Gust research

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NATIONAL RESEARCH COUNCIL OF CANADA

GUST RESEARCH

BY

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1. Introduction

The study of gusts and of their effect on very large aircraft has become a matter of major importance. It constitutes one part of the general investigation of the atmosphere in relation to aircraft.

An intimate knowledge of the conditions under which aircraft are required to fly in each country is of great importance, and this is particularly so in a country in which topography and climate conditions vary so widely as in Canada.

2. Historical

Consideration has been given to the undertaking of an investigation of gusts in Canada.

December, 1944

During a visit to England, A.V.M. Stedman, and J. H. Parkin, found considerable interest in the question of the effects of gusts on very large aircraft. A brief summary of the views expressed is given in Appendix A.

7 May, 1945

In a memorandum "Investigation of Gust Loads" Mr. R.D. Hiscocks dealt with the need for reliable and comprehensive information concerning gusts (See Appendix B).

1945

The question of gusts was discussed by A.V.M. Stedman, with Mr. W.G.A. Perring, and Dr. D. Williams of the R.A.E. during the visit to Canada of the Perring Mission (Appendix C).

27 July, 1945

Sir Ben Lockspeiser, Director of Scientific Research M.A.P. wrote outlining the need for work on the detection of gusts - (Appendix D). Air Vice-Marshal

Stedman commented thereon in a letter dated September 5, Appendix E, and Dr. P.B. McTaggart-Cowan in a letter dated September 22, (Appendix F).

3. Action by the Associate Committee on Aeronautical Research

Minute 818 of the meeting held in Ottawa, Aug. 27, 1945.

Unfinished Business of the Fifty-Second Meeting

Mr. Parkin then gave a brief outline of the three phases of an investigation of gusts and their effect on aircraft which it had been proposed might be undertaken advantageously in Canada, in order that the members in preparing these priorities might understand the scope of this research.

Minute 834 of the meeting held in Ottawa, 26 November, 1945.

Post-War Research Problems

Subcommittee on Aircraft Structures
- Construction to retain laminar flow
- Flutter and vibration research
- Buckling of curved panels
- Cable control systems

Mr. Parkin outlined the gust research project and read a letter from Mr. Lockspeisser and a memorandum from Mr. Hiscocks which are included as Appendix E and F. It was agreed that this project should be undertaken by the Committee although it was not placed under any Subcommittee.

Minute 55 of meeting of the Committee held in Ottawa, 13 March, 1945.

The Effect of Gusts on Aircraft

Air Vice-Marshal Stedman reported that he had sent a letter to Sir Melvill Jones (included as Appendix C) suggesting that he forward a questionnaire defining the problem of gust effect on aircraft, and the reply from Sir Melvill Jones (Appendix D) stated that he would bring it up at the next meeting of the British Aeronautical Research Committee. Air Vice-Marshal Stedman further stated that he believed that there would be a surplus of V.G. recorders in England, and that if these were installed on R.C.A.F. Transport and T.C.A. Planes, some valuable information might be obtained. The Chairman stated that he would ask Dr. Green to search the literature on this subject, but that no action would be taken now and the subject would be brought up at the next Associate Committee meeting.

Minute 832 of meeting held in Ottawa, 6-7 May, 1946.

Program of Work for the Coming Year.

Information on Aircraft Structures.

The Gust Research was tentatively approved, and Mr. Parkin stated that he will discuss it in detail when in England, Air Vice-Marshal James stated that gusts at low altitude were important, and that both the investigation of the gust itself, and the reaction to the gust as well as gust warning would have to be studied.

4. Discussion at R.A.E., 15 July, 1946, with Dr. D.W. Williams and others

Gusts

The letter and report on the first V.G. record from T.C.A. was tabled.

The R.A.E. has made flights in a Spitfire, to an altitude above the Tropopause, and gusts have been encountered, resulting apparently from high rates of shear in the atmosphere, caused by widely different wind speeds at altitudes differing by two or three thousand feet. It is proposed to make daily flights in a fully instrumented Spitfire in the near future.

It was suggested that more information on gusts was needed and that a suitable program would be:

1. Collection of statistical information using instruments fitted in commercial aircraft operating on regular air routes.

