An Analysis of the Structure of a Stabilized Cold Front

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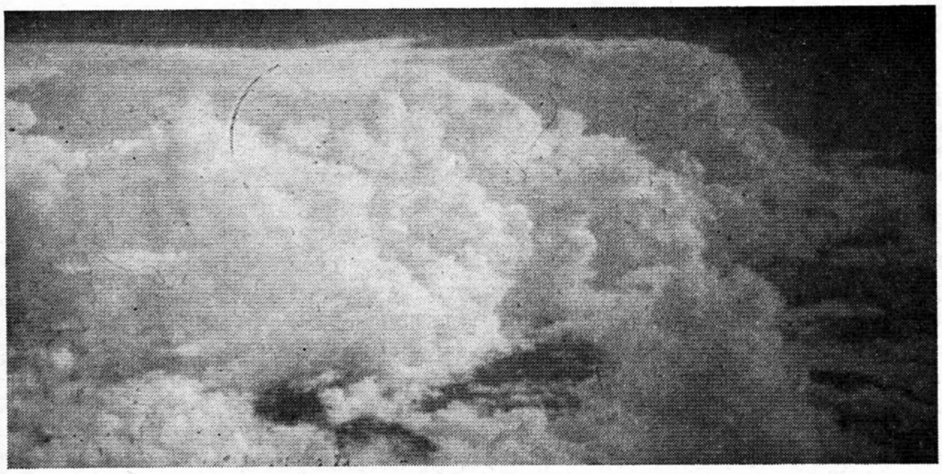
Paper read at XIth OSTIV Congress, Leszno, June 1968

On consideration of my title I am now conscious that a Stabilized Cold Front may be far from a properly understood term for the phenomenon I wish to describe. The stability implied is not in the vertical structure. Indeed, the type of front discussed is distinguished by vertical instability leading to cumulonimbus and thunderstorm activity of at least moderate intensity. Rather stability is meant in the sense of persistance of the horizontal pattern of the front and it seems likely a persistance in time and, to a degree, in intensity over periods of hours or even days, if not always persistance in geographic position. I am conscious that others are feeling their way to an understanding of this type of front which I do not attempt to define here except by general description. It may be for them to define and find the proper name.
It is casually thought that the commercial pilot merely avoids the major fronts, but this is not always possible – the divergence alone cutting seriously into his fuel reserves. Twenty-five years ago when long commercial flights were made with the Dakota aircraft, if one were to meet a tropical disturbance line after the "Point of No Return" this had to be tackled. Already experience had been gained, sometimes at great cost, and the method used to tackle it followed roughly these lines. The darkest part of the storm was selected and the aircraft, fortunately equipped with nearly waterproof ignition harnesses (they were subjected to the full intensity of the rain) was flown direct at the storm halfway between the lip of the cloudfree vault and the ground and it continued in this fashion come what may. What did come as a rule was a very rough spell as one passed the lip and then fairly calm conditions in the cloudfree vault for we were near the ground, perhaps only 100 metres above the trees, then all hell let loose as the rain was met. Hell continued for some ten minutes. Fortunately, even small hail is rare in tropical squall lines. In more temperate latitudes there was often a high degree of polish and no paint at all on leading edges. Of course, one did not notice this when the aircraft had rubber de-icer boots. They usually took it with little complaint.
There were many reasons for this method. The low wing loading, the lack of oxygen if one were carried inadvertently from medium to high altitudes, and the generally lower vertical velocities low down in the major up and down draughts were some. Slow rates of roll and the need to avoid the considerable centre of pressure movement with greatly fluctuating airspeed and angles of incidence were others. In the next generation of four engined unpressurised transports one followed roughly the same technique – as the control forces were larger they were just harder work. But with no radar one could find oneself inadvertently in the top right hand corner or back of the cloudfree vault as it were and by closing the throttles exit could be made visual under the lip without exceeding V_{MO} by much! Many an innocent looking rain squall approached from behind concealed a frontal line of considerable energy. By that time, 1948, the exceedingly strong lift in the arch above the cloudfree vault – sometimes as much as 25 to 30 metres per second – was recognised.
Having satisfied myself that the methods in use worked, I began to look around for reasons, making an analysis of the obvious characteristics of the storm.
It was clear that very strong lift existed on the arch above the vault and indeed a year or two later, say 1954, I did more than a hundred miles at about a hundred knots above my normal cruising speed flying visual just above the arch of a Saharan line squall, in a DC 6. The face of such a storm consists of a great series of columns nearly touching, partly masked by entrainment cloud, with the lift apparently concentrated in the centres of these columns above the arch. Above this are bands of horizontal cloud, thin like cirrus nothus and, depending on the strength and direction of the upper wind, an over-arch of cirrus or the bubbly cauliflower of cumulus congestus far out of reach above.
About this time a paper was read at the Kronfeld Club on the generation of cumulus, showing that in stable inversion conditions they rose and died in a pattern closely resembling that of the cells of a honeycomb. It seemed to me that the multiple structure of parallel columns above the arch of a cold front might well be the side face of such a honeycomb structure two or three or more cells deep.
Another very puzzling feature was seen in the tropical disturbance line. If the wind aloft were light, the air seemed to flow up and into the storm from below and in front, up through the tropical easterlies in middle altitudes and then proceed onwards minus its water, expanded but with its momentum unchanged, towards the east.
More of this later, but it will be evident that if a front is not substantially stable, undisturbed by orographic features, it is exceedingly difficult to make understandable observations, especially with the care of a thirty metres aluminium tube strapped to the seat of one's pants to be considered as well.
In 1951 the four-engined pressurized transport arrived, cruising at middle altitudes. It was evident that while the aircraft had increased capabilities in power-weight ratio, watertightness, stability and increased longitudinal and lateral control, it was exceedingly undignified to descend from a majestic altitude of five thousend metres to a mere five hundred and expensive in fuel to climb back up. A new method was needed but the Thunderstorm Research Centre in Florida made it clear that it was at middle altitudes that the largest draughts were encountered and in the temperate zone a tendency towards middling hail and high electrical content was evident there also. A compromise was needed, say a passage at about 2,000 metres.
Accordingly a method developed of approaching the storm, again at right angles, but above the lift of the arch and aiming to penetrate the darkest parts between the columns. However, in order to follow the honeycomb path and avoid the major up draughts, the aircraft was aimed straight at a column. Then, before entering, turned sixty degrees left or right, and as the dark column junction was neared, turned sixty degrees back again and so into the storm substantially at right angles, the duration of the diagonal leg being noted. In this way the size of the cell for the day was gauged, and this pattern of turning and timed news followed through the equal line.
Results were varied; sometimes by continuing this timed honeycomb pattern a smooth passage was accomplished; sometimes again all hell broke loose. Perhaps I had not got it

