Wake Turbulence is Dangerous

AVIATION SAFETY DIGEST Publication

Department of Civil Aviation, Australia

In our flying training days, perhaps especially for those of us who learnt to fly in Tiger Moths, one of the measures of a skilfully executed steep turn was the ability to strike one's own "slip-stream" at the completion of a full 360 degree turn. In light training aeroplanes the effect of this encounter was little more than a sudden jolt which, though it might momentarily throw the aeroplane about, could be easily corrected with the controls. Inconsequential though its effects were, the sharpness of this "slip-stream" and the suddenness with which it was met and passed, left no possible doubt of its identity—it was in fact quite unlike any other form of turbulence which we had experienced at that stage of our flying careers. As our flying training progressed, we probably experienced slip-stream encounters in other phases of flight—at the completion of a loop while practising aerobatics, or at odd times while learning to fly in formation.

Until comparatively recent years, these "slip-stream" effects were generally attributed to the wash of the aircraft's propeller. With the advent of large multi-engined aircraft with high wing loadings however, it was found that by far the larger proportion of an aircraft's wake is produced by vortex turbulence, generated at the wing tips of the aircraft, as a side effect to the lift which the aircraft's wings are producing. These vortices are formed in flight, by air in the region of high pressure beneath the wings, spilling around the wing tips, into the region of low pressure which the aerofoil shape is producing above the wing surface. This motion, coupled with the forward movement of the aircraft, creates a vortex of air funnelling back from each wing tip. Like all clear air turbulence, this wake turbulence is of course, invisible, but if the vortices could be seen, they would appear as a pair of narrow horizontal whirlwinds rotating in opposite directions and streaming rearwards from each wingtip of an aircraft. (See figure 1). The twin vortices induced in this

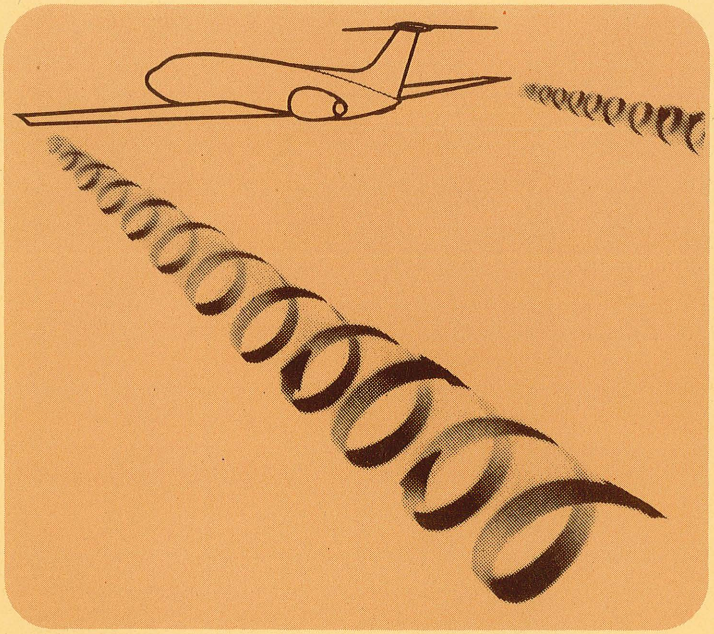


Fig. 1: Diagram showing direction of rotation of wing tip vortices generated behind an aircraft in flight.

way are of relatively narrow diameter. They normally reach their greatest intensity at a distance behind the aircraft between two and four times its wing span, but remain very compact for considerable distances behind. In rough air, the whirling funnels can be expected to break up and weaken in less than a minute, but in calm conditions, vortices of large magnitude can persist for several miles behind the generating aircraft and for at least five minutes after the aircraft has passed. As a result of their own motion, the vortices tend to settle below and behind the generating aircraft, but if the aircraft is close to the ground, as in an approach to land, the vortices will reach the ground and tend to fan out laterally. (See figure 2).

