MICROBURST AT MURRAY BRIDGE
MICROBURSTS, DOWNBURSTS AND DOWN-DRAUGHTS WITH REGARD TO GLIDING OPERATIONS
A Case Study of a Microburst in South Australia

By W.J. Grace and M.J. Hancy

Bureau of Meteorology, Adelaide, South Australia

Presented at the XX OSTIV Congress, Benalla, Australia (1987)

Summary

Photographic observations of a wind raised dust pattern in South Australia are presented as evidence of a microburst. Estimates of dimensions and velocities are obtained and compared to those derived from a simple model based on the conservation of mass and kinetic energy. The hazard presented to aviation and gliding operations by microbursts is discussed.

Introduction

Downburst

From conservation of mass considerations, a downward draught of air in the middle levels of the atmosphere will eventually become an outflow of horizontal winds if it reaches the ground. Fujita (1978) classified a downdraught as a "downburst" if these horizontal winds are potentially damaging (generally taken as speeds in excess of 18 m/s). The air spreading horizontally is known as the outward burst.

Near the ground, the outward burst often has a violent lifting effect at the outer perimeter. Swirls of dust and leaves, and even roll-type clouds, may be associated with it. Frequently, there is a loud roaring noise, similar to that of a tornado. In the worst cases, trees may be blown down and buildings destroyed. However, a downburst, not strong enough to damage buildings, may still present a danger to gliding operations. It is estimated that twenty percent of downbursts are more intense than a typical tornado (Fujita 1978).

An idealized downburst, in otherwise still air, will produce a radially uniform outward burst (Figure 1). If the downburst is moving horizontally and embedded in the overall wind flow, then the area affected by the outward burst will approximate an ellipse with the major diameter, or path length, being aligned with the overall wind flow (Figure 2). The lateral diameter is called the path width, and typically would be about half to a third of the path length, although occasionally, the downdraught rotates as it descends, causing the path width to be greater than the path length. With increasing observations of associated surface damage patterns, the downburst became classified as "microburst" or "macroburst" according to the horizontal dimensions of the damaging winds (Fujita 1985).

A microburst is a downburst with horizontal dimensions less than 4 km as distinct from a macroburst, which has horizontal dimensions greater than 4 km (Fujita 1985). A typical macroburst has horizontal dimensions of 3 km, a lifetime of 10 minutes and a horizontal wind differential of 25 m/s (McCarthy and Wilson 1984). The vertical depth of the outflow is usually between 300m and 1200m (Wilson, et al. 1984).

FIG. 1 An idealized downburst in otherwise still air producing a uniform, radial outburst. Lines with arrowheads indicate air motion and dotted lines show the boundary between the moving air and the undisturbed air.

