

Potential Exploration and Use of Miniscale Lift Patterns

By C. E. Wallington

A contribution to the 18th OSTIV Congress at Hobbs, USA 1983

1. Introduction

Early glider pilots had one basic soaring problem: How to stay up. Their demands on the meteorologists were slight. As glider and pilot performance improved, more extensive cross-country and competition soaring became possible—but with considerable dependence on wind and weather. Hence the close involvement of the meteorologist—primarily to advise pilots and particularly task setters on the meteorological feasibility of proposed courses.

As weather science was new to most pilots it was not difficult for the meteorologist, in collaboration with exceptionally experienced pilots, to extend his own science and the pilot's soaring horizons. For both meteorologist and pilot the 1950s and 60s brought substantially new knowledge of thermal structure, thermal and cloud streets, line squalls from convective storms, mountain waves, sea breeze fronts, and various locally named phenomena.

The meteorologist also improved his techniques of analyzing and forecasting miscellaneous mesoscale patterns of weather systems. During this era glider and pilot performance also made substantial progress, but I think the metman came out a little ahead. He now had a substantial store of new knowledge, and even some to spare. Although weather forecasts could not, and probably never will be, entirely accurate, the gliding metman had developed the techniques and capability of forecasting at cross-country and competitive gliding events with enough precision and reliability for current glider performance.

Since about 1970, however, it is the glider designer and glider pilot who have leaped ahead. The modern pilot in his super high performance sailplane of the eighties has to get somewhere fast if he wants to win a race or break a speed or

distance record. On many a soaring day he does not need to stray far away from course to find adequate lift. And, perhaps all too often, signposts to such lift are gaggles of his rivals in the sky rather than thermal clues coded in the ground. When he is in lift he mustn't waste time circling in it too long; he must be on his way. So, although he still uses current well-known soaring techniques, he also tries to dolphin-soar through successive thermals and weave along even tenuous strands of thermal streets or any other apparent bands of lift that may enable him to press on to his next turn point or goal. When he starts a long-distance flight he may have to set off in thermal or orographic lift conditions that even now would be considered pitifully weak, or in weak anabatic or hill lift conditions

which may also harbour radical wind changes with height. And his goal, approaching which he may again have only weak soaring conditions, may be 1000 km or more from base.

High-speed soaring is not the only path to fresh achievement. There is likely to be a growing body of lightweight-sailplane enthusiasts who, like the hang glider pilots, will also aim to stretch their horizons of achievement by learning and using the fine detail of wind and convection patterns appropriate to their end of the soaring spectrum. Thus the modern achievers of the soaring world will want more detailed information and prediction covering a wider range of phenomena than the meteorologist is currently prepared for. The meteorologist's repertoire of thermal, wave and mesoscale phenomena is no longer ahead of the advanced pilot's requirements. What can the metman contribute towards further advancement of soaring techniques? In this paper my purpose is to call attention to some elements of meteorological research and development likely to feature in fresh studies and concepts of soaring meteorology in a miniscale range some-

