REPORT No. 132

AERONAUTIC INSTRUMENTS

SECTION VIII

RECENT DEVELOPMENTS AND OUTSTANDING PROBLÈMS

BY F. L. HUNT
Bureau of Standards

REPORT No. 132.

AERONAUTIC INSTRUMENTS.

RECENT DEVELOPMENTS AND OUTSTANDING PROBLEMS.

By Franklin L. Hunt.

INTRODUCTION.

This report is Section VIII of a series of reports on aeronautic instruments (Technical Reports Nos. 125 to 132, inclusive) prepared by the Aeronautic Instruments Section of the Bureau of Standards under research authorizations formulated and recommended by the Subcommittee on Aerodynamics and approved by the National Advisory Committee for Aeronautics.

The preceding reports in this series have discussed in detail the various types of aeronautic instruments which have reached a state of practical development such that they have already found extensive use. It is the purpose of this paper to discuss briefly some of the more recent developments in the field of aeronautic instrument design and to suggest some of the outstanding problems awaiting solution. The different types of instruments will be considered as far as possible in the order in which they are discussed in the preceding papers. Practically all the new designs mentioned which are not otherwise accredited have been developed by the Bureau of Standards at the request of and with funds provided by the War and Navy Departments and the National Advisory Committee for Aeronautics.

ALTITUDE INSTRUMENTS.

PRECISION ALTIMETER.

The altitude of aircraft is determined in practice almost exclusively by the use of aneroid barometers, which have been described in detail in Report No. 126. The essential working element in these instruments is an exhausted metal capsule made ordinarily by soldering together two thin corrugated metal disks. The capsule is kept from collapse by the use of internal or external springs. Owing to the imperfect elasticity of the springs and the metal of which the aneroid capsule is made (usually German silver or bronze), the diaphragm, after the distention caused by rising to an altitude, fails to recover its initial position on descent, and the pointer of the altimeter fails to return quite to zero. This is a serious imperfection, particularly when it is desired to use the altimeter in bombing operations, in landing, or in other cases where the altitude must be accurately known. Experiments have led to the development of altimeters in which this difficulty is almost completely overcome. The error due to inelasticity or hysteresis, as it is ordinarily called, has been found to be due almost entirely to the imperfect elasticity of the diaphragm itself. By making the spring so stiff compared with the diaphragm that the elastic effect of the latter is negligible, altimeters have been constructed in which the elastic effect is confined almost entirely to the spring itself. With proper design the hysteresis of the distending spring can be made negligible. In this way altimeters have been made which show a hysteresis error not exceeding 10 feet in altitude, while in ordinary instruments this error may amount to several hundred feet. One of these altimeters is described in Report No. 126 of this series. In a more recent model the mainspring is mounted on knife-edges instead of being suspended, as in the earlier instrument, and phosphor-bronze strips and pulleys are used instead of a sector and pinion in the transfer mechanism.

JENKINS NIGHT ALTITUDE INDICATOR.

A radically different altitude indicator, a device of an optical type, known as the Jenkins night altitude indicator, has recently been developed in England. This consists essentially of two telescopic projectors, which throw spots of light on the ground below the aircraft. One of the projectors is maintained vertical, the other is rotatable about a horizontal axis so that for any altitude the spots from both projectors can be brought into coincidence. The angle subtended by the projectors is then a measure of the altitude. In the actual instrument the rotatable telescope projects on the ground the figures representing the altitude in feet at the time of observation. The range is limited to a few hundred feet, as it is intended for use in landing at night.

PRECISION BAROGRAPH.

When a record of the altitude attained by aircraft is desired, barographs or recording altimeters are ordinarily used. In the most usual types the actuating mechanism consists of a battery of aneroid diaphragms, such as are used in altimeters, which operates a lever arm with recording pen. The hysteresis effects above mentioned in the case of altimeters are equally troublesome in barographs. It has been recently shown, however, that the hysteresis error can be greatly diminished by using instead of the usual battery of ordinary diaphragms a so-called "sylphon" diaphragm element, which is spun in the form of a cylindrical bellows from a single piece of bronze tubing. The "sylphon" diaphragm is maintained distended by an internal coiled spring. In this case, as in that of the improved type of altimeter above described, the elastic effect is concentrated almost entirely in the spring.