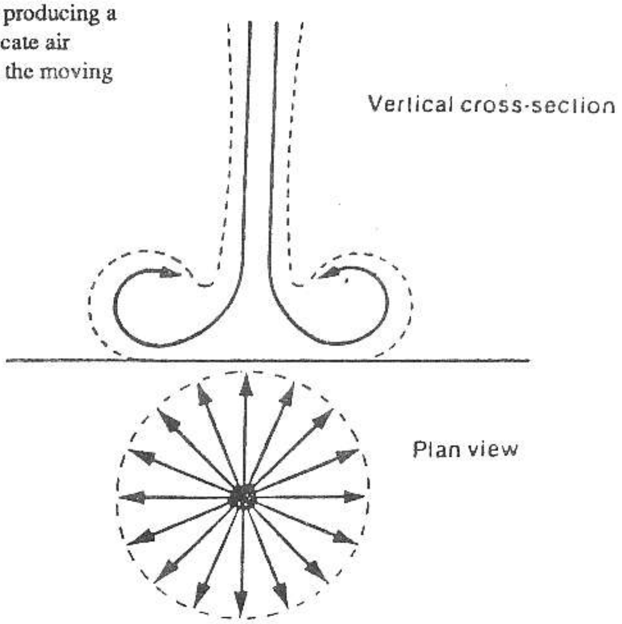
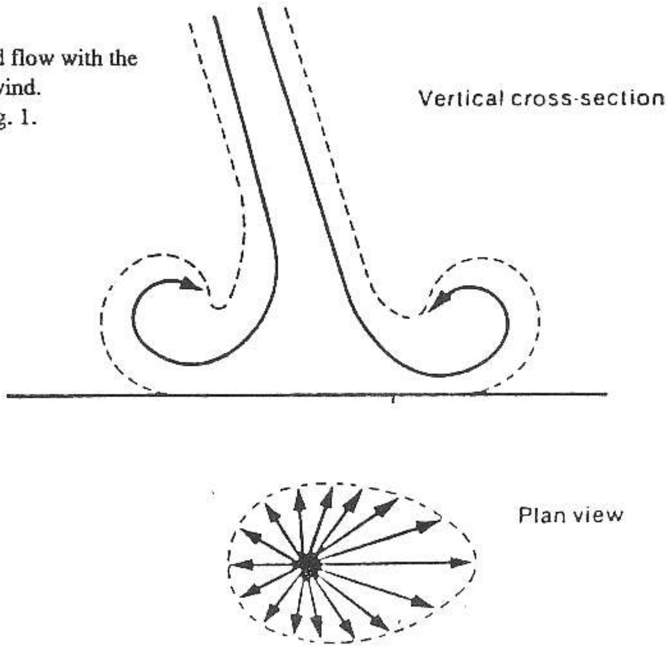


FIG. 2 A downburst embedded in an overall wind flow with the major diameter aligned with the direction of the wind. Lines with arrowheads or dotted are used as in Fig. 1.



The hazard to aviation and gliding operations

Since 1964, nearly 500 people have been killed in aviation accidents known to involve microbrusts (McCarthy and Serafin 1984). The fact that this type of phenomenon is hazardous to aviation was documented by the Bureau of Air Safety Investigation in its examination of an accident which occurred at Bathurst NSW on May 31, 1974 (McCarthy and Wilson 1984).

A possible outcome of an aircraft taking off into a microburst is shown in Figure 3. As the aircraft enters the microburst, it initially encounters a strong headwind component, which generates extra lift. However, this lift is lost as the aircraft encounters the downdraught, loses altitude and moves into the region where it experiences a strong tail wind component. With insufficient air speed and altitude, corrective action is impossible, and a crash is unavoidable. The sequence described may happen within thirty seconds. Fujita (1978) investigated four accident cases involving large jets and concluded that the "loss of air speed within 30 seconds, coupled with downward air currents, resulted in the unexpected loss of flight altitude. Most of the cases were associated with 'weak looking' afternoon summertime convection." The danger to operations such as launching sailplanes is considerable.

Evolution of downbursts and microbursts

In the simplest case, the downburst is a consequence of evaporative cooling of precipitation in mid-tropospheric air. Rain falling through relatively dry air below a cloud cools the air by evaporation. On becoming denser than the surrounding air, the cooled air accelerates downwards. The amount of cooling depends on many factors, but chiefly upon the intensity of the rainfall and the temperature and humidity of the subcloud air. In some circumstances, the size and type of precipitation is important (Wakimoto 1985). Usually, it is the air from immediately beneath the cloud, which is most readily brought to the ground as a consequence of the evaporation of precipitation. When the cloud base is high and the layer of air beneath the cloud is deep and adiabatic, the flux of negative buoyancy is maintained in the downdraught. Such downdraughts can reach the ground from the middle troposphere and produce strong squalls (Ludlam 1980). An evaporatively driven model by a layer 370m deep generates intense downdraughts with the very small amounts of rainwater associated with virga. Conditions particularly favor such occurrences on hot days, since the layer of air from the surface to the base of a convective cloud will be dry adiabatic, or nearly so. By convention, if the precipitation that initiates the downdraught