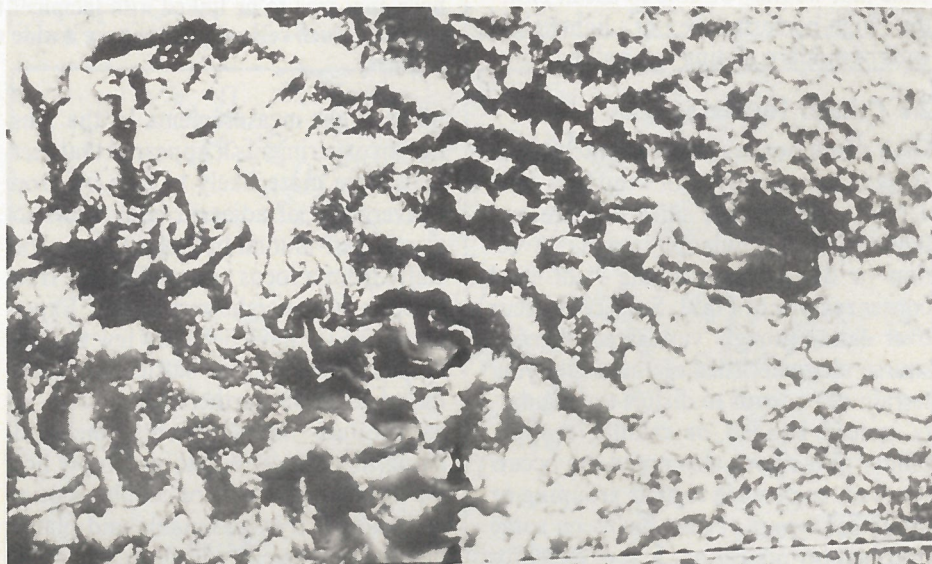


Fig. 1 High-resolution photograph of cloud patterns including two "Karman Streets" or vortices (left), cellular convection (left corner regions) and a few thermal streets with breaks and irregularities (upper central region). Soarable lift is probably closely linked to the locations and shape of these cloud lines. The general airflow is approximately along the main direction of the thermal streets. The Karman Streets comprise vortices streaming downwind from two mountain peaks indicated by the black dot in the sketch. Close to the mountain the vortices alternate in direction of circulation. They gradually disappear downstream—probably because they are destroyed by broader scale features of the airstream.

where between the new well-known mesoscale phenomena and the so-called random turbulence. The chances of predicting small-scale patterns in detail are remote, but if we find that some distinctive patterns or lift in this range of scale occur, then the advanced soaring pilot will have a better chance of recognizing and using them in the air.

2. The Chaotic Coherent Atmosphere

When we measure meteorological variables we always deal with averages over time and over distances, areas, or volumes. Maps of some suitably chosen averages show familiar patterns, which we treat as coherent recognizable entities. We usually describe smaller-scale phenomena such as turbulence or eddying as random motion, and mesoscale features that we cannot explain are still sometimes viewed as anomalies super-imposed on a steadier more explainable flow. But the distinction between coherence and chaos is subjective. As analytical meteorology progresses, more elements of flow patterns have been shifted from the chaotic or anomalous class to the coherent, explainable category. Let us look at some of the pointers to discerning more of the small-scale coherence that we may be able to use at either the high-performance or lightweight ends of modern gliding technology.

2.1 Cellular Thermal Systems

High-resolution weather-satellite photos show that in a fairly light wind flow over a fairly uniform sea surface, there is a tendency for a cellular pattern of convection to develop—as in the right-hand corner regions of Fig. 1. Such cells occur over land, though variegated thermal source characteristics of the underlying terrain often tends to distort the regularly spaced banded or cellular motion. Glider pilots have also noted the occurrence of small-scale regular grouping or cyclic behaviour of dust devils on some dry thermal occasions. A few meteorological experiments have been made to look into the actual rather than statistical structures of eddies. In one type of experiment, at Porton Down in England in 1965, wind speeds and directions measured by a line of anemometers set up at intervals of about 10–20 meters at two

meters above the ground were recorded at 10-second intervals. Numerical data processing was used to extract and draw patterns of horizontal eddies of sizes between 20 and 200 meters that crossed the line of anemometers. Similar experiments with anemometer spacing of about 100 meters were subsequently carried out at Hay in Australia. The character of the eddy patterns discovered were typified by that sketched in Fig. 2. Air-flow directions in the eddies appeared to occur in cells or polygons. From sail-

2.2 Thermal Streams and Streets

Thermal streams from persistent thermal sources and streets in convection orientated along wind are already well known. Like convection cells in cold air-streams over not quite so cold sea surfaces, thermal streets are particularly well formed if the underlying sea or land surface is fairly uniform. Over land their length and regularity of spacing tends to be broken by the thermal imprint of the underlying variegated terrain. The com-