Vortices generated by large aircraft can be very powerful, especially when high lift devices are being employed. The energy of this turbulence at its source is in fact directly proportional to the wing span loading of the aircraft and inversely proportional to its speed. Thus the most violent vortex turbulence will be generated by large, heavily laden, swept wing aircraft flying at low speed with all high lift devices extended, such as during an approach to land or immediately after take off. These are of course, the very phases of flight in which a light aircraft is most likely to encounter the wake of a large aircraft.

The hazard which wing tip vortices of large aircraft can obviously pose to light aircraft taking off or landing behind them, has not so far been a problem in Australia, but it is likely to become one now that numbers of smaller types of aircraft are using the primary airports of our capital cities. Indeed, if overseas experience is any guide, a great deal of caution will need to be exercised by pilots of these aircraft if some of them are not to become victims of vortex turbulence. The following examples will give some indication of the hazards for which we must be prepared:

● *On final approach to land at Vancouver, Canada, shortly after a large aircraft had landed, a Cessna 175 encountered an area of extreme turbulence and the pilot was unable to recover control. The aircraft's starboard wing struck a telephone line and the aircraft crashed to the ground. The pilot and passengers were seriously injured and the aircraft was substantially damaged.*

The Cessna had joined the downwind leg of the circuit at about the same time as the larger aircraft was on final approach. The larger aircraft touched down while the Cessna was on base leg, and the Cessna then turned on to final three quarters of a mile from the runway threshold. Evidently at fairly low altitude, the Cessna encountered the turbulence about half a mile out from the runway, a minute and a half after the large aircraft had passed.

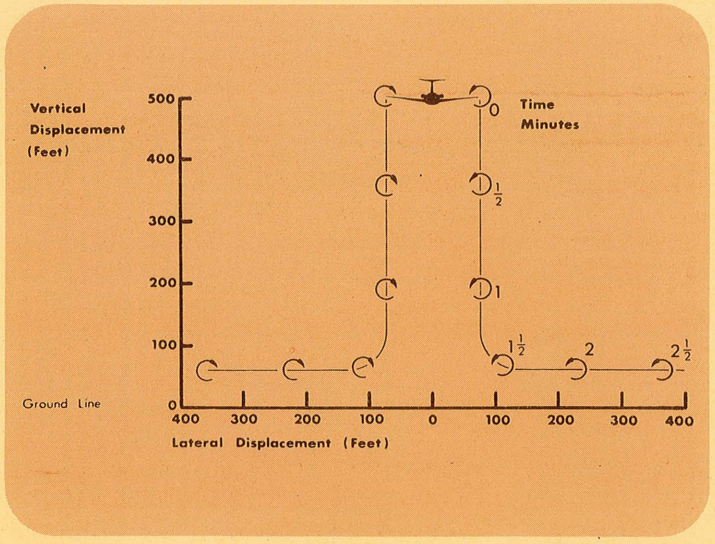


Fig. 2: Wing tip vortices tend to settle behind the generating aircraft, and to spread out laterally on reaching the ground. This graph shows the rate of sink and lateral movement that can be expected in calm conditions.

● *A Cessna 172, being flown by a highly experienced pilot, was making an approach to land at Vancouver at the conclusion of a cross-country flight. While on base leg for a landing on Runway 08, the Cessna pilot heard a DC-6 requesting a clearance to take off from the same runway. The Cessna pilot advised the tower he would do a 360 degree turn to allow time for the DC-6 to depart, and on completing the turn, continued his approach towards the right hand side of the runway. When about twenty-feet above the runway, during the final stages of its approach, the Cessna suddenly assumed a nose-high attitude and rolled more than 90 degrees to starboard. The pilot attempted to recover, but the aircraft struck the ground with the starboard wing, skidded about seventy-feet and came to rest badly damaged. The occupants received minor injuries.*

The weather at the time was cool and cloudy and the wind was 090 degrees at eight knots. The pilot said later, that as he was levelling out above the runway, his aircraft had suddenly assumed a steep nose-up attitude and banked violently. He had immediately applied full power with forward stick and opposite aileron and rudder but this was insufficient to prevent the aircraft striking the ground.