2. Study of local gusts in regions of severe gustiness using research aircraft.

While the V.G. Recorder is reasonably satisfactory, an instrument of small size, recording rather more information is desirable. The R.A.E. has under development an accelerometer recording acceleration and velocity, on a time base.

There were reported to be some three very good accelerometers available in the U.S., one being an instrument developed by the Martin Company. The Hathaway instrument was considered to be good but too bulky.

Mr. Williams recommended the use of a magnetized wire type of recorder.

It was agreed that the R.A.E. would prepare a general review of the work on gusts for our information.

It was indicated that we should be glad to co-operate in any investigation planned and that the co-operation of T.C.A. would also likely be available.

5. Commonwealth Conference on Aeronautical Research

Extracts from the report of the conference, to which the official delegates from Canada were Dr. C. J. Mackenzie, Air Vice-Marshal A.L. James, and Mr. J.H. Parkin, having a bearing on this question are:

Planning of Aeronautical Research

One of the main objects of the proposed Council is to review broadly the progress of Aeronautical Research and to advise on the broad planning of programs. This is considered necessary to ensure a co-ordination of effort and a continuity of purpose within the Commonwealth. The fields of research for civil and military aircraft are so many and varied that the present r esources of the whole Commonwealth both in staff and equipment cannot cover them all. The immediate need therefore is to limit the field by the selection of certain main lines of advance of greatest significance and to concentrate the Commonwealth effort accordingly making use of existing or readily obtainable equipment both on the ground and in the air.

These possibilities were fully discussed and there was a general agreement on the desirability of s tarting, as soon as possible, certain lines of investigation in Canada and Australia in co-ordination with parallel activities in the United Kingdom. Agreement was reached on the most sifnificant lines of advance and detailed discussions arising therefrom have been held among the United Kingdom, Canadian and Australian delegations. Appendices I, II, and III summarize the results of these discussions. The conference recommends the adoption of these programs.

Flight Research in the Dominions

In the future many brances of aeronautical research will require experiments to be made in flight as well as in wind tunnels. For some types of experiment the geographical and meteorological conditions in the Dominions are more favourable than in the United Kingdom and the conference strongly recommends that research in flight on a considerable scale should be undertaken in the Dominions.

It will be necessary to design and build aircraft specifically and entirely for research purposes. If some of those experiment aircraft are designed, built and tested in the Dominions, the Commonwealth as a whole will benefit by the extension of research facilities and the Dominion will have opportunities of developing design teams with experience in advance fields.

Operational Research

The conference desired to stress the need for operational research. Resting as it does on the detailed analysis of a large number of observations on the operation and behaviour of aircraft under a variety of conditions, this subject was recognized by the conference as an especially suitable and productive field for Commonwealth study.

The conference recommends that all the countries participating in the C.A.A.R.C. should engage in operational research and that provision should be made for organizing the work and for collecting and analysing the data obtained.

The program of research to be undertaken in Canada, as submitted to the conference, included:

Aerodynamics

1. Continuation of the study of the balancing of controls and its possible extension to power operation of controls.

2. Flight investigation of the stability and control of tailless aircraft.

3. Study and design of supersonic wind tunnel.

4. Flight investigation of local gusts.

6. Participation by Trans-Canada Air Lines

The problem was presented to Mr. J.T. Dyment, of Trans-Canada Air Lines, Feb. 12, 1945, and in reply he indicated that T.C.A. would be only too pleased to co-operate in the project by fitting accelerometers in their aircraft to obtain continuous records of the accelerations encountered in Canada.

Two V.G. Recorders, furnished by the M.A.P. through the R.C.A.F. were, in due course, supplied by T.C.A. and installed, one in a Lodestar engaged in schedule runs and the other in a Lockheed Model 14.08 engaged on pilot training and engineering flight testing in Winnipeg.

The first records were received in May and transmitted to the R.A.E. by Mr. Parkin, when in England. A further set of records was received in August and forwarded to the R.A.E.

7. Outline of the problem

The problem as visualized embraces several phases:

(a) An investigation of the general magnitude of gusts encountered in Airline operation in Canada. This stage involves the fitting of aircraft operating on organized air lines with accelerators to record the magnitude of accelerations encountered. The results should indicate the locality in which the most severe gusts are encountered.