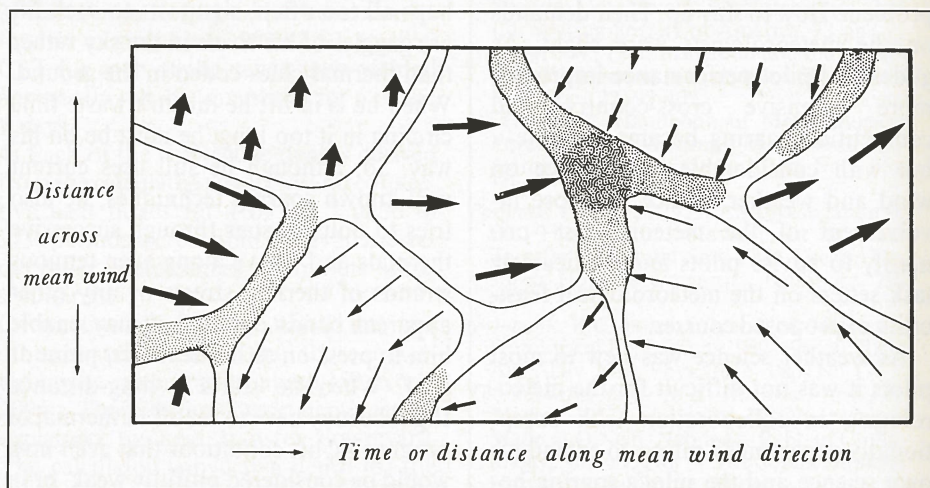


Fig. 2 A schematic example of eddy patterns found in a few experiments carried out in wind flow a few meters above ground level. Shading indicates convergence zones (which have appeared to be linked with incipient thermals) between cells of distinctive eddy directions. Such cells appear to have a wide range of sizes from tens to hundreds of meters at least.

plane flight measurements in the Australian experiments it appeared that thermals were more likely to take off from convergence of adjacent eddy flows towards their mutual boundary, and especially from a focus or convergence from three or more neighbouring cells. Experiments so far have been too few to draw firm conclusions, but sufficiently interesting to merit further study (with air temperature measurements included) along these lines. We do not know how far upwards this type of cellular motion will extend. It is reasonable and plausible that some cells will decrease in size and disappear with height—leading to fewer larger cells aloft. Modern hang gliders, that can be soared in very narrow thermals and landed on very small patches of ground, may be used to explore the low-level structure more directly.

In combination of thermal street, thermal stream and possibly low-level cellular eddy structure appears to produce approximately along wind bands of lift that are broken and shift their cross-wind position and spacing in the neighbourhood of thermal downwind streams from dominant ground. The central towards lower-right region of Fig. 1 shows an example of combined cellular and street patterns. Dry thermal patterns would almost certainly present similar and possibly more coherent patterns—if they were visible. Advanced pilots already appear to envisage and use elements of such patterns, in a somewhat ad hoc spontaneous way, to minimize unnecessary circling in a race.

2.3 Wind Shear in Convection Layers

Up to the mid-1960s it was widely believed that the vertical mixing of air

within a vigorous thermal soaring layer would substantially reduce any wind shear that may have existed before convection developed. However, there is now abundant soaring experience indicating the not uncommon persistence of such shears. When a wind shear exists, the whole thermal soaring layer becomes a sandwich of two sub-layers—or possibly more, if there are other shears. The strength, size, spacing and coherence of the thermals differ from one layer to the other—usually the lower layer is the more difficult to use—and to thermal up across the interface it is necessary to make a positive shift of position within a thermal in the direction of the wind shear. Wave-and-shear theory suggests that such shears are likely to impose elements of wave or banded structures in the lift and sink patterns. But such patterns are likely to be visible only in the relatively rare occasions when cloud forms only in wave or rotor crests.

2.4 Thermal and Shear Waves

Thermal waves formed when thermal streets appear to act as a series of mountain ridges triggering off waves in an upper flow with a cross-street wind component are documented and have been used for wave-soaring climbs up to over 20,000 ft. Shear waves which appear from time to time in association with marked changes of wind with height but not necessarily associated with underlying thermal streets are less known and less used. These shear waves are usually moving waves and sometimes appear as precursors of an approaching front. They seem to be indicated mostly by lenticular clouds at medium cloud levels. But, of course, we have scarcely any information on moving shear waves that are too dry to produce wave cloud. Pilots encountering such invisible moving waves have recognized the lift as the smooth wave type, but have not yet been able to keep track of their movement for very long.

