Sailplane Flights Through Funnel Clouds

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ABSTRACT

This paper reports on three intentional flights through small south Florida funnel clouds in sailplane. Two of the penetrations were through vertical funnels, and one was through a sloping funnel cloud. The latter allowed a more significant immersion time interval within the vortex, and this resulted in much greater effects on the aircraft. With use of the induced variation from normal flight, the instrumentation carried, the physiological observations of the pilot, and the meteorological sounding data, it is possible to deduce some of the characteristics of these funnels.

1. INTRODUCTION

Most tornado and funnel cloud characteristics are arrived at from studies of the damage produced or from indirect observations using remote sensing, as pointed out by Kessler (1970). The remote sensors used have included cameras, weather radars, Doppler radars, sferics sensors, and sonic equipment. Some of these have been used from the ground as well as from satellites and aircraft. However, aircraft that have penetrated such severe storms have either done so inadvertently or have done so at such high speeds that only the general characteristics of the surrounding cloud and atmosphere could be inferred (e.f., Bates, 1969).

Obviously, a very slow moving aircraft such as a sailplane would be a more suitable observation platform. Sailplanes have regularly used thermals, and Texas and California "dust devils" (Mooney, 1958) to provide lift and gain altitude, gusty postfrontal orographic winds in hilly or mountainous terrain for world record distance attempts, and mountain waves with their severely turbulent rotor zones for world record altitudes. Their ability to fly slowly, withstand high stresses from turbulence, and to recover quickly from upsetting flight conditions makes them good research tools. Their chief disadvantages are: 1.) their general inability to travel great distances rapidly enough to reconnoiter a weather disturbance, and 2.) their dependence on areas of lift (absence of "sink") to remain in a given area and to get *in situ* measurements at a given place and time. Occasionally, circumstances may be fortuitous enough to put an experienced observer in a position to make unique observations of interest to other scientists.

The purpose of this paper is to report on three intentional flights through small south Florida funnel clouds in a sailplane. Although a special microbarograph and a tape recorder were the only recording instruments carried, the observations of the meteorologist-pilot may prove interesting and shed new light on funnels.

The first traverse through a funnel cloud by the author was in 1972, and several other higher-performance fiberglass sailplanes also flew through it. However the two passes through different parts of a funnel cloud on 21 August 1976 by the author alone were much more interesting and better documented; there, most of the details that follow relate to these flights. Reasonably reliable estimates of distances, elevations, and funnel sizes are possible because the radius of turning the sailplane at a given speed and bank angle is known (at a speed of 20 ms^{-1} and bank angle of 45°, the sailplane will complete a circle in $\backsim$16 seconds at a radius of $\backsim$50 meters) and because, in each case, several other 15-meter wingspan sailplanes reconnoitering at various levels,