(b) An investigation of the specific characteristics of the gusts, in the locality or localities in which the most severe gusts are prevalent. This phase would be undertaken using experimental aircraft fitted with instruments designed to record the character of the gusts.

(c) A study of the behaviour of aircraft, preferably the largest available in gusts. For this phase accelerometers should be fitted at different points in the aircraft to study the reaction of the aircraft, i.e. the influence of the elasticity of the structure.

(d) A possible fourth phase is the investigation of the detection of gusts by radar or other means as suggested by Sir Ben Lockspeiser.

(e) An essential supplementary investigation would be involved to study available accelerometers and other instrumentation to select that best suited for the work, and if necessary, develop instruments for the project.

Recommendations:

If the study of gusts is undertaken under the auspices of the Associate Committee, and one or more of its Subcommittees, it is suggested, that because of its scope the work might well be undertaken under the general guidance of a small panel of from four to six members comprising specialists in the different fields involved.

APPENDIX A

Gusts - Views Expressed in England - December 1944

There was a good deal of interest in the question of gust effects on very large aircraft. It was said that with aircraft of large size, such as the C-99 in the United States and the Bristol Brabazon in England, the natural period of the wing is approaching dangerously close to the period of gust on the one hand and to the period of the undercarriage on the other hand.

Knowledge of the work which has been proceeding in the United States for some years on the study of atmospheric gusts did not appear to have reached England, and it was suggested at Farnborough that a general study of gusts might be undertaken with advantage in Canada. It is proposed to study gusts in England in two ways:

1. By fitting a Spitfire and possibly a light aircraft with accelerometers.

2. By studying the effect of changes in the characteristics of an aeroplane on its behaviour in gusts, i.e. by observing the interplay of variations in fin, tailplane, etc. It is proposed to use a Dakota for this work.

In general, it was stated that there are two basic problems:

a. To understand the nature of the atmosphere.

b. What happens to an aircraft flying in the atmosphere. This becomes increasingly important as the size of the aircraft increases.

It was further suggested at the R.A.E. that a very valuable contribution could be made to the knowledge if aircraft operating on an organized air route could be fitted with recording accelerometers in order to obtain continuous records of the accelerations encountered by commercial aircraft in Canada. Aside from fitting the accelerometers, the only other record necessary would be that of the weight of the aircraft and this would normally be available from the passenger and freight records for each trip.

APPENDIX B

Investigation of Gust Loads

R. D. Hiscocks

The need for reliable and comprehensive gust data in aeroplane structural design has become acute.

1. Large aeroplanes are not highly manoeuverable and transport pilots are trained not to indulge in aerobatics. As a result the strength factors required for manoeuvering are very low in large aircraft and probable gust loads are critical in wing design.

2. Recent experimental data indicates that gusts of high velocity are not necessarily associated with large gradient distances. This discovery casts considerable doubt upon the validity of the gust formula in use for the past fifteen years derived on the assumption that the gust velocity varies as the gradient distance.

   If extremely local gusts of high intensity are probable the usual design assumption that all spanwise wing elements penetrate a gust simultaneously is liable to introduce large errors, especially with wings of large span. Attempts are at present being made to derive accurate data on the loads produced by aileron action in order to rationalize the asymmetric wing load factors. Any such "rationalization" which does not include gust asymmetrics is very dangerous.

3. As a result of increase in size, aspect ratio and the knowledge of the factors governing flutter wing natural frequencies have decreased to a marked extent recently. In large aeroplanes loads have been spread spanwise to such an extent that stiffness rather than strength considerations predominate in the design.

   The present knowledge of gust frequency, shape and distribution in the atmosphere is totally inadequate to permit the designer to estimate the response of the wing structure and the probability of dynamic overstress or fatigue.

4. As a result of recent tail structural failures due to load asymmetrics airworthiness boards in many countries are considering the adoption of gust conditions for tail surface design. Before rational figures can be determined more data is necessary on gusts generally, on the response of an aeroplane to gusts and on the maximum dynamic lift coefficient of various aerofoils.