2.5 Pseudo Sea Breeze Fronts

Sea breeze fronts are also well documented and used, but pseudo sea breeze fronts occur much more often than is generally realized. Pseudo sea breeze fronts can be produced in any situation

that creates a temperature gradient across a fairly distinctive line or transition zone (corresponding to a coastline). The temperature gradient may be between sunlit ground bordering either a sharp edged cloud cover or thick smog zone preventing the sun's radiant heat from reaching the ground. Or the transition zone can be between a plateau bordering air (over the adjacent lowland) which is colder at the level of the plateau than the solar heated air over the plateau itself. Or between airflows that have converged after following different paths across or around mountainous terrain. Such a temperature gradient has the potential for creating three-dimensional motion in and near the temperature transition zone—whereupon the transition zone which can become self-propa-

gating, gets narrow—and moves off as a mini-front towards its warmer side. And, like a sea breeze front (or any other front) the pseudo sea breeze front is likely to persist until well after the initial cause of its formation has ceased. Conditions suitable for the creation of a pseudo sea breeze front are mainly: differential heating across a line, general wind flow approximately along rather than across the line, and convection on the warm side of the line to spread the heat up to at least a few thousand feet. Often pseudo sea breeze fronts have visible markers such as convergence of smoke plumes at ground level, haze on one side of the front, a line of cumulus or wisps of curtain like cloud; but sometimes they are invisible. Undoubtedly, many of them are not recognized or used as soar-