● *A Piper PA-15 was taking off from Runway 16 at Calgary Airport, Alberta, Canada, two minutes after a Viscount had departed from the same runway. A few seconds after the Piper became airborne, it banked very sharply to the left, the nose dropped and the aircraft struck the ground. The pilot was seriously injured and the aircraft substantially damaged.*

The weather at the time was fine and the wind was from the south-south-east at four to eight knots. Calgary's runway 16 is 12,000 feet long, but the Piper had commenced its take-off from a runway intersection 3,000 feet from the south-eastern end of the runway. The point where the Piper crashed was 1,500 feet from the beginning of its take-off run. The pilot said that before taking off, he had taxied his aircraft to the runway intersection to await his take-off clearance. He watched the Viscount taking off and it passed the runway intersection at a height of between 200 and 300 feet. He was then cleared for take-off and taxied his aircraft to the centre line of the runway and took off smoothly. At about 60 knots, when the aircraft was at about 50 feet, it rolled almost instantaneously to the left more than 90 degrees, and despite his attempts to regain control, struck the ground.

The tower controller who was watching the take-off, said that when the Piper was about 50 feet off the ground, it suddenly yawed to the left, the starboard wing lifted, and the aircraft turned through approximately two hundred degrees before striking the ground. At the time he had issued the take-off clearance to the Piper, the Viscount was nearly three miles beyond the far end of the runway. A further minute would have elapsed before the Piper became airborne.

● *An instructor was giving a student instruction in circuits and landings in a PA-22 at Tucson Airport, Arizona, U.S.A., using the 4,200 feet 12R runway. At the same time, a Boeing 707 was carrying out circuits and landings on the 12,000 feet 12L runway. The two runways are parallel and 800 feet apart.*

The Boeing had taken off and was turning cross-wind as the PA-22 was making its third approach to land. At 50 feet, the nose of the PA-22 suddenly pitched up and the port wing dropped violently. The aircraft failed to respond to control corrections, veered to port and crashed into the ground. Both occupants were injured, one seriously.

The surface wind at the time was a steady 080/10 and the loss of control was attributed to the Boeing's wing tip vortices being carried down-wind into the light aircraft's approach.

These cases, with others that have occurred overseas from time to time, clearly demonstrate that the forces which can be encountered in the wake of a large, heavily laden aircraft, considerably exceed the control capability of light aircraft. Studies actually show that the core of a wing tip vortex rotates at a rate of about 80 degrees per second. This is about double the rate of roll than can be achieved by many light aircraft even with full aileron deflection. Similarly, the downdraught which a light aircraft would encounter if it entered the area between the centres of the twin vortex cores of a large jet aircraft, would exceed the light aircraft's climbing performance by several hundred feet per minute. But apart from any possibility of being able to counteract the effects of vortex turbulence, the sudden, violent aerodynamic loads, which such an encounter would impose on a light aircraft, coupled with the pilot's attempts to apply corrective control, could exceed the design strength of the airframe. For example, a light aircraft crossing behind a heavy aircraft and encountering its trail of vortex turbulence, would be subjected to four sudden near vertical gusts —UP, DOWN, DOWN, UP, in rapid succession as the peripheries of each of the two vortices were encountered in turn. Because there would be sufficient time between each pair of blows for the pilot to react with elevator control, this could compound the effect of the second pair of gusts and result in structural failure in flight. Several cases of structural failure in light aircraft, resulting from wake turbulence encounters, have occurred in the United States, with fatal results to the occupants. The problem of wake turbulence is of course a particularly serious one in the United States, where large numbers of light aeroplanes share primary airports with heavy jet transport aircraft.

What then is the answer to this problem, to ensure complete safety for light aircraft using major airports? Clearly the only answer that can guarantee immunity from the danger, is for light aircraft to stay away from these airports altogether! Quite obviously however, this is not a practical solution, and some commonsense approach to the problem must be found which will reduce the risk of an encounter to an acceptable level.

