Royal Meteorological Society

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in
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and

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THE USE OF METEOROLOGICAL DATA IN AIRCRAFT DESIGN

J.A. Chamberlin

Since detailed and accurate weather forecasts are essential to the efficient operation of aircraft, the association between aircraft operators and meteorologists is very well established. Accordingly there is no doubt that meteorologists are very familiar with the uses, the limitations and the requirements of the data which they produce for this aspect of aviation.

However meteorological data play an important role in the basic design of aircraft, and since there is normally virtually no association between aircraft designers and meteorologists, it is assumed that the type of data required, and the uses to which it is put are relatively unfamiliar to meteorologists. Accordingly I thought it would be of interest to discuss this field. Since the problems are of a basic character they are not specially applicable to any one type of aircraft. However, the increases in performance made possible by the jet engine and the advent of electronic equipment have made it necessary to secure more and better data than was thought adequate formerly.

MAXIMUM GUST VELOCITY

The most important piece of meteorological information used in design is the maximum gust velocity. This determines the maximum intensity of bump that the aircraft structure need be designed to stand. Several important deductions can be made from the simplified formula for the increase of load on the airplane:-

$$\Delta n \propto \frac{KUVa}{w}$$

where K is a coefficient to relate the actual gust velocity to that of an equivalent sharp-edged gust.
U is the equivalent velocity of the sharp-edged gust at sea level.
V is the equivalent velocity of the aircraft at sea level.
a is a coefficient indicating the increase of lift on the wing per unit change of the angle of the wing relative to the airstream.
w is the wing loading.

This shows that as an aircraft goes faster the harder is the bump, while the higher the wing loading, the less severe the bump. This has obvious implications in design, i.e., that higher speed aircraft must be stronger unless their wing loading is increased. Since increased strength requires increased weight, the tendency in recent years has been towards increased wing loadings as speeds have increased.

It can also be seen that the change of lift per unit angle of the wing relative to the wind is a very important factor in determining the load on the aircraft. For a given airplane this usually varies considerably, with the speed of the aircraft relative to the speed of sound, or Mach number as it is called. However this variation itself depends on the frequency of the gusts. This is because the properties of wings are considerably different when their motion is oscillatory relative to the wind than when steady. The reason for this may be explained qualitatively by considering that a wing in steady flow generates a disturbance in the air, which although it takes time to build up initially, eventually becomes stable. When either the air or the wing is oscillating, certain portions of the disturbance created by the wing are of opposite sense, and if the frequency of motion is high enough, these impulses are sufficiently close together to cancel one another out, thus giving substantially differing properties than when this is not the case. Although the difference between the static and oscillatory values is very little at low speeds it may be as much as 20-30% at higher speeds, or more exactly at higher Mach numbers. Hence it can be assumed that a detailed knowledge of the structure of gusts would be necessary to accurately assess the loads on the aircraft. While the incentive to this is very much increased by the higher speeds that are customary today, not only is sufficiently detailed information on gusts almost totally lacking, but also, although the properties of wings for static conditions and for very high frequencies are known, there is inadequate information about intermediate frequencies. Hence quantitative data is required on both these subjects before a really fundamental attack on the problem can be successful. In the meantime a statistical approach has been used, in which several airplanes were flown simultaneously at different speeds in the same area of turbulence. This gives answers, it is true, but they are influenced by the size and characteristics of the aircraft as well as the type of gusts found in the particular cases investigated. This method is obviously much too cumbersome to be applied extensively enough to involve samples of all types of atmospheric turbulence. Hence a more scientific approach is certainly needed.

There is another interesting thing about the lift per unit angle. That is, that although high speeds increase the loads due to gusts, the planforms that are becoming necessary to attain very high speeds have reduced values of this factor, so that the effect of speed is to a large extent counteracted. The effect is due not only to the increased stubbiness of the wings, i.e., their width is high relative to their span, but also to the sweep which is becoming increasingly prevalent as speeds are increased. Both these factors are quite powerful and when combined in the arrowhead type of wing, a considerable reduction in the effect of gust is obtained.

For convenience in analysing and applying data on gusts, they are usually expressed in terms of their sharp-edged equivalent at sea level. This makes it possible to compare data obtained under a variety of conditions and analyse it statistically. However, although this conception is expedient, it is not entirely adequate to lump too much data together.