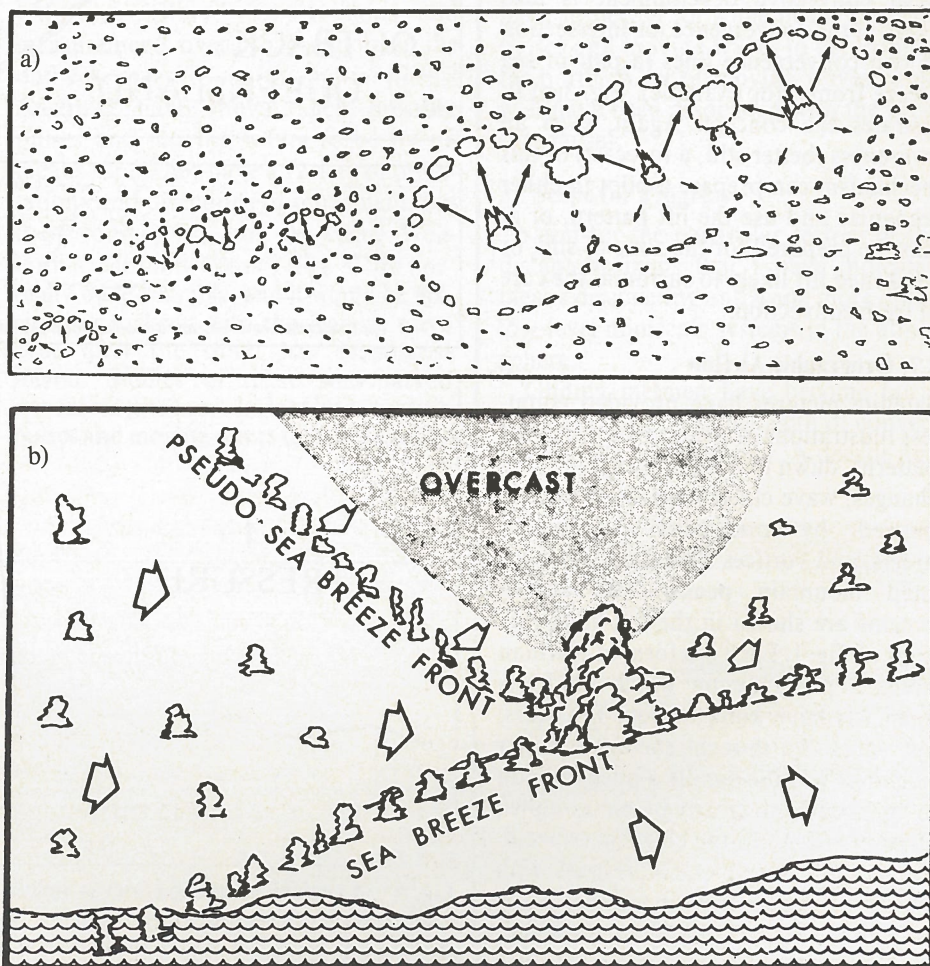


Fig. 3 Convergence or intersection of convergence lines (as illustrated here for intersecting lines from (a) thunderstorm downdraughts, and (b) for a sea breeze front and pseudo sea breeze front) tend to be locations for fresh convective developments. Plan views of cumulus clouds, winds and convergence lines and zones are denoted by schematically sketched clouds, arrows, and larger clouds respectively.

able lines of lift. Here again, the meteorologist's task is to look more determinedly for them; he may not have adequate means to predict them but he must at least help the pilot to be aware of their nature so that the pilot can recognize and use them opportunely in the air.

2.6 Convergence of Convergence Lines

For the past twenty years at least it has been known that when two or more convective storms exist, the most likely localities for fresh storm development or propagation are in the convergence zones of flows of cold air spreading out from downdraughts below the storm cells. Satellite cloud pictures have confirmed this concept and illustrated more detail, like that sketched in Fig. 3(a). Satellite pictures have also confirmed that fresh convective development is also likely at the convergence, or intersection of two convergence lines (a pair of sea breeze fronts, for example). Fig. 3(b) illustrates the concept. Again, even an awareness (better still, a forecast) of this mechanism can prepare a pilot to either recognize and use the lift pattern, or at least be prepared for the zone of sink or weakened lift likely to surround the core of fresh convection.

2.7 Orographic Airflow

Satellite pictures have provided countless illustrations of details of wave cloud patterns, dawn to dusk orographic cloud changes, wave cloud patterns seemingly sheared by orthogonal convection streets, and vortices streaming from isolated mountain peaks. Two vortex streams are shown in the left-hand sections of Fig. 1. Each is a form of Karman street, a phenomenon which fluid dynamicists have known about for years, but which we thought (before weather satellites) was too simple a phenomenon to be revealed so clearly by our complex atmosphere. As in the classical concept, the mountain peak sheds vortices with alternate directions of circulation. However, in the example in Fig. 1, the clockwise rotating vortices appear to weaken as they move downstream, while the counterclockwise whorls increase in size. This difference between the development of two sides of the street is no doubt related to the wind and temperature pro-