5. With refinements in design and with tailless aircraft particularly it is important to consider the effect of the stability characteristics of the aeroplane upon the response to a gust. This is of paramount importance with tailless aircraft having a pronounced sweepback because large pitching moments may develop upon entry into a gust and the pitching moment of inertia is relatively small.

The staff and equipment necessary to this investigation is not beyond the resources of the Division of Mechanical Engineering within the immediate future. The principal item would be the long term loan of an aircraft with a large span, preferably a Liberator. Lesser items would include recording accelerometers and manometers and dynamic strain gauge equipment, all of which are in preparation. Staff requirements in addition to pilot, navigator, and maintenance crew would include one Research Engineer, two Junior Research Engineers, one Computor and one of two people to perform installation work.

If the Associate Committee on Aeronautical Research is prepared to authorize the investigation it is suggested that the R.C.A.F. be approached concerning the loan of a suitable aeroplane and that a small panel be appointed to draw up a detailed program.

APPENDIX C

Discussion with
Mr. W.G.A. Perring - Deputy Director
Dr. D. Williams - Royal Aircraft Establishment

Gust Measurement

At various times the question of the measurement of gust has been discussed with officials in Britain and the United States, and Mr. Perring came to tell us of the work that is being done at Farnborough, and to give us some indication of the way in which they thought we should undertake the work here.

In laying a smoke trail for other purposes at Farnborough it was found that the trail gave a good indication of the structure of gusts, and this is well illustrated in the attached photographs. From this it is evident that if one aeroplane laid a smoke trail then two aeroplanes could fly parallel courses, taking photographs of the smoke trail from the side and from vertically above. If the pictures included the aeroplane itself, this would give a linear scale, and the spacing of the exposures would give a time scale. From these results the rate of build up and decay of gusts could be obtained.

It is very important that each country should have an intimate knowledge of the conditions under which aeroplanes are required to fly, and this is particularly so in a country like Canada where climatic and physical conditions are very different from those in England. It is quite likely that gusts of much greater intensity may be encountered here as compared with those measured in England.

Mr. Perring left two R.A.E. technical notes dealing with this subject, namely 1443 revised and 1628.

If an accelerometer is carried in a fixed position in an aeroplane it will record accelerations which are the acceleration of that particular part of the aeroplane. An accelerometer carried in a more flexible part of the aeroplane would measure different accelerations, and neither of these would be the average acceleration due to the gust. In the first instance, therefore, it appears necessary to fit a large number of accelerometers in the aeroplane adjacent to the principal masses, and by integrating the masses and accelerations it is possible to obtain an average acceleration for the whole aeroplane from which the gust can be calculated. From preliminary tests of this kind it would perhaps be possible to find some position in the aeroplane where an accelerometer would read the average accelerations of the whole aeroplane. This position would be used in subsequent tests, and the necessity for a large number of accelerometers would be eliminated.

Having these preliminary experiments, an aeroplane should be fitted up for gust measurements and flown all over the country, but particularly in those parts of the country where it was found that the most difficult atmospheric conditions could be met. By continuing this work for sometime it would be possible to obtain a good idea of the type of gusts that might be expected.

It was suggested that this work might be suitable for the National Research Council to undertake with R.C.A.F. co-operation, and that in the first instance it might be advisable to send a scientist who would be responsible for the work to Farnborough to work with the men who are doing similar work in England.

The Vg recorders available in England are of American manufacture and are not really suitable for the purpose, because it is more desirable to have a record of accelerations against time in order to determine the structure of the gust. It is necessary to have an accelerometer of high frequency, certainly 40 cycles per second or more, and those generally available are much lower than this.

There is a Stratham accelerometer available, which consists of a small weight suspended in the middle of a fine wire. The two lengths of wire, which are under tension, form two arms of a Wheatstone bridge. An acceleration in the direction of the wire alters the resistance, which can be measured. These accelerometers have a frequency of about 400 cycles a second, and can be made even higher.

APPENDIX D

The Detection of Gusts

You will be interested in the attached note on the detection of gusts which is one portion of our program on this difficult subject. Notes on some American work with which you are probably familiar are also attached. Our own resources are limited and will not allow of the scale of effort required to obtain all the information required in the time necessary to allow us to take advantage of it on new types. Any assistance you could give would therefore be highly appreciated, and I suggest that in Canada you are in a good position to do this type of work. In this country the Meteorological Office are considering a program of long term research on the same subject but as you will understand we require a quick answer if we are to take advantage of "Gust Warning" on new types.

