shift along these echoes.

An SMS picture taken at 6:00 pm CST depicted two giant anvil clouds, each about 300-km long and 100-km wide. Beneath these interconnected anvils, there were over 20 cellular echoes. The most pronounced cells of these were located in central Kansas, forming a large echo complex (see Fig. 3).

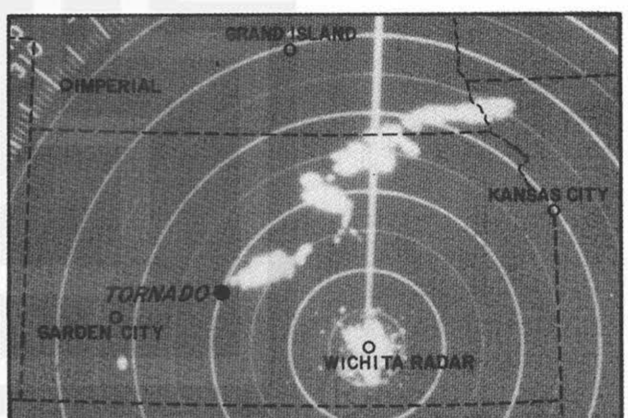

Fig. 2. A line of echoes at 6:00 pm CST, August 30, 1974. Individual cells were moving in easterly directions. The Great Bend tornadoes occurred near the southwest edge of a large echo complex in central Kansas.

Apparently, a series of tornadoes formed on the southwest edge of this echo complex, where new echoes kept forming one after another. The SMS picture shows a line of cumuliform clouds extending from the western edge of the anvil toward the south of Garden City. A significant wind shift on both sides of this line was evidenced by the Garden City and Dodge City winds.

A combined analysis of SMS and Wichita radar pictures revealed that a series of tornadoes formed on a wind-shift line beneath a newly developing echo. It is extremely likely that the source vorticity was provided by the wind-shift line and a stretching was performed by an updraft beneath the new cell.

Tornado-echo relationships were determined accurately based on the Garden City radar located 75 n. miles west-southwest of Ash Valley (see Fig. 4).

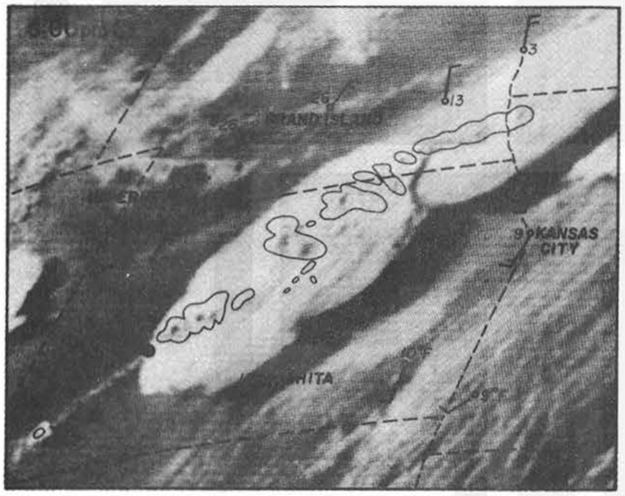

Fig. 3. Two giant anvil clouds in a SMS picture at 6:00 pm CST, August 30, 1974. Winds, Wichita radar echoes, and dew-point depressions were superimposed upon the picture.

At 5:45 pm CST, the Timken tornado was dissipating beneath a cell at 80 n. mile range from radar. It was a strong echo moving toward the ESE at 14 kts. A new echo on the 75 n. mile marker was moving ESE at 22 kts. It was beneath this echo where a new tornado had developed.

A few minutes later at 6:00 pm, the tornado touched down 2.5 miles to the northwest of Ash Valley. It then moved toward the SSE at 15 kts. Due to the difference in velocities of the tornado and its parent echo, the echo moved away from the tornado. At 5:55 pm the echo was 4 miles to the east of the tornado.

The tornado was swirling over the dry ground while light rain was encountered by Dundas as he was driving about 3 miles east of the tornado.

At 6:00 pm, the weak echo, moving eastward at 19 kts, merged with a major echo. The tornado kept moving SSE in an echo-free area while growing into a giant column of swirling dust picked up from the dry fields southeast of Ash Valley.

