The Evidence of Mountain Sized Eddies in the Lee of LowMountains

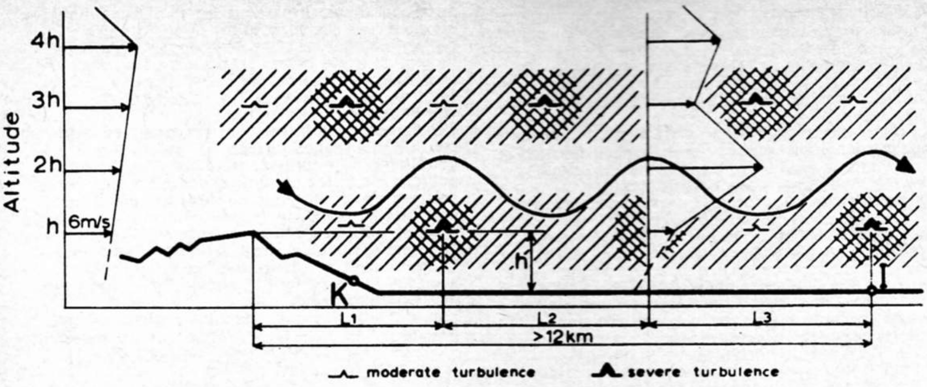
Dr. Jiří Förchtgott
Hydrometeorological Institute, Prague, Czechoslovakia

Paper presented at the XIth OSTIV Congress 1968, Leszno, Poland

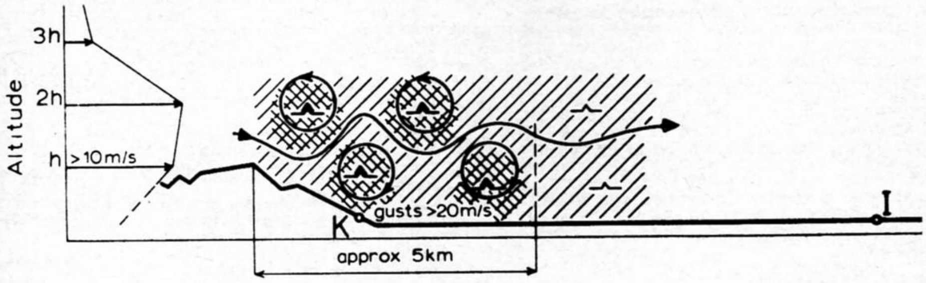
The majority of serious meteorologically-induced difficulties arise on account of lack of appreciation of the physical phenomena; there may be released in the atmosphere unexpected forces, with which one is not always able to cope. For example inadequate experience may often result in quite rapid loss of control of an airliner.
The lack of measurements and records of orographically induced phenomena, due to the limited extent and duration of their occurrence, leads to inadequate meteorological knowledge of such conditions, for example those connected with low mountain ridges. Consequently the extreme low level turbulence associated with such phenomena is often considered by forecasters only after it has already been experienced and reported by the pilots!
This fact covers a hidden danger, occurring rarely but always suddenly and without warning in the area of mezzometeorological extent.
The problem of local gales and gustiness to the Lee of Little Carpathian ridge was dealt first in 1950 by Prof. Steinhauser [1]. His findings have been confirmed and completed by means of voluntary pilot reports collected in 1955–57 from most scheduled and some special flights to and from the airport Bratislava [2]. During three years there were 185 pilot reports on turbulence, stating time, locality, altitude and an assessment of gustiness, up- and downdrafts, forced altitude-changes and altimeter errors. The results are summarized in table I, those for the Little Carpathian and Low Tatra mountains forming the majority of the observations. Turbulence of convective nature has been excluded from consideration.
The most impressive fact is the high number of reports from the Little Carpathian area with heavy gustiness in 73 cases and "a few seconds" loss of control in 3 cases. Up- and downdrafts exceeding 10 m/s were experienced in 5 cases, forced altitude changes of over 300 m in 2 cases (extreme loss of 500 m, gain of 350 m) and altimeter errors of over 60 m in 2 cases.
Every accepted extreme-case report contains information on a single extreme component of turbulence only.
No case has been identified with the simultaneous action of two or more extremes. But during the last 15 years two airliners were lost in the area of question and each case occurred in airflow conditions corresponding to lee wave or rotor streaming, i. e. in conditions similar to those investigated in 1955 to 1957. No technical failures were found; both cases have been explained by failure of the human element.
There is the question of whether this "failure of human element" could be the consequence of crossing the turbulent area with more than one of the above-mentioned components acting in an extreme degree. Alternatively is there any real possibility of the highest degree of gustiness, reported as "loss of control", existing for a longer period than "a few seconds"?
As the first approach to the solution of that degree of turbulence leading to loss of control to the lee of a low mountain ridge it has been assumed that the airflow conditions could be similar to those existing during the rotor streaming in the area of Little Carpathian ridge. The relative elevation is about 400 m above the lee plane. The ridge extends from SW to NE and its lee slope for NW winds is very regular and about 40 km long.
Fortunately there are two meteorological stations where permanent routine records are made. The first station Koliba ("K") is situated just to the lee of the southerly border of the ridge, and the second one is on the airport Bratislava-Ivánka ("I") about 12 km to the lee of the ridge. A day of typical rotor streaming development was 24th November 1966. The winds aloft, as well as the lapse rate changes, were evaluated from routine aerological reports of the station at Wien. The wind component normal to the Little Carpathian ridge increased up to 15 m/s during the afternoon within a thin windlayer adjacent to the ground.
The thickness of the windlayer according to the noon TEMP report was 800 m, which increased gradually until 1800 GMT to 1900 m, the wind aloft of the NW direction being within the windlayer at least 7 m/s. Stable temperature lapse rate was maintained until midnight, when the upper limit of the wind layer surpassed the 3000 m level.
The increasing NW wind layer was obviously related to a cold air advection behind a weak trough, passing in the afternoon through the area from W to E. A well marked pressure rise in front of a coming ridge of high pressure resulted in a gradual increase of pressure gradient and increasing wind velocity within the strengthening NW wind layer.
These conditions presented a convenient situation for the gradual development of a stable turbulent system and associated active turbulent layer, responsible for two types of airflow to the lee of mountain ridges – the rotor streaming and the wave streaming (Fig. 1, 2).
The detailed study of anemograms of the stations "K" and "I" for the considered period indicated some well marked wind characteristics, as well as their regular propagation from the nearby locality "K" to the more distant station "I". First the commencement of