If you decide to undertake it, one or more aircraft carrying X band radar will be required and I think you will agree that the work should be done in close conjunction with meteorological staff. In the case of cumulo nimbus clouds it would be very unwise to attempt to measure gust velocities to obtain correlation with the records. In other cases, however, an attempt at correlation will be desirable and the aircraft chosen should, therefore, take this into account. The cases where this type of correlation is particularly necessary is in exploring clouds which are not normally associated with violent gusts, but which may give radar traces. As you will appreciate it is essential to establish:

(a) That violent gusts are associated with phenomena which will give radar traces.

(b) That radar traces are not frequently obtained from phenomena not associated with gusts.

If you consider that you could undertake this work I should be grateful if you could sent your program on it in order that we can link it with our own. We might then arrange a discussion.

APPENDIX E

Gust Research

The documents attached to your above referenced letter have been examined with interest here and I am now prepared to state that the R.C.A.F. is definitely interested in taking under consideration, a program of work in connection with Gust Research. you are, no doubt, aware of the work which has been done since June, 1944, in "Stormy Weather". This work has been moderately successful and I believe that an air-borne program in Gust Research, complimentary to it, would prove of mutual benefit to both.

I would propose forming a Gust Research Flight which could operate out of Rockcliffe and would consist of two Ventura aircraft equipped with "X"-Band Radar and cameras for photographing the indicator screens. Vg recorders would also be installed. These aircraft would work in conjunction with the Stormy Weather project which, I believe, could easily put them in the location of turbulence which might be very productive of gusts. After photographs of the indicator screens had been taken and measurements of the actual gust recorded on the Vg recorders, this information, I would suggest, could best be analysed by some of your scientific personnel in order to determine the exact gust structure.

I suggest that the matter be discussed at the next meeting of the Executive of the Associate Committee on Aeronautical Research, with the object of preparing a brief, setting out the program, which would be submitted to Air Council for their approval.

APPENDIX F

Further to my previous letter concerning gust research I have now studied the matter in detail and offer the following suggestions:

(a) It is doubtful whether any practical application of this investigation will be discovered in view of the fact that even assuming an adequate gust warning device the evastion of the turbulent region would require the aircraft to climb to very great altitudes or detour very considerably from its course. Either of these would increase the cost of operation and I would rather expect that this increased cost of operation could to a considerable extent offset the increased payload resulting from the ability to stay out of extreme turbulence.

(b) These remarks of course apply to low and mid-level aircraft operation. If high level operation is contemplated then the turbulence problem will be largely associated with the/initial climb and final descent of the aircraft and in this case the evasion of turbulent regions might well be a practical proposition.

(c) From an examination of the results obtained by the Canadian Army Operational Research Group in the use of radar for detection of weather I do not think that S band radar would be satisfactory. I understand that optimum echo from water particles in the air is obtained by the use of X band radar, and this, therefore, might result in the recording of all cloud associated with serious turbulence but it is doubtful whether it would give warning of extreme turbulence not associated with cloud.

I understand that there is under consideration at the present time the advisability of the National Research Council continuing the Canadian Army stormy weather project. If the National Research Council decide to carry on this project then research in this line and in the detection of gusts could to a considerable extent be integrated. Both investigations would be working with X band radar and the aircraft could be despatched to areas of expected severe turbulence as a result of ground equipment observation as well as conducting gust research.

Regardless of the eventual practicability of the results derived from gust research I think its basic nature and close association with the stormy weather project would make it a very suitable and interesting field of experimentation for the National Research Council, and if any practical result was obtained it would be a very substantial contribution to the aircraft industry.

BIBLIOGRAPHY ON GUSTS - REPORTS ISSUED 1941-1946

UNITED STATES

N.A.C.A.