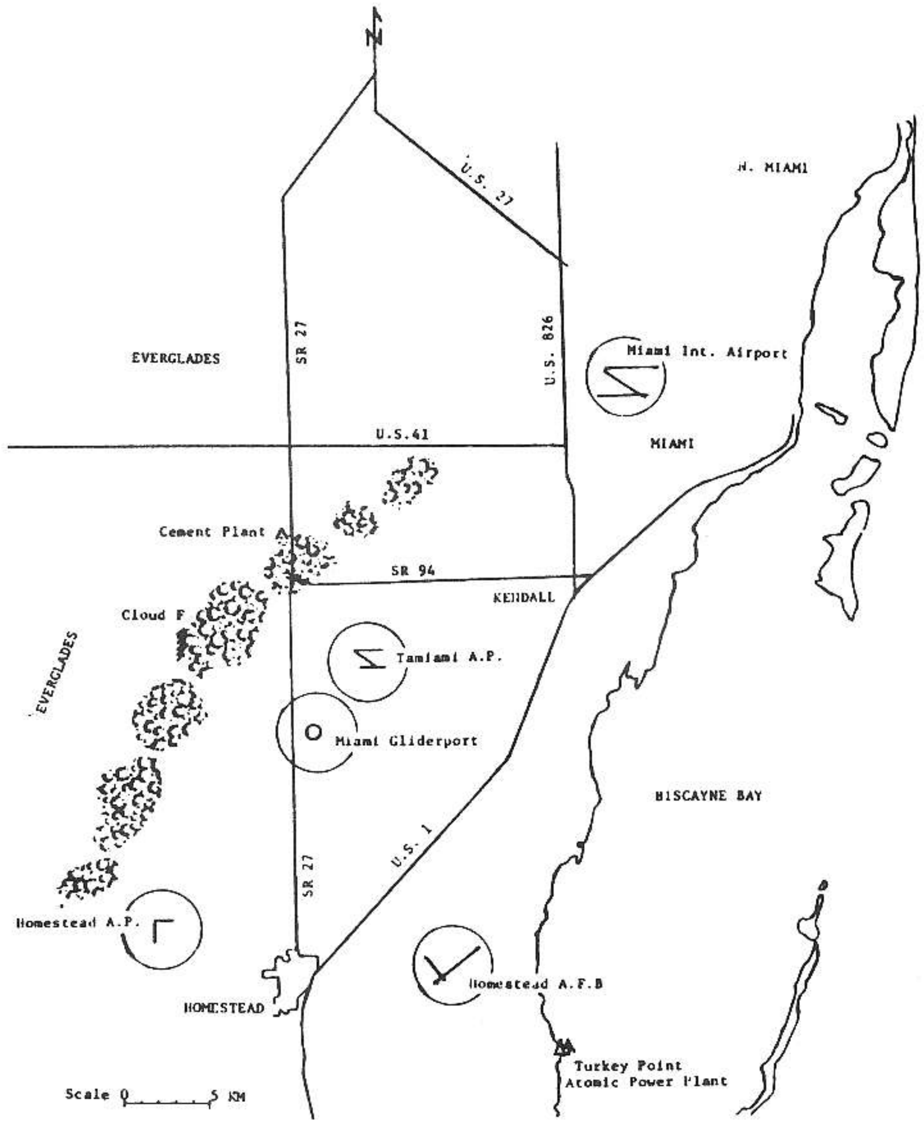

Figure 1—Florida map and cloud line ~1230 EDST, 21 August 1976.

often at distances of less than 50 meters from the funnels and the author's plane, gave a basis for comparison. The sailplane used in all three penetrations was a Schweizer SGS 1-26B. Because of its low wing loading, it is extremely responsive to small-scale atmospheric motions.

GENERAL GEOGRAPHIC AND METEOROLOGICAL CONDITIONS

The weather was typical for summer in both the 1972 and 1976 cases except that cloud bases were 1 km, ~200m higher than normal when the funnels formed. **Figure 1** shows a map of the southeast corner of the Florida peninsula including the vast area of wetlands called the Everglades, west of route SR 27. The shape of the coastline is important in the orientation of the sea breeze "frontal zone" (SBF), which often dominates much of the area. The Miami Gliderport (MG) was west of the SBF during takeoff at 1140 EDST and until about 1400, as indicated by south to south-southwest winds of 3–5 ms^{-1} there and southeast winds of 5 ms^{-1} at the Turkey Point Atomic Power Plant on the coast ~25 km southeast. On 21 August 1976, the sky cover was 0.2 cumulus humilis with bases at 750 m at 1200 EDST, increasing to 0.4 with some cumulus congestus to the west with bases at 1 km at 1230. By this time, the clouds had cleared from the coast to within 5 km of the MG, and the small cloud bases in the MG area were ~300 m lower than the larger cloud bases 5–10 km to the west, all very normal with SBF conditions. Where average sailplane lift rates had been 0.5–1 ms^{-1} just after takeoff, they were 1–2 ms^{-1} with peaks of 4 $ms^{-1}$by 1230. It was clear that rain would occur within an hour.

At 1200 EDST the SGS 1-26B and three 15-Meter high-performance sailplanes were cruising up and down the 20 km-long line of cumulus congestus indicated in **Figure 1**. Rain was beginning to fall from the extreme western portion of Cloud F, which was ~2 km wide by 4 km long in the north-south direction. Lift was widespread and gentle along the eastern one-third of these cumulus with occasional strong areas.

One of the other pilots observed a funnel cloud just beginning to protrude from the eastern portion of the base of Cloud F, ~1 mile behind the SGS 1-26B. I immediately turned the plane around to investigate it. On arrival, the funnel was observed to extend ~300 m below a 1 km-high black cloud base. The funnel length was steadily increasing, and the cloud base around the funnel was higher by 50–100 m than the base near the rain to the west.