One aspect of the problem is that the factor relating the actual gust velocity to equivalent sharp-edged gust varies not only with the wing loading as usually assumed but also with the characteristics of the aircraft such as size and altitude. The aircraft in so far as its response to a gust is concerned may be represented by a mass suspended on a spring with a pneumatic damper. The response depends on the relation between the natural frequency of the system, i.e., the airplane, and the forcing function, i.e., the gusts, and also on the damping, which is governed by the pressure of the air in the damping cylinder of the equivalent system or the altitude for the real airplane. As airplanes become larger, their size relative to the wave length of gusts become significantly altered. Also the natural frequency of wings is reduced to values more nearly comparable with those of gusts. The frequency response characteristics are hence altered by appreciable amounts. Furthermore the altitude range has been extended to such an extent that its effect is no longer negligible. For these reasons the use of equivalent sharp-edged gusts is becoming an oversimplification of the problem and the conception of the graded gust is becoming current. A linear gradient for 100 feet is normally specified. There is however very little information on whether this is a really representative gust or not. Thus there is a great need for more accurate data on this point. However the amount of work involved in the analysis of an airplane for any one gust condition is so great that the incentive to simplification and generalisation is such that the most difficult problem may well be to reduce the data to a usable form rather than to obtain it in the first place.

Because aircraft must be light in order to carry a load, the structural strength relative to gusts is based on the probability of not exceeding certain maximum gust velocities in the normal life of the aircraft. It has been assumed that the probability of meeting any given gust intensity varies considerably with operating conditions. Thus a comparatively high gust velocity is assumed for the comparatively low speeds corresponding to the approach condition during which the high turbulence near the ground must be met. For the cruising case a somewhat lower gust velocity is assumed because the pilot usually has the option of flying in smoother air in this case, thus reducing the probability of meeting high gusts. Even if he finds himself cruising in an area of high turbulence, he can reduce the effects of the gusts by flying slower. The existence of clear air turbulence partially vitiates this latter argument. Lower gust velocities still are assumed to be probable at the extreme diving speed of the airplane since this is a very infrequent manoeuver, and would normally not be done if there was a suspicion of high turbulence. The gradation of gust velocities assumed usually results in the strength required being approximately the same at all speeds. The maximum gust velocities at present assumed appear to be sufficiently high so that failures due to gusts are very rare indeed. There is a strong suspicion that lower values might be equally satisfactory if more accurate information on their detailed nature and their probability of occurrence was available.

A detailed knowledge of gusts has several other applications. One is in the study of the strength under the cumulative effect of repetitions of load or fatigue as it is called. Another is in the design of autopilots. An airplane is normally sufficiently stable to fly by itself for a reasonable period. However if allowed to do this, it would be continually thrown off its course by gusts. It is the purpose of the autopilot to supply a restoring force to bring it back on a predetermined course. This requires that the autopilot respond to the motion caused by the gust in an appropriate manner considering the characteristics of the airplane. Thus the motion must be smooth and well damped with no tendency to hunt. This is often not an easy feat for a human pilot, let alone an automatic device. It accordingly cannot be obtained haphazardly but only by detailed calculations including all the factors involved. Previously parts of these investigations were empirical. However more recently the use of autopilots for blind landing and for fire control has pointed to the necessity for more rational "closed loop" calculations to secure the much higher precision required. Progress in this field has been almost spectacular in recent years, so that now autopilots are more efficient in certain respects than human pilots. For this reason there is no doubt that the human pilot must eventually give way to his mechanical counterpart in the very delicate operation of aiming the offensive armament of fighters. This requires a very high order of accuracy which can only be obtained by calculations involving a most complete knowledge of all the factors involved. Again one of these is atmospheric gusts.

Another somewhat similar use to which gust data can be put is in the design of "gust alleviators." These are devices which when a gust hits the airplane, operate in such a way as to reduce the load produced by it. This is obviously a very desirable device for it not only reduces the strength that has to be built into an airplane and hence its weight but also by reducing the severity of the bumps increases the comfort of the occupants. There are several forms of these devices and none has so far passed the experimental stage. One of the most popular is to have a probe on the front of the aircraft, which senses the gust and relays the signal to the ailerons so that they are deflected in such a way as to relieve the load produced by the gust when it hits the wing. It is fairly obvious that a very complete knowledge of gusts, especially their wave lengths, is necessary to design a mechanism of this kind. It is possible that a completely satisfactory solution to this problem will not be obtained until more data on gusts is obtained. The objection to its complication and hence unreliability is not entirely valid, since the aircraft would still be strong enough to withstand the probable gusts for a very large percentage of the time with the alleviator inoperative. The chances of meeting a higher gust when the device had broken down would then be sufficiently remote if the degree of reliability is as good as that achieved by other aircraft components. It is accordingly felt that with increased knowledge, gust alleviators will be developed not only for the sake of weight savings but also for passenger comfort.