XC-35 Gust Research Project

ARR* (13 pt.1)	Bulletin no. 1: Operations in vicinity of cold front, May 23, 1941. Evaluation of max. gust intensities. September 1941.
ARR (13 pt.2)	Bulletin no. 2: Operations in vicinity of cold front, May 23, 1941. Reactions of pilot's instruments. October 1941.
RB	Bulletin no. 3: Operations in cumulo-nimbus congestus clouds on July 3, 1941. Maximum gust intensities. 1942.
RB	Bulletin no. 4: Operations in cululus congestus cloud on July 31, 1941. Maximum gust intensities. April, 1942.
RB	Bulletin no. 5: Operations near cold front on August 12, 1941. Maximum gust intensities. April 1942.
RB	Bulletin no. 6: Preliminary analysis of gust measurements. April 1942.
RB	Bulletin no. 7: Preliminary analysis of the lateral distribution of gust velocity along the span of an airplane. March 1943.
RB L4D22	Bulletin no. 8: Analysis of gust measurements. April 1944.
RB L4E17	Bulletin no. 9: Flight measurement of liquid-water content of clouds and precipitation regions. May 1944.
RB L5A03	Bulletin no. 10: Characteristics of vertical drafts and associated vertical-gust velocities within convective-type clouds. January 1945.

ARR* - Advanced Restricted Report; RB - Restricted Bulletin

OTHER NACA REPORTS

ARR (7)	A semi-rational criterion for unsymmetrical gust loads. August 1941.
ARR (10)	Dynamic stress calculations for two airplanes in various gusts. September 1941.
ARR L4I21	Frequency of occurrence of atmospheric gusts and of related loads on airplane structures. November, 1944.
ARR L5B14	Frequency of occurrence of critical gust loads on overloaded airplanes. March 1945.
ARR L5F27	Airspeed fluctuations as a measure of atmospheric turbulence. July 1945.
ARR L5F27a	An analysis of life expectancy of airplane wings in normal cruising flight. July 1945.
MR (C)	Acceleration, stress, and deflection measurements on the XB-15 bomber in gusty air. June 1939.
Report 692	Effective gust structure at low altitudes as determined from the reactions of an airplane. 1940.
RB	Gust loads on transport airplanes. 1942.
TM 654	Stresses produced in airplane wings by gusts.
TM 992	Statistical analysis of the time and fatigue strength of aircraft wing structures. October 1941.

CIVIL AERONAUTICS ADMINISTRATION

AAS Report 7	Gust load factor principles.
FER 17	The apparent effect of pilot technique and atmospheric disturbances upon the measured rate of climb of an airplane. May 1945.

(The bibliography from A.V.M. Stedman's office listed also:

Civil Air Regulations Part 04 Airplane Airworthiness
Civil Aeronautics Manual 04 Airplane Airworthiness
Proposed Revisions to CAR 04 and to CAM 04.)

GREAT BRITAIN

AERONAUTICAL RESEARCH COUNCIL

7478 0.398	Effect of a flexurally-geared aileron control on binary flutter of a wing-aileron system ("To minimize the effect of gusts") February 1944.

ROYAL AIRCRAFT ESTABLISHMENT

Aero 1952	The theoretical response of a high speed aeroplane to a side gust. July 1944.
Aero 2033	Variation with height of the influence of winds on civil aircraft. April 1945.
Aero TN 1628	Brief notes relating to an experimental program of gust measurements now being started in Aero Dept. April 1945.
RAE SME 3258	A summary of some recent American work on gusts and its relation to British work. July 1943.
SME TN 294	Fin and rudder loads due to a lateral gust. December 1944.
SME TN 295	Negative acceleration in flight from V-g records. December 1944.

The above list includes gust loads only. It does not include other dynamic loads, e.g. acceleration loads. The two following reports included in the list prepared by A.V.M. Stedman's office were not included in the above list for that reason.

NACA ARR 4H10	Dynamic loads in aircraft structures during landing.
SAE Preprint (33/44)	A current outlook on the effects of dynamic loads on aircraft.

Res. Inst. 3956/SR. 1/PDB

The Detection of Gusts

1. Introduction

Gust loads have caused little concern in design of the relatively small, low speed aeroplanes built in the past. For the very large, high speed, long range civil transports now under development, however, the gust case is the design criterion for the wings. To cite one instance, it may be necessary to increase the aircraft structure weight as much as 7,000 lb. to meet the present gust requirements in the case of the Brabazon I, weighing 250,000 lb. If therefore, sufficient warning of the presence of a gust ahead of an aeroplane could be obtained so that either (a) the aeroplane speed be reduced thus relieving the gust loads, or (b) the gust be avoided altogether, it would be possible to effect an appreciable saving in the aircraft structure weight.