THERMOMETRIC ALTIMETER.

Aside from the instrumental errors of altimeters and barographs due to mechanical imperfections, altitude determinations are also subject to temperature corrections resulting from the variations of the temperature of the atmosphere. The scales of ordinary barometers and barographs are graduated either on the assumption that the temperature remains at some arbitrary constant value, ordinarily 10° C., or varies with the altitude in some empirical manner. In either case the readings are subject to corrections, due to the inevitable deviations of the temperature experienced in flight from the standard temperature which was assumed in laying out the pressure altitude scale for the instruments. To overcome this difficulty, an altimeter with temperature compensation has been made, which greatly reduces the errors due to temperature change. This instrument consists of an altimeter of the type described above with aneroid capsule and stiff external spring. In addition, it is provided with a thermometric element, which consists of a bimetallic bar attached to the indicating system, so as to vary the deflection of the pointer according to the surrounding temperature.

"SYLPHON" RATE-OF-CLIMB INDICATOR.

Rate-of-climb indicators generally depend for their operation upon the differential pressures set up between the external atmosphere and a confined volume of air within the instrument. The forces available for operating the indicating mechanism are very slight, consequently if metal diaphragms are used to measure this pressure they must be extremely thin. Recent experiments indicate the possibility of substituting for the ordinary corrugated metal diaphragm a very thin diaphragm of the "sylphon" type. In this way the necessary motion can be obtained while at the same time the volume of the confined air, and consequently the size of the instrument, can be considerably reduced.

RECORDING RATE-OF-CLIMB INDICATOR.

Experiments are also now being conducted on recording rate-of-climb indicators. These instruments give a permanent record of the rate of ascent or descent throughout the period of flight. Here again the problem is made difficult because of the feeble forces available for operating the recording mechanism. On this account an optical record is used, the light from a small incandescent lamp being reflected by a suitable lens and mirror system onto the surface of a light-sensitive paper on the surface of a revolving drum.

COMBINED STATOSCOPE AND RATE-OF-CLIMB INDICATOR.

In certain instances it is desirable to have on aircraft not only a sensitive statoscope to indicate qualitatively very slight changes in altitude but also a less sensitive instrument to indicate quantitatively rates of ascent and descent. To fill this need a combined statoscope and rate-of-climb indicator has been made which can be used either as a sensitive statoscope or as a rate-of-climb indicator. The device consists of a model III Bureau of Standards rate-of-climb indicator described in Report No. 126 provided with a special cut-off valve between the capillary tube and the chamber and a breaking bubble of the ordinary statoscope type. By rotating a thumbscrew the capillary opening can be closed and the bubble tube connected, in which case the instrument becomes a statoscope and the pointer continues to move away from the zero in one direction or the other, according to whether the instrument is ascending or descending, until the bubble breaks. Under the dial and concentric with it is a rotatable sector which is also connected to the thumbscrew. The words "statoscope" and "rate-of-climb indicator" are printed on the sector, and one or the other legend is exposed through a slit in the dial according to the setting of the thumbscrew, so that the aviator always knows which element of the combined instrument is functioning.

AIRCRAFT SPEED INSTRUMENTS.

LOW SPEED AIR-SPEED INDICATOR.

In the navigating of lighter-than-air craft under certain circumstances it is desirable to measure accurately air speeds of less than 10 miles per hour. Air-speed indicators of the ordinary type such as are used on heavier-than-air craft are not suitable for this purpose. The two methods of approach which have been tried recently to satisfy this need include (1) using a Pitot tube in connection with an indicator much more sensitive than is ordinarily made and (2) using sensitive rotating anemometers. It has been found that Pitot indicators with doped fabric diaphragms and thin flat springs for the elastic element can be made sufficiently sensitive for the purpose, but they get out of adjustment easily. The problem of developing an air-speed indicator of the anemometer type was therefore attacked. This is complicated by the difficulty of transferring the motion of the anemometer to the instrument board without putting a sufficient load on the anemometer to cause it to slip appreciably. Synchronizing commutators have been tried in the French Favre-Bulle indicator, which is of this type. Another method which has been applied in a recent model is that of automatically charging a condenser and discharging it by means of a suitably constructed commutator through a sensitive two-pivot galvanometer at rapid intervals proportional to the rate of revolution of the anemometer. The effective current and consequently the deflection of the galvanometer is then proportional to the speed of the anemometer. This method requires a constant voltage which is maintained by using a potentiometer in connection with the generator or batteries available as standard equipment on aircraft.