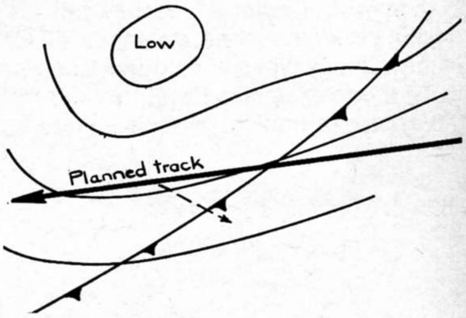
1 Cold front over mid-Western plains, U.S.A. Location approx 45° N 97° W.



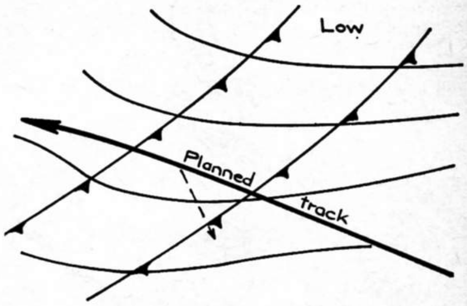
2 Cold front over Pacific Ocean. Location approx 34° N 170° E.

quite right as yet! But of course it was better controlled! Attitude flying in turbulent conditions, stridently recommended by American Airlines and quietly fostered by other major airlines and Air Forces, gave me a better understanding at least of what to do on instruments.
Then in 1958 came the jet transport and a new zone of contact with the storm, combined with a prohibitive penalty for descent and climb. A new series of problems came up. On half the occasions the structure of the storm was largely masked by the overhanging cirrus anvil and, with the swept wing, a diminished, but not dangerously diminished control capacity was evident. The swept wing aircraft had a roll-yaw coupling that had to be unterstood and for those who had only learnt to fly comparatively recently one old problem was revived, the variable incidence tail plane. But against these problems was an overwhelming advantage. Airborne radar, which we had longed for since the war, was with us in civil form.
At about the same time a great study was made to understand the structure of the major thunderstorm. Frank Ludlam's paper and the work of the Severe Storms Project showed where the areas of lift and down draught were situated in an individual storm and indeed Ludlam showed air coming in at the bottom left hand corner and much of it going out at the top right hand corner – at least it did in my copy of the Journal of the Royal Meteorological Society. This confirmed observation, and when it came out at the top left hand corner it was clear that more severe conditions could be expected. May I emphasize that it is clear that not everything that goes up comes down – at least not close at hand.