At 6:05 pm, a small echo formed just to the north of the tornado. It was at this time when Seeman photographed the disintegrating dust cloud and mini-funnel hanging from the low cloud base.

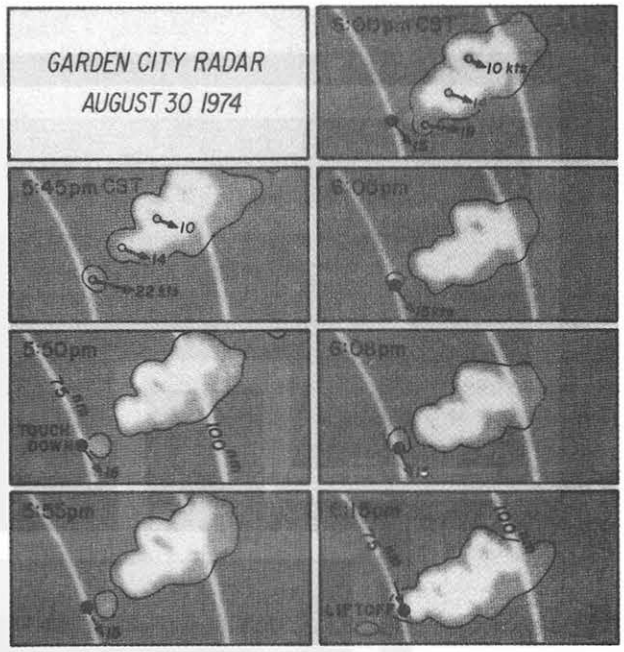

Fig. 4. Location and movement of the Ash Valley tornado in relation to an echo complex in central Kansas. 5:45 - 6:15 pm CST, August 30, 1974.

From 6:08 to 6:15 pm, the area of the tornado was in heavy rain accompanied by a cold downdraft from the northeast. The mini-funnel rapidly descended to the ground while the tornado continued to weaken. The funnel lifted off at approximately 6:15 pm.

3. LIFECYCLE OF ASH VALLEY TORNADO

A detailed triangulation of tornado positions was performed by computing the azimuths of the center viewed from 21 photographic locations (see Fig. 5).

The result revealed that the tornado first moved rather smoothly toward the southeast. After traveling about 1.5 miles, the direction of motion changed toward the south, then southeast, showing a wavy pattern, ending at 3 path miles. Then from 3 to 4 path miles the wavy pattern was repeated again.

Finally, the tornado made a complete loop before dissipating while moving toward the SSE. The looping path was evidenced by the following eyewitnesses:

Rabenseifner .... Saw the tornado coming straight toward him from the NW; rushed into the shelter and stayed inside for a few minutes until it calmed down; saw a vapor funnel to the north.

Dundas .... While filming from location 3r, noticed the tornado coming toward him (north); jumped into the car to back up all the way to Ash Valley.

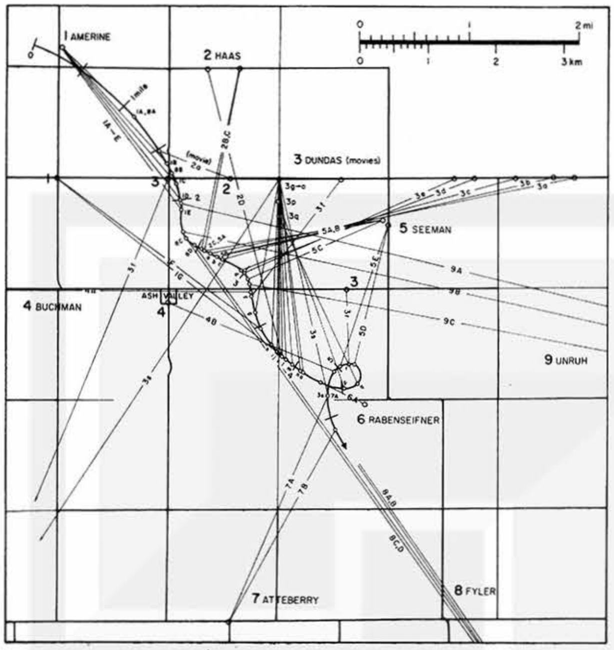

Fig. 5. Triangulated positions of the Ash Valley tornado. Forty-five azimuths of tornadoes viewed from 21 photographic locations were used in triangulating the path.