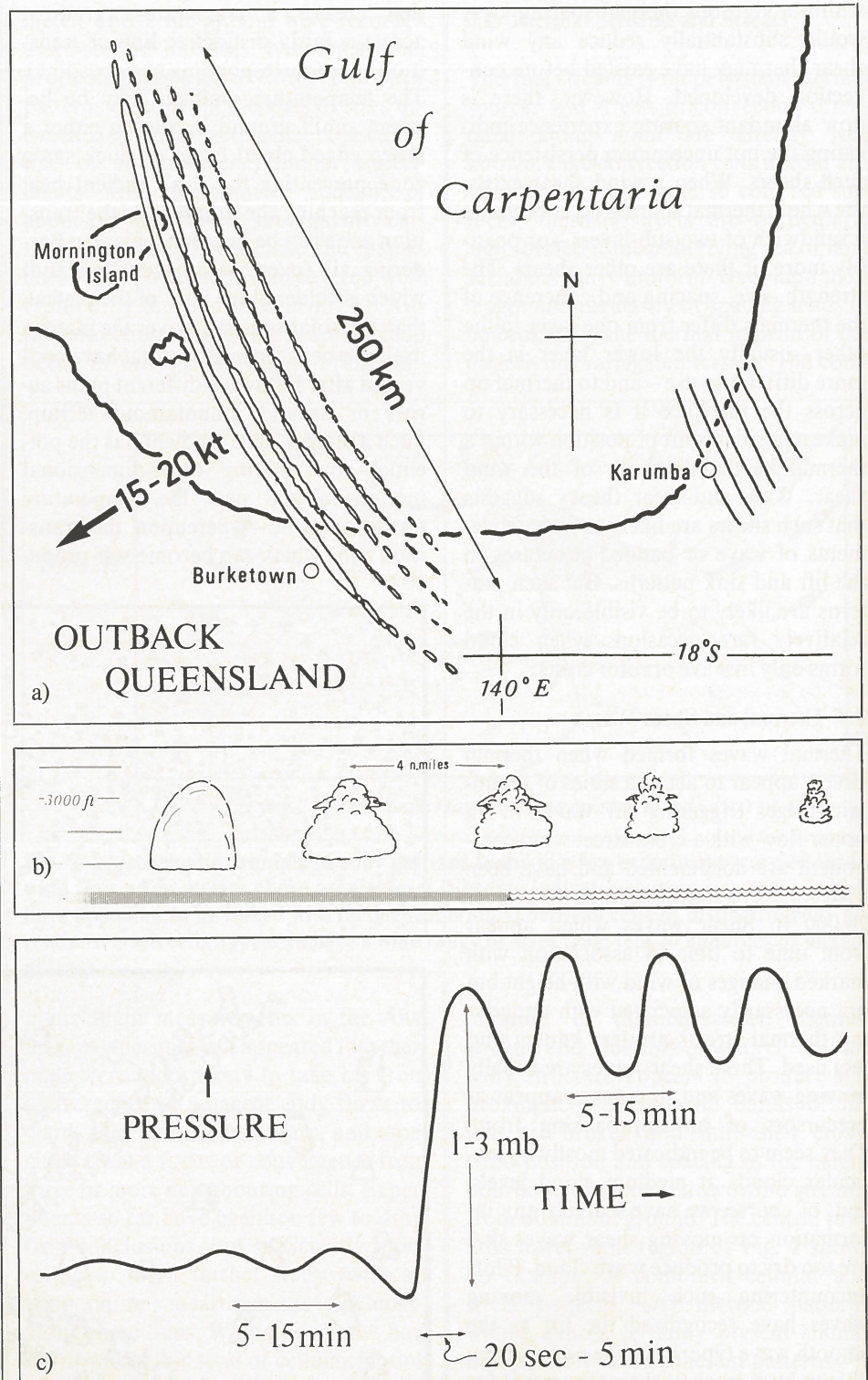


Fig. 4 A typical Morning Glory is visible as bars of wave cloud moving at about 15-20 knots towards the southeast, as sketched in (a). As in this example (11 October 1981) the leading bar often has a well-formed wave shape while the subsequent bars tend towards being more cumiliform. The lines sketched through and west of Karumba indicate typical positions of the waves in the early hours of the morning. The waves usually reach Burketown at or soon after dawn. It is not uncommon for the set of waves to have more visible bars of cloud at Karumba than at Burketown. (b) shows the cloud SW-NE cross-section near Burketown on 11 October 1981, and (c) illustrates characteristic pressure changes associated with the waves.

files of the broad airstream. But, whatever the detail is in this particular illustration, we see another example of coherence, and almost certainly bands of lift, in which might have been expected to be a chaotic disorganized flow. How many other examples have not yet been revealed to us because they are cloudless?

2.8 Moving Waves and Pressure Pulses

We have known for a long time that there are moving as well as standing waves in the atmosphere. Shear waves have already been mentioned as an example. But there is evidence for waves that propagate as pressure pulses. It is far from easy to study moving waves. You have to move with them or make sure that you and your instruments are in their path. And, of course, if the air is too dry you won't even see them. However, we have found some moving waves that are often so well marked by wave clouds that we can see them coming and, if we're quick, investigate them before they're gone. This species of moving wave is found in the tropical north of Australia, where early morning conditions are often suitable for pressure pulses and waves at low levels to radiate like ripples from a source. Sources seem to include various phenomena such as sea breeze fronts, sudden downdraughts from deep convection clouds and possibly large-scale diurnal heating and cooling effects. One characteristic set of such waves appears to be triggered by the sea breeze front which often forms on the eastern coast of the York Peninsula. The front usually penetrates inland, reaching the central axis of the peninsula towards midnight—and, through a mechanism which is not yet entirely clear, appears to produce a pressure surge of one, two or even three millibars. The pressure pulse propagates at about 15–20 knots across the western half of the peninsula and the southeast corner of the Gulf of Carpentaria, reaching Karumba in the early hours of the morning, and Burketown soon after dawn. There is usually a low-level stable layer or temperature inversion over the Gulf and the nocturnally cooled land at the time, with calm or very light winds. Air at low levels oscillates up and down as the pressure pulse

