Vol. 8, No. 3.

Royal Meteorological Society

UPPER WINDS FOR AVIATION

R. C. Graham

CANADIAN BRANCH

25¢

Vol. 8 No.3

A Publication of the

Royal Meteorological Society, Canadian Branch

EXECUTIVE COMMITTEE 1957

President..........................	Dr. W. L. Godson
Vice-President.....................	R. H. Douglas
Secretary..........................	R. Lee
Treasurer..........................	C. G. Goodbrand
Councillors-at-large...............	Chairman of the Montreal Centre
	Chairman of the Winnipeg Centre
	M. Hardman
	S. J. Buckler
	B. V. Benedictson
R.M.S. Vice-President for Canada...............	R. C. Graham

Editorial Committee................	F. W. Benum
	C. M. Penner
	M. K. Thomas (Editor)

Additional copies of this publication are available at a price of 25 cents each. All enquiries and correspondence concerning the Canadian Branch of the Royal Meteorological Society and its publications should be addressed to

The Secretary,
Royal Meteorological Society, Canadian Branch
315 Bloor Street West
Toronto 5, Ontario

UPPER WINDS FOR AVIATION

by

R. C. GRAHAM

Meteorological Services of Canada

Presidential address presented to the
Royal Meteorological Society, Canadian Branch
at Toronto on Thursday, February 7, 1957.

UPPER WINDS FOR AVIATION

by

R. C. Graham

It has become a custom that once per year, the President of your Branch addresses you on a subject of his choosing. While my subject tonight may seem to be of specialized interest, in fact the forecasting of upper winds for aviation draws upon knowledge and techniques of wide application in meteorology. It is a fortunate characteristic of applied meteorology that the effort that goes into most forms of service, up to the final phase of imparting the information to the recipient, is common to many fields of application.

The forecasting of winds aloft for aviation is an excellent example of this community of interest. In many parts of the world it was primarily the aviation requirement that initiated upper air observing networks that are needed for meteorology in general. These networks in turn have made possible advancements in our knowledge and are opening new frontiers in forecasting techniques. Out of these developments are coming new possibilities for forecasting winds for aviation, just at a time when aviation requirements are starting to develop beyond the scope of methods used in the past.

Aviation is big business today. It has taken its place with rail and marine transport as one of the major modes of travel and is growing at almost an explosive rate. I.C.A.O. statistics show that on a world-wide basis aviation has been doubling every five years. Who would have believed, when Lindberg made his famous flight in 1929, or even in the late 1930's when the first experimental trans-Atlantic commercial flights were being made, that by today a major problem of trans-Atlantic aviation would be congestion of air traffic - that aircraft would be waiting their turn for a block of air space in which to fly across the ocean. Yet such is now the case.

Despite the increasing capability of aircraft, the requirements of aviation for weather service seem to increase rather than decrease. Developments in aircraft design are used to permit more efficient operation, using the optimum meteorological service available, rather than to diminish the demands for meteorological service. Moreover, aircraft are remarkably long-lived, and although new types are introduced, the older types remain in operation, and so we have not only to anticipate the requirements of aircraft that will appear in 1960, but we still have to meet the requirements of aircraft that were designed in the 1930's. Meteorological requirements remain stringent, although they change in character, and they are extended to cover greater areas and higher

- -

Robert C. Graham is Superintendent of the Trans-Oceanic Aviation Section, Forecast Division, Meteorological Branch, Department of Transport, Toronto, and has represented Canada at several international conferences on aviation meteorology. Mr. Graham served as President of the Canadian Branch of the Royal Meteorological Society in 1955 and 1956.

altitudes. We can probably expect little reduction in demands for wind information for aviation as long as it is more profitable to carry pay load than fuel.

To keep this talk from being entirely devoid of equations, I will suggest that we may consider meteorologists and aircraft operators as being constrained by an equation of the form $M = F(s,r,e)$, where M is a measure of the meteorological service required, s is a measure of the safety of operation, r is a measure of the regularity of operation, and e is a measure of the efficiency of operation.

Ideally, the values of s, r, and e would be defined by the operators and the regulatory authorities, and we meteorologists would solve the equation for M, and provide service accordingly. However, it is sometimes the case that the M so defined is beyond reach, so that in effect it is r and e that are the dependent variables.

For example, if on a given route, approaching the limit of capability of the aircraft with full pay load, the meteorological service is less than adequate, the operator may take a penalty in efficiency by carrying extra fuel at the expense of pay load, or by making intermediate stops, or he may take a penalty in regularity by delaying flights until conditions are most favourable. Carrying excess fuel may not be an easy solution. Having taken off fully loaded, a large aircraft must, before landing again, either fly long enough or dump fuel in order that the gross weight will be within the landing limits. This may restrict the selection of intermediate alternates.