Seeman .... From location 5, photographed tornado moving left to right (east to west).

The tornado was characterized by a waterspout-like funnel cloud during its final 0.8-mile path. The final stage of the funnel was photographed by Atteberry, looking towards NNE.

CORE RADIUS, R_0

In the past, when engineers were using the Dallas tornado of 1957 as being the model tornado, core diameter was assumed to be rather small. Recent studies of violent tornadoes suggested, however, that the core diameter of 150 m is more realistic than 150 ft as far as the design-basis tornado is concerned.

The Ash Valley tornado, which was by no means the largest storm, was characterized by an up to 185m core radius (see Fig. 6).

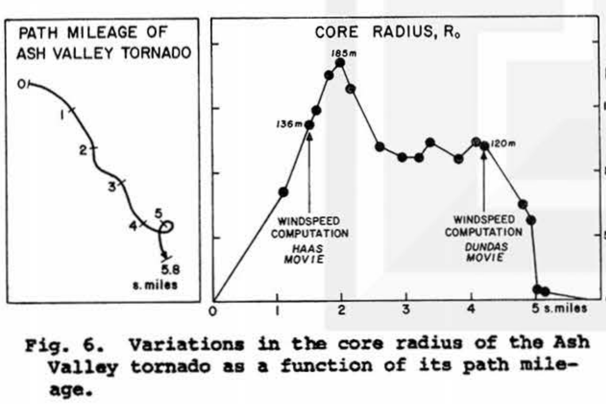

Fig. 6. Variations in the core radius of the Ash Valley tornado as a function of its path mileage.

From touchdown to about 2 path miles, the core radius increased to 185m at the rate of 30 meters per minute. Upon reaching the peak radius, it shrunk to about 120m. The stablized radius was maintained for sometime until the dust column began disintegrating at 4 path miles.

Thereafter, a vapor funnel descended from the cloud base along the center line of a faint, swirling dust cloud.

LIFE CYCLE

The initial disturbance of the Ash Valley tornado was a swirl of dust just to the west of the Amerine farm. When Mrs. Amerine came out of the house with her camera, the dust swirl was located about one mile to the southeast. It extended upward to a small funnel cloud at 1600 m (see Figs. 7 and 8).

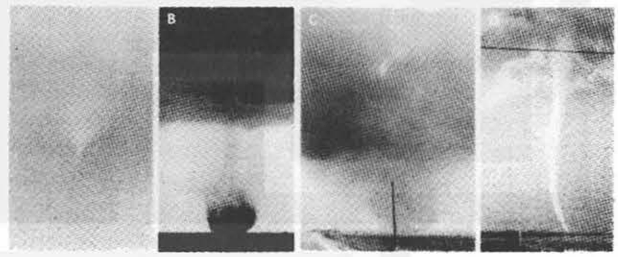

Fig. 7. Photographic views by (A) Amerine 1A, (B) Fyler 8B, (C) Seeman 5D, and (D) Buckman 4B. Note that (C) was taken in rain.

The Fyler picture shows a large, dark dust swirl on the ground. A faint core extended upward but there was no funnel cloud at the cloud base.

The most gigantic dust column with its peak radius was photographed by Mrs. Amerine when it was at 2.0 path miles. One would expect that such a tornado is accompanied by a large funnel cloud hidden inside the dust column. Against expectation, there was a tiny funnel cloud at 1.8 km level, associated with a swirling feature of the cloud base.

Until Dundas filmed the tornado at 4.1 path miles, it was characterized by a huge dust column on the dry ground. Within a few minutes, a cold outflow from a thunderstorm to the northeast reached the location of the tornado. The cold air undercut the inflow vorticity, resulting in a rapid decay of the dust column.

Funnel cloud of a tornado forms when moisture condenses due to adiabatic expansion. In this case, however, a vapor funnel descended to the ground when tornado was weakening. A logical explanation for this paradox is that a decrease in the pressure deficit inside the weakening vortex was overshadowed by an increase in humidity of the inflow air.

An identical phenomenon was reported by Fujita (1977a) in his analysis of an anticyclonic tornado in central Iowa. The funnel cloud descended gradually to the ground while the rotational speed decreased from 60 m/sec to 40 m/sec. It remained on the ground until the speed further decreased to 20 m/sec.