As I circumnavigated it at a radius of 35 m, there was gentle lift to the north and west, strong lift of 2 ms^{-1cl2} to the south, and 0 to the east. After three trips around it, ~1½ minutes, the funnel was much better formed and had a total diameter of ~15m. Very definite counterclockwise rotation of dark cloud elements was observed around a white core, and the former light lift on the north side had become a slight sink (probably +0.5 ms^{-1} air motion).

FIRST PENETRATION

I decided to fly directly through the center from south to north. Spoilers were deployed in order to drop the SGS 1-26B sailplane from 100 to 200m below the cloud base so as to prevent being lifted into the cloud inadvertently. The speed was adjusted to ~25^{-1} to maintain good control, minimize the possibility of stalling, and to keep the stresses on the aircraft low.

The results were as expected. Only a single bump was felt on the approach, and a very short period of <1s of drastically reduced visibility was experienced. Simultaneously, a rapid roll of 10°–20° to the right developed due to the relative decrease in airspeed over the right wing and the increase over the left wing. No appreciable yaw was experienced (rotation of the aircraft about a vertical axis), probably because of the short immersion time and the almost immediate and subconscious use of aileron to correct the roll (they have an adverse yaw effect on the aircraft, which is also opposite to the funnel rotation).

What was relatively unexpected was the almost total lack of appreciable lift within the funnel and the very brief transition time from little or no horizontal rotary movement to funnel conditions and then to calm environment on the other side.

The barograph trace shown in **Figure 2** is from a very sensitive modified Bendix-Friez microbarograph with a total pressure altitude range of surface to 1800 m and a very fast drum rotation time of 2.3 h. Although it is damped with dual dashpots filled with silicone fluid, sudden vertical motion (rarely observed in several hundred hours of normal flight) will produce erratic pen motion, as will be discussed later.

SECOND PENETRATION

Turbulence, stress, and control problems were minimal during the first penetration, just as they had been in the traverse of a 20m-wide funnel cloud two years earlier. Upon observing that this funnel now bent toward the horizontal and extended another 300 or 400m toward the ground, I decided to penetrate again at a lower level, maximizing the immersion time. The lower portion had no dark cloud elements surrounding the 5–10 m wide white, steamy-looking vortex, whose long, pointed tip angled toward the ground only ~300 m below it.

During another circumnavigation of the vertical portion, including a turbulence-free flight 20–30 m over the lower 45° sloping end, the consequences of a descending pass at 30° horizontal angle to the funnel were carefully reviewed. Upon entering the top edge of the lower portion in a northeasterly direction, the left wing of the sailplane should be pulled downward; as the fuselage enters, it should be accelerated toward the left and forward and over the top of the funnel; and because the immersion time would be greater, any up-

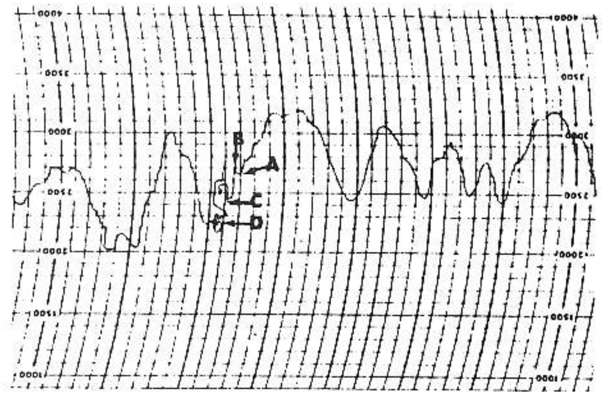

Figure 2—Microbarograph trace of part of the 21 August 1976 flight. Small time division are at 2 min intervals, and small height divisions are at 30 m intervals. The letters denote the following: A, first penetration through vertical portion of funnel; B, beginning of descent to lose height prior to second penetration through quasi-horizontal portion: C, beginning of second penetration: and D, end of second penetration.

ward motion in the center of the vortex would become much more apparent by a possible sudden increase in indicated airspeed and deceleration of the sailplane (with respect to the earth) while in the funnel and a sharp drop in indicated airspeed to near stall immediately after leaving it, all assuming a constant pitch attitude of the plane.

Unfortunately, although the forecast was partially correct, at ~250d m below cloud base and 700 m above ground, the sailplane was flipped out of the side of the funnel on its back with simultaneous rolling and pitching moments lasting only on the order of 1 second. Recover to normal flight attitude was effected quickly and automatically within a few seconds and with a nominal 60 m loss of altitude, as shown in the barograph trace in Figure 2.