When considering passenger comfort, there is the possibility of adjusting the operating altitude and wing loading to give the smoothest ride possible. For this purpose data are required on the variation in intensity and frequency of gusts with altitude, with special emphasis on the relatively small gusts that are most frequently encountered. On the basis of existing experience it is considered too uncomfortable to fly much above 300 mph under 5000 ft. More data on this subject is needed.

The uses of information on atmospheric gusts in aircraft design have now been summarised. Accordingly the methods of obtaining such data as exists remain to be discussed.

METHODS OF MEASURING GUST VELOCITIES

By far the most commonly used method of measuring gust velocities is the use of V-G recorders installed in aircraft. In this instrument a stylus preserves a record on a smoked glass slide of the position given it by a sensitive accelerometer and the airspeed system of the aircraft. The equivalent sharp-edged gust velocity can be calculated from these quantities by the formula given earlier. This instrument is very simple, reliable, and easy to install and service. It has been fitted very extensively on both airline and service airplanes in the U.S., U.K., and Germany.

This instrument gives an envelope at the maximum values of the sharp-edged gust vs. speed that have been obtained until the slide has been replaced. The statistical analysis of large numbers of slides taken from aircraft operating under a wide variety of conditions and routes gives the information at present being used for design. However most of the present data has been obtained at relatively low altitudes, and there is insufficient evidence as to whether it is applicable to higher altitudes. In fact, it is a limitation of the instrument that no record is kept of the altitude or of the meteorological conditions at the time of the gust. Also the values obtained are to a certain extent tempered by the characteristics of the airplane, the exact shape of the gust and the altitude, as discussed previously. It may however be argued that most of these things will average out if a sufficiently large number of records are kept on a variety of aircraft types.

It is also a limitation of this method that it provides very little information about the profile of the turbulence, especially if it is below the maximum.

As an attempt to secure more adequate data, flight recorders have been installed that give a time history of the flight. The instruments required to do this are considerably heavier and more complicated than the simple V-G recorder. Although they have often been used for research investigations, it has not been possible to fit them to a sufficient number of aircraft for a long enough period to get a really adequate sampling of data. The thorough analysis of this type of record is especially tedious, and has taxed the capacity of the various research teams that have used it. Accordingly the volume of data to be processed from a program of sufficient magnitude to be really definitive is so great as to render the job very formidable even with the assistance of an array of high-speed computing devices. In spite of the difficulties, progress along these lines is quite feasible, owing to the developments in both the recording instrument and the equipment for processing the data. However it still suffers from the limitation of recording the reaction of the airplane to the gust and not the gust itself and hence is subject to certain errors.

A further method that has been used to measure gusts is to provide pressure orifices around the contour of the wing of an aircraft. If the aircraft is flown on a straight and level course, any sudden changes in the pressures recorded are due to gusts. If pressures at several spanwise stations are recorded vs. time and speed, a picture of the structure of the gust over an area is obtained. It is fairly obvious that this is a complicated technique that could only have a very limited application and hence could only secure an inadequate sampling of atmospheric conditions. However it has been used to produce some very interesting results. For some reason the results were interpreted to show that the gusts encountered were related to the dimensions of the aircraft in a rather singular way. This seems hardly likely to say the least. This serves only to emphasize the need for divorcing the characteristics of the airplane from the measuring instrument.

All the methods referred to are inadequate and although they have to do with what is essentially meteorological phenomena, they are not conducted by meteorologists nor do they use meteorological techniques. It is accordingly felt that this situation presents a definite challenge to the meteorologist, especially since the conventional sounding equipment would appear to have the makings of an excellent vehicle, if fitted with specialized instrumentation.

TEMPERATURE ACCOUNTABILITY

"Temperature accountability" is becoming a common phrase in the present day airline operating procedures. However the jet engine is about three times as sensitive to temperature as the reciprocating engine. Hence the effect of temperature must be allowed for right from the first in a modern design. A typical effect on the take-off distance is shown in the following table.