GROUND-SPEED INDICATOR.

One of the problems which is now demanding a great deal of attention is that of developing an accurate ground-speed indicator. The various methods which have been proposed are discussed in Report No. 127. While it is theoretically possible to make instruments of the absolute integrating type, the practical difficulties encountered are almost insuperable. If the ground is visible, however, optical devices can be used. A ground-speed indicator of this type in which the apparent motion of the ground is neutralized by the rotation of a hexagonal prism about an axis perpendicular to the direction of motion of the aircraft relative to the ground has been constructed recently. Knowing the altitude and the rate of rotation of the prism required to cause the objects on the ground to appear to remain still, the ground speed can be determined. In the instrument in question the ground speed is read directly from the dial of a tachometer connected to the rotating prism. The readings of the instrument may also be automatically corrected for the effect of altitude.

DIRECTION INSTRUMENTS.

COMPASSES.

The compass still remains one of the least satisfactory aeronautic instruments. Aside from the inherent difficulties due to the smallness of the directional force of the earth's magnetic field, its location on the instrument board of the airplane in the proximity of large moving masses of magnetic material seriously limits its dependability. Airplane compasses of comparatively long period and high damping have been used. These are less subject to disturbance due to momentary accelerations and the northerly turning error than short-period quick-acting compasses, but in general the latter type are preferred, especially when used in connection with turn indicators of which several satisfactory types have recently been developed. One of the difficulties encountered is that due to the unsteadiness and swirling of the liquid set up by the maneuvering of the airplane. Efforts have been made to overcome this difficulty by mounting the compass element proper in the center of a spherical bowl. Another method is to make the needle system very light by eliminating the ordinary card and mounting the needles on a light spider made of small straight wires projecting radially in the damping liquid from the point of support. The effect of the light radial arms is to damp the motion so heavily that the system is aperiodic and when displaced returns to its equilibrium position without oscillation. An instrument of this type known as an aperiodic compass has recently been developed in England and is described in Report No. 128.

An effort to overcome the difficulties caused by the disturbing effect of masses of iron in the vicinity of the instrument board has been made in a distant reading compass recently developed in Germany. It is described in the paper just mentioned. In its present form this compass, with its auxiliary course setting and rotating devices, is very heavy compared with compasses of the ordinary type. Flight tests have shown it to be insensitive. It is also complicated and has not been used sufficiently in practice to determine its reliability under continued use.

In another type of distant reading compass the current developed in a coil rotating in the earth's magnetic field is used to indicate direction. It is known as the earth inductor compass. An instrument of this type for use on aircraft has recently been developed for the United States Army Air Service. It differs from previous instruments in that the indications are by a null method instead of the usual galvanometer deflection method. A course-setting device of novel type is also provided in which by turning a movable dial at the instrument board the galvanometer connections are so arranged that the indicating pointer reads zero when the aircraft assumes the desired direction. A method is also provided for eliminating the effect due to rolling and pitching on the effective component of the earth's magnetic field. A more detailed description of this instrument is found in Report No. 128.

TURN INDICATORS.