passes and, if the air is humid, the phenomenon is visible as a series of several bars of low wave cloud. Often 200–400 km long and about 5 km apart, the waves move at the speed of the pressure pulse through rather than with the general airflow. Fig. 4 illustrates the pattern. Surface winds increase sharply but temporarily at the arrival of the wave clouds, particularly at the leading bar. Very long bands of lift and sink, sometimes as much as 1000 ft./minute between 500 and 3500 ft. over the land and sea have been found in these waves. As the waves travel inland the wave clouds disappear, but there is evidence that the pressure pulse and moving waves persist further inland. Because these wave clouds are dramatically colourful in some localities at sunrise the phenomenon is called the "Morning Glory". Observations and measurements over broad regions in the outback areas of north and northeast Australia have shown such pressure pulses and moving waves to be by no means rare. They have a variety of orientations and directions of movement, but their sources are not yet clear. Well-formed Morning Glories (Fig. 5) are normally wave-soarable, and it would be fascinating to keep with the leading wave even after the cloud has evaporated inland. Studies of these well-marked waves will give more insight into pressure pulses and moving waves that are less dra-

matic but more frequent than generally supposed in other regions. Having watched an ordinary barograph more carefully than I ever did before flying in a Morning Glory and witnessing the pressure surge, I have no doubt that many a real pressure jump on simple standard barographs have been dismissed as due to instrument lag, friction or jolting.

At a recent Sports Class Championships at Leeton (400 km inland from the S.E. corner of Australia) I noted a sharp pressure jump of between 0.9 and 2.3 mb at between 07.45 and 09.30 local time every morning of 10 consecutive days of clear-sky anticyclonic conditions. As there was almost no cloud over the whole continent for much of the time, it is likely that the pulse was related to large-scale diurnal heating and cooling—as we have suspected for some of the pressure pulses and moving waves in the tropical far north. A set of moving waves could well have been associated with the pressure pulses.

3. Scope for Progress

To aim for the particular sectors of the distant horizons that I have indicated means discovering and using more of the low-level miniscale systems in the atmosphere.

Gliding metmen have become fairly good at forecasting the depth of convection during a contest day. A decade ago



Fig. 5 The bars of Morning Glory wave and cumiliform cloud approaching Burketown on 11 October 1981.

development and use of a simple linear relationship between thermal depth and thermal strength was a significant advance, but it is now too coarse for current demands. We need to develop usable relationships between strengths of thermals and other significant factors, such as wind and humidity profiles and rate of change of convection depth. We also need to improve our understanding and forecasting of thermal size, spacing and the variation with height of these factors.

The metman can also predict thermal or cloud streets with useful reliability, but how can he help the advanced pilot who wants to maximize soaring use of such patterns as those depicted in Fig. 1? Although the metman could not forecast the detail, he could aim at a goal of predicting useful characteristics of such patterns. He could aim to answer such questions as: Would a pattern be primarily composed of cells, clusters or streets? What would be the relative tendencies

for these varieties? What typical spacing or scale would apply to elements of the pattern? What would be the likelihood and characteristics of Karman street vortices in lee of mountain peaks or hills? Even qualitative answers to such questions would be of great value to the advanced pilot.