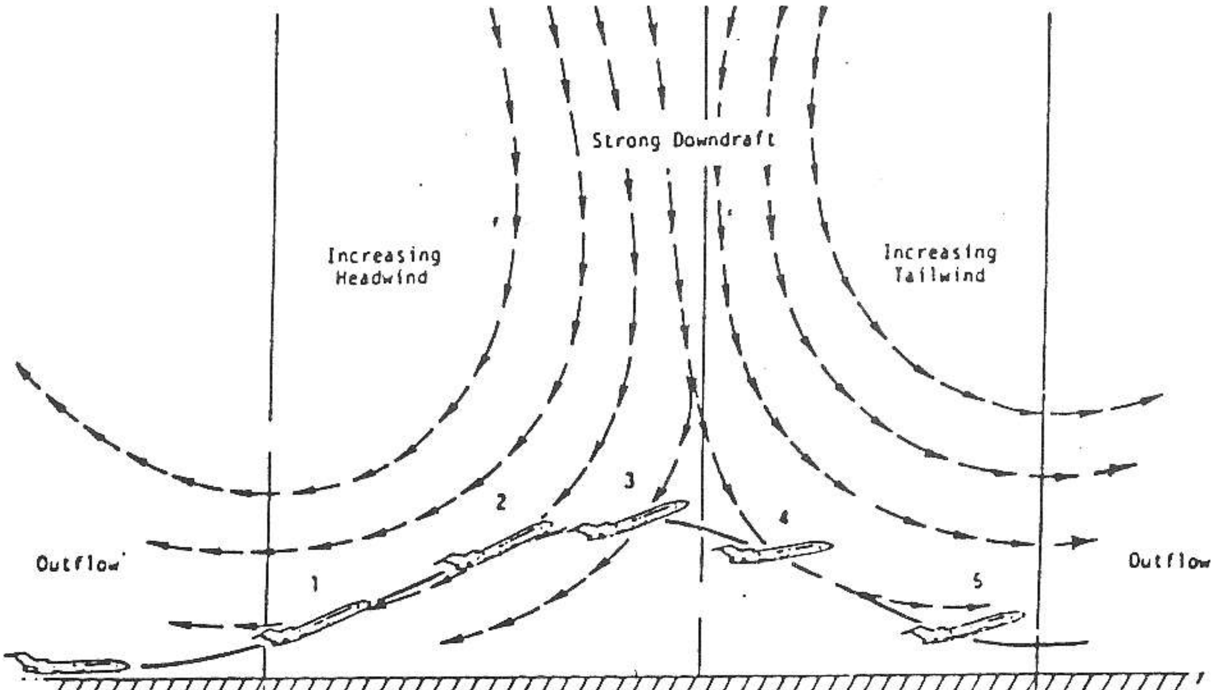


FIG. 3 Microburst situation similar to that present during the takeoff of PanAm Flight 759 in New Orleans in July 1982. The airplane first encounters a headwind and experiences increasing performance (1); this is followed in short succession by a decreasing headwind component (2), a downdraft (3), and finally a strong tailwind (4), where 2 through 5 all result in decreasing performance of the airplane. Position (5) represents an extreme situation just prior to impact. Figure courtesy of Walter Frost, FWG Associates, Inc., Tullahoma, Tennessee.