TABLE I
Survey of Turbulence Reports from Air Routes over Czechoslovakia srom CSA crews 1955–57.

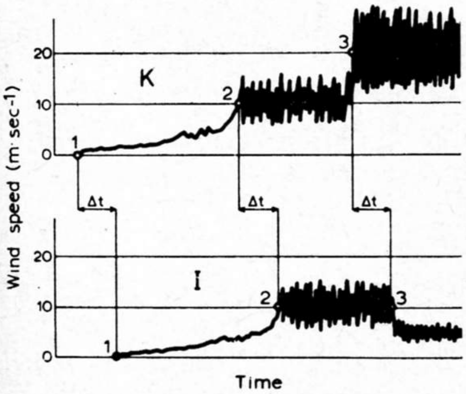
Mountains	Little Carpathians				Low Tatra				Other Areas				All Areas	
Day D Night N Total T	D	N	T		D	N	T		D	N	T		T	
Gustiness														
Moderate	12	4	16		7	1	8		9	0	9		33	
Severe	55	18	13	92	19	7	26	35	12	3	15	25	114	152
Loss of control	3	0	3		1	0	1		1	0	1		5	
Vertical drafts														
Up to 5 m/s	7	0	7		5	1	6		8	0	8		21	
5 to 10 m/s	6	2	8	20	7	1	8	20	6	1	7	15	23	55
Over 10 m/s	4	1	5		3	3	6		0	0	0		11	
Forced altitude changes														
100 to 300 m	1	1	2	4	0	0	0	4	0	0	0	0	2	8
Over 300 m	1	1	2		1	3	4		0	0	0		6	
Pressure altimeter errors														
Up to 30 m	10	2	12		0	0	0		0	0	0		12	
30 to 60 m	5	0	5	19	1	0	1	1	0	0	0	0	6	20
Over 60 m	2	2	2		0	0	0		0	0	0		2	