Temp. Rise	Increase in T.O. run % for same WT.	Decrease in WT % for same T.O. run	Decrease in Payload % for same T.O. run
$10^{\circ}C$	13	4	35
$20^{\circ}C$	26	8	70

Since it is the object of any given design to take a certain payload out of certain airports, it is obvious that effects as large as that shown must receive very earnest consideration. For service aircraft the specification of runway length and pay- or military-load must of necessity be rather generalized, since military aircraft may have to operate almost anywhere. However for civil aircraft, it is usual to get down to specific airports and the temperature variations on them. The percentage occurrence of the temperatures becomes very important. Thus one could design conservatively so the maximum payload capacity could always be gotten out of all airports on the routes under consideration. If high temperatures were very infrequent, as is usual, then a large payload capacity which could have been provided would be going to waste, i.e., potential revenue may be lost. However, if extra payload capacity is provided, it is heavy and enlarges the airplane and increases its drag. Accordingly the capacity on a hot day is actually reduced, although on colder days it may be possible to use it. The number of potential ton-miles that can be carried is very much increased if a nice compromise is made by using a variable payload. However this has its problems. It is difficult to keep passenger relations on an even keel if passengers have to be "bumped" at the last moment due to temperature, or even if they can only get bookings in advance subject to temperature. Hence it is almost essential that at least most of the variable payload be freight which can be put on other flights. Even then the most efficient system will involve a certain amount of statistical analysis trying to secure a balance between the frequency of high temperatures and traffic peaks. If the coincidence of extra passengers and high temperatures is sufficiently improbable, the risk of "bumping" a passenger or two may be run, especially since it may be hoped that those "bumped" would be last-minute bookings who accordingly would not know that they had been "bumped".

In studying the actual flying of a route, temperature must also be taken into account. If the cruising speed is governed by the maximum rpm allowed by the engine manufacturer, then the speed will fall considerably, for example, 5% for 20°C above normal. Accordingly if a certain speed is found to be most efficient, it will be necessary to provide extra thrust on the engine to ensure that the speed does not fall excessively too often to disrupt schedules.

WINDS ALOFT

The flight problem is by no means simple since not only is temperature important but also winds are a major factor. While it is generally appreciated how winds affect aircraft operation, the importance of the gradient with height becomes more important with aircraft that operate at very high altitudes. In some cases it pays to fly lower to take advantage of lower winds. For jet aircraft this involves some penalty in the way of fuel, but this may or may not be large, depending on the circumstances. An interesting aspect of this is, that if the risk of running into a jet stream would seem to be much lower if one stays low when the forecast winds at high altitudes are high, a small amount of extra fuel burned may well be worthwhile rather than carry very large extra reserves to meet the contingency of running into the jet stream.

Due to the complication of the problem most of the possibilities must be foreseen in advance and general operating procedures worked out from climatological data. If this is done, detail adjustments can then be made based on the forecast for the actual flight relatively quickly.

While I believe the meteorologists are to be congratulated on their store of climatological data on winds and temperatures up to the altitudes which are of interest for modern jet aircraft, they have not given much of a clue as to the correlation of these data. It may be that there is no correlation, although to the layman this seems somewhat hard to believe. Nevertheless it can easily be seen that both temperature and winds must be considered simultaneously in a detail problem, and hence some relationship must implicitly be considered every time the problem is dealt with.

ICING

Another field in which meteorological data is important is in the design of anti- and de-icing gear. Data has been obtained on the probable range of conditions under which icing may be met and on the maximum water content of the air under these conditions. This information is usually sufficient to design the appropriate system to protect either the engine or the airframe surfaces.

The foregoing remarks have been intended to show that meteorological data has an important place in the basic design of aircraft. However meteorologists have been rather less active in this field than in the operational field. This is probably, at least in part, due to a lack of appreciation of the problems faced in aircraft design. It is accordingly hoped that this paper and others like it will stimulate interest in this aspect of the meteorological problem.

METEOROLOGICAL ASPECTS OF THE FLIGHT TESTING OF JET AIRCRAFT

D.H. Rogers.

A generation-and-a-half ago Sir Alliot Verdun Roe designed and built a flying machine with which he managed to attain a height of about 30 to 40 feet and an airspeed of 40 to 50 m.p.h.

A couple of years ago the Canadian company which bears his name, A.V. Roe Canada Limited, made the first flight of an aircraft which flies at 30 to 40 thousand feet and at 400 to 500 m.p.h.