The result of this work and everyone's anxiety to update and expand their knowledge of radar interpretation was to treat each front as a series of thunderstorms standing side by side and to go through the gaps. But a heavily loaded jet transport has a limited ceiling, often ten to eleven thousand metres and these gaps had to be tackled on radar, for cloud often extended three thousand metres or more above the aircraft and on occasion a rough passage was found. But as radar serviceability improved and also, later, radar definition, and when one's interpretation had been bettered by considerable experience of what various types of echoes entailed in the upper part of the troposphere, it became evident that many comparatively stable fronts had a definite large scale horizontal structure. It is this structure that I wish to discuss
Figures 1 and 2 show two cold fronts, one in the Middle West of the U.S. in August '66, and the other in the Pacific in the fall of '67. Both these fronts had persisted for several days, that in the Middle West had remained in the same position for that length of time.



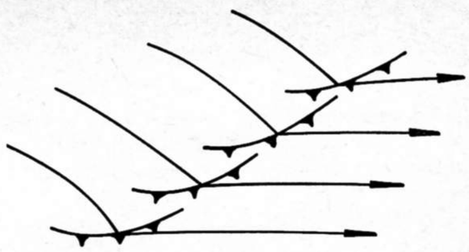
3 Synoptic situation for front of fig. 1.



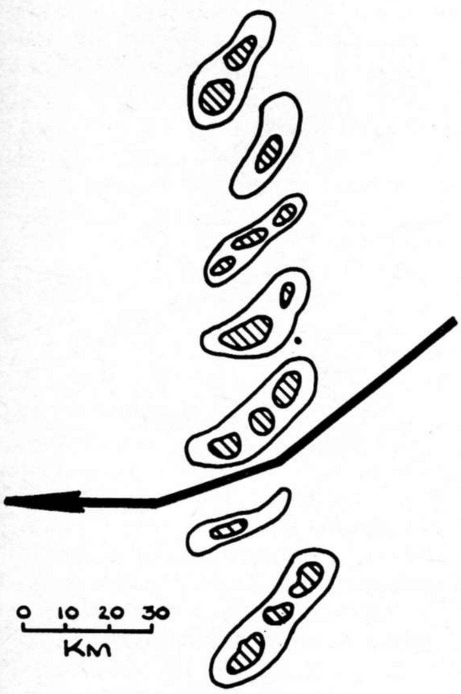
4 Synoptic situation for front of fig. 2.

The surface synoptic situations were approximately as detailed in Figures 3 and 4 respectively, in which the track lines are shown by solid arrows and the relative bearings of the photographs are indicated by the dotted arrows.

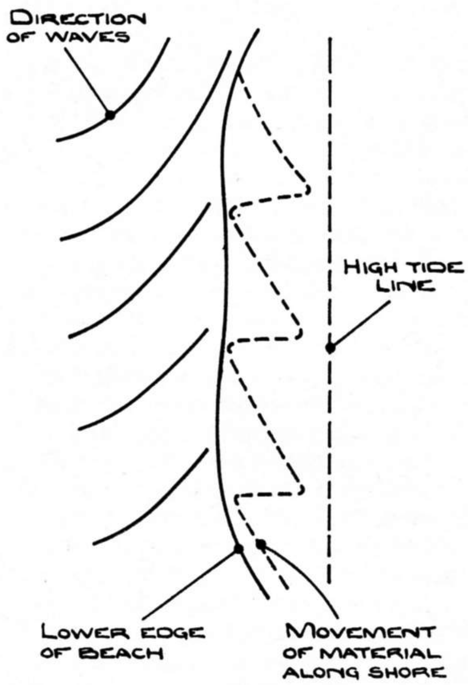
Figure 5 gives an idea of the picture on the radar screen upon which avoiding action was taken on these occasions. In each case a turn to the left of about 40 degrees followed by a stepped return to track, 20 degrees at a time, allowed the aircraft to pass through a comparatively smooth gap. Again, in each case power had to be increased to maintain height and airspeed; the height lock has to be taken out and the aircraft flown attitude on the auto pilot in more than light turbulence, and airspeed maintained at the optimum turbulence speed of 280 knots (for Boeing 707) in the firm down-draught conditions.
It will be seen from Figur 5 that the front consisted not of a honeycomb cell arrangement but of overlapping kidney shaped cells or flakes each composed of two or three more or less circular cells contiguous to each other and separated by a gap of some ten or fifteen kilometres. The tops of the circular cells push their way dynamically through the tropopause and then surge out and down. This particular structure occurs not only in severe thunderstorms but is not uncommon in smaller sizes and intensities at nearly all altitudes where single cells penetrate strong inversions.
With improved radar this kidney cell type of structure appears commonplace in many types of cold frontal activity. If one examines the structure of the arms of a tropical cyclone either by radar or by satellite photography this type of overlapping plate structure is clearly seen in individual arms. In the stabilised cold front that often persists for days in the western Atlantic along the Gulf Stream between New York and Bermuda it is again evident. Here there is often an area of general rain behind the front where a honeycomb structure may be thought to be found but on the front itself, often lying almost north-south, the face consists of overlapping flakes perhaps ten, fifteen or even thirty kilometres in lenght and lying Ne—SW.
A tropical disturbance line, varying slightly in structure depending on whether its crown lies in the equatorial easterly jet or as it sometimes seems in the high westerlies of the subtropics, again shows this overlapping flake structure with the added interest that the flakes reverse in their direction of overlap N and S of its central progress line — but that is another story.
Perhaps a tenable analogy of the structure is that of the wave formation out from the beach when a swell not parallel to the coast line is proceeding inshore, Figure 6.
What is pertinent is the way the flakes overlap. One has to visualise each flake as an individual cold front with the characeristic baroclinic gradient and wind structure. In the northern hemisphere this structure comes out clearly as in Figure 7.