1. Turbulent layers during wave streaming to the lee of Little Carpathian ridge.



2. The rotor zone – severe gustiness area to the lee of Little Carpathian ridge due to rotor streaming.



3. Three successive surface wind changes on two meteorological stations "K" and "I" located at different distances from the Little Carpathian ridge during the initial stage of the rotor flow.

the flow from the NW direction was registered on the station "I" 22 minutes later than on the station "K" (Fig. 3, points 1 and 1').

Secondly the peak gust within the first hour of the NW wind was found on both stations 53 minutes after the NW direction began, i. e. with the delay of 22 minutes between the two stations again (Fig. 3, points 2 and 2'). Thirdly, a particularly interesting effect was the increase of mean wind velocity from 10 m/s to 20 m/s at station "K", followed after precisely 22 minutes by a drop in the mean velocity at station "I" from 10 m/s to 5 m/s (Fig. 3 points 3 and 3'). At the same time the surface wind gustiness increased significantly at "K", while he coming negligible at "I". This latter condition was maintained at both stations for a few hours, and was accompanied by a pressure fall of 2 mb at station "K", but no pressure change at all at "I". No significant change of the temperature was indicated on the thermogram of either station.

As the opposite wind changes at points 3 and 3' on Fig. 3 evidently correspond each to the other, it may be concluded that they are due to the sudden development of huge mountain-sized eddies just to the lee of the obstacle (the area of station "K"). This conclusion is supported by the pressure fall recorded at station "K" also.

The above-described state of the airflow, with a narrow well-defined zone of heavy turbulence just to the lee of the low mountain ridge, is thought to depend on some critical value of the wind layer thickness having been reached. If this happened at about 1500 GMT, the critical thickness must correspond to some value between 800 m and 1900 m, most probably to 1000–1200 m that is to say between 2,5 and 3 times the height of 400 m.

It is obvious that careful evaluation of routine aerological reports might be taken as a warning well before the critical wind change and subsequent development of very gusty rotor flow take place. In addition, the isallobaric changes on synoptic charts usually enable the onset of the dangerous wind direction to be predicted some hours in advance.

The main differences between the airflow structures for wave and rotor streaming behind a low ridge are expressed in Fig. 1 and 2. The centres of heavy gusts for wave streaming are isolated and the two gusty layers are separated by a thin layer between without gustiness, but with a markedly increased horizontal wind component. The circulations of the active turbulent layer gradually more a considerable distance downstream from the obstacle, provoking with their slowly weakening action the development and maintenance of second, third, etc. waves.

The rotor flow represents the case of mountain sized eddies squeezed into a very limited zone just to the lee of the low ridge. There is no distinct separation between individual circulations within the rotor zone. Strong and opposing action of eddies in close proximity leads to rapid dissipation, not only of individual eddies but of the system as a whole, so that the more distant area remains free of appreciable gustiness.

Besides extreme gustiness the rotor zone always results in local pressure deviations of several millibars, which can easily escape of the attention of pilots owing to them being fully occupied by the effort needed to maintain control of the aircraft. It seems likely that the response of the aircraft would be slightly different when flying through the rotor zone across or along the low mountain ridge.

When the rotor zone is crossed along the ridge, the time spent within severe gustiness is appreciably longer and the vertical drafts must be taken into account. The rotor zone thickness corresponds to the relatively thin wind layer and its width does not exceed ten times the obstacle elevation.

The flight velocity of about 300 km/h applicable to transport aircraft operations near airfields is sufficient to prevent the desired freedom from the effects of the flow streaming to the lee of any low mountain ridge, the wave length being within limits from 2 to

5 km. Thus the rotor flow itself behind a low ridge – during its initial stage – produces completely chaotic and severe gustiness for any aircraft of today.
Such severe gustiness the lee of low mountains is usual during appropriate airflow conditions. But flight in close vicinity of low ridges under such severe conditions is not usual, so that actual experience is as yet limited [4, 5, 6]. Such experience as there is supports the idea that the common term "fail are of the human elements" is in reality closely connected with the severe effect of low mountain ridges.
It is suggested that in routine aviation meteorology attention must be paid to the conditions described above, namely on airfields with mountains of any size in close proximity. Appropriate use of routine meteorological data by means of mezzometeorological analysis of local airflow situations may permit precise forecasting of severe low-level turbulence in advance.