2. Method of Investigation

Possible means of detecting gusts are under consideration, and the method which shows the most promise at present is that employing radar to detect the clouds and areas of precipitation with which gusts are normally associated. Some work has already been done, and it has been recommended that X-band equipment would be the most suitable for this application.

It would probably not be possible by radar to detect gusts which are not associated with clouds or precipitation; but this may not be a serious handicap since severe gusts are normally found in cloud (with or without precipitation) above 10,000 ft., where a majority of the large civil transports will operate. In tropical zones, however, severe turbulence may occassionally be found in sandstorms or even in clear air over the desert in bright sunshine at altitudes exceeding 10,000 ft. Considerable bumpiness may also be experienced in the neighbourhood of the tropopause.

3. Range of Investigations

It is recommended that a programme of flight work be put in hand as soon as possible in order to investigate the potentialities of

/radar

radar as a reliable method of gust detection at heights above 5,000 - 10,000 10,000 ft. and if the results are favourable, to develop a suitable technique for regular use on large civil transport aircraft.

Information is required on the response of X-band radar to the following phenomena, and photographs should be obtained of typical records and of the clound formation.

(i) Cumulo-nimbus cumulo-congestus clouds preciptating rain; snow and hail.

(ii) Cumulus clouds.

(iii) Nimbo-stratus clouds.

(iv) Any other atmospheric phenomenon in which the presence of gusts is suspected.

Special attention should be given to cases in which the above clouds form part of a general cloud system.

Cases in which echoes are received from meteorological phenomena not generally associated with gusts (e.g. stratus and nimbo stratus clouds) and cases in which echoes are not received from phenomena normally associated with gusts should be particularly noted. In these cases the phenomena should be explored where possible to ascertain whether or not any appreciable turbulence is present.

4. The desirable scanning range should be explored. It will probably be sufficient to scan ± 60° in the horizontal and ± 5° in the vertical plane, in which case it will be possible to produce a suitable airborne X-band set weighing 100-150 lb. in about one years time. (Existing equipment weighs of the order of 300 lb). The weight of the equipment should not be a serious handicap if it will enable the aircraft to avoid gusts, since a saving of many times that weight in structure might result. It is anticipated that it will be possible to obtain a range of 20 miles with airborne X-band radar equipment, in which case it would be possible to use the equipment for "coastline painting" as an aid to navigation.

Severe turbulence due to thermal convection and geographical relief can be encountered at low altitudes and it is recommended that

/if

if an aeroplane were to rely entirely on radar for gust detection, it should fly at reduced speed at altitudes below 10,000 ft. in conditions where gusts might be expected.

5. Detection of Atmospherics

Another possible method of detecting regions of severe gustiness id yo make use of "atmospherics". These are produced by lightning discharges with which clouds of the cumulo-nimbus type are usually associated; but the possibility of cumulo-nimbus clouds being dangerously turbulent without producing lighting cannot be excluded. The atmospherics could readily be detected by aircraft fitted with D.F. loops but it would not be possible to measure the range in this way. Bearings could be obtained and it might therefore be possible to avoid a single source of gusts. A picture of a front would not however be given in this way and the method would therefore be more limited than the use of radar, which it has already been shown by American experience, will allow of navigation through a front by picking out the areas of low precipitation.

However, despite its limitations, the method has the advantage that no additional weight is involved and it is therefore recommended that the potentialities be fully investigated, and in particular that the amount and type of static noise associated with different types of cloud should be determined.

SR.1.
7/7/45.

CONFIDENTIAL

Res.Inst.3956/SR.1/PDB.

NOTES ON USAAF PROJECT NO. H.3730

"Radar Storm Detection by Airborne Radar Set AN/APQ-13"

The US Army Air Force issued a report in March, 1945 on a programme of flight tests recently completed to determine what information could be deduced from radar cloud echoes concerning the location, intensity, and vertical and horizontal extent of storm areas.