Unlike the vertical portion, this part of the funnel had cyclonic vortex motion outside of the core, which was not visible because of the complete lack of cloud element. Immediate reconstruction of events, as entered on the tape recorder, indicated that the left wing stalled due to air moving in its flight direction at the top of the funnel. The stalled tip was then pulled violently downward as it entered the invisible outer vortex on the far side. The next portion of the sailplane to be affected was the front of the fuselage, which was pushed to the left and then also pulled violently downward just as the tail portion was pushed rapidly upward on its side of the funnel. As the sailplane continued through and over, now in a most unnatural attitude, the right wing was pushed up and over the top by the vortex as the sailplane completed its exit from the lower far side of the funnel in a 180° roll to the left. No deceleration or other effects in the central part of the core were noted, although, admittedly, most of the action was induced by the upper half of the vortex. But air motion up or down the central core would have had to be very strong to be evident under the circumstances. If any airspeed effects were present, they were not noticed by me.

Shoulder straps, standard equipment in sailplanes, had tightened before the first penetration and prevented more than a slight head bump on the canopy only 15 cm above. Normal tie-downs for batteries and other cockpit items kept them all secure except for a plastic, 1-liter water bottle, which bounced out of its holder and hit the sides of the cockpit and canopy two or three times before coming to a rest.

Both cylinders of damping fluid were emptied within the barograph case. The trace in Figure 2 shows that despite a special friction finger modification installed to restrict spurious drum rotation, the drum rotated in a forward direction; the weighted pen arm moved in response to both positive and negative *g* forces, and the drum rotated back against the clock drive, all within a few seconds.

A *g*-meter is normally carried, but it was not installed on this flight. Several years of previous experience with the meter indicated that the maximum forces were on the order of +3 and -2 *g*. Although such forces are not a very great portion of ultimate design loads for the SGS 1-26B, they might possibly be serious for a powered aircraft that would also consume considerably more altitude in recovering from inverted flight.

None of the other sailplanes penetrated the funnel, although they observed it from near the cloud base, ~200 m to the south where the average lift rates were <2-1. The four sailplanes thoroughly explored all of the subcloud regions, except the rain area, for greater lift. The maximum was 4 ms-1 about 200 m to the south while the funnel was growing during the first penetration. A minute later, it had decreased to half of that.

POST-PENETRATION WEATHER

The funnel cloud lasted ~8 min from sighting to dissipation. Cloud F in Fig. 1 joined the clouds southwest and northeast of it. Within 20 min, the rain from the west half of a 10km-long line was falling at a rate of 25–50 mm h^{-1}, and thunder and lightning were becoming more frequent.

Flight into the clear air to the east showed that the cloud had become a cumulonimbus, growing to ~10 km high, and a mamma cloud deck extended out of it to the east. The eastern portion of its base had increased to 1.3 km above ground within 30 min, and lightning occurred as often as every 10–20 sec on the eastern edge of the rain and into the subcloud flight areas that I traversed in the SGS 1-26B.

In another 30 min, the rain area increased, outflow developed, and winds over a 10 km area southeast of the clouds, including MG, became northwesterly at 5–7 ms^{-1}, with gusts to 10 ms^{-1}. I continued to fly in constant lift under the easter one-third of the storm, very near the rain, for over an hour. The SGS 1-26B flight was terminated at 1550 EDST, but the cloud line did not move more than a few kilometers during its lifetime. Instead, it rained out, with rapid clearing by 1700, except for local high clouds generated by the storm.

The evening sounding, taken at 2000 EDST, is reproduced in **Figure 3**. It shows typical, conditionally unstable air in the lower levels, and widely scattered showers were forecast for the Miami area. The maximum temperature was 32°C,l which should have produced lift and a dry adiabatic lapse rate to ~1.5 km. It should be remembered, however, that the sounding at Miami International Airport was taken several hours after the rain to the southwest had ended and probably does not adequately represent condition in the region of the clouds where the funnel was observed because of sea breeze effects. **Figure 4** shows the surface weather map for the United States on the morning of 21 August. Winds over the entire state were light, and no important weather systems were affecting the area of interest.

Radar film from the WSR-57W was examined for possible hooked echoes, etc. Unfortunately, the thunderstorms never grew to very large size, and they remained will within the ground pattern area of the radar. Consequently, the long-range radar coverage was of little use in studying the flight area.