As previously stated, the development of satisfactory turn indicators has made the weaknesses of the compass a matter of less serious concern to the aviator since the turn indicator enables him to maintain the direction of his course when the compass is subjected to disturbing accelerations which make its readings temporarily unreliable. The most successful types of instruments of this class include as the essential directing element a gyroscopic rotor. The two distinct types which have reached a state of practical development include (1) instruments in which the gyroscopic element is driven by the impact of a wind stream (Sperry type; Pioneer type) and (2) instruments in which the rotor is an induction motor (Drexler type). In the wind-driven type the differential pressure is usually maintained by a Venturi tube. This is a simple and effective way of applying the necessary power, but not an economical one from the point of view of power consumption, since experiments show that a large amount of energy is absorbed in driving the Venturi through the air. Electrical types usually depend upon a small auxiliary generator driven by a wind propeller for their power. It has also been proposed to operate the wind-driven instrument by an electrically operated pump connected to the generator of the airplane. Still another suggestion is to develop the necessary differential air pressure by the use of a hollow propeller with a tube extending longitudinally inside each blade (Pioneer type). These tubes are connected through a hollow axle to the turn indicator. The centrifugal force set up by the rotation of the propeller forces the air out radially through the propeller tubes and a differential pressure is thereby established. The difficulty here is to secure a sufficient pressure difference without rotating the propeller too fast for safety. The wind-driven type of turn indicator has the advantage that it can be made of nonmagnetic metal, so that it can be located on the instrument board without disturbing the compass. It is also simpler and lighter in construction than the electrically driven type. On the other hand, the electric type can be made to give more precise indications and is not subject to disturbing precessions which are present in the wind-driven type.

POWER PLANT INSTRUMENTS.

TACHOMETERS.

Of the various types of airplane tachometers which have been proposed the only two which have thus far been in extensive use are the centrifugal and chronometric. Laboratory experiments have shown that the chronometric type in general gives more accurate indications than the centrifugal instruments, but it is of complicated construction, inclined to get out of order easily, and is difficult to repair. On the other hand, the centrifugal type has the distinct advantage of greater simplicity of construction and greater durability. It, therefore, has appeared advisable to undertake experiments on centrifugal tachometers in the hope of overcoming the defects in existing instruments of this type. Investigations have led to the development of a centrifugal tachometer of the double inclined weight type, which is balanced to eliminate the disturbing effect of accelerations of the airplane. The differences between the readings with increasing and decreasing scale deflection have also been reduced considerably below that of ordinary instruments of this type.

DISTANT CONTROL METHODS.

The increase in the size of airplanes and the installation of tachometers in large airships necessitates the development of methods of distant control for tachometers other than the use of flexible shafts. This problem still awaits a satisfactory practical solution. Various methods have been proposed. One is to attach a small three-phase generator to the engine shaft and connect it to a synchronous motor, with an ordinary tachometer attached, located on the instrument board. A modification of this method is to attach to the engine shaft a synchronizing commutator so constructed as to convert direct current into three-phase alternating current, the frequency of which is proportional to the speed of revolution of the engine. By supplying this current to a three-phase synchronous motor with attached tachometer the indications of the instrument can be read at any desired distance from the engine itself. The French Favre-Bulle tachometer is of this type. Still another possibility is the method suggested previously in this paper (see aircraft speed instruments), in which the frequency of charging and discharging of a condenser through a galvanometer is determined by the rate of revolution of the engine. The deflection of the galvanometer would then be proportional to the rate of revolution of the engine. It has also been proposed to operate a tachometer on the instrument board by air pulses transmitted through tubing connecting the pulsator on the engine shaft to the tachometer, the rapidity of the pulsations being proportional to the rate of revolution of the engine (Hamilton type).

ELECTRIC THERMOMETER.

A similar problem of distant transmission for large aircraft has necessitated the development of distant reading thermometers other than those of the liquid-filled or vapor-pressure type. The most successful of the distant reading instruments are electrical resistance thermometers. A Hartman and Braun instrument of this type has been extensively used in Germany. The thermometric element consists of silk covered platinum wire wound on micanite. This unit is inclosed in a metal tube which is soldered into the engine radiator. The indicator is a small moving coil galvanometer.

OXYGEN INSTRUMENTS.

DEVELOPMENT OF LIQUID TYPE.

The necessity of supplying aviators with artificial oxygen at the high altitudes now attained in flight has resulted in the development of apparatus for the use of oxygen, both as compressed gas and in liquid form. A detailed description of these instruments has been given in Report No. 130. During the recent war compressed oxygen was used almost entirely by the Allies and liquid oxygen by the Germans. The weight and bulk of the supply tanks required by instruments of the compressed oxygen type has led recently to the further development of liquid oxygen apparatus which becomes particularly advantageous for use during long flights or where several persons must be supplied. The disadvantages of instruments of the liquid type is that the oxygen must be used at comparatively short distances from the source of supply and within a comparatively short time after liquefaction. In most of these instruments the evaporation losses are reduced as much as possible by the use of vacuum jacketed containers, and hand operated or automatically controlled cut-off valves are used to regulate the supply to the aviators.