Because of the large number of variables involved, it is not possible to set out inflexible rules, but when something of the behaviour and likely movement of wing tip vortices near the ground is known, it is possible to adopt precautions to suit a particular situation. As a general rule, because the vortices tend to settle towards the ground, a light aircraft which is obliged to operate behind a heavy aircraft, should try to remain above the flight path of the heavy aircraft, whether landing or taking off. The measures recommended in the following situations should serve as examples of the type of precautions which can be taken.

TAKING OFF:

Pilots of light aircraft taking off on a runway from which a large aircraft had just departed, should start their take-off run from the end of the runway so as to be airborne before reaching the point where the heavy aircraft has lifted off. With a normal take-off and climb, this should place the light aircraft above the settling vortices of the heavy aircraft. Discretion should be exercised if there is a light crosswind component on the runway or if the light aircraft is taking off on a path parallel to the runway. In these conditions, the lateral movement of the settling vortices could place one of them in the path of the light aircraft. A light crosswind of the right order can in fact, cause a vortex to linger directly over the runway from which the generating aircraft took off. (See figure 3). In the accident at Calgary Airport for instance, it is evident that just such a combination of circumstances existed at the time the Piper departed.

The pilot of a light aircraft, taking off in a direction which intersects a runway from which a heavy aircraft has just taken off, should ensure that his flight path is above the flight path of the larger aircraft. If the take-off is being made after a heavy aircraft has just landed however, the pilot should plan to be airborne beyond the point where the heavy aircraft touched down. A little thought will show that this is necessary to enable the light aircraft to clear the vortices generated by the landing aircraft.

CIRCUIT AREA FLYING:

Pilots of light aircraft should avoid flying below and behind large aircraft in the circuit area. If possible, light aircraft should stay laterally separated from heavy aircraft by at least several hundred feet. On final approach, as already mentioned, light aircraft should assume an "above and behind" position to remain clear of the turbulence being generated by the preceding aircraft.

LANDING:

Maintaining the same the "above and behind" position during final approach, should place the pilot of a light aircraft in a good position to touch down beyond the point where a preceding large aircraft has already landed. But when a light aircraft is landing after a large aircraft has departed, the light aircraft pilot should aim to touch down well to the rear of the point where the larger aircraft has lifted off—as near to the threshold of the runway as possible. In the case of the Cessna that encountered vortex turbulence at Vancouver just after the DC-6 had departed, marks on the runway indicated that the Cessna struck the runway no less than 4,000 feet in from the threshold.

An instance somewhat similar to this one occurred in Australia recently, while a Twin Comanche was landing at Canberra about two minutes after a BAC-111 had departed from the same runway.

The Twin Comanche, approaching Canberra from the south, had been cleared to descend from 7,000 feet about the time the BAC-111 requested a taxi clearance. The BAC-111 was subsequently cleared for take-off, shortly after the Twin Comanche had begun a long final straight-in approach to Runway 35 from 4,000 feet. The Twin Comanche's approach was uneventful until the pilot flared for landing. At this point, just as the aircraft seemed to be settling normally, it suddenly yawed violently to starboard and began to roll in the same direction. Despite severe turbulence, the pilot managed to regain a level attitude, but could not re-align the aircraft with the runway, and it touched down tracking about 40 degrees to the right of the runway heading. The aircraft ran off the runway, ground-looped to the right, striking and demolishing a runway gable marker, then came to rest facing west, 130 feet from the edge of the runway. Fortunately none of the occupants were injured and damage to the aircraft was confined to a bent undercarriage door.

The weather at the time was fine with a very light wind, the very conditions in which the vortices generated at the wing tips of an aircraft are likely to persist for some minutes before dissipating, and they had apparently drifted down-wind towards the point where the Twin Comanche was touching down.

When planning an approach or take-off to keep well clear of the wake of a preceding aircraft, pilots should remember that vortices are not formed until lift is being produced, so they will not be generated by an aircraft until just before it lifts off. Similarly, vortices cease to be generated once an aircraft has landed and its wings are no longer producing lift. It is important to note however, that in calm conditions, a large aircraft could have taken off and be out of sight, or have landed and taxied to the terminal, yet the dangerous vortices it has created could still exist in the vicinity of the duty runway. Figure 3 illustrates an example of planning an approach to reduce the possibility of encountering wake turbulence.