Provided terrain and communication factors are satisfactory there appears to be scope for soaring appreciable distances along the leading wave of a pressure surge. With a not unduly expensive network of microbarograph stations a metman could probably determine and make a short-range forecast of the orientation, speed and position of a surge. Such information would give a pilot a reasonable chance of staying with the moving wave. It may be possible for the line of the main surge to be detected in the air, but it is not yet known how much the amplitude of the pressure oscillation varies with height. The low-level type of moving waves and pressure surge are fundamentally associated with a low-level temperature inversion or stable layer. Thus, as the day's heating proceeds the moving wave will tend to collapse as convection develops, but there is a chance, and maybe a probability that the transition between moving wave and thermal soaring conditions may contain weak thermals but just enough to enable an advanced pilot with a modern sailplane to bridge the transition (having already covered two or three hundred kilometers in the wave).

Field and flight studies in the buildup of more experience in miniscale meteorology will need more measurements, processing and recording of data. Here there is ample scope for the metman working with an electronics colleague to develop inexpensive microprocessing units tailored to his particular requirements. Such processing is already enabling small atmospheric research departments as well as large institutes to equip motor gliders for high-quality research flying. Microprocessor aids to pilots in flight could well include units for calculation of air density from temperature and humidity sensors as in some thermals at mid levels of the thermal layer temperature decreases while humidity increases.

On board microcomputing may also be developed for in-flight objective analysis of flight data to devise the likely orientation and axis of local lift.

We must not forget the paramount importance of individuals in gliding. A problem with many an organized research project is that field work, including research flights, is normally limited by cost and available time. Of the thousands of glider pilots who fly for personal enjoyment and competition, however, a proportion of them encounter meso- or miniscale phenomena by chance, and a fraction of these pilots (including gliding metmen) note and pass on their experience or impressions. This process has guided research progress in the past and still provides scope for the future. The growing numbers of enthusiasts in air sports (ballooning, hang gliding and microlight aircraft flying as well as our own gliding) and meteorologists are gradually finding more of the small pieces in the miniscale jigsaw.

It's not clear yet how these small pieces will fit together, but several likely looking links suggest that some useful and stimulating progress will be made to extract even more soaring speed, achievement and fascination out of the atmosphere.

Summary

In the 1950s and 60s substantial advances in gliding meteorology, particularly in the mesoscale range of phenomena, were made by meteorologists and sailplane pilots. Subsequent advances in sailplane performance and pressure for greater achievements call for more detailed knowledge and understanding of patterns of lift and sink in a submesoscale range. Miscellaneous items of past and recent research coupled with detail in satellite cloud pictures suggest distinctive elements of miniscale phenomena likely to feature in new soaring meteorology developments. Such elements include convection cells, clusters, mixed thermal streets, streams and cells, cellular eddy structures, pseudo sea breeze fronts, convergence of convergence lines, moving waves and pressure surges.

Zusammenfassung:

Mögliche Untersuchung und Ausnützung kleinräumiger Aufwindströmungen, von C.E. Wallington, Canberra, Australien

In den 50er und 60er Jahren wurden durch Meteorologen und Segelflieger beträchtliche Fortschritte in der Segelflugmeteorologie gemacht, vor allem was den Bereich der mesoskaligen Phänomene mit charakteristischen Längen zwischen 2 km (Meso- γ) und 2000 km (Meso- α) anbetrifft. Die ständige Verbesserung der Segelflugzeugleistungen sowie die immer grösseren sportlichen Zielsetzungen erfordern zunehmende Detailkenntnisse und Beachtung von Auf- und Abwindgebieten auch in kleinräumigeren Abmessungen unter etwa 2 km. Verschiedene Untersuchungen älteren wie auch jüngeren Datums in Verbindung mit Auswertung von Satellitenbildern lassen erwarten, dass bestimmte kleinräumige Vorgänge zu neuen Erkenntnissen der Segelflugmeteorologie führen könnten. Solche Vorgänge treten auf bei Konvektionszellen, Wolkenclustern, gemischten Strukturen von thermisch erzeugten Wolkenstrassen, Strömungsvorgängen und Zellenbildungen, zellularen Turbulenzstrukturen, Pseudo-Fronten bei Seebrisen, Zusammenlaufen von Konvergenzlinien, wandernden Wellen und Druckwellen.