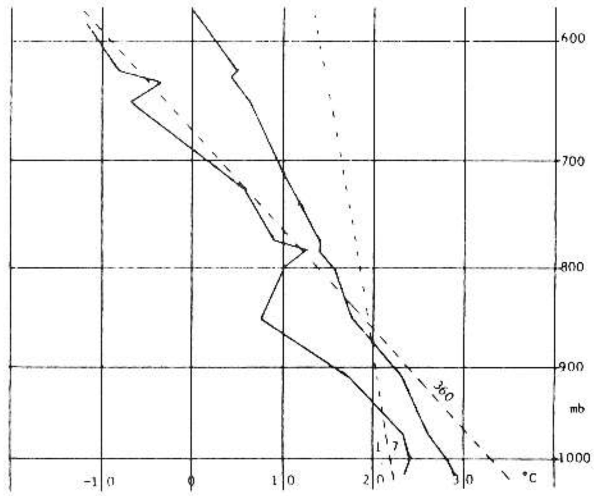

Figure 3 — Miami sounding at 2000 EDST, 21 August 1976

DISCUSSION AND CONCLUSIONS

These three penetrations showed very little air rotation outside of the visible gray sheath of the vertical funnels and rotation of about the same magnitude and radius outside of the visible white core in the absence of the gray sheath. The tangential velocities were on the order of 20 ms^{-1} at a radius of 10 m, as deduced from aircraft roll and yaw motion. This is in contrast to data taken from faster aircraft on much larger and more severe storms, which showed considerable air rotation outside of the visible gray funnels (Sinclair, 1973).

Although the duration of these funnel clouds corresponded with Golden's (1974) mature waterspout lifetimes of 2–17 min, none of his five basic waterspout stages was observed. This could have been due to the lack of similar surface features, even though the Everglades surface was over two thirds water. However, even the "decay stage" was not accompanied by the funnel being "intercepted by cool downdrafts from nearby rain," as in his waterspouts studied. Instead, the broad area of ascending air persisted in nearly the same location for nearly another hour after funnel dissipation as the rain area in the same clouds grew larger.

The sounding in Fig. 3 was used to gain an estimate of the pressure drop at the funnel center in the 21 August case. Since the lower tip of the funnel condensation was observed at the 300 m level above ground, temperature and moisture data from the 972 mb level were used to determine that dry adiabatic expansion of air at that level would result in cooling to the dew point with a pressure drop of ~40 mb. Although no upward motion was observed within any of the funnels, the sounding data on this case show relatively constant saturation mixing ratios for most air below the 300 m level. Note that Golden (1974) computed pressure drops of 44 and 64 mb for two Florida waterspouts.

The flight microbarograph trace in Fig. 2 may not be entirely reliable, but it shows a jump of 100 m, equivalent to a pressure drop of only 12 mb during the longer penetration through the sloping portions of that funnel. However, damping of the instrument is intended to completely eliminate very short perturbations, and the sailplane was descending rapidly (increasing pressure) while entering the region of lower pressure. Vertical velocities wefe so small as to be unnoticed either by me or my instrumentation in even the longest im-