Meteorological considerations were of prime importance in the operation of both aircraft but — there was a difference. In the former case the problem was extremely simple — in the latter very complex.

It seems ironical that the early aircraft, which required almost perfect weather conditions, demanded virtually no meteorological apparatus and very little knowledge of "weather" as we know it today. I understand that the primary "met" instrument in the early days was a cigarette. If the smoke went any way except straight up the weather was unsatisfactory. On the other hand the operation of a modern aeroplane, which at times may be hopefully referred to as an "all-weather" aircraft, demands a vast network of complex equipment staffed by highly trained technicians of meteorology. The reason for the change, of course, is the great increase in utilization and operating range of modern aircraft, both transport and military.

Keeping pace with this development has been a corresponding expansion and complication of the procedures for the testing of aircraft in flight. I recently read a pilot's report of an aircraft tested in 1912 and it was just four short sentences stating that the B.E.I. had a speed of 58-59 m.p.h., a rate of climb of 185 f.p.m., and that the machine would stand a loading of 3G. This latter fact was determined by suspending the aircraft inverted and loading the wings with sand bags.

The complete testing of a modern aircraft literally requires filing cabinets full of graphs, tables and reports. In the early days it was sufficient to merely demonstrate that the aeroplane would fly and could be controlled to a safe landing. The development of a modern aircraft usually requires hundreds of hours of exhaustive test flying. Broadly speaking, the program can be divided into three general categories of tests — Handling Trials, Performance Testing and Proving or Safety Flights.

HANDLING TRIALS

During the 1920's as the aircraft increased in number, variety and complexity the flight testing procedures also became more detailed — but the results of Handling Tests were still largely expressed qualitatively, i.e., "the Controls are light and effective." It was not until the 1930's that a serious effort was made to interpret quantitatively as many of the handling characteristics of an aircraft as possible. By the second world war, although qualitative pilot's reports were — and still are —required, almost every function of the aircraft could be stated quantitatively and compared to established standards for the category. For example, instead of—or in addition to—saying, "the Controls are light and effective", graphs and tables are prepared to show exactly what the forces are for each of the controls and what response they produce for every degree of movement and for different weights, centre of gravity, altitude, speed, etc. Needless to say this involves a great many hours of accurate test flying, complete records in flight, and lengthy and accurate analysis of the observations. So many instantaneous readings of instruments are now required during a manoeuvre that it is beyond the capacity of a pilot or engineering observer to obtain them all and this problem is now solved by the installation of a unit known as an automatic-observer. This is a special group of carefully calibrated instruments, including the usual things such as airspeed, altitude, etc., but with the addition of a "G" indicator, Mach meter, and indicators for rudder, elevator and aileron angles, trim tab angles, the force the pilot is exerting on the controls and many other factors. This panel of instruments is usually enclosed in a well-lighted box and a camera is arranged to photograph the instruments. Single shots can be made when the pilot has the aircraft in the exact condition and attitude desired or the camera can be set to take a series of pictures during a manoeuvre. By the use of strain gauges, etc., other simultaneous readings are possible of actual forces acting in any part of the aircraft structure during the manoeuvre.

Weather considerations are not a particularly vital factor in this phase of the testing program. As always during test flights it is desirable to have a minimum of atmospheric turbulence in order to produce steady readings of the many test instruments and to assist the pilot in obtaining and holding a steady condition of flight.

PERFORMANCE TESTING

In the case of Performance Testing, however, the weather conditions are a very important consideration and this is particularly true of jet-powered aircraft. Performance Testing is the phase covering the measurement of everything from takeoff distance to landing run, including rate of climb with all engines operating, or with partial engine failure; level speeds at all altitudes; maximum and service ceilings; normal and maximum rates of descent; and fuel consumption under varying conditions of aircraft weight, power and altitude.

The effect of atmospheric conditions during this type of testing is particularly important in the case of gas-turbine-powered aircraft because of two characteristics of this type of airframe and engine configuration.

First, the engine power is more adversely affected by high ambient temperatures than is the case with conventional power plants. This not only increases the takeoff run and reduces the rate of climb but, of almost equal importance, an increase of even a few degrees of temperature at high altitude reduces the aircraft range and consequently the payload by a surprisingly large amount.

The adverse effects of high temperature during the takeoff case can be largely overcome by the use of such devices as water-methynol injection to lower the temperature of the air entering the engine, thus increasing the mass flow, but no practical method has, as yet, been devised to prevent the losses resulting from a higher than normal temperature at cruising altitude.