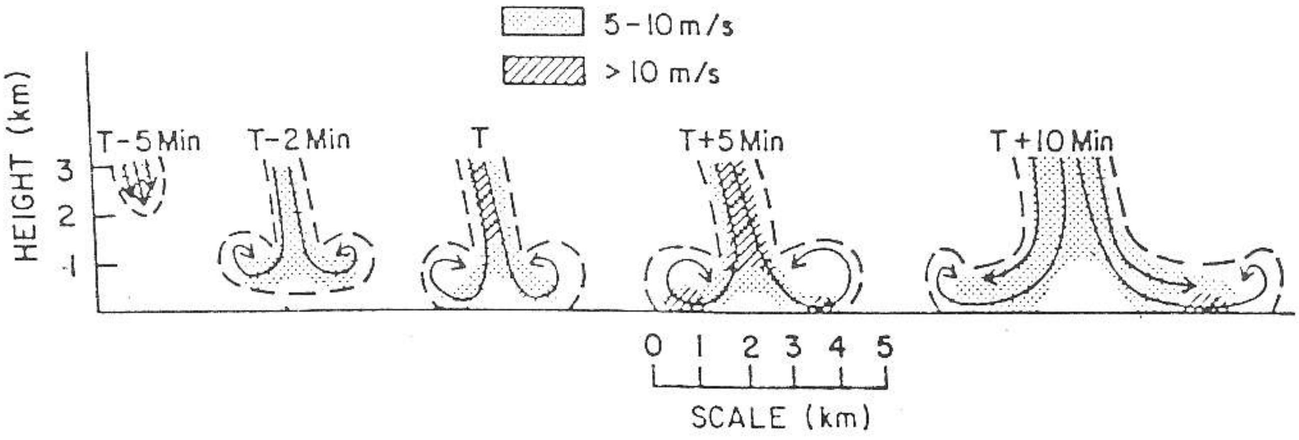


FIG. 4 Vertical cross section of the evolution of the microburst wind field based on a summary of data: T is the time of initial divergence at the surface. The shading denotes the vector wind speeds, from the joint airport weather studies (JAWS) project, J. Wilson, et al. From Journal of Climate and Applied Meteorology, Vol. 23, No. 6, 1984, p. 906.

evaporates before reaching the ground, such microbursts are classified as "Dry."

In the JAWS Project, using Doppler radar at Stapleton International Airport in Denver, Colorado, 1982-1984, an average of about 1.5 microbursts per day within a 1600 square km area were detected during the summer. Approximately one half of these microbursts were dry (McCarthy and Wilson 1985). The same study showed that if a microburst were detected, then a further two or more were usually observed on the same day (Wilson, et al. 1984). The evolution of the typical JAWS microburst is illustrated in Figure 4. Both Wakimoto (1985) and Srivastava (1985) suggest that most of these microbursts were evaporatively driven and originated near the cloud base.

Estimation of dimensions and velocities in dry microbursts

Numerical experiments by Srivastava (1985) show that with a cloud base of 3700m and near-adiabatic conditions and no entrainment, a dry microburst downdraught generated by evaporative cooling could be in excess of 20 m/s, regardless of rainfall intensity and raindrop size. Further experiments indicated that for a downdraught with diameter sufficiently large (2 km), the effect of entrainment was relatively minor. By using a factor of 1.4 (explained below) on these downdraught speeds, then the horizontal outflow speeds are computed to be in excess of 28 m/s.

As described in Appendix 1, considerations of mass and kinetic energy conservation in a simple model of the outward burst indicate that the outflow speed near the surface is between 1.0 and 1.4 times the downdraught speed. (The factor 1.0 applies if the outflow speed is constant with height up to the top of the outflow, while the factor of 1.4 applies if the outflow speed decreases uniformly from a maximum near the surface to zero at the top of the outflow.) For such outflow conditions, the height of the outflow is 0.25 and 0.35 of the diameter of the initial downdraught, respectively.

Observation of a dry microburst in South Australia

During the late afternoon on December 12, 1982, members of the Murray Bridge Gliding Club (Anon '1983) observed and photogaphed a huge expanding ring of dust (Figure 5). The initial core of the downdraught was dust-free and estimated to be between 600 and 700m in diameter with an outer ring of dust estimated at 200 to 250m in depth and width.

After about four minutes, the dust-free core had expanded to about 10 km in diameter, and the outer ring of dust became higher, wider and more diffuse. Overall, the impression was of "a huge explosion." The space and time scales of the event closely parallel the typical JAWS microburst, shown in Figure 4. Gliders flying in the vicinity, probably within other downdraughts, reported sink rates of 5 m/s, and, in one case, of 10 m/s. No showers were reported, although some virga is apparent in Figure 5. Cloud base was estimated at 3000m. Consistent with that estimate, consideration of the Adelaide Airport upper air temperature sounding at 2100 Central Summer Standard Time (CSST), in conjunction with the maximum surface temperature recorded at Murray Bridge that afternoon (37 C), suggests that the lapse rate was at, or near, the dry adiabatic and showed that convective cloud would have a base of around 3200m (Figure 6).