Such a transition from "DRY TORNADO" into "WET TORNADO" is important in estimating tornado windspeeds. The funnel cloud could be on the ground inside a wet tornado swirling at 20 m/sec while a 100 m/sec dry tornado may not be characterized by a visible funnel cloud.

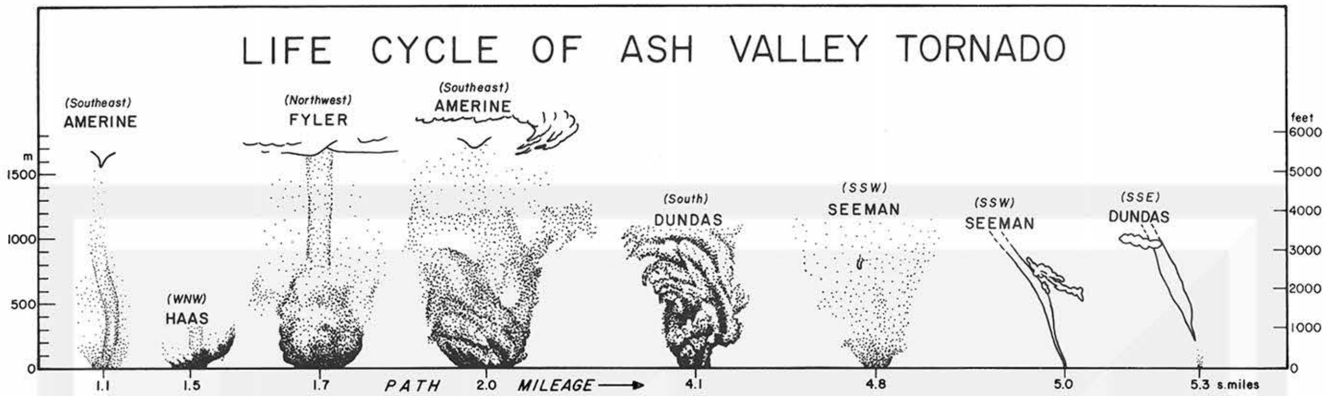

Fig. 8. Variations of the Ash Valley tornado. The funnel cloud was insignificantly small until 4.8 path mileage when tornado was undercut by cold downdraft from northeast. A waterspout-like funnel formed as a result of increased humidity.

4. WINDSPEED COMPUTATIONS

Photogrammetric analyses of tornado movies have added substantially to the estimate of tornado windspeeds. Nevertheless, such an estimate is complicated and difficult by the fact that the maximum windspeeds vary with time and space, thus;

$$V_m = f(R, \theta, H, t)$$

where four parameters on the right side are radial distance, azimuth angle, height above the surface, and time, respectively.

Unfortunately, it is unlikely that maximum windspeeds can be computed as a function of time and space because

(1) Tornado movies do not cover the entire life of a tornado.
(2) A movie shows only the photographic side of a tornado, allowing us to compute the velocity component tangent to the line of sight.
(3) Location of the maximum windspeed is often hidden inside the swirling dust and debris.
(4) Analysts may overlook the fastest motion lasting for a short time in a small area on the image.
(5) Photogrammetric equipment along with analysts' knowledge and experience always result in different answers.

In spite of these handicaps, the Nuclear Regulatory Commission must establish a design-basis tornado for protection of nuclear power plants and facilities. Photogrammetric analyses of new movies, as well as re-analyses of old ones, have been recommended and pursued by NRC in an attempt to obtain the best possible windspeeds.

WINDSPEEDS FROM HAAS MOVIE

Mr. John Haas took his movie looking WNW toward bright background. Because the tornado was in its growing stage one could look through relatively thin dust clouds to determine dust motions on both front and back sides.

Enlarged frames at 1/3-sec intervals are shown in Fig. 9. This sequence shows that dust clouds "a", "b" and "c" rising from ground were moving from left to right, becoming progressively taller as they approached the left edge of the dust column of the tornado.