NAVIGATING INSTRUMENTS.

SEXTANTS.

The practicability of long distance flying and night flying have recently emphasized the necessity of developing types of instruments for navigating aircraft analogous to those used in determining the position of ships at sea. One of the most important instruments of this class is the sextant. A number of aircraft sextants have recently been developed. In general they resemble an ordinary marine sextant except that an artificial horizon is used. The artificial horizon is ordinarily of the bubble level type. It has also been proposed to use for this purpose a small pendulum or gyroscopic rotor. A serious objection to sextants of the ordinary type from the point of view of aircraft navigation is their weight and size. Efforts have recently been made to design a sextant especially suited to the conditions experienced in air navigation. This has resulted in the development of an instrument in which a small sector with micrometer head or a rotating drum has been substituted for the large sextant scale of the ordinary type of instrument. Means for adjusting the size of the bubble, which varies greatly because of the wide variations in temperature experienced in flight, are also provided. This is effected by making one side of the bubble chamber a flexible diaphragm controlled by a thumbscrew. By turning the thumbscrew the effective volume of the bubble chamber can be altered at will. Artificial illumination for the bubble and scales is also provided for reading at night.

ASTRONOMICAL POSITION FINDER.

The Engineering Division of the Air Service has recently suggested the development of an instrument for determining the position of aircraft from the position of any two known celestial objects, such as two stars, and the Greenwich siderial time. This in effect is an optical instrument for determining the altitude of the pole and hour angle of one of the two celestial objects chosen. Such an instrument under construction consists essentially of a telescope and two prisms or mirrors to reflect the light of the two objects chosen into the telescope. The mirrors are each independently rotatable about the axis of the telescope and about an axis at right angles to the telescope. A bubble horizon is used.

HORIZONTAL ANGLE INDICATORS.

The use of aircraft in connection with range finding has emphasized the importance of developing horizontal angle indicators suitable for use on aircraft. A number of instruments of this class have been designed and are now under construction. They consist essentially of graduated quadrants or sextants, and mirrors or prism systems so oriented as to make it possible to bring the images of the two objects under observation first into the same horizontal plane and then into coincidence.

SPECIAL PROBLEMS.

DIAPHRAGM INVESTIGATION.

Reference has been made in previous papers of this report to the difficulty encountered in all aeronautic instruments depending for their action upon metallic diaphragms which results from the imperfect elasticity of the metal of which the diaphragms are made. A study of the conditions determining the magnitude of this effect has been for some time in progress It is found that the effect varies markedly not only with the composition of the metal but also with the mechanical processes and temperature treatment to which it has been subjected. For example, spun diaphragms in general exhibit better elastic properties than pressed or stamped samples, probably because spinning hardens the metal uniformly while the stamping tends to crush and tear the surface layers. It has also been found that subjecting the diaphragms several thousand times to deflections such as they would experience in use decreases appreciably the elastic lag or hysteresis effect. A similar result is also obtained by heating the diaphragms for a time, approximately a half hour, at temperatures depending on the composition of the metal but varying from 200° to 400° C.

In connection with this investigation the behavior of slack diaphragms of rubber and doped fabric is also being undertaken. Since it is possible with instruments of this type to concentrate the elastic resistance almost entirely in a spring it should be possible to make the hysteresis effect small in accordance with the principle applied in the precision altimeter already described. However, this is not found to be the case with instruments of the slack-diaphragm type now in use which show a hysteresis effect as large as that of instruments with metallic diaphragms. The porosity of diaphragms of this type is an important factor and is being determined experimentally. The stiffening of such diaphragms at low temperatures has also to be considered and is under investigation.

BOURDON TUBE INVESTIGATION.

It has been proposed that Bourdon tubes be substituted for metallic diaphragms in aeronautic instruments. Experiments on the elastic properties of such tubes have also been undertaken. Since these tubes are made of metal similar to that used in diaphragms and therefore imperfectly elastic, it is reasonable to assume that they would display hysteresis effects. Experiments indicate such to be the case and from the results thus far at hand it is not evident that the effect is appreciably less than in the case of metallic diaphragms.