The second complication arises due to the high altitude at which jet aircraft must be tested.

Since they operate in the region of the tropopause they are likely to be flying in an area of high altitude "clear air" turbulence. Furthermore ground speed may be unexpectedly higher or less than anticipated because of having encountered a high velocity flow of air sometimes mysteriously referred to as a "Jet Stream".

Turbulence at the higher altitudes can be quite severe at times but usually the rough air will occur in a relatively thin layer, although on one occasion over Toronto we found the air to be rough over six or seven thousand feet from about 28,000 feet to 34,000 feet. It was much too rough for steadv test flying and severe enough in spots to cause us to reduce speed. At other times a climb or descent of 500 or 1,000 feet will be enough to clear the turbulent layer. However, as far as our experience goes, the implication in the expression "clear air" gust has not been quite correct. We have not encountered any single, sharp-edge gusts of notable severity in clear air and at no time have we run into a layer of high altitude turbulence without also observing a demarcation in the atmospheric levels although such an indication may be very faint. There may be no solid cloud at all but only a very indistinct layer of haze or just a vaguely discernible change of shade of the horizon line of the atmosphere. Often these manifestations will be so filmy as to be quite invisible when looking up at the sky from the ground, or down to the ground when flying above the layer. At other times the turbulence will be associated with the thin wispy clouds visible from the ground as cirrus. In flight these will completely obscure any indication of horizon when operating near their level as of course, one is then attempting to look through the layer horizontally.

However, we have on more than one occasion seen CB build-ups at least three times as high as were formerly thought possible. It is amusing to think back a few years (not so many either) to the days when it was considered unlikely that clouds would form much above 12,000 feet. When aircraft began operating at 12,000 to 15,000 feet, and the clouds were still found to be above this height it was conceded that perhaps they would extend to 18,000 or 20,000 feet. As aircraft altitudes continued to increase the thinking on the subject of maximum cloud heights had to be revised steadily upwards. We have flown in the vicinity of CB clouds at nearly 40,000 feet with the tops still considerably above that height.

The dangerous possibility of inadvertently flying into one of the very high CB build-ups in bad visibility or at night is considered sufficiently serious to warrant the installation of radar in jet transports to search out such manifestations of Nature's might. One often hears of light aircraft being damaged or destroyed by attempting, intentionally or inadvertently, to fly through heavy cumulus but even large aircraft can be overcome at times. During the war a B17 Flying Fortress attempted to fly through a thunderstorm cloud near the Equator and bits and pieces of aeroplane continued to fall out of the sky for some considerable time over a very wide area. It certainly is important that the pilot of a jet aircraft be advised of the existence and location of such phenomena.

The disillusionment of finding clouds or haze at 25 to 35 thousand feet any day of the week has unfortunately disproven the optimistic predictions that no weather or turbulence would be encountered above 15,000-18,000 feet. In addition to being uncomfortably rough at times the haze occurring at the levels of atmospheric change at 30 to 35 thousand feet may take the form of ice crystals which have a very detrimental effect on aircraft radio reception. After flying for about an hour through ice haze at 35,000 feet between Miami and New York even the V.H.F. equipment was becoming very noisy.

I don't propose to make much comment about "Jet Streams". They are not the unpredictable mystery they were once thought to be. Their existence, location, direction and force can be plotted by the meteorologists with a degree of accuracy depending on the volume of weather information available for the high altitudes. The importance of this information will become greatly intensified when long range flights are planned with consideration of limited fuel reserves.

One interesting thought I would like to present in this connection is the possibility of obtaining a favourable wind (or at least a less unfavourable one) by changing cruising height in relation to high altitude turbulence. An experimental flight test unit of the U.S.A.F. has advanced the theory that, in the vicinity of the tropopause, where the turbulence is caused by the abrasion of two different layers of air, all eastbound flights should operate just on top of the turbulence and conversely westbound flights should fly just below (or vice versa). I am sorry to say I am not positive as to which direction should be flown above or below the rough layer and we have not had an opportunity to investigate this matter ourselves. You will, however, appreciate the potential importance of this procedure if it is reliable and practical and a really accurate knowledge before flight of the existing lapse rate and the exact altitude of the tropopause would be of great assistance to flight planning.