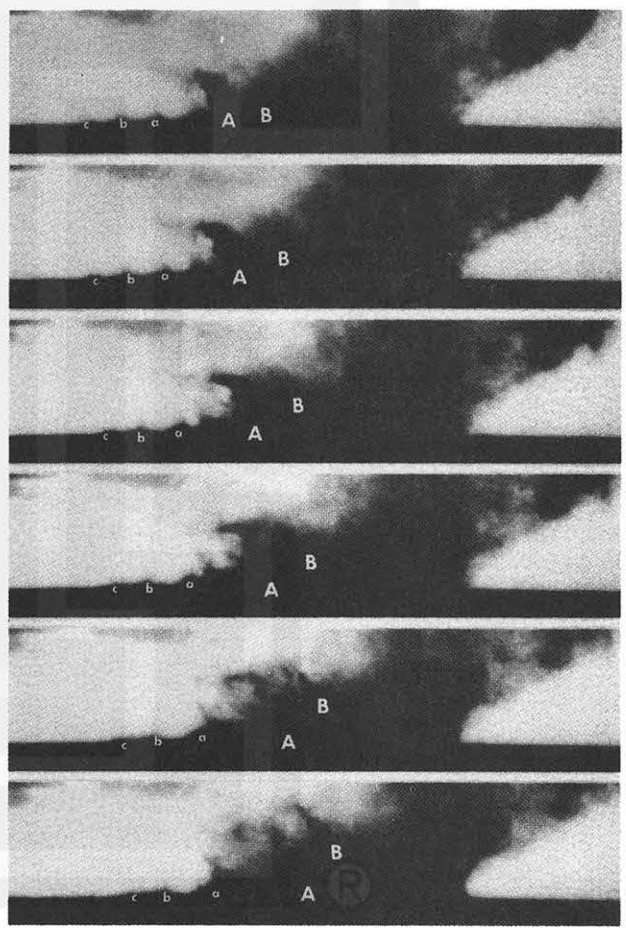

Fig. 9. A dust cloud with suction vortices seen in Haas movie printed at 1/3-sec intervals.

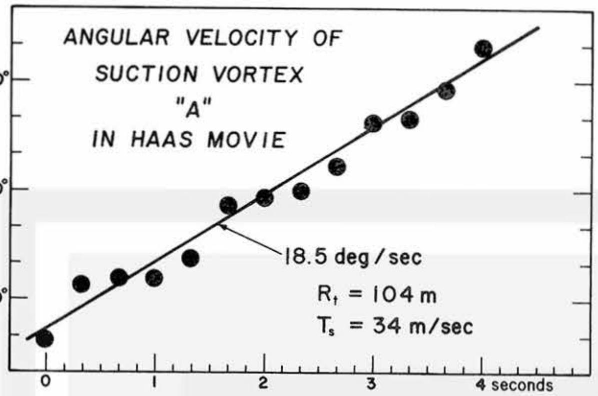

Fig. 10. Angular velocity of suction vortex "A" in Haas movie.

Traveling around the tornado center were several suction vortices as evidenced by tilted dust swirls "A" and "B" in the figure. Suction vortex "A" was traveling at an angular velocity of 18.5 deg/sec or 19.5-sec period of revolution around the tornado center. It was located at R_t = 104m from the center, traveling at a translational speed, T_s = 34 m/sec (see Fig. 10).

A schematic flow field in Fig. 11 reveals that the estimated core diameters of tornado and suction vortex "A" were 132m and 18m, respectively. It was found, in reviewing Haas's movie, that the core diameter of tornado shrunk to as much as 10m when a strong suction vortex passed along the western edge. This evidence strongly suggests that suction vortices form when the inflow air converges locally inside the outer portion of the core region.

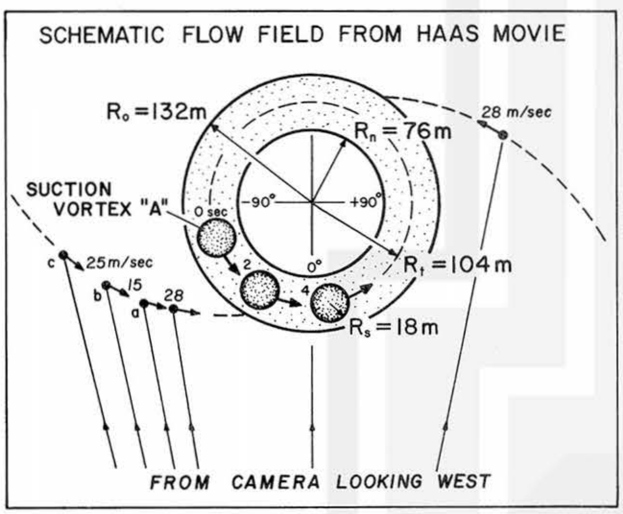

Fig. 11. Suction vortex "A" and dust clouds "a", "b", and "c" within the flow field of the Ash Valley tornado.