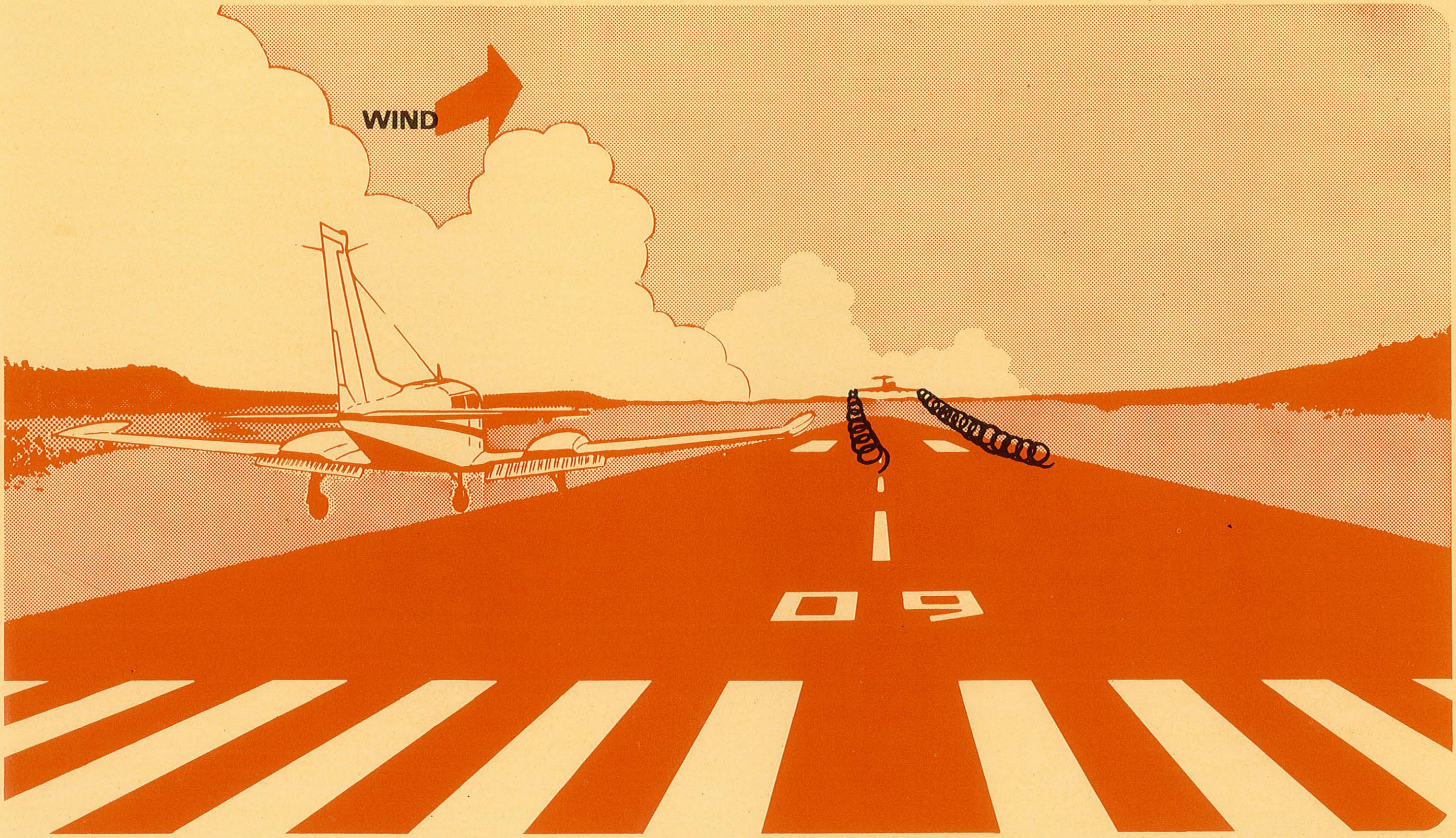
AIR TRAFFIC CONTROL PROCEDURES

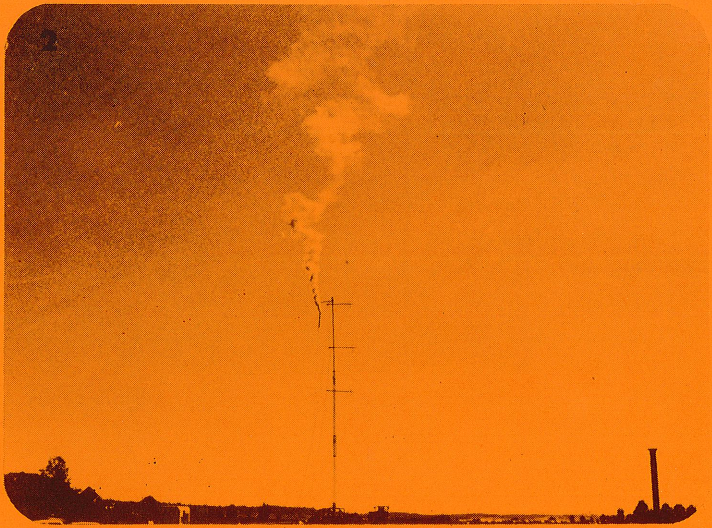
At controlled aerodromes, the phrase "Caution–Wake Turbulence" is used to warn pilots when tower controllers consider that vortex turbulence generated by a preceding aircraft could be of significance. Pilots receiving this advice should analyse the situation. They may request further information or they may ask the controller for an alternative clearance if they consider another course of action preferable, *e.g.,* when taking off after a large aircraft and there is a cross-wind on the runway, a pilot may request to diverge to the windward side of the runway, or to diverge from the runway heading as soon as possible after becoming airborne, to keep clear of the vortices left by the preceding aircraft.