This problem of investigating conditions at high altitude and high speed raises interesting secondary problems in connection with the attempt to measure conditions sufficiently accurately to give clinically reliable test results. High altitude and high speed means high Mach numbers and this introduces a new series of correction factors for indicated airspeed, altitude and outside air temperature. For example, on one flight we made to Winnipeg at 35,000 feet last winter, our most accurate and detailed corrections for speed and altitude gave an outside air temperature of -89°F but this has been disclaimed by certain meteorological centres as being impossible at that time — who is right and who is wrong? If the "Met" office estimate of minus 75°F is more correct this would throw doubt on all our high altitude correction factors. In this case however, we feel that our procedures do result in obtaining "true" corrections.

Furthermore, the exact measurement of ground speed is far from easy unless a very long flight is undertaken. It is unusual to have sufficiently clear air at both ends of a trip to allow accurate visual pin-pointing of position from 30 or 35,000 feet. Radiobeams, cones of silence, and 75 megacycle marker-beacons are all so broad at height as to require special techniques to even approximate a really close pin-point. Some work has been done with radar tracking of aircraft and this has promise of considerable accuracy but can only be obtained with a rather elaborate set-up of equipment and trained operators. This use of radar tracking, plus "telemetering" (which takes the photographing of a panel of test instruments in the aircraft one step further by the instantaneous and continuous transmission of the information to engineering observers on the ground) would appear to be the coming thing for the testing of jet aircraft. The use of telemetering will be particularly useful in the case of jet fighters. In a transport-type aircraft such as the Jetliner we always carry engineering observers who follow the progress of the flight and are available to consult with the test pilot if it is considered advisable to alter the flight procedure in order to obtain better results in some other way or because of a change in some condition affecting the flight. The pilot is largely on his own in the case of fighter testing of course but, as the engineering section slyly points out when discussing the merits of telemetering, they will be able to radio up to the pilot to pay attention to what he is doing; that, say, he is flying at 29,990 feet instead of "precisely 30,000 feet" as they so glibly state in their pre-flight briefing. (This test flying is becoming tougher every day!) Seriously of course it will be an excellent aid to the accurate and expeditious obtaining of results by flight testing and may add something to safety as well.

Before I leave the subject of the effect of the atmospheric conditions on Performance Testing there are two other conditions which are unsatisfactory, depending on the type of test being conducted. One is the presence of an inversion during climb tests which spoils the continuity of the results. The other is the presence of very long waves or undulations occasionally encountered in level flight. These waves may be as much as 40 or 50 miles from crest to crest but the aircraft attitude and speed are never truly stabilized in these conditions because one is always flying on a gradual up-slope or down-slope. Whether such conditions really have an appreciable effect on the actual performance or not, I do not know but in any case, the resulting irregularity and inconsistency of the observer readings are a source of such great annoyance to the flight analysis department that they are usually considered unsatisfactory because too many correction factors are introduced to give the results the desired degree of accuracy.

PROVING AND SAFETY FLIGHTS

The third general classification of test flying is the Proving and Safety Flights. These involve such things as limiting Mach number, limiting indicated airspeed, night flying, de-icing trials, etc. The importance of the weather factor varies greatly depending on the particular type of test. For example it is much more conclusive if de-icing flights can be carried out in actual icing conditions rather than simulating the conditions by a water spray and other artificial devices. It also simplifies things to carry out the night flying tests after dark!

When investigating the limiting Mach number characteristics of the aircraft these flights are carried out at high altitude and at low temperature because, as you probably know, a decrease of atmospheric pressure and air temperature results in a corresponding decrease of the speed of sound. Consequently the aircraft can fly at a higher percentage of the speed of sound (or a higher Mach number) with a lower indicated airspeed under these conditions. This is an important advantage since the Mach number of an aircraft is usually limited by an initial moderate airframe buffeting followed, as the aircraft is pushed still further to a higher Mach number, by a sudden, and sometimes severe, deterioration of handling characteristics. This loss of control may take the form of sharp wing dropping, directional snaking or a sudden uncontrolled steepening of the dive. The violence of these gyrations can be such that actual structural damage could occur to the aircraft. This danger is reduced by flying at the higher altitudes because the lower indicated airspeeds mean a corresponding reduction of air loads on the aircraft surfaces.