BIMETALLIC BARS.

Still another problem presented in the development of aeronautic instruments relates to the behavior of bimetallic bars which are used in temperature compensation and also in certain cases as temperature-measuring elements. Here again the imperfect elasticity of the metals of which the strips are made has to be taken into consideration. This is not ordinarily a serious factor where the bimetallic bars are used for temperature compensation since a comparatively small corrective factor is involved, but it becomes important in temperature-measuring instruments based upon the bimetallic principle and warrants careful investigation.

ALTITUDE EFFECT ON AIR-SPEED INDICATORS.

The behavior of air-speed measuring instruments, particularly of the Pitot or Venturi type, under the conditions of reduced pressure and low temperature experienced in high altitude flight is difficult if not impossible to investigate in the airplane itself. The possibility of simulating in the laboratory the conditions of actual use have therefore recently been considered. For some time past an investigation has been in progress in a reduced pressure wind tunnel which consists essentially of a chamber containing a small wind channel so arranged that the air can be partially exhausted from the chamber. The results thus far obtained show that for Venturi nozzles there are appreciable deviations from the ρV^2 law for high altitudes or low speeds.[1]

[1] See The Altitude Effect on Air Speed Indicators; Report No. 110 of N. A. C. A. 1920, by M. D. Hersey, F. L. Hunt, and H. N. Eaton.

The behavior of instruments of the anemometer and wind propeller type should be investigated at reduced pressures. While it is ordinarily assumed that the indications of such instruments are independent of the density this is known not to be strictly true.

INK SUBSTITUTES FOR RECORDING INSTRUMENTS.

In connection with the development of recording aeronautic instruments it has been found that ink records which are ordinarily made by such instruments are not entirely satisfactory for use in aircraft because the ink coagulates at the excessively low temperatures encountered at high altitudes. Other possibilities have therefore been surveyed.

Records can be made on smoked surfaces with very light contact by the recording pen but the records are easily effaced and can be made permanent only by coating them with paraffin, spraying with shellac, or by using some similar adhesive agent. A mixture of alcohol, white shellac, and glycerin has been found satisfactory in our experiments. Paraffin-coated carbon copy paper may also be used with a fine jewel point recorder. These records, except at extreme temperatures, are more permanent than those obtained on smoked paper but require greater pressure by the recording pen with consequent decrease in the sensitiveness of response of the instrument to slight changes of reading. Paper coated with zinc oxide, such as is used for engine indicator diagrams, was also considered. This is used with a rather blunt brass recording point. The pressure required is excessive in view of the sensitiveness of response required in the recording mechanism.

Perforated records can be made by using an auxiliary clockwork mechanism to bring the recording point forcibly in contact with the record and thus perforate it several times per minute. The pointer ordinarily would not touch the record paper. This method is positive and sure but discontinuous, and it involves the added complication of an auxiliary clock or similar driving mechanism.

Records may also be obtained by perforation with an electric spark by connecting the metal drum on which the paper is fastened to one terminal of an induction coil, connecting the other terminal to the recording point and attaching an auxiliary contact breaker to the driving clock mechanism to make and break the induction coil circuit several times a minute. A device of this kind was made and attached to a barograph. It has the advantage that the sensitiveness of response of the pointer is not affected by contact with the record. On the other hand it requires the accessory of an induction coil, and the spark sometimes jumps sidewise a short though appreciable distance from the point.

Record paper previously impregnated with starch and potassium iodide can be used and the potassium iodide decomposed by passing an electric current at low voltage through the record paper from the pointer, which in this case is in contact with the record, to the drum. A purple record is obtained. The color, however, is inclined to spread, which makes the record abnormally broad.

Where dark-room facilities are available, records on photographic films can be obtained by allowing a beam of light to fall upon the record after it has been deflected by a suitable optical system attached to the indicating mechanism of the instrument. This may be done either by reflecting light from a light source, which may be a small incandescent lamp, from a mirror onto the film or by use of a suitable lens system. The disadvantage of this method is the necessity of developing the record and its extreme sensitiveness to extraneous light.

Experiments have also been carried out with a view to the possibility of using a small quantity of radioactive material on the end of the pointer of recording instruments. A metallic screen, which was perforated by a pin hole, was mounted on the pointer between the radioactive material and the recording film, to avoid diffuseness in the record. Satisfactory records on ordinary photographic films were obtained in this way. This method has the advantage of simplicity and reliability.

The possibility of photographing ordinary dial indicating instrument at frequents intervals with a magazine or motion-picture camera also presents itself. This offers the advantage of obtaining permanent simultaneous records of a large number of instruments which would be useful both in performance tests of airplanes and on investigating instruments themselves.

DUMMY OBSERVER

The last-mentioned method has been applied in the development of an automatic photographic apparatus known as a dummy observer, to be installed in an airplane for airplane performance tests. Records of the speed of the engine, air speed, altitude, temperature, pressure gage readings, and time were desired. Most of the instruments ordinarily employed for the measurement of these factors involve such small forces as to make the use of relays or amplifiers to operate recording mechanisms necessary if graphical records of the ordinary type are to be obtained. The advantage of the photographic method is that a simultaneous record of all the instruments can be made at intervals, which may be varied at will according to the conditions of flight down to approximately 20 exposures per second. The exact time of successive exposures can be recorded on the negatives by including among the instruments photographed a clock with hour, minute, and second hands.

The instantaneous behavior of the airplane with respect to each of the factors under investigation can thus be had as a permanent record at intervals of a fraction of a second throughout the flight and the history of the flight afterwards studied by magnifying the negatives and tabulating and plotting at leisure the readings of the various instruments. The advantages of this method are the absolute coordination in time of all the records; the possibility of controlling the time interval between the records and of detecting sudden changes and studying such changes in greater detail by making rapid records while these changes are taking place.

The apparatus as it was finally worked out consisted of a Mark I gun camera mounted at one end of a box approximately 14 inches square and 18 inches long. At the other end of the box were mounted the instruments to be photographed. The instruments were illuminated by a series of electric lamps inside the box, and the camera mechanism was modified to operate automatically at rates varying from 2 to 10 exposures per minute by the use of a centrifugal governor. Unperforated motion-picture film was used. To prevent excessive heating the lamps were automatically illuminated at the moment when the exposure was made. The instruments used were of the ordinary dial type, but it was found necessary to use white dials with black graduations for greater contrast. To avoid troublesome reflections the cover glasses were removed on all the instruments, except the air-speed indicator, where the glass dial is necessary to maintain the air pressure in the case. Care was taken to arrange the instruments to occupy as small an area as possible. An improved model of the dummy observer is being developed by the Engineering Division of the Air Service.

CONCLUSION.

One of the most important of the outstanding problems in the field of aeronautic instruments at present relates to the development of navigating instruments for use in long-distance flights and for flying at night and landing in fog. These include not only development of optical instruments used in connection with astronomical position finding but also improvements in altimeter, compass, and turn indicator construction. There is also reason to believe that commercial flying may soon be undertaken at very high altitudes to take advantage of favorable winds of high velocity. In this connection the importance of oxygen instruments will unquestionably be emphasized. The extensive use of large aircraft, particularly of lighter-than-air craft, requires the development of satisfactory distant reading instruments of various types. The proposed methods applicable to distant reading compasses, air-speed indicators, tachometers, and thermometers, previously discussed in this paper, are still in a preliminary state and have not been used extensively in practice.

The development of greater precision in all of the aeronautic instruments should be attained. While errors of from 1 to 5 per cent which are now common in instruments as actually installed in the airplane are not fatal under ordinary circumstances, such errors are much greater than could be desired. In certain instruments, particularly those used in navigation and in landing, errors of this magnitude constitute a serious if not fatal defect. Moreover, under certain special conditions, for instance, in aircraft performance tests, it is essential that the instruments have the greatest accuracy obtainable.

ADDITIONAL COPIES
OF THIS PUBLICATION MAY BE PROCURED FROM
THE SUPERINTENDENT OF DOCUMENTS
GOVERNMENT PRINTING OFFICE
WASHINGTON, D. C.
AT
$1.50 PER COPY
PURCHASER AGREES NOT TO RESELL OR DISTRIBUTE THIS
COPY FOR PROFIT.—PUB. RES. 57, APPROVED MAY 11, 1922
▽