7 Synoptic diagram for a front of the type shown in fig. 5.

In the southern hemisphere the opposite is seen and was seen on radar by the author as recently as May 9th, 1968, south west of Canton Island in the South Pacific. It could be contended that beam width alone could give such a structure as an illusion and this is granted. However, modern radar has narrow beam widths, and the fact that one can go right up to an individual feature under the increasing magnification of decreasing distance combined with progressive transfer from the 150 to the 50 and the 20 mile scales (240, 80 and 32 km respectively), can confirm beyond doubt that features perceived are real, persistent and individually identifiable.
The question then arises as to how a glider pilot might make use of the power and structure described and portrayed, and avoid other features that research and experiences tell us are there. With small experience in gliding I feel it would be improper for me to make more than the most general statement. Of course the glider pilot knows very well how to use the lift above the vault and arch, indeed it is more than enough. Perhaps the best course is to detail areas of apparent difficulty and leave those skilled in gliding to produce a constructive solution avoiding them. The points raised are not only from the kidney flake hypothesis but concern as well difficulties to be expected if parts of the storm other than those that clearly give lift are penetrated. Only small areas of a storm give smooth lift. The spaces between the kidney flakes are, while smooth or comparatively so, unquestionably areas of sink.
The central cells lead vertically to areas of severe turbulence and outflow towards areas of sink.
The region around the freezing level is highly electrified and in a glider one needs dark glasses, nerve and static wicks of considerable efficiency to tackle its interior.
The region around —36° C has much free water in it which can ice the aircraft and, unless it is waterproof, penetrate and freeze on the controls.



5 Arrangement of cold front showing kidney-shaped flakes.



6 Wave formation on beach with swell proceeding diagonally inshore.

This free water has been found in areas even with considerably lower temperatures in the tropics.
As positioning around areas of lift must be visual the cirrus overhang is a servere impediment and furthermore, in the rather severe storms, underneath it can be the area where severe hail can be found.
Electrical effects, apart from their morale value (dealt with earlier), can interfere with properly bonded but delicate electrical apparatus, and create continuous and undesirable noise to blank out VHF radio, and the shock wave from a lightning bolt has been known to stall two engines on a Comet II.
Perhaps the only simple area is that on the building side of the front where it rises into clear air. But how to reach this area from the arch if the structure is such that the general direction of advance is on the opposite side from that on which the front is primarily building is a question I would not care to tackle.
Experience shows that considerable areas of lift exist in clear air around the front. Above the arch and the forward lip this is often very strong and it may be continued in the entrainment air being drawn into the front of the columns.
Towards my conclusion, I should like to emphasize that the type of front described is uncomplicated by disturbing orographic features and by intensification by such a factor as that causing the night thunderstorms of the Middle West, upper air cooling. Least of all is it meant to describe the type of extreme intensification on a stabilised or persistant front represented by the type of phenomena known as the "Wokingham" storm, the growth and existance of which is a rare but ever present danger to those who must tackle a cold front without radar.
Nor would I wish to claim that this is more than an attempt at a start at understanding. Investigation of isolated thunderstorms or outbreaks of cumulo limbus where air only accents, and of the intense electrification in medium levels that appears to precede the building of the "Wokingham" type storm, are but two additional examples of what may widen our understanding. Such facts contain all the power a glider pilot could need. Difficulties and dangers submit to knowledge. A knowledge of the frontal structure allows are to put these problems in their place.
The author would like to express his gratitude to Mrs B. Pedgeley for preparing the various diagrams.

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