Processes contributing to the Murray Bridge microburst

On the available evidence, it appears that the Murray Bridge microburst was initiated by virga falling from a cloud base at 3200m. Consequent evaporative cooling caused air just below the cloud to sink. Since the layer of air from the ground to cloud base was adiabatic, or nearly adiabatic, then the cooled air continued to accelerate downwards.

From the surface dust pattern, pilot estimates of the initial downdraught diameter and the outflow depth were 225m and 650m respectively, a ratio of 0.35. This is consistent with the results of the model. The diameter of the dust-free ring increased from an initial 650m to 10 km in the space of

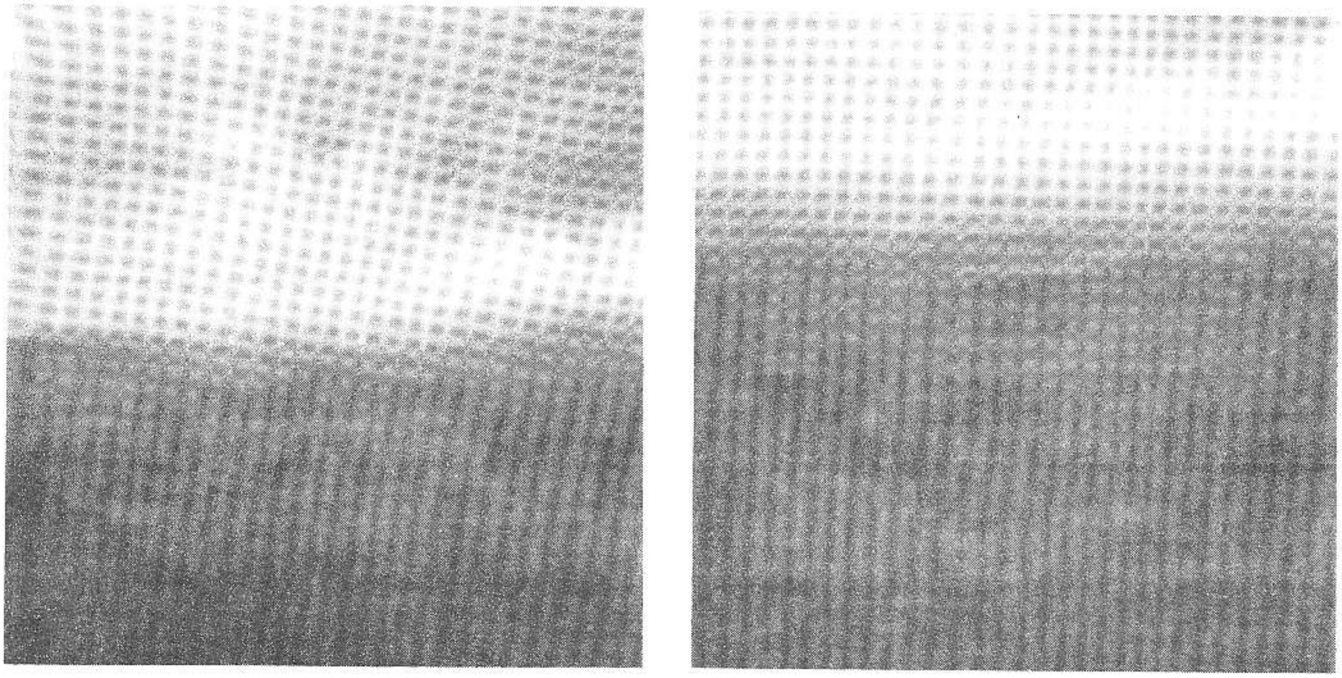


FIG. 5 Successive photographs of an expanding dust ring "kicked up" by a microburst over dry fields near Murray Bridge, South Australia on the afternoon of December 12, 1982. The clear core of the dust ring is located near the centre of each photograph.