In his design-basis tornado model (DBT-77), Fujita (1977b) divided a tornado core into the "outer core" and "inner core". As shown in Fig. 11, the estimated core radii from Haas movie were

Outer core .... R_o = 132m
Inner core .... R_n = 76m

An example of velocity vectors computed from Haas movie is shown in Fig. 12. Results reveal that the maximum tangential velocity on the front side was about 40 m/sec while that on the back side was 50 m/sec. The difference of 10 m/sec is the result of the tornado movement from right to left at about 5 m/sec (see Fig. 12).

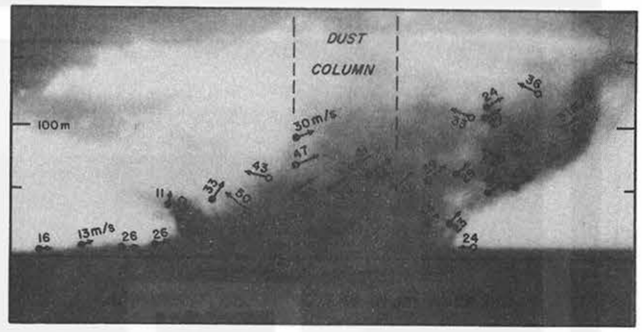

Fig. 12. Apparent motions computed from the Haas movie. Vectors with open circles denote the motion on the back side.

The tornado parameters estimated from Haas movie are

Maximum tangential velocity	V_{max} = 45 m/sec
Maximum vertical velocity	W_{max} = 25 m/sec
Radius of suction vortex	R_s = 18 m
Translational vel. of S. V.	T_s = 34 m/sec
Spinning velocity of S. V.	Unknown

WINDSPEEDS FROM DUNDAS MOVIE

An initial examination of the Dundas movie gave an impression that the tornado was characterized by a huge, single column of swirling dust.

Repeated examinations of the movie revealed, however, that there were dust columns corresponding to three suction vortices -- "A", "B", and "C". "A" was the oldest one, followed by "B" which turned into the shape of "A" only several seconds later. "C" had just formed near the left edge of the huge dust column. Each of these suction vortices was characterized by a fast-rotating dust column topped by a mushroom-shaped configuration (see Fig. 13).

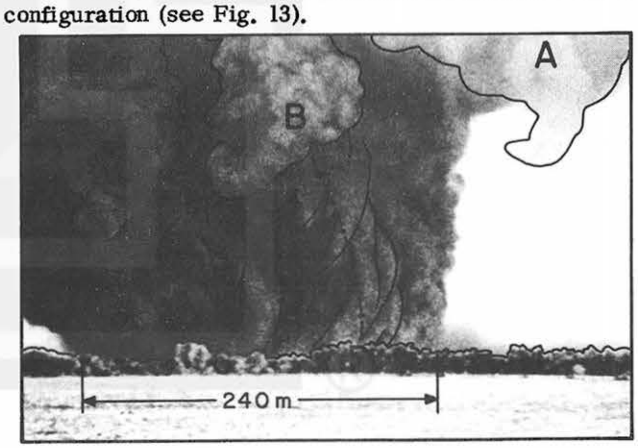

Fig. 13. Three suction vorticies seen in one frame of the Dundas movie. These vorticies formed on the left side and progressively increased in height as they moved from left to right.

Velocity vectors computed from a telephoto scene were superimposed upon the first picture of the computation sequence. Since good, trackable targets were selected for computations, most vectors originate from small brightness centers. It should be noted that variations in speeds are often in excess of 25 %, suggesting that the dust swirl around tornado center is by no means uniform (see Fig. 14).