Résumé

Il est arrivé souvent que des pilotes d'avions de ligne aient perdu le contrôle de leur avion sous le vent d'une chaîne de montagnes et, normalement, leurs observations sur la turbulence ont été rapportées avant la prévision du phénomène.
Au cours d'une période de trois ans, 185 rapports de turbulence, de rafales verticales, de changements forcés d'altitude, d'erreurs altimétriques, ont été établis par des pilotes volant en Tchécoslovaquie, principalement au voisinage de la crête des Petites Carpates (voir table 1).
La turbulence due à des phénomènes de conversion a été éliminée de ces données. Il n'y a pas de cas dans lesquels plus d'une valeur extrême des différents phénomènes aurait été constatée. Dans les 15 dernières années, deux avions de ligne furent perdus dans des conditions semblables à celles que nous mentionnons; dans les deux cas, on parla de «défaillance humaine», mais on peut se demander s'il n'est pas arrivé que des valeurs extrêmes se soient conjugées?
Deux types d'écoulement de l'air sous le vent d'une chaîne de montagnes peuvent provoquer un système de turbulence stabilisé, avec rotors et ondes. C'est ce que représentent les figures 1 et 2.
Quelques observations effectuées en date du 24 novembre 1966 à deux stations, Kolibra («K»), juste près de la crête des Petites Carpates, et Bratislava-Ivanka («I»), éloignée de 12 km, sont représentées dans la figure 3. Le début du vent du N-W (points 1 et 1′), le passage du régime constant au régime turbulent (points 2 et 2′) et un autre changement de la vitesse moyenne du vent (points 3 et 3′) se produisèrent à la station «I» précisément 22 minutes plus tard qu'à la station «K». En outre, le changement soudain de la vitesse moyenne du vent fut de 10 m/s à 20 m/s à la station «K» et de 10 m/s à 5 m/s à la station «I»; la turbulence s'accrut en «K» et disparut presque en «I». On peut en conclure que les tourbillons dus à la crête de la montagne se sont développés juste sous le vent de cette crête; cette conclusion est renforcée par une baisse de la pression de 2 mb en «K», tandis qu'il n'y avait pas de variation correspondante en «I».
Des turbulences fortes sont courantes sous le vent de montagnes basses, s'il existe des conditions appropriées, mais notre expérience actuelle de telles conditions reste limitée, car il est rare qu'on entreprenne délibérément des vols de reconnaissances près du relief. Cependant de telles expériences appuyent l'idée que l'expression banale «défaillance de l'élément humain» peut en rèalité être en étroite relation avec les effets d'une turbulence forte, due à des montagnes basses.
L'auteur suggère que, dans les régions montagneuses, une analyse appropriée de l'écoulement local de l'air soit entreprise, qui permette de prévoir les fortes turbulences.

Literatur

1. Steinhauser, F.: Windverstärkung an Gebirgszügen. Berichte des deutschen Wetterdienstes in der US-Zone Nr. 12, Bad Kissingen 1950.
2. Förchtgott, J.: Turbulence on Air Routes over CSR. Letecký obzor, č. 10, Praha 1959.
3. Förchtgott, J.: Active turbulent layer downwind of mountain ridges. OSTIV Publication IV, VIth OSTIV Congress, St Yan 1956.
4. Gray, A. and Stewart, W. J.: Orographic effects at Acklington. Met. Magazin 94, p. 8, London 1965.
5. Vasiljev, A. A.: Meteorological conditions of atmospheric turbulence within the low layer to the lee of mountain ridge. TRUDY CIP, vyp. 157, Leningrad 1966.
6. Cashmore, R. A.: Severe turbulence at low levels over the United Kingdom. Met. Mag. 95, London 1966.