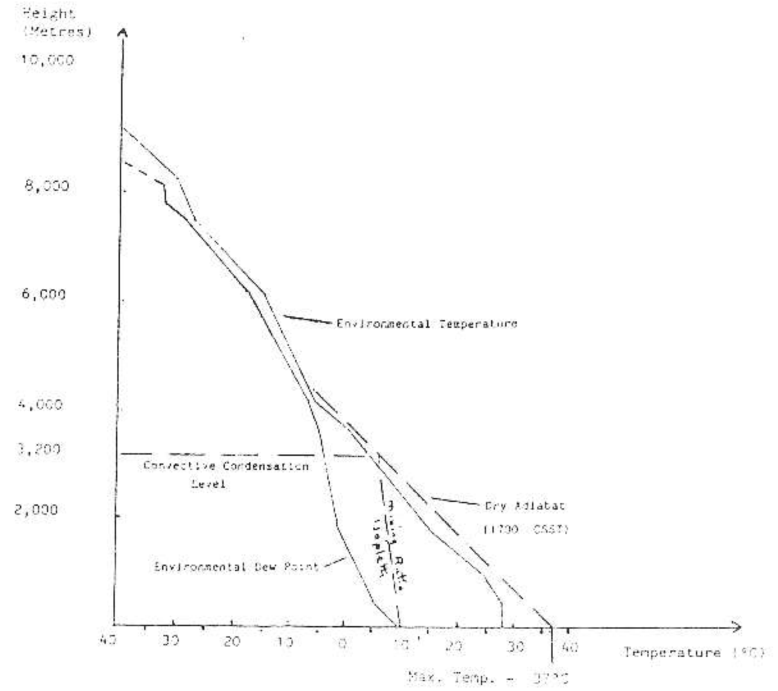


FIG. 6 Temperature profile as at 2100 CSST on December 12, 1982 at Adelaide Airport with the maximum temperature for Murray Bridge shown; Suggesting a convective cloud base s of about 3200 m.

approximately four minutes. Therefore, the outflow winds must have been nearly 20 m/s.

From the model, it was shown that outflow winds are a factor of 1.0 to 1.4 times the terminal downdraught speed. Assuming a factor of 1.2, then the terminal downdraught speed in this case would have been 16 m/s. Assuming further that there was little or no entrainment into the downdraught, then it can be deduced that the cooling, due to evaporation of the virga, was 1 C and that 10 to 12 minutes elapsed from the initial evaporative cooling to the dissipation of the outward burst winds at 10 km diameter.

Discussion

The factors which make a downburst or microburst potentially dangerous are sink rate, wind shear, invisibility and unexpectedness.

The example shows that sink rates can be at least 10-16 m/s, and confirms similar estimates in the literature. The example also shows outflow winds of nearly 20 m/s, implying a wind differential of about 40 m/s. This wind differential may occur within a distance of only one or two kilometers. Both the sink rate and wind shear of the microburst are most severe near the surface where aircraft are especially vulnerable while landing or taking off.

In many cases, the downbursts will not be detected because downbursts are not necessarily associated with thunderstorms. Strong downdraughts can also occur in the rain-free air below harmless looking clouds, such as altocumulus and fair-weather cumulus. Because dry microbursts can occur in clear air, not only are they undetected, they might be completely unexpected. It was shown in the example that the lifetime of the microburst was about 10 to 12 minutes, so that within 5 minutes, a relatively quiet area can become hazardous, as illustrated in Figure 4. However, visible clues include virga or a dust ring on the ground, as in the Murray Bridge case.

Concluding remarks

Microbursts and downbursts are potentially a serious hazard to aviation and gliding operations in Australia. Overseas studies suggest that their frequency of occurrence may be underestimated, since many go undetected.