These variations were highly influenced by suction vortices which were traveling around the tornado center along the radius of about R_t = 100m at the rate of T_s = 32 m/sec.

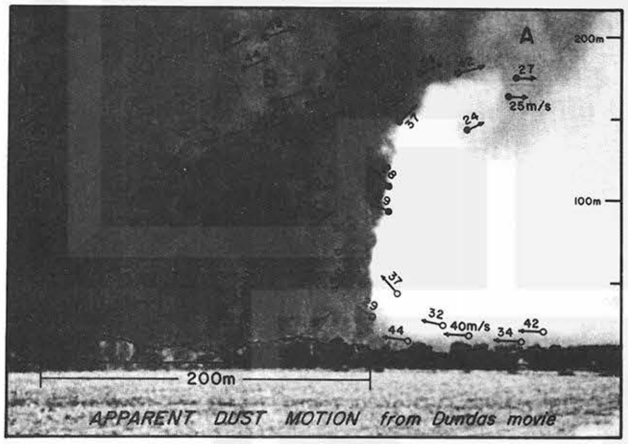

Fig. 14. Velocity vectors superimposed upon a telephoto view of Dundas movie. Vectors with open circles denote inflow motion.

The vertical distribution of tangential velocities is presented in the scatter diagram of Fig. 15. Most of the scatter is attributed to suction vortices which travel around the tornado center. If this tornado were characterized by a more or less axial-symmetric vortex, the scatter could have been much less.

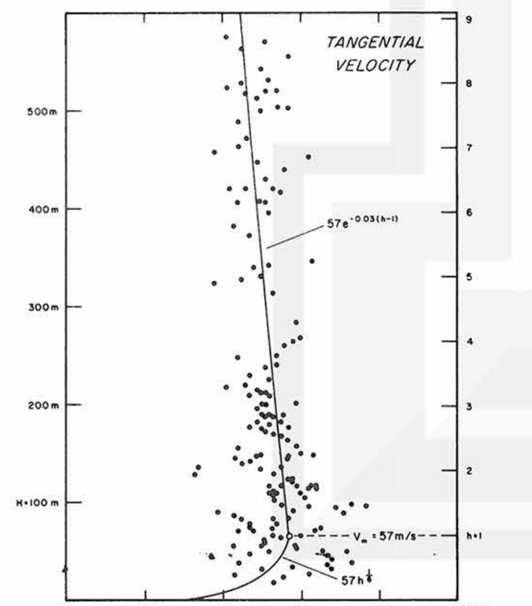

Fig. 15. Vertical distribution of tangential velocities computed from Dundas movie. Two curves joining at the top of inflow layer are those of DBT-77 by Fujita (1977b).

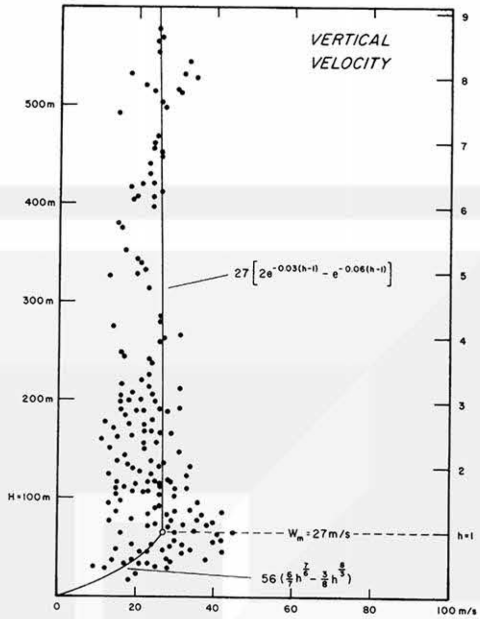

Fig. 16. Vertical distribution of vertical velocities computed from Dundas movie. Two curves are from DBT-77 by Fujita (1977b).

The vertical distribution of the vertical velocities is shown in the scatter diagram of Fig. 16. Again, a large degree of the scatter can be attributed to the influence of suction vortices.

Tornado parameters estimated from the Dundas movie are

Maximum tangential velocity	V_{max} =57 m/sec
Maximum vertical velocity	W_{max} =27 m/sec
Radius of suction vortex	R_s = 20-30 m
Translational velocity of S.V.	T_s = 32 m/sec

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