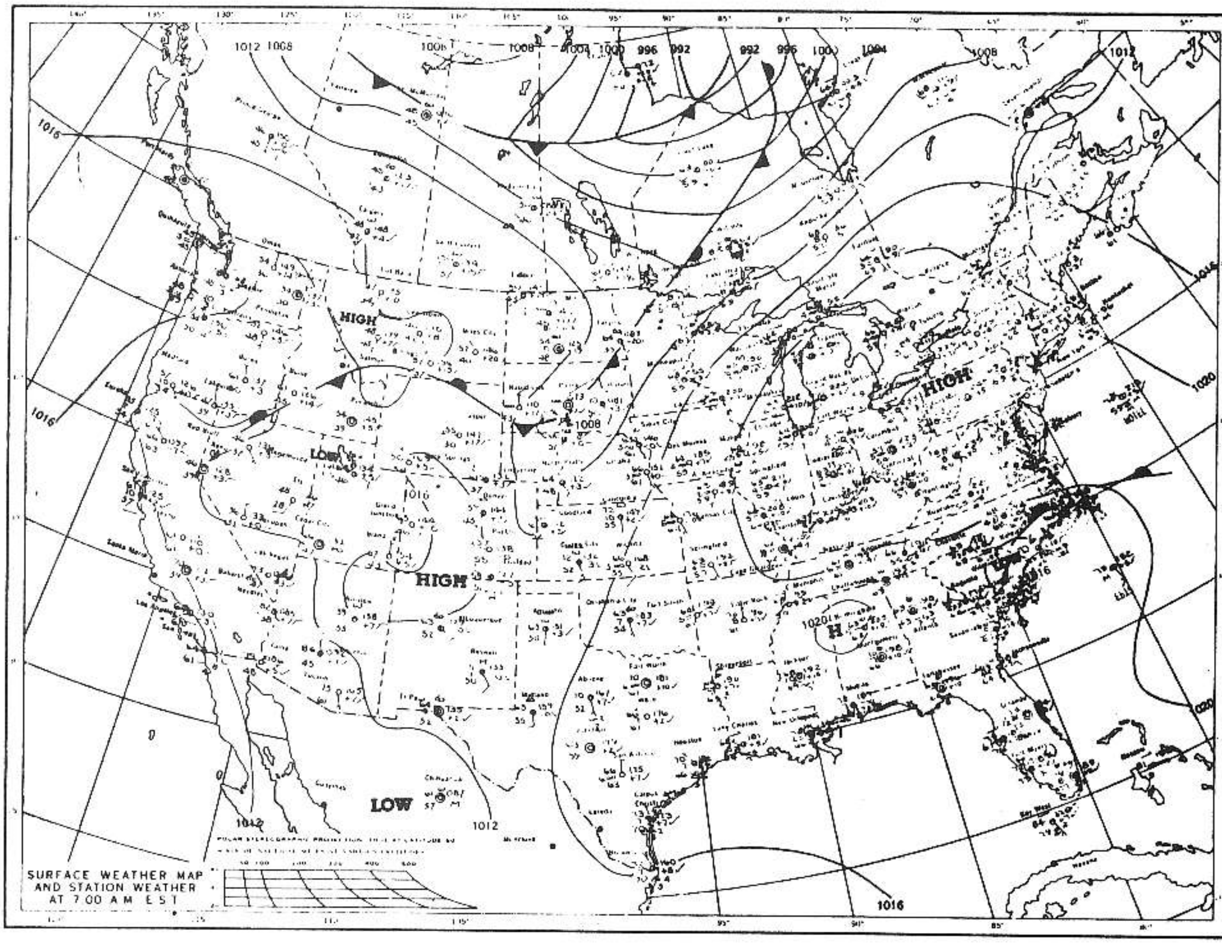

Figure 4 Surface weather map for 0800 EDST, 21 August 1976

mersion within the cyclonic vortices, but it should be remembered that most of the air for a considerable distance around the funnel was going up smoothly and relatively uniformly. I have flown dust devils over the Mojave Desert that had much more turbulence and much greater vertical velocities, both within their cores and for some distance around them. With these funnels, lack of any signs or surface indications of inflow or other lift precluded descending for a pass below the condensation level because of the unfriendly terrain, should that flight have to be terminated in that area.

The parent cloud was only slightly larger and faster growing than others in the vicinity, but it had far more electrical activity than the other clouds after the rain became widespread and heavy. Subcloud vertical velocities were not <24% greater than those beneath other clouds that day. They were comparable to velocities experienced on days when no funnels were reported. The most rapidly rising air was ~100–200 m to the south of the funnel. In short, these funnel clouds had many of the characteristics found in waterspouts by Golden (1974) except that they were slightly more severe and mamatus, thunder and lightning were observed, but without a visible eye or other surface features. Like waterspouts, local terrain and wind shear probably did not affect the direction of rotation of these funnels since the land upwind does not vary vertically by more than 2 m for a distance of 30–40 km, and even the nearest 10–20 m tall trees are many kilometers distant. Unlike Golden's (1969) waterspouts, these did not have "collar clouds" extending downward from the main cloud bases. Instead, they had broad, inverted saucer-shaped indentations, typical of the smooth, dark cloud bases that sailplane pilots find in situations where thermals are relatively large and uniform while the cloud is still in its growing or premature stages.

The funnel clouds reported here appear to be typical of those in south Florida, but should *not* be assumed to be typical of even small midwestern funnels. Now would it be wise to assume that all funnel clouds may be routinely penetrated by either sailplanes or small powered aircraft without more serious consequences than were suffered in these flights.

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