Even the most sophisticated continuous atmospheric sounding equipment can only identify the actual occurrence and offer no assistance in prediction. It therefore rests with forecasters and pilots to increase their understanding of atmospheric conditions which give rise to the phenomena, and to work towards the development of an accurate aid to prediction of their possible occurrence.

Acknowledgements

Acknowledgements are due to Mr. B. Roberts, who photographed the dust pattern associated with the microburst, and to other members of the Murray Bridge Gliding Club for their personal accounts. Figure 3 is courtesy of Walter Frost of FWG Associates, Inc., Tullahoma, Tennessee.

Considerable improvements to the manuscript resulted from suggestions from Dr. K.T. Spillane, and other reviewers of the Bureau of Meteorology, Melbourne. Thanks are due to Yvonne Bennett and Bett Charlesworth for typing of the drafts.

References

Anon. 1983 Australian Gliding. August 1983 p. 16-17.

Fujita, T.T. 1978 Manual of Downburst Identification for Project Nimrod. SMRP No. 156. Univ. of Chicago

Fujita, T.T. 1981 "Five Scales of Airflow Associated with a Series of Downbursts on 16th July 1980." Monthly Weather Review. Vol. 109 July. p 1438.

Fujita, T.T. 1985 The Downburst. SMRP No. 210 Univ. of Chicago

Ludlam, F.H. 1980 Clouds and Storms. P. 254. Penn. State Univ. Press.

McCarthy, J. and Serafin, R. 1984 The Microburst Hazard to Aircraft. Weatherwise June. P. 120.

McCarthy, J. and Wilson, J.W. 1984 The Microburst as a Hazard to Aviation: Structure, Mechanisms, Climatology and Nowcasting. Proc. Nowcasting — II Symp Norrkoping Sweden. Sept. 3-7. P. 21.

McCarthy, J. and Wilson, J.W. 1985 The Classify, Locate and Avoid Wind Shear (CLAWS) Project at Denver's Stapleton International Airport: Operational testing of terminal weather hazard warnings with an emphasis on microburst windshear. Second International Conference on the Aviation Weather System. June 19-21. Montreal, Canada.

Srivastava, R. 1985 A simple model of evaporatively driven downdraught: application to microburst downdraught. Journal of the Atmospheric Sciences. Vol. 42 No. 10 P. 1004.

Wakimoto, R.M. 1985 Forecasting Dry Microburst Activity over the High Plains. Monthly Weather Review Vol. 113. No. 7 P. 1131.

Wilson, J.W., Roberts, R.D., Kessinger, C., and McCarthy, J. 1984 Microburst Wind Structure and Evaluation of Doppler Radar for Airport Wind Shear Detection. Journal of Climate and Applied Meteorology. Vol. 23. No. 6 P. 898.

Appendix 1

A simple model of a downdraught, which hits the surface and consequently results in an outward burst, is constructed.

Consider a downdraught with circular cross section of radius R and downward velocity W which, upon impact with the surface, diverges equally in all directions within the outflow layer which is of height H.

Assume that:

(a) the outflow layer has radial velocity U which is constant with height (see Figure 7),

(b) mass is conserved and

(c) kinetic energy is conserved

By assumptions (a) and (b) it follows that in a unit time interval mass flow through top surface = mass flow through sides, i.e.

$$\pi R^2W = 2\pi R H U \qquad \ldots 1$$

$$U/W = R/(2H) \qquad \ldots 2$$

By assumption (a) and (c) it follows that in a unit time interval

kinetic energy inflow = kinetic energy
through top surface through sides

i.e.

$$\pi R^2W^3 = 2\pi R H U^3 \qquad \ldots 3$$

$$U/W = (R/2H)^{1/3} \qquad \ldots 4$$

Combining equations 2 and 4 then

$$R = 2H \qquad \ldots 5$$

$$\text{and } U = W \qquad \ldots 6$$

Now consider the case where the outflow velocity u(z) is a function of height z and decreases linearly from a maximum at or near the surface of U to zero at height z = H (See Figure 8).