While it is hardly possible to measure the value of meteorological service in terms of safety, it is sometimes possible to evaluate meteorological service to aviation in terms of economy. For example, for an aircraft with 200 knots air speed, a variation of one knot in wind speed is equivalent to a variation of about three minutes in flight time on a ten-hour flight. Assuming a fuel consumption of 2000 lbs. per hour, a reasonable figure for a medium-sized four-engine aircraft, this is 100 lbs. of fuel, or about half the weight allowance for a passenger paying a fare of some $400. If the aircraft is larger the fuel consumption per hour is higher and the penalty is greater. With higher speed, the relative effect of wind in terms of flight time is less, but the economic effect is greater because fuel consumption mounts so rapidly with increasing speed.

In aircraft operation it is not sufficient to allow for the average error in wind forecasting - allowance must be made for extreme errors. This does not mean that an aircraft must carry fuel sufficient to complete its journey regardless of how great the error in the preflight forecast may be. On long flights it is customary to obtain new wind forecasts in flight, and if necessary it is possible to make intermediate stops, divert, or turn back before reaching the point of no return. But such stops are obviously undesirable and reserves are carried so that they will not be necessary more than a very low percentage of the time. Therefore it is the occasional gross errors, rather than frequent small errors, that we should try to reduce.

The increasing congestion of air traffic appears to be creating more stringent requirements for accuracy of wind forecasts. It is becoming more and more necessary for aircraft to adhere to planned tracks and speed, and as aircraft become larger and faster, it becomes increasingly desirable to operate at optimum airspeed and altitude. Thus the penalties of compensating for errors in preflight forecasts become greater, and the importance of reliable preflight forecasts is increasingly emphasized.

In looking at methods of wind forecasting that have been used, I divide them into two classes: the quick and intuitive on the one hand, as against the more elaborate and systematic on the other. Both have their advantages. An example of the former is simple analysis of the contours of constant pressure surfaces, without the aid of thickness analysis, and forecasting mainly by extrapolation of the contour pattern, with the aid of latest reports and a large measure of forecaster's intuition, developed through experience. The method has the virtue of flexibility and encourages the use of latest data in whatever form it may be. However, the application of knowledge in it is more qualitative than quantitative. This general approach is widely used, and in the hands of an experienced forecaster, produces surprisingly good results for short-term forecasts.

An example of a more systematic approach, common in offices serving long-range aviation, involves the use of thickness charts in analysis and prognosis. This helps to promote hydrostatic consistency between the analyses of constant pressure surfaces, and thus permits greater certainty in forecasting the change of wind with height. It encourages thinking in terms of layers instead of merely surfaces. The simplicity and conservatism of the thickness patterns in the troposphere, in comparison with the contour patterns, makes the technique useful. One risk is that the method may be applied mechanically rather than thoughtfully, and the forecaster has to be careful not to place too much weight on the process to the exclusion of consideration of latest actual wind reports.

Sometimes this technique is criticized as being laborious, but when facility is achieved through practice in graphical addition, it should not take any longer than to construct a chart of similar quality by other methods.

There is some danger of over-smoothing in carrying a differential analysis through several levels, unless care is taken to correctly place the thickness lines in relation to the 3-dimensional frontal structure. However, with care, the method permits the analysis and forecasting of detail aloft that would otherwise be missed.

For many years, most forecast offices using differential methods had been starting at the surface and building up, both in analysis and prognosis. This approach stemmed from the greater density and frequency of surface reports, and the greater experience of most forecasters in using surface data. In recent years, quantitative and semi-quantitative methods of considering wave motions on a large scale, indicate that in forecasting at least, the 500 mb. layer is a promising starting point. This approach has shown new possibilities in forecasting of developments. Quantitative methods such as the graphical techniques of Fjortoft and the application of the electronic computer seem destined to play an increasing role.

So far I have been speaking mainly of methods of forecasting upper winds up to about the 500 mb. level. The wind pattern is usually sufficiently linear between 500 and 300 mbs., that the effort of constructing 400 mb. charts will hardly be worthwile when 300 mb. charts are regularly drawn.

In carrying the analyses from 500 mb. up to 300 mb. the jet stream becomes a major feature, and care is necessary not to smooth it out. In analyzing the 300 mb. chart it is most important that jet streams be fixed as accurately as possible, and indirect methods - e.g. use of models, may be necessary. However, as the charts produced by the Canadian Central Analysis Office show, it is quite possible to produce a good consistent 300 mb. analysis with present knowledge.