The primary task of Air Traffic Controllers is of course to prevent collisions between aircraft. Within the limitations imposed by regulating air traffic for this purpose however, Air Traffic Controllers will assist pilots in any way they can to avoid the hazards of wake turbulence.

* * *

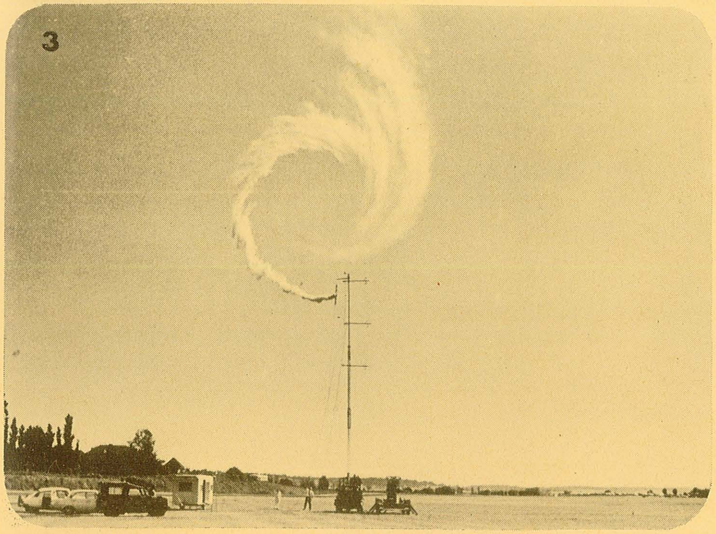
Fig. 3: *One example of planning to avoid wake turbulence. The light twin is landing as near to the threshold as possible, using the up-wind side of the runway to keep clear of the vortices generated by the large departing aircraft. In such a case the direction and rate of movement of the up-wind vortex would depend on the strength of the cross-wind and would need to be assessed in the light of the information shown in Fig. 2.*