Thus it follows that —

$$u(z) = U(1-z/H) \text{ for } 0 < Z < H \qquad \ldots 7$$

As before under assumption (b)

$$\pi R^2W = 2\pi R \int_{z=o}^{z=H} U(1-z/H)\,dz \qquad \ldots 8$$

$$\pi R^2W = \pi R U H \qquad \ldots 9$$

$$U/W = R/H \qquad \ldots 10$$

Similarly under assumption (c)

$$\pi R^2W^3 = 2\pi R \int_{z=o}^{z=H} u^3(z)\,dz \qquad \ldots 11$$

$$= 2\pi R U^3 \int_{z=o}^{z=H} (1-z/H)^3\,dz \qquad \ldots 12$$

$$= \pi R U^3 H/2 \qquad \ldots 13$$

$$\text{Thus } U/W)^3 = 2R/H \qquad \ldots 14$$

Combining (10) and (14) gives

$$R = 2^{0.3}H \qquad \ldots 15$$

$$U = 2^{0.3}W \qquad \ldots 16$$

Because of surface friction, it is to be expected that the maximum outflow speed would occur at some height above the surface. Wilson, et al. (1984) found that this maximum typically occurred at a height of 75m with a gradual decrease above and below. It therefore appears reasonable to support that a realistic vertical profile of outflow speed is in between the two theoretical profiles studied. Thus, outflow speed can be expected to be between 1.0 and 1.4 times the downdraught speed and the ratio of the diameter of the downdraught to its height to be between 0.25 and 0.35.

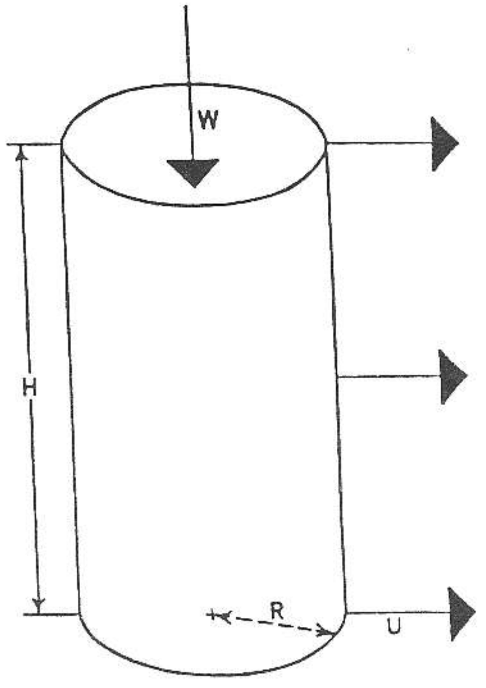


FIG. 7 Circular downdraught diverging isotropically with radial velocity U constant with height from near the surface to height H.

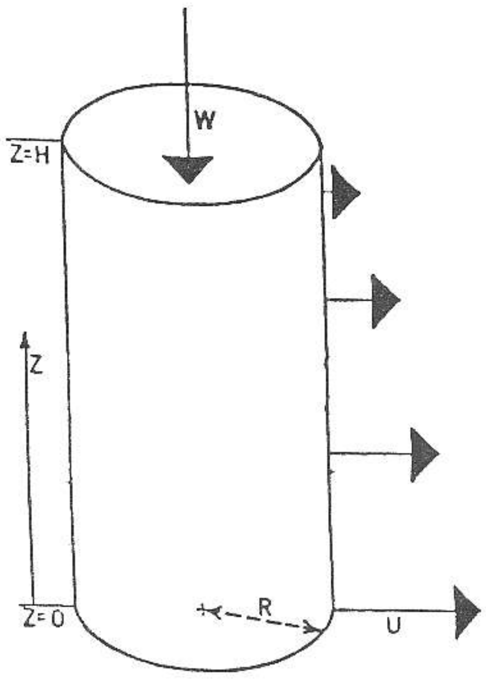


FIG. 8 Circular downdraught diverging isotropically with radial velocity u (z) decreasing linearly with height from a maximum of U near the surface to zero at height H.