In temperate latitudes the tropopause is commonly between 300 and 200 mb. and the thickness pattern loses the simple, conservative character seen in the lower layers. There has been considerable variety of views among forecasters as to how thickness analysis should be used, or if it should be used, in constructing 200 mb. charts, but there seems to be value in using it, provided the analyst keeps in mind the effect of the tropopause on the thickness gradient.

Above the tropopause, the thickness pattern seems to become more definite and simpler, but reversed in direction from that in the tropopause. Consequently one sometimes finds parts of the 100 mb. chart in which the thickness gradient is almost equal and opposite to the 200 mb. contour gradient, giving rise to a weak indeterminate 100 mb. contour pattern.

In forecasting for high levels, most experience at operating forecast offices in Canada has so far been in providing forecasts for relatively short flights. We will soon have the problem of forecasting for long flights at these altitudes. Sutcliffe and Sawyer, in a paper in the

Proceedings of the Toronto Meteorological Conference, 1953, show that if conventional methods, used in the lower atmosphere, are used in preparing prognostic charts for the higher levels, the forecasting skill diminishes with height as does also the accuracy of analyses, while on the other hand the variability of winds decreases with height. The net result is that the forecast error is less at 100 mbs. than at 300. Durst has suggested the use of statistical methods for forecasting high altitude winds, and has shown how to predict statistically the most probable future wind using the latest observed wind and seasonal mean winds.

A technical report of the Air Weather Service of the USAF, entitled "The Black Sheep System of Forecasting Winds", suggests constructing the 300 mb. prognostic chart by building up from the prognostic 500 mb. chart, advecting the 500 to 300 mb. thickness with the aid of the Fjortoft vorticity chart and space mean chart used in preparing the 500 mb. prognostic. Whether or not a method as elaborate as this is necessary, I think it safe to assume that as forecasters gain more practice and devote more attention to producing 300 mb. prognostics, their skill will approach that of the production of 500 mb. prognostics, which will be the base on which the 300 mb. prognostic will be built.

Because of the effect of the tropopause, linear interpolation is not sufficient in some areas to describe the winds between 300 and 200 mbs. This has led to a suggestion that 250 mb. charts are essential, but I do not agree with this conclusion - it still does not solve the problem because the tropopause does not choose to lie parallel to any constant pressure surface. The above mentioned, "Black Sheep Method" suggests one attack. The method is to carry out analyses of the topography of the height of maximum wind, which usually occurs just below the tropopause, and also to construct charts of the mean wind shear above and below this level of maximum wind. These charts are forecast, mainly by extrapolation methods. Given a forecast of the 300 mb. wind at any point, the mean wind shear between 300 mb. and the level of maximum wind, the height of the maximum wind, and the mean wind shear above that height, one could define the wind speed at any height between 300 and 200 mbs.

A suggestion has been made that above 300 mb., and away from the vicinity of jet streams, the wind variations might be small enough in relation to aviation requirements that they could be derived from seasonal mean charts, or latest actual charts, or a combination. This would bear investigation. If so, forecasting effort might be concentrated on locating and determining the structure of the jet streams.

Regardless of whether any of these techniques, or others, eventually rise to general use, it seems evident that wind forecasting will be a more elaborate process than it has been. But however elaborate the process, it will no doubt be imperfect and there will always be the question of weighing a forecast based on data several hours old, with a value observed a few minutes ago.

When one considers desirable attributes of an organization for producing upper wind forecasts for aviation, some of these attributes appear to conflict. Among them are the following:

The system should encourage the efficient use of what might be called large-scale techniques, even though such techniques may be laborious or require costly equipment. This attribute points toward centralization.

The system should permit the rapid incorporation of current reports, and provision for either rapid amendment or re-issue, in order that the forecast for the next few hours may be as up to date as possible. Also the system should permit taking account of local geographical effects insofar as they affect the upper wind pattern. This attribute suggest a decentralized system.

Unless and until the forecasts become perfect and complete within the limits of operational significance, there will be a requirement for briefing the recipient. This also suggests decentralization.

The system should be flexible enough to permit ready adaptation to changing requirements, and should encourage continuing improvement in methods. Too high a degree of decentralization may mean that the individual units are too small to use more than elementary techniques. Too high a degree of centralization may mean units that become inflexible and unwieldy.

Traditionally the responsibility for provision of wind forecasts for international aviation has rested on the meteorological office serving the departure aerodrome. That office may obtain assistance from other offices but essentially the system is highly decentralized. Duplication is the most obvious criticism of this system. However, in fairness it should be pointed out that the system has been a product of evolution and had good reasons when it was developed. It was developed under the concept of low-density traffic, served by individual flight forecasts and individual flight meteorological watch, and under limitations of communications that made it more reliable to exchange basic data and prepare forecasts where needed, than to exchange the forecasts themselves. Forecasting techniques were simple enough that they were not burdensome to the small office, and at the same time the sparseness of data introduced a high degree of subjectivity that created a demand for briefing by the forecaster who prepared the forecast. However, while this division of responsibility had good reasons, some of these reasons have changed and the matter bears re-examination.