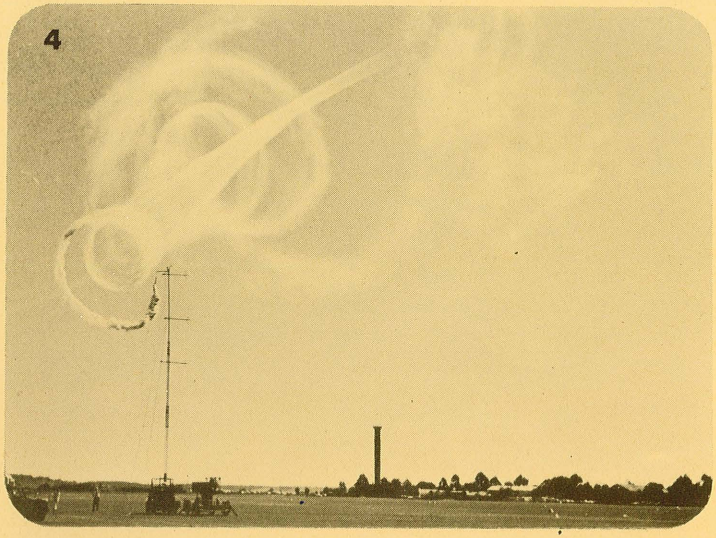




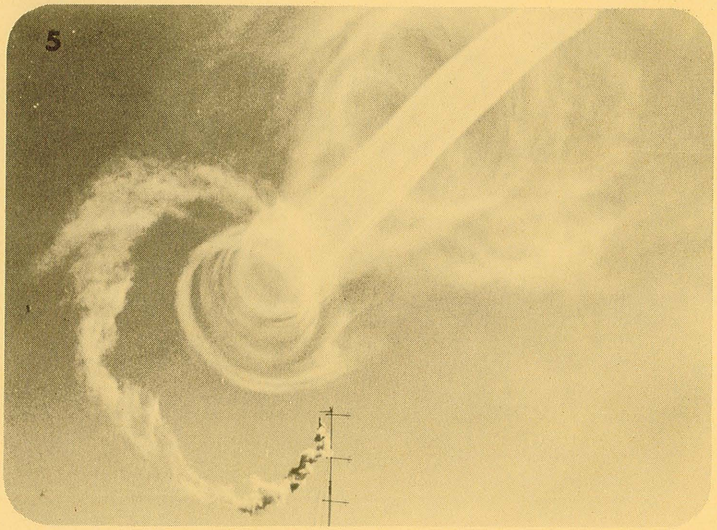
One slightly encouraging aspect of the rather dismal overall picture is that, for the destructive potential to persist, vortex turbulence must remain in the compact cylinders of between 15 and 20 feet diameter in which it was generated. The chances of flying into such a narrow band of airspace are thus relatively small, particularly away from the immediate vicinity of aerodromes. Nevertheless, with more and more small aeroplanes mixing it with "heavies" at our primary airports in Australia (and by "small aeroplanes" we mean anything in the "below 12,500 lb." category) the potential for wake turbulence accidents can only increase. Fortunately the few encounters that have already occurred in Australia have had no serious consequences. Let's keep it that way. Keeping your distance from large aircraft is the only sure way to avoid the danger!

This remarkable series of pictures was taken by a research team from the Aeronautics Department of the University of Sydney during a study of wake turbulence made for the Department of Civil Aviation. The aim of this experiment, conducted at the RAAF station at Richmond, N.S.W., was to render a wing tip vortex visible by allowing it to drift across a smoke source. The smoke source was provided by a smoke generator mounted on the steel mast in the foreground of the pictures.





To begin the experiment, a Lockheed Hercules aircraft is flown at low level past the mast (Picture 1). A few seconds later, the smoke generator is ignited (Picture 2). As the vortex from the port wing of the aircraft drifts over the mast, the rising smoke is suddenly whipped into the rapidly rotating horizontal column of air (Picture 3). The smoke is rapidly drawn into the core of the vortex as well as into the more open, induced airflow spirals surrounding the core itself (Picture 4). In Picture 5, showing the final stage of the smoke development, the compact spiral character of the core is clearly visible.



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