Journal of the Minnesota Academy of Science

Volume 12 | Number 1 Article 4

1944

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Upton, A. P. (1944). Aircraft Electronic Instrumentation. *Journal of the Minnesota Academy of Science, Vol. 12 No.1*, 15-33.
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The war has precipitated widespread criticism of American education at the high school and college levels. However well founded these criticisms may be, it is clear that the time is ripe for a courageous self-appraisal of our educational programs and procedures in reference to the broad framework of the fundamental purposes of high school and college education. The fact that before the war only a minority of the students who started a four-year college program ever completed it, and that approximately half did not last beyond the second year, would seem to imply that it is not a question of standards so much as inappropriate educational choice or program. In a democratic society, all who can profit from education beyond high school should have such an opportunity, but it is the obligation of society to provide a type of education at that level which would be more suitable to the interests and needs of the majority and equip them to take a productive and satisfying place in the economic and social order. A sound program of general education in combination with terminal occupational training, coupled with a technically sound and effective guidance system, would seem to constitute a decisive step in the direction of giving fullest consideration to the educational and counseling needs of returned service personnel.

AIRCRAFT ELECTRONIC INSTRUMENTATION

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Dr. E. U. Condon, Director of the National Bureau of Standards, has chosen to define electronics as "The Science, Art, and Practice of Particles." Such a definition takes us beyond the usual concept of prewar radio communications into automatic avigation and navigation in its various phases such as Loran and Shoran, and other forms of radar in which intelligence is transmitted and received.

It includes television of all kinds, the study of the ionosphere, and the field of high frequency heating.

By that definition also we include electronic calculators, and many of the newer classifications of instrumentation and control, expanding to also include the mass spectograph.

Dr. Condon also includes the work being done in accelerating particles, and the development made in uranium changes in this age of atomics with which we have been made familiar within recent months.

Radioactive tracers, so valuable in biochemistry, and cosmic radiation projects likewise form a part of the field of electronics by this definition.

Reference to such a panorama may cause the reaction that the subject of Electronic Instrumentation occupies but a small space in this field. This is not true, however, and were this branch to be expanded in detail, the result would be to indelibly emphasize the enormous scope of the complete electronic field as defined by Dr. Condon.

In this article only three electronic instruments will be considered. These three concern the safety; accuracy of performance in flight, and hence the efficiency of operations of air transportation. These are chosen from among the many with which progress has been made by this company. In each case of instrumentation and control, some sensing device applicable to the medium that is to be instrumented or controlled, is required. In this paper we shall consider:

1. The pickup or *sensing* of *capacity changes* as illustrated in the Electronic Fuel Gage.
2. The utilization of the *rectifying action* of a *flame* in the *sensing* of the presence of fire as applied in the Electronic Fire Detector.
3. The *sensing* of the horizontal component of the *earth's magnetic field* as applied to the indication and control of the direction of flight of aircraft with the Cathotrol Compass (cathode ray).

ELECTRONIC FUEL GAGE

What are the performance requirements of a satisfactory fuel gage, and what are the field conditions (environmental, electrical, and mechanical) with which a fuel gage must contend to be successful?

Accuracy is vital. The cost of operation and the range of effectiveness of aircraft in warfare is governed by the gross weight that must be airborne. The results are apparent if extra gasoline must be carried to offset the possibility of gage errors. As an example, each percent of increase in accuracy of the gasoline gages used in a B-29 bomber means a saving of 396 pounds of gasoline. At a carrying cost of $150.00 a year per pound of weight, an airline's profits can become appreciably diluted if from one-half to one and one-half extra tons of fuel must be carried as gage inaccuracy protection.

Errors are introduced through the measurement of the volume of gas rather than the weight, through mechanical instability of registering devices, through electrical losses introduced by environmental effects, through the presence of foreign material in the gas tanks, variations in gas tanks, errors in calibration, performance variations with voltage fluctuations, actual errors in the specific indicating device or meter itself, and the deterioration with age of a system or any of its components. Fuel gages which register the volume of gasoline are subject to the deviations indicated in Figure 1 within the usual temperature range through which such equipment must function. For example, if 77° F. is the basis of comparison, the volume of 100 octane gasoline might increase almost 6% at 160° F.

This figure also shows the corresponding gasoline dielectric constant change. It is apparent that this is approximately inversely proportional to the volume change. The carefully designed capacity type fuel gage measuring the weight of gasoline, therefore, registers with reasonable accuracy within this wide range of temperatures.

The dielectric constant averages about two at 77° F. If a pair of concentric tubes is mounted in a gasoline tank, the capacity between them will vary in the ratio of 1 to 2 between empty and full tank conditions. At partially filled tank points, parts of the tubes will be submerged in gasoline and the remainder will be in air. The result is practically a straight line indication (except for tank irregularities). This, when properly translated into a gage scale, interprets this capacity in terms of pounds of fuel or gallons of gasoline. Figure 2 shows a typical tank unit with a third tube surrounding the active elements—added for mechanical protection, and for maintaining constant capacity between the active elements and ground.

The electrical circuit is of the self-balancing type which insures immunity from the effects of line voltage changes and electron tube deterioration. Changes in capacity cause the indicating motor (gage) electrically driven, to balance out as gasoline is consumed.

Figure 3 shows the capacity bridge principle of the electronic fuel gage. If the fixed capacity chosen is equal to the capacity in the tank, the circuit is at balance because equal voltages appear across the two condensers. Should the gasoline level rise, additional capacity is required in the fixed capacitor to maintain voltage balance, or the required voltage change can be introduced by shifting the transformer tap down to restore balance.

This voltage change is actually introduced smoothly and automatically by a motor driven voltage divider which in turn is operated in either direction as required by a phase sensitive amplifier whose input is connected across the bridge. Filling the tank means that less voltage is necessary across the fixed or "standard" capacitor to maintain balance.

As gasoline is consumed an unbalance in the bridge causes the motor to be energized through the amplifier and the motor turns to restore the bridge to balance. Simultaneously, the gas quantity is indicated on a scale over which moves a pointer driven by the same motor. The operation is thus continuous and automatic with changes in fuel level, up or down. Figure 4.

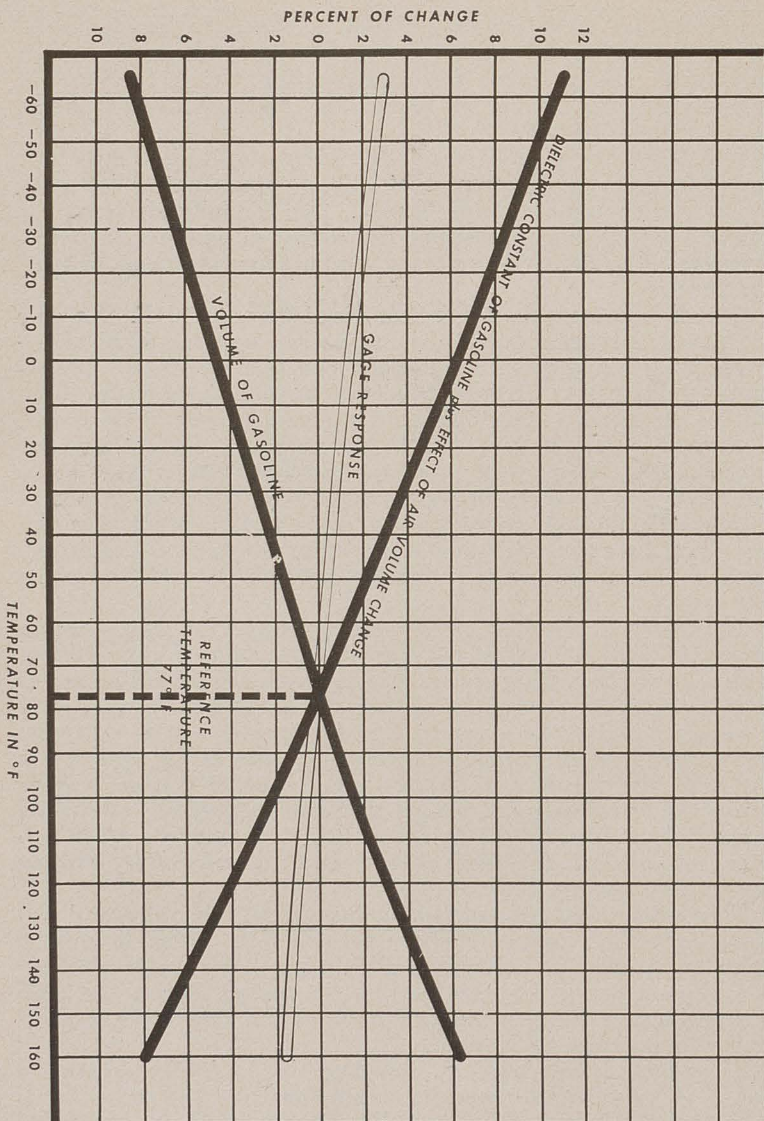

FIGURE 1. Volumetric & Dielectric Constant Changes in Gasoline with Temperature.

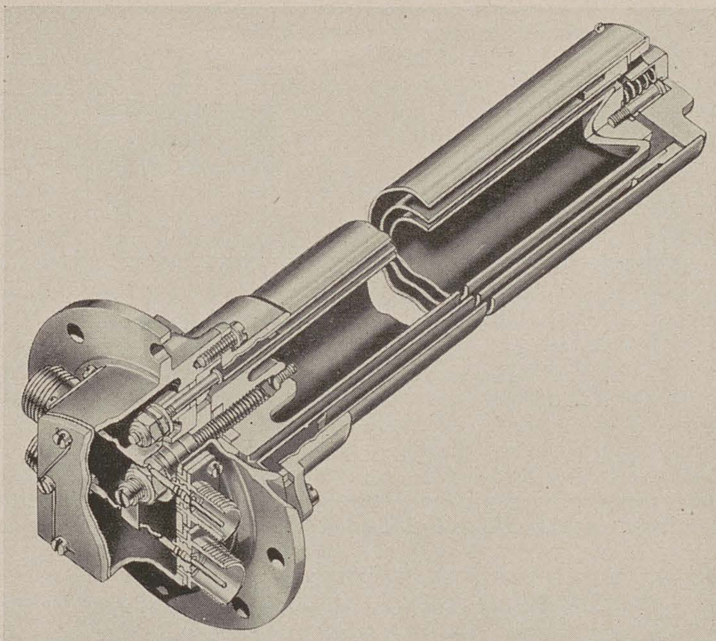

FIGURE 2. Typical Sensing or Pickup Unit for Electronic Fuel Gage System

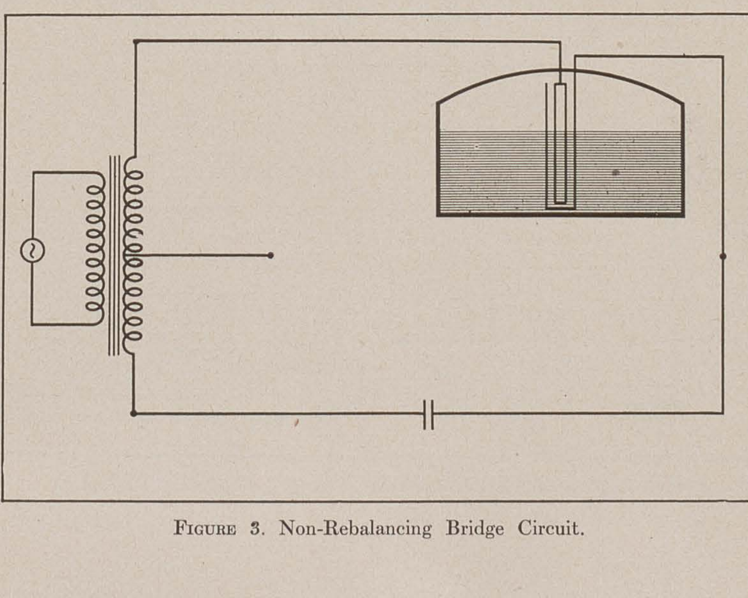

FIGURE 3. Non-Rebalancing Bridge Circuit.

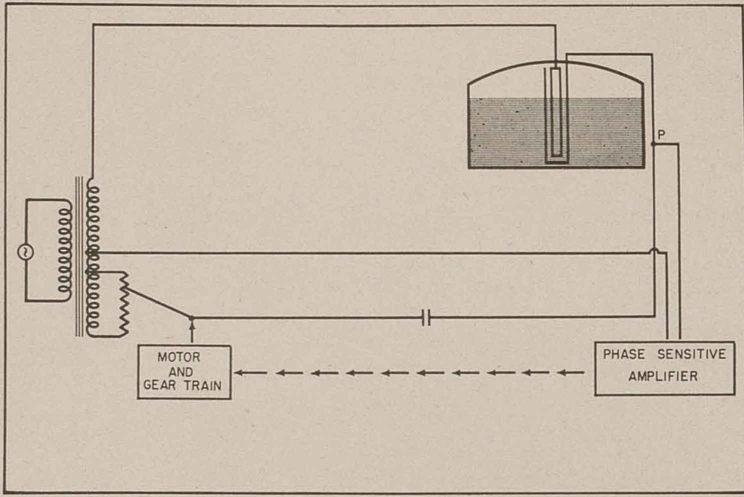

FIGURE 4. Re-Balancing Bridge Circuit

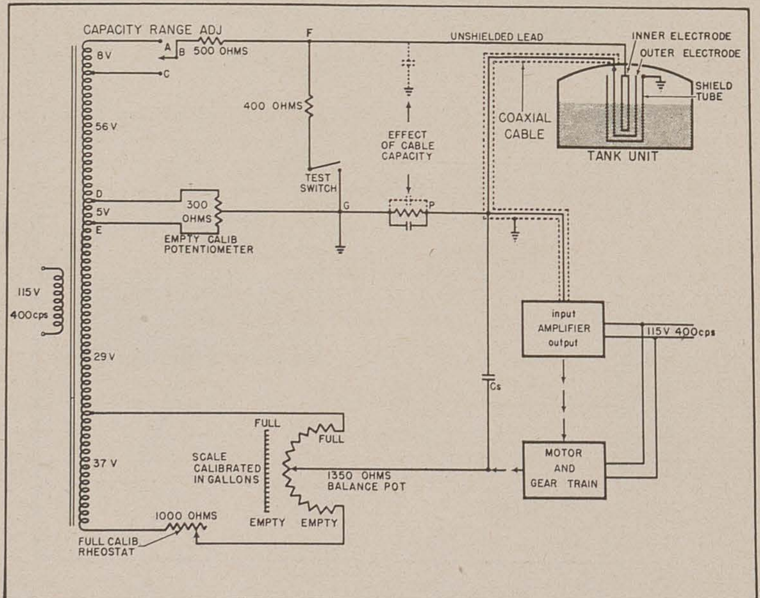

FIGURE 5. Practical Working Bridge Circuit — Electronic Fuel Gage

The practical working circuit in which the capacity pickup device functions is shown in Figure 5. Condenser Cs is the "standard" or reference condenser so made that it possesses a nearly zero temperature-capacity coefficient. Its capacity, therefore, varies a negligible amount within the operating range of −65° F. to +160° F. of the system. The "Tank Unit" typifies a partly filled gasoline tank containing the sensing unit.

The "Empty Calibration Potentiometer" permits calibration at the zero setting of the gage as is necessitated by the usual small variations and tolerances that accumulate during the manufacturing process of quantity production items, and small differences in installations from plane to plane. The "Full Calibration Rheostat" provides the same function at full scale reading.

To provide flexibility over a wide range of tank sizes (and the accompanying differences in tank unit capacities) two voltage choices are possible at "Capacity Range Adjustment," in Figure 5.

The "Test Switch" permits checking the operation of the circuit by upsetting the bridge balance purposely to cause gage pointer rotation. Releasing the test button restores the setting to normal balance. This switch is mounted on the indicator.

Shielded cable is used in certain important parts to insure continued operation under adverse conditions.

Figure 6 shows an indicator — the registering device which the Pilot or Flight Engineer observes when watching the fuel consumption during flight. Dial scales are not linear because of the odd shapes and dimensions of tanks made so to fit into the wings.

In Figure 7 is shown the uncased Amplifier and Power-Calibrator units used in each channel or with each group of tanks.

Figure 8 gives an idea of the complete system installation in a B-29 bomber. Note that multiple cell combinations give gasoline quantity indications through parallel connected tank units so distributed as to allow for fuel level variations resulting from cell differences, wing dihedral, airplane attitude, and banking in flight.

ELECTRONIC FIRE DETECTOR

Our imagination needs no stimulation when recalling details of catastrophic fires about which we have heard, particularly when such fires have originated in unfrequented or inaccessible spots such as a ship's hold or an aircraft engine nacelle. There have been too numerous and too disastrous fires to permit us to forget them.

Ignorance of the existence of such fires prevents corrective action if no automatic extinguisher apparatus has been installed. Whether the quenching is automatic or attained through manual attention, some warning of the presence of the fire is highly desirable.

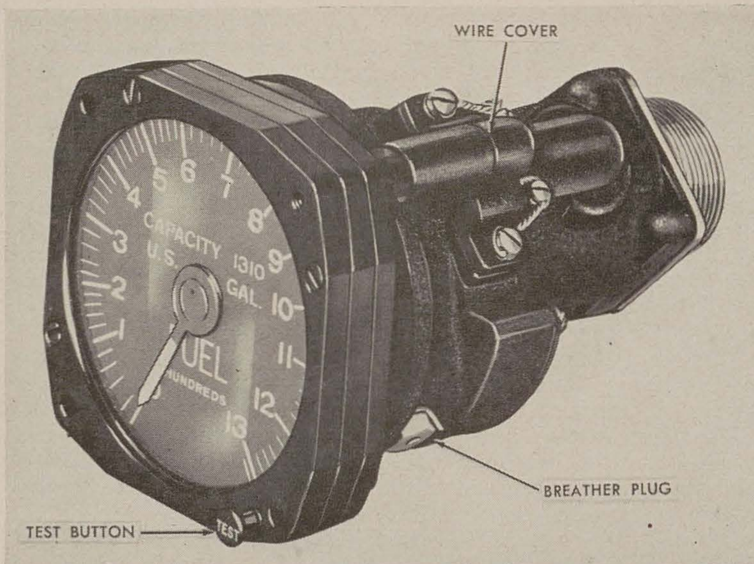

FIGURE 6. Fuel Gage Indicator.

Some of the requirements of such an installation are as follows:

1. It must be simple and reliable.
2. Servicing should be simple routine.
3. The system should be remotely indicating and adaptable to extinguisher apparatus operation.
4. The detector should be immediate in its action and should give no false readings.
5. The system should be capable of being checked at will, quickly and simply, to insure performance at all times.

The photo-electric cell is one of the obvious means of sensing the presence of fire or smoke. Detecting the former involves differentiating between daylight and firelight. Sensing the latter requires a constant light source whose rays must be interrupted by the smoke of the impending or existing fire. A multiplicity of cells and light source pairs is required to cover any space of appreciable size.

Fuseable links or thermocouples actuated by the increased temperatures caused by fires may be used to sound an alarm or actuate extinguisher provisions.

The Geiger tube method is one which is showing possibilities in development work now being carried on. Such tubes must be sensitive to the ultra violet emanations from the usual fires while

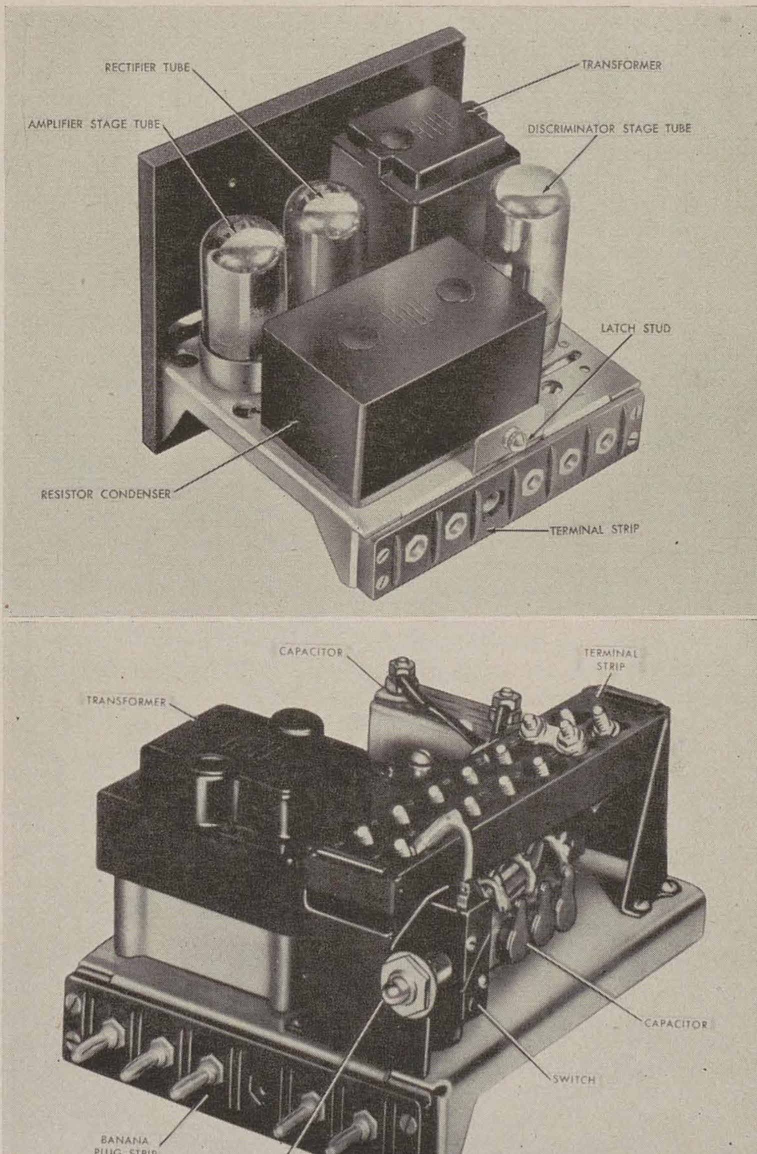

FIGURE 7. Uncased Fuel Gage Amplifier, and Power & Calibration Units.