In Canada, under different conditions, there evolved at an early stage in the provision of meteorological service to continental aviation, the concept of the District Aviation forecast Office, issuing routine forecasts including winds, for its own area of responsibility. These forecasts are exchanged, and thus only one office is responsible for forecasting winds for a given area. There are ten such areas in Canada. For wind forecasting alone, a lesser number would probably be chosen, but the allocation of areas of responsibility involves other considerations.

The chief difficulty of this system is the problem of finding a form of forecast, covering an area and a substantial period of time, that is easily communicated and readily usable at the receiving end. Also, while this allocation of responsibility cuts down greatly on duplication of effort, the areas are small enough that there is a tendency to use elementary methods of wind forecasting to the exclusion of more elaborate techniques. This is being overcome in Canada by the Central Analysis Office.

Ideas have been suggested for serving international aviation by concentrating the production of wind forecasts in a very few large highly centralized offices. As can be seen if one pursues the argument to its logical conclusion - one wind forecasting centre for the world - such a system appears to be overly idealistic in the forseeable future. A highly centralized system would indeed permit large concentration of staff and equipment, and the communication requirements could conceivably be met with existing technical knowledge if enough money were spent. But beyond a certain point, such a system would become unwieldy, both technically and administratively.

However, I believe that it would be possible to develop a system that would incorporate the advantages of centralization and decentralization. In such a system, a few analysis centers would carry out those phases of analysis and forecasting that can best be done centrally, and would distribute their products in the form of large area, current and prognostic charts.

These charts would then be used by designated area forecast offices with their own analysis of information on a more local and continuous basis, to issue routine wind forecasts on an area basis for non-overlapping areas of responsibility. These wind forecasts would be distributed to all meteorological offices providing preflight and inflight service to flights through the areas in question, and would serve as a basis for information provided to flights by these individual offices.

There is precedent for such an arrangement in an experiment that is going on now in the I.C.A.O. Caribbean Region, and in the long-standing practices in Canada and U. S. A. for serving aviation within North America.

The prerequisite for the successful implementation of such a system is a suitable form for exchange of the wind forecasts on an area basis. Facsimilie can now provide an answer, using prognostic charts of contours and isotachs, but since we may hardly expect within the next few years an adequate world-wide meteorological facsimile network, there is also a need for a form of forecast amenable to teletype transmission that will accomplish the above purpose.

The basic difficulty is that a line of type is essentially one-dimensional, whereas a wind forecast for a block of air space involves three dimensions of space and one of time. However, there are means of solution. The time scale can be simplified, as it is not necessary to give a continuous description of changes, if the wind pattern is described at discreet times, such that interpolation is possible with sufficient accuracy. The space dimensions could be simplified, by giving the winds at specified levels over specified points. If the areas of responsibility are not too large, the points could be made sufficiently close together that this would describe the winds in adequate detail. In addition at the higher levels it would probably be necessary to define the expected axis of jet streams and associated wind speeds along the axis.

The area forecasts would be either issued at sufficiently frequent intervals that amendments would seldom be necessary, or some system of amending would have to be provided.

One argument against such a system is that there would be inconsistencies between the forecasts provided for adjacent areas. I do not think that this would be a major problem. Even without the central analysis for guidance, if such forecasts were issued and exchanged, their use would reduce inconsistencies by the exchange of ideas between adjacent offices. On top of this, the broad scale forecasts from a central analysis office would introduce a high measure of inconsistency. Moreover, there is a question of whether consistency throughout an entire route, unless it is the consistency that results from a high degree of accuracy, is actually the optimum for the operator. It may well be that the gross errors experienced in wind forecasts over a long route, which are after all the important errors for the operator, would be less if they used forecasts issued for various segments by individual meteorological offices instead of one forecast issued for the entire route by one office. There is probably an optimum size of areas of responsibility, between those of extreme centralization on one hand and extreme decentralization on the other.

The proposal above is far from complete, and is made more to stir up thought than as a finished proposition. I think it is quite clear that aviation requirements have reached a point where it is uneconomic and technically inefficient to try to meet them merely by expanding the methods used in the past. I have every confidence that in time, far better procedures will be implemented. The starting point is to put forward ideas on the subject, good or bad, out of which the better ones will inevitably emerge. Time will tell the category of the ideas that I have expressed here.