Two B.25-D aircraft (Mitchells) fitted with AN/APQ-13 radar sets (X-band) were used for this project, and a total of 112 hours of flying were completed in temperate and tropical zones.

Downward scanning was employed on this project, so that a plan view of the area over which the aircraft was flying was obtained on the PPI scope.

A large number of excellent photographs of radar cloud echoes indicated on the PPI scope, and of the actual clouds themselves are included in the report.

Brief Summary of Results and Conclusions.

With the aid of AN/APQ-13 it is quite simple to direct an aeroplane through the points of minimum turbulence in frontal systems and line squalls or to circumnavigate isolated air mass convective clouds (cumulo-nimbus and cumulus-congestus). The equipment was found to be unsuitable for the basic purpose of weather reconnaissance, however.

In general, radar echoes will be obtained at all times of the year in temperate and tropical zones with an AN/APQ-13 set, of all cumulo-nimbus and cumulus-congestus having a minimum vertical development of 9,000 - 10,000 ft., within a range depending upon the vertical extent of the clouds (up to a 100 miles for clouds over 35,000 ft. high). The range, azimuth and horizontal extent of the phenomenon are indicated on the PPI scope. An estimate of the intensity and vertical extent of such clouds may be made by noting the brightness of the radar return.

The same information can be obtained for heavy precipitating nimbo-stratus clouds up to a maximum range of 35 miles, but the echoes are very difficult to recognise over land surfaces due to their merging with the strong ground return.

Experience gained on the flights through frontal weather indicated that seldom will the cloud systems transversed in winter in temperate zones be indicated on the radar scope due to insufficient convective action, and even if some indication of clouds is given itwill only be a small percentage of the total overcast condition associated with frontal cloud systems. However, a large majority of these fronts which are too weak to give radar return could be penetrated or topped in the clear at about 10,000 ft., this being an altitude above which a large proportion of the civil air traffic will probably operate.

No thunderstorms, squalls, or other dangerous atmospheric phenomenon were observed visually which did not give returns on the radar scope.

All the radar cloud echoes are not associated with phenomenon hazardous to aircraft, but they should be regarded as potentially dangerous and flight should not be attempted through areas giving radar echoes unless visual inspection indicates that safe transit may be made. Numerous atmospheric conditions giving the strongest radar echoes were flown through during the course of this project and only twice, for a total duration of 15 minutes was other than light turbulence encountered. Hence, a thorough correlation of the turbulence

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of a cloud and the possibility of a radar return being received could not be made. The degree of turbulence was a personal judgement and no values of acceleration or gust velocity are quoted in the report (e.g. "light" turbulence was considered to be "noticeable"; "moderate" turbulence caused undue discomfort sufficient to justify a change of flight path; turbulence was considered to be severe if it caused structural damage to the aircraft).

It is still not clear what phenomenon associated with storm areas causes the radar echoes. Reflection from water droplets, electrical phenomenon, rapid continuous evaporation and condensation of water droplets, turbulence, and temperature and humidity gradients are all suggested as possible causes. Results obtained with X-band radar indicate that rain is nearly always falling from the source area of cloud echoes indicated by X-band equipment.

Instruction book on Radar Storm Detection

The Americans have also issued an instruction booklet (CRB ref. 44/3776) for met. officers using radar ground stations, which provides a very useful "childs guide" in the use of radar for the detection of storm areas, and is in general agreement with the conclusions given above. The characteristics by which different types of echoes may be distinguished are discussed, and photographs of various types of cloud echo with explanatary notes are included.

Discussion.

Airborne X-band radar shows great promise as a method of detecting atmospheric phenomenon hazardous to aircraft and will allow of the navigation through storm areas without encountering severe turbulence.

A more detailed investigation is still required however,

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and in particular a closer correlation is required of the turbulence of different clouds types and the possibility of receiving radar echoes. In the present project, little use appears to have been made of the V-g recorders installed in the aircraft to measure turbulence.

Special attention should be given to cases in which convective clouds form part of a general cloud system.

Forward scanning radar would probably be more appropriate to an aircraft gust warning installation so that an elevation view would be obtained of the area to be traversed; ground return would be largely eliminated.

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