When the limiting airspeed is being investigated the flights are normally carried out at low altitude and high temperature because the speed of sound is higher in such conditions and this means that the aircraft can be flown at higher indicated airspeeds at a lower percentage of the speed of sound thus avoiding the type of complication I was just discussing of serious deterioration of handling characteristics due to compressibility effects. This advantage is becoming continuously more marginal however because, as the power of modern jet aircraft increases, they have begun to reach the point where they are capable of level indicated airspeeds so close to the speed of sound that they are definitely in that range known as "trans-sonic" where the effects of increasing compressibility can be felt.

Another adverse factor in connection with very high indicated airspeeds at low altitudes, particularly with the desired high temperatures, is the severity of the effect of turbulence. In addition to being very uncomfortable for the pilot and resulting in bruises about the shoulders and thighs and necessitating the use of a crash helmet, it can also cause structural damage to the aircraft, sometimes sufficiently severe to be catastrophic.

Another series of trials where ideal weather conditions are essential is the accelerate-stop tests, to determine the runway length required to accelerate to safety speed at maximum gross weight and then, in the event of engine failure, to throttle back and brake to a stop.

As you will realize the weather is a very important factor in almost every phase of test flying and I would like to mention briefly the way in which the forecasting of the general weather is important too, in its effect on the overall flight test program.

THE ROLE OF FORECASTS IN FLIGHT TESTING

It is characteristic of experimental aircraft that it is always difficult to get them out of the hands of the shop and into the air. So many sections of the organization have modifications they wish made to test instruments installed or special inspections carried out that someone is always standing by with work to be done when the aircraft is on the ground due to weather (or any other cause). Consequently it really helps our program planning to know a day or so ahead if the weather will or will not be suitable for test flying. If not,the aircraft can be made temporarily unserviceable for the completion of some work in the shop or, if it is known that the weather will be good, this ground work can often be postponed and the aircraft inspected by the night shift and prepared for a morning test flight.

In this connection I would just like to stick my neck out to mention my observations on the forecasting of general area weather. I am quite sure my thoughts on the subject are not at all original but, for what they are worth, here they are.

I am invariably surprised by the accuracy of the forecasts of general weather conditions and temperature. But it appears to me that in the greatest percentage of "misfires" just one thing has happened. The weather as forecast exists all right but it isn't where it was supposed to be because it has been forced to change either speed or direction or both. This is probably a vast oversimplification of a very complex problem but I am very hopeful and confident that, in the not too distant future, the tremendous background of observations and your constant study and analysis will reveal the hidden formula which will unfailingly indicate what the resulting movement of each air mass will be for any combination of pressure patterns.

Before concluding, I would like to mention, for your consideration, one phase other than the test flying of a jet-powered aircraft in which really accurate weather forecasting could make a tremendous difference in the overall picture of the operation of such an aircraft. This is a very difficult requirement to meet and involves the forecasting with extreme accuracy of terminal conditions when such conditions are right "on limits".

Although it is quite possible for a multi-engined jet-powered aircraft to stretch its endurance at low altitude by a reduction of power, or even the stopping of one or more engines, it requires almost prohibitive quantities of reserve fuel to be able to climb again in order to fly to the alternate airport after descending to have a look at the terminal weather. However T.C.A. states that a large percentage of their schedules can presently be completed because they almost invariably allow the pilot to come down to execute an instrument approach in the hope that conditions will be on, or slightly above, limits at the particular moment he is letting down between the range and the airport. As you are well aware it is a very difficult problem for the forecaster to predict accurately whether the terminal weather will be 400 and 1 or perhaps only 300 and 1/2 for a period 30 or 45 minutes hence. The margin is so critical between permissible and "below limits" weather that the slightest variation of wind, temperature, pressure or humidity can make the difference between a completed approach or a diversion to an alternate.

In the case of jet aircraft the sure knowledge that field conditions would or would not be "below limits" might make possible a substantial reduction of the reserve fuel. By eliminating any necessity of descending to check the terminal conditions, with the ever-present possibility of having to consume the large quantity of fuel required to climb and then proceed to the alternate, a portion of this fuel could be replaced with payload. I realize though that this will be an extremely hard nut to crack.

In conclusion I would like to voice our appreciation for the continuous help and co-operation we receive from the Airways Forecasters at Malton. When the weather is variable we sometimes have to call them several times a day in order to check current conditions because, as I have tried to point out, the test flying of jet aircraft requires more information than that conditions are above or below V.F.R. They have always been sympathetic to our requests, and interested in our special problems, and it has meant a great deal to us to have their ready help and advice.