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AIRBORNE WEATHER RADAR

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FOREWORD

The use of airborne radar equipment for a variety of purposes is rapidly growing. Its value as a means of displaying precipitation areas and, hence, of giving indications concerning severe or hazardous weather conditions associated therewith, such as turbulence, lightning and icing conditions, has been actively explored in recent years. Airline operators, recognizing its important potentialities for the avoidance of adverse flight conditions en route, have commenced its application in regular commercial operations, thus ensuring improved flight safety through storm areas, reduction of structural damage from turbulence and hail, greater riding comfort for passengers and generally improved flight schedules through minimized flight course detours and cancellations.

Other applications, e.g., as an anti-collision device, as an aid in terrain clearance and as a tool for terrain mapping, are generally reported as by-products of the primary function.

The main attention amongst operators and the industry alike is, therefore, concentrated on improved performance, and the extension of the use of airborne radar, for weather detection purposes. Aeronautical meteorological services have, accordingly, been alerted and now regard the indications on the radar scope in commercial aircraft as a potential source of information regarding the structure of relatively small-scale weather systems associated with precipitation, information which, thus far, could at best be derived by inference from such "spot" surface and upper air observations and aircraft reports as happened to provide sample values of certain elements in these systems.

The Air Navigation Commission, recognizing the importance of this new equipment, agreed that the subject warranted discussion by the two technical Divisions directly involved. The Communications Division, during its fifth Session (1954), discussed current technical developments in airborne radar and included in its Report information regarding common features in the technical characteristics of the equipment.

The fourth Session of the Meteorology Division (1954), held simultaneously with the first Session of the Commission for Aeronautical Meteorology of the World Meteorological Organization, subsequently explored the use of airborne equipment for meteorological warning purposes.

The latter meeting considered that experience would be a factor of very great value in assisting a pilot to make the most complete interpretation possible of the radar screen display. The meeting also expressed the opinion that there was still considerable room for development in the technique of interpretation as applied to weather characteristics. It therefore recommended (Recommendation 61) the establishment of a panel of experts which should:

a) prepare an illustrated summary of existing knowledge on interpretation of weather echoes received on various standard types of radar display;

b) advise on problems of the interpretation of the echo pattern display in order to provide aircrews with the necessary basis for the best operational use of the weather information so obtained from airborne equipment.

Secretariat study

States were provided, prior to the fourth Session of the Meteorology Division, with a working paper, prepared by the ICAO Secretariat, giving a resumé of the main developments regarding the basic principles underlying the relationship between the radar display and the corresponding physical conditions of the atmosphere within the range of the presently available equipment.

This Secretariat study drew attention also to certain factors, common to airborne and ground radar, but did not expand on the latter subject, as its development is being fostered by the World Meteorological Organization. WMO was requested by the MET Division/CAeM to explore the potentialities of ground radar for meteorological purposes and to circulate information concerning ground radar equipment (Recommendations 15 and 17).

The report by the ICAO Secretariat was considered by various delegations to form a convenient source of reference and, therefore, to warrant reproduction and wider circulation. The Air Navigation Commission, when reviewing the results of the fourth Session of the MET Division, supported this view.

The present Circular has, accordingly, been issued. It is a reprint, with slight editorial changes only, of the Secretariat study referred to above.

SUMMARY

The primary function of airborne radar equipment is generally accepted to be cockpit display of hazardous weather. Technical development of the equipment has progressed to the stage where an investigation is warranted regarding the extent to which its use can provide reliable warning of these hazards to enable the pilot-in-command to take evasive action. A great amount of information has been published in meteorological literature but there is a lack of generally accepted and easily accessible basic knowledge for an effective interpretation of the radar picture.

This Circular outlines the main developments in the field, with particular reference to the basic principles underlying the relationship between the characteristic features of the airborne radar display and corresponding physical conditions of the atmosphere within the area under radar observation.

Information concerning technical details of equipment used at ground weather radar stations and their performance characteristics will be published by the World Meteorological Organization.

1. - INTRODUCTION

A little more than ten years have elapsed since the first storms were detected by radar equipment. Most of the findings at that time did not receive wide dissemination owing to the restrictions imposed by the state of war. The potentialities of the new equipment were very soon evident for meteorologists, and within a decade it became not only an essential tool in cloud physics and storm structure research, but also an instrument of considerable operational application. By the end of 1951 a census of radar-weather projects, published in the Proceedings of the Conference on Water Resources (Illinois State Water Survey), showed that at least 32 weather-radar research projects were being conducted at different Universities, Laboratories and other military and civilian research centres in Australia, U.K. and U.S.

Within the widespread field covered by radar studies, some of the topics have a direct bearing on aircraft operations. Several projects have been engaged in investigating the use of airborne radar in thunderstorms and squall lines. The determination of the location and density of cloud layers above and below an aircraft, and the detection of areas of turbulence and lightning have been within the objectives of these projects. The results indicate that the method is ready for practical application.

The operators themselves have shown increasing interest in the development of an airborne equipment which could be used for weather warning purposes. In June 1953 the Airlines Electronic Engineering Committee (AEEC) held a meeting which considered, among other topics, a report on the activities of the Airborne Radar Subcommittee. It was reported at that time (see Reference 1) that the development of airborne radar equipment had reached such a state that no serious problem appeared to prevent the immediate adoption of a satisfactory solution.

The Air Navigation Commission has recognized the applicability of airborne radar for giving in-flight warning of certain en-route hazards, such as severe turbulence and critical icing, which, though known to exist in recognizable meteorological situations, cannot be forecast in time and space with sufficient accuracy to permit avoidance by minor departures from the general flight path. The Commission believes that the technical development of the equipment has progressed to the stage where an investigation is warranted regarding the extent to which its use can provide reliable warning of the imminence of these hazards sufficiently far ahead of the aircraft to enable the pilot-in-command to take evasive action. The subject was therefore put on the Agenda of the Meteorology Division, fourth Session, in the hope that the Division would indicate the present prospects of using airborne radar for weather warning in civil operations.

General application of airborne radar equipment for weather avoidance would require careful planning, in order that maximum profit might be derived from the new technique. Both aircrews and meteorologists should be aware of the possibilities and limitations of airborne radar, while standard interpretations of the structures appearing on the radar scopes should be agreed upon. As a complement, appropriate methods of transmission need to be developed, in order that the radar information obtained in the cockpit may be made available to the forecaster. Before such a programme can be realized, it seems necessary first to fill a gap which appears evident in the present status of radar meteorology. Being essentially an outcome of radio-electronics, radar equipment development is primarily an engineering problem. The operational use of radar has heretofore been restricted largely to purposes other than weather detection. Functions such as warning of impending collisions with terrain or detection of the presence of aircraft flying at the same level are in themselves strictly confined to the engineering field and no serious problems of interpretation of the echo patterns are connected with them. Parallel with this application, radar meteorology has developed as a branch devoted especially to research in cloud physics, precipitation and structure of particular "weather systems" such as fronts, tornadoes and tropical cyclones. In this field, interpretation of the radar information appears to be the essential problem. It requires a highly specialized type of meteorologist - the radar meteorologist - who knows as much about the equipment itself as about the physical processes associated with the weather phenomena. The language and procedures of this branch of meteorology are, in general, foreign to meteorologists working on routine forecasting, and this situation, although continuously improving owing to the great amount of information published in meteorological literature, could hamper the success of any large scale application of a radar observational programme with either ground or airborne equipment. In this respect, there seems to be a lack of balance in the field. Whereas operators, in view of the progress made on all engineering problems, appear to be ready to launch a plan to provide commercial aircraft with airborne radar equipment for weather detection purposes, meteorologists - and pilots themselves - will face the lack of a generally accepted and easily accessible body of basic knowledge for an effective interpretation of the radar-picture.

This circular aims to outline the main developments in the field. The purpose is not to offer a scientific exposition of the subject, but rather to present, in an integrated form, the main factors involved, and to facilitate access to the relevant literature. In its original form, it was presented to the MET Division to provide the necessary technical background for consideration of the use of airborne radar for weather warning purposes.

2. - THE FUNDAMENTAL PRINCIPLES OF RADAR

It is well known that the word "radar" has been coined as an abbreviation to denote "radio detection and ranging". Radar is based on the finite and constant velocity of propagation of electromagnetic waves and on the reflection and scattering of them by matter. A sharp pulse of radio frequency energy is sent out by the transmitter and repeated a number of times per second (repetition frequency). The object to be detected (target) receives the waves and scatters and reflects part of them. The re-radiation (echo) travels back to the site of transmission and it is detected by the radar as a signal coming from the target. The time taken for the pulse to leave the antenna of the set and travel back as an echo gives the distance at which the target is located. The set operates, in this process, as a transmitter-receiver. A special device permits the same antenna to be used for transmitting and receiving. The pulse and the repetition frequency are selected in such a way that waves reflected within a certain range return to the antenna when the transmitter is quiet (i. e. during the interval between the transmissions of consecutive pulses). A special cell blocks the path to the oscillator, and the echo wave is channelled through an amplifier until it finally reaches a cathode-ray tube indicator.

The transmitted energy is concentrated in a very narrow beam which can be aimed in any direction by rotating the antenna. By narrowing the beam it is possible to concentrate the energy upon the target and, therefore, to increase the energy of the echo. A systematic movement of the antenna (scanning) is thus necessary in order to search through space for the location of the target.

The wavelength of the transmitted energy is an important characteristic of the equipment. Very narrow beams require wavelengths of the order of centimeters. In addition, the need for sensitivity of the set in the detection of certain targets further restricts the selection of wavelengths. The proper balance between pulse, repetition frequency, size and scan of the antenna, beam width and wavelength is a delicate problem which should be solved with reference to the particular purpose for which the set is intended to be used.

From a purely meteorological viewpoint, the main problems are the following:

<u>Selection of the most suitable wavelength.</u> This requires a consideration of the physical characteristics and size of the elements forming the phenomena to be observed, i. e. liquid water (cloud droplets or rain drops) or solid water (snowflakes, hail). Wavelengths between 3 and 10 cm will serve to detect water drops in precipitation,

whereas the small droplets forming clouds would require a wavelength of about 1 cm. On the other hand, the same elements which provide the echoes, by reflecting back the electromagnetic waves, also absorb and scatter them, so that they act as an attenuating medium. The shorter the wavelength, the greater will the attenuation be. It turns out, therefore, that a compromise must always be made between how much the radar set is wanted to "see" and how far the radar-beam is expected to penetrate into the reflecting medium (see "Attenuation", paragraph 3). Two standard sets are commonly used in meteorology having wavelengths around 3 and 10 cm. For airborne radar sets, studies made recently on the subject have indicated an optimum wavelength of 5.7 cm (see paragraph 9, third sub-paragraph).

Presentation of the echo pattern. The echoes are made visible by means of a cathode-ray tube (scope) which can present the pattern in many different ways, according to the type of analysis to be made. A description of the types of scope which are of interest for meteorology is given in Reference 14. In this paper reference will be made to only three types of scope:

a) Plan Position Indicator (PPI). A map-like presentation, drawing a plan in polar co-ordinates (range and azimuth). For airborne radar sets, the PPI-scope has been accepted as the most convenient one.

b) Range and Height Indicator (RHI). A two-dimensional display in cartesian co-ordinates in which range is the abscissa and height the ordinate.

c) The A-scope. A one-dimensional display in which the horizontal axis represents range, whereas in the vertical axis the amplitude of the echo is represented by deflection of the beam. This type of presentation is more precise than any of the previous ones in showing echo amplitudes and it is used whenever this information is important.

Two different problems are connected with the interpretation of the echo pattern obtained in a particular meteorological situation:

The configuration of echoes in space and time. The space distribution of echo regions and its variation in time provide definite indications about the synoptic situation to which the precipitation belongs, such as fronts, squall lines, thunderstorms, tornadoes, etc. This subject is treated in Reference 9.

The structure of the pattern. From the intensity of the echoes and its variation in space, information can be obtained about the structure of the phenomenon which is detected. This subject will be dealt with in the following paragraphs. Reference will be made to detection (direct or indirect) of rainfall, clouds, lightning, turbulence and associated phenomena such as freezing level and wind shears. It is considered that this type of information, when properly integrated and completely explored, will give considerable help to pilots in finding the path of best flying conditions through a given region of bad weather and will, at the same time, be a source of valuable data for the meteorologist.

3.- RAINFALL INTENSITY

Measurement of rainfall

The determination of rainfall intensity from the radar signal intensity associated with precipitation echoes has been made possible through several theoretical investigations (see References 14, 15, 22, 25). The derivation of the corresponding equation involves the following steps:

a) An effective scattering cross-section of a particle is defined as the cross section of a perfectly reflecting sphere which would reflect in the direction of the radar an amount of energy equal to the energy back-scattered by the actual particle. The power of the echo received is taken to be proportional to the sum of the effective scattering cross-sections of all precipitation particles in unit volume, the factor of proportionality being a function of the characteristics of the set itself and the range.

b) The effective scattering cross-section of a raindrop is obtained, as a first approximation, by Rayleigh's law. For a group of raindrops, the theory, as extended by Stratton, gives an effective scattering cross-section which is inversely proportional to the fourth power of the wavelength, and directly proportional to the sum of the sixth powers of the diameters of the drops in unit volume.

c) A relationship between the rate of rainfall and the sum of the sixth powers of the diameters of the drops in unit volume is obtained by assuming a certain size distribution of the drops in the rainfall.

By combining these three relationships, the rate of rainfall may be calculated as a function of known parameters depending on the radar characteristics and the power received at the radar.

The abovementioned steps involve special assumptions, namely:

a) that the beam is fully intercepted by the rain;

b) that the particles are small in relation to the wavelength;

c) that the drop-size distribution is a unique function of rain intensity.

The limitations connected with these assumptions can be summarized as follows:

The assumption that the beam is fully intercepted by the rain reduces the range of the radar. No simple and reliable correction is known which could be introduced when the beam is not fully intercepted. The useful range of the radar depends, therefore, on the height of the initial echo and the antenna beam width. Farnsworth (Reference 8) has computed curves showing how the levels of the initial echo and beam width will affect the useful ranges.

When the rain drop diameter is small compared to the wavelength, the power reflected is proportional to Nd^6, where N is the number of drops in a given volume, and d is the diameter of the drop. There may be considerable variation in the mean drop diameter for any particular rainfall rate. Farnsworth (Reference 8) computed the effect of maximum and minimum drop diameters for a given rainfall intensity on the intensity computed from the return power. He found that even though the radar is very accurately calibrated, it could indicate rainfall rates from .48 to 1.40 mm/hr for an actual rate of 1.0 mm/hr. This indicates an unavoidable limitation in the accuracy of rainfall intensities determination by radar, since the difficulty could only be overcome by knowing the particular drop size distribution for each rainfall and by applying a different equation for each type.

Besides the limitation due to theoretical assumptions, the determination of rainfall intensities within certain limits of accuracy depends upon accurate measurement of the electrical characteristics of the radar. A one decibel* change in either transmitter power or receiver sensitivity will produce approximately a 12% change in calculated rainfall intensity. Standard 3-cm and 10-cm radar sets commonly used are likely to introduce errors of about 3 db.

Special techniques for rainfall intensity analysis

The distribution of rainfall intensity within a storm is an important factor which enters not only into theoretical studies connected with the structure of storms and the origin and development of precipitation, but also into the practical application of radar for operational purposes. In fact, rainfall gradient is the most important element for detecting turbulent areas. Atlas (Reference 2) and Langille and Gunn (Reference 13) have suggested techniques which could be used with both the PPI and the RHI displays in order to show the distribution of reflected power in the two-dimensional sections through a storm. The device consists essentially of a series of potentiometers with a stepping switch. Each step the switch advances increases the bias a fixed amount, thus reducing the sensitivity. The echo area is therefore reduced in a stepwise fashion, with the smaller areas representing the more intense

Note: * The "decibel" (db) is a unit widely used in telecommunications engineering. It expresses the ratio of two values of sound, of power, of voltage or of current. The number of decibels is 10 times the logarithm, to the base 10, of the ratio of the two values.

portions of the rain. Each setting produces a contour chart showing an isopleth of equal echo intensity. These isopleths are referred to as "iso-echo lines", "power contours" or "iso-echo contours".

This technique was first applied by Langille and Gunn for the analysis of internal motion and developments of showers in storms, using an RHI display. Jones and Hiser (Reference 12) utilized the method to collect and record detailed information on the rainfall intensities at any point and total rainfall over the area scanned by the radar. The radar sets they operated had an automatic system which controlled both the stepping switch of the potentiometers and a movie camera. Each revolution of the antenna reduced the sensitivity a fixed amount and a picture of the PPI scope was obtained for each sensitivity setting.

Attenuation

The atmosphere is transparent for waves of frequency below 1000 Mc/s, and the attenuation (or absorption) is negligible even for paths hundreds of miles long. At higher frequencies absorption occurs because of the gases of the atmosphere, and also because of water drops. Oxygen has an absorption band in the neighbourhood of a wavelength of 5 mm because of the permanent dipole moment of the oxygen molecule and a small residual exists up to 20 cm or higher. Water vapour has an absorption band near 1.3 cm wavelength plus a residual effect of bands at much shorter wavelengths due to the electric dipole moment of the water molecule. The attenuation at any temperature and humidity is proportional to the water vapour content. Liquid water drops have a different effect from water vapour. They cause attenuation of a wave by absorption and by scattering. Absorption takes place owing to the fact that the water is an imperfect dielectric. A further portion of the energy of the beam is lost by scattering caused by the droplets acting as small dielectric spheres.

Absorption and scattering by water drops are functions of the wavelength. For short wavelengths the attenuation is considerable, so that the rain itself becomes an attenuating medium. Ryde has shown (Reference 19) that the fractional loss in intensity is proportional to the rate of rainfall. The implications of this fact on the determination of the position of maximum rain intensity and structure of the rainfall pattern were studied in detail by D. Atlas and H. Banks (Reference 2). They found that the position of maximum echo intensity indicated in the radar display rarely represents the position of maximum rain intensity. Furthermore, by studying some simple "model-rainstorms", they considered the nature of distortions in the resulting echo pattern. The iso-echo contour technique was used to plot the distribution of echo intensity, and a comparison was made between the isohyetal pattern of the model-rainstorms and the corresponding theoretical iso-echo contour patterns. The distortions found by this method were considerable for short wavelengths, but at wavelengths greater than approximately 7 cm, the distortions were negligible. When the range to the storm is greater than twice the maximum radial depth of the storm, the iso-echo contour display obtained using a wavelength of about 7 cm or more will generally agree with the isohyetal pattern, except for exceptionally strong rainfalls. For shorter wavelengths, the resulting contour pattern may show such large deviations as to bear no resemblance to the true rain intensity structure.

4. - CLOUD DETECTION

The 3-cm and 10-cm storm detection sets are not able to detect clouds. This is due to the small size of the cloud particles (about one hundredth of the size of the rain drops), the signal return being inversely proportional to the fourth power of the wavelength. It has been found, however, that a set with a wavelength of approximately one centimeter would serve to detect and locate clouds and cloud layers. The equipment referred to by W.B. Gould (Reference 10) has detected clouds up to 45,000 feet. The equipment has also permitted the location of several layers of clouds, and clouds situated beyond an area of several thousand feet of rain.

The equipment mentioned above has an A-scope and a wavelength of about 0.9 cm was chosen to avoid the attenuation bands of oxygen and water vapour. The paper by Gould includes several photographs of cloud base and cloud top records.

5. - THE "BRIGHT BAND"

The phenomenon known as the "bright line" or "bright band" has been observed in stratified clouds as a horizontal band, roughly at the height of the freezing level, which produces a stronger return than the parts above or below it. P.M. Austin and A.C. Bemis (Reference 3) gave the now accepted theoretical explanation according to which the bright band is caused by the coalescence and melting of snowflakes. It indicates that the precipitation consists of snow above, melting snow in the bright band and rain below.

The fact that the location of the bright band gives an approximate and continuous indication of the freezing level makes this phenomenon of direct interest for aircraft operations in connection with icing conditions. Austin and Bemis, in the publication mentioned above also indicate that the thickness of the bright band bears a roughly inverse relationship to stability.

6. - THE "UPPER BAND"

Besides the well-defined maximum near the freezing level, precipitation echoes show other regions of maximum intensities at higher levels. The "upper band", first described and interpreted by Bowen (Reference 6), appears as a band of maximum echo intensity first located at a level where the temperature is between -12°C and -17°C. The level of maximum sometimes moves downwards, retaining its identity, at a rate of about 2 m.p.s. until it merges with the bright band. The process shows a tendency to repeat itself at intervals of about 20 to 30 minutes. Stationary bands, remaining at the same level for periods as long as 40 minutes, have also been reported. The explanation given by Bowen ascribes the phenomenon to the spontaneous freezing of very large (400μ in diameter) supercooled drops, which have been carried to the level of -12°C to -17°C by updraughts, and to their subsequent rapid growth by a Bergeron's process. However, calculations of the changes in radar signal strength which could be produced by the freezing of such large drops and the subsequent growth of the ice crystals by diffusion led other investigators to reject this explanation.

Alternative theories have been offered to account for the upper band. R. Wexler has proposed a theory (Reference 26) based on the formation of graupel (crystals with attached frozen water droplets) in the upper portion of a cloud, and the rapid growth by coagulation under an increasing rate of fall, denuding the rising currents of liquid water and thus reducing the liquid water content of the upper portions of the cloud below a critical value. The subject has been subsequently discussed in detail by Browne (Reference 7) and Marshall (References 16, 17) and it seems now generally agreed that, although the process described by Wexler could take place, a considerable number of the observed "upper bands" are due to streams of precipitation of snow-flakes falling through a region of strong wind shear ("precipitation streaks").

The analysis of the origin and structure of these phenomena is still confined to purely theoretical investigations of the physics of clouds and precipitation. It suggests, however, that the results thereby obtained might eventually find an important operational application in providing useful information concerning regions of icing, strong updraughts and other processes hazardous to air navigation and that further research along these lines would be useful.

7. - LIGHTNING

Observations of radar echoes produced by lightning discharges have been reported by several investigators (References 14, 17, 18). Lightning echoes from distant storms are very short in duration, of the order of 1/50 sec., whereas lightning echoes from a storm overhead may last 1/2 sec. or more. By analysis of echoes observed with 10-cm and 3-cm radars, Marshall (Reference 17) concludes that all lightning echoes are in snowfall regions and suggests that they are connected with interaction between obliquely falling snow and shower precipitation. It seems, therefore, that this problem is linked with that discussed in paragraph 6.

8. - TURBULENCE AND RAINFALL INTENSITY

The principle of echo signal contouring, outlined in paragraph 3 (Special Techniques for rainfall intensity analysis) was applied by American Airlines on a research project under contract with the U.S. Navy, during 1947-49, and by the U.S. Naval Air Station under the direction of the Bureau of Aeronautics. (See report by F.C. White, Reference 11, p. 321-322). They both used a 3-cm airborne radar with a "two-tone" PPI display. The circuitry used in the set creates two iso-echo contours - the threshold contour, around the periphery of the echo, and a contour surrounding a dark area, corresponding to the region of heaviest rain, where the echo has been erased. The two contours were separated by an interval equivalent to ten decibels in the signal level. The comparison of a number of pictures of the two-tone PPI display with simultaneous recordings of effective gust velocity indicates a correlation between iso-echo contour separation and turbulence. Where the contours were closer together, more turbulence and stronger gusts were encountered. Since the signal level interval between the two contours is fixed, closer contours correspond to greater horizontal variation of rainfall. It appears, therefore, that turbulence is associated with rainfall gradient, and that the iso-echo contour technique provides an indirect way of detecting areas of greater turbulence.

The subject has been studied in detail in a paper by H.B. Tolefson in Reference 21. By plotting the results of atmospheric turbulence measurements by the NACA in various weather conditions and measurements taken during routine flights (diagram of gust velocity versus average flight miles) he shows that the worst conditions are found within thunderstorms. The quantitative analysis of this result, together with the comparison of gusts experienced in various regions of the thunderstorms and the effect of the iso-echo technique discussed in the preceding sub-paragraph, allows him to draw the following conclusions (quoted from his paper mentioned above):

> "1. If airborne radar is used for thunderstorm avoidance, present-day low-altitude transports might realize an approximate 10 percent reduction in maximum gust loads. A reduction of this amount would be significant to the designer and the operator.
>
> 2. The reduction obtained by use of radar in the smaller and more numerous gust loads which are important to fatigue life would be negligible.
>
> 3. The passenger might expect considerably greater riding comfort on radar equipped airplanes than he experiences at present.
>
> 4. Contour radar would be desirable for selecting the smoothest flight path through extensive storms that could not be avoided."

9.- AIRBORNE RADAR EQUIPMENT

The problems connected with airborne radar equipment and the feasibility of immediate application for operational use have been under active consideration by the Air Transport Association of America and Aeronautical Radio Inc. (ARINC). It has been recognized that the characteristics of a radar set would vary with the specific purpose for which it is applied. No radar equipment is equally satisfactory for all purposes. This means that the first decision to be made when establishing the specifications for an airborne radar is the primary purpose for which it is intended. There appears to be unanimous agreement among the airline operators who have been concerned with this problem that the primary function of airborne radar equipment is cockpit display of hazardous weather. Other uses, such as display of nearby aircraft and terrain collision avoidance are considered to be by-products of the primary function. (See paper by W.T. Carnes, Reference 21).

The development of airborne weather radar equipment involves practical as well as technical and theoretical problems. The location and mounting of the antenna within the nose of transport aircraft and the limitations as to size and shape in the various types of transport aircraft, have to be considered in addition to the physical problems arising from the type of performance which is expected from the equipment. The AEEC Airborne Radar Subcommittee has made a careful study of all aspects of this problem and has laid down a detailed description of the characteristics which a satisfactory airborne radar should meet (Reference 1). From a purely meteorological point of view the main decision concerns the selection of the proper wavelength to be used.

The most exhaustive study of the propagation characteristics of various radar frequencies has been made by Marshall and Hitschfeld in a research project sponsored by ATA and ARINC. In their report "Calculated sensitivity of airborne weather radar", they conclude that 5.7 cm is the most suitable wavelength for airborne radar. This wavelength has the advantage over the commonly used 3.2 cm of making the radar less sensitive to rainfall attenuation. The 3.2 cm radar is rendered practically inoperative by an intervening rainfall of one inch/hour over a 20-mile range.

The conclusions of Marshall and Hitschfeld were incorporated into the ARINC characteristic for a 5.7 cm airborne radar equipment approved by the AEEC (Airlines Electronic Engineering Committee). One manufacturer is reported as already planning production of a 5.7 cm radar with the ARINC specifications, whereas another firm is ready to build and market a 3-cm airborne radar. Progress in the development of equipment is proceeding rapidly and it is expected that in the course of the current year standard equipment will be available on the market (see the article "Weather Radar Design Progress Rapid" in American Aviation, Vol. 17, No. 15, December 21, 1953).

10. ACTION PROPOSED TO THE MET DIVISION, FOURTH SESSION

Two types of problems may be considered in connection with airborne radar weather observations:

a) Pilot's interpretation of the echo pattern display on the PPI scope, and operational use of the information obtained through it;

b) Transmission of the significant information to meteorological centres, and application of these data in analysis and forecasting.

A solution of both problems requires, as a preliminary step, a systematic analysis of the radar data which have been compiled up to now. No information is available concerning any attempt to make a classification of general types of display which could serve as a guide for interpretation of the echo patterns obtained on the scope. This could be done in a way somewhat similar to what has been achieved with cloud classification and cloud atlases. It is realized that many characteristics of precipitation echoes, which may be significant, are difficult to interpret and still more difficult to describe. However, the amount of material published in the last few years suggests that there is already considerable knowledge of this subject available and that, if this were systematized, it could lead to a classification which would increase greatly the usefulness of radar information for meteorological purposes. A satisfactory classification of the phenomena which a radar set can detect would include:

Characteristic appearance on the PPI scope of elements producing the echo (rain, snow, hail) and ways of distinguishing between them;

Interpretation of the complex radar echo pattern in terms of the synoptic situation (fronts, squall lines, tornadoes);

Indirect detection of the elements which cannot be observed directly (turbulence, vertical motion, freezing level).

The second major step would involve a decision about what is to be transmitted to meteorological offices. This would require a consideration of three different aspects:

The type of information which would be required by aeronautical meteorologists;

The amount of interpretation which the observer himself (the pilot) would include in the information transmitted;

The form of messages to be used for radar weather information and the procedures to be used in reporting.

The MET Division was invited to consider the feasibility of a programme of the scope outlined in the preceding two sub-paragraphs. It was suggested that this might be carried out by one of the following means:

The appointment of a panel of experts in the field, with Secretariat assistance;

The reference of the problem to States through the Secretariat, which could subsequently integrate the information received and arrange for its publication in a suitable form.*

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* The MET Division, at its fourth Session, accepted the first alternative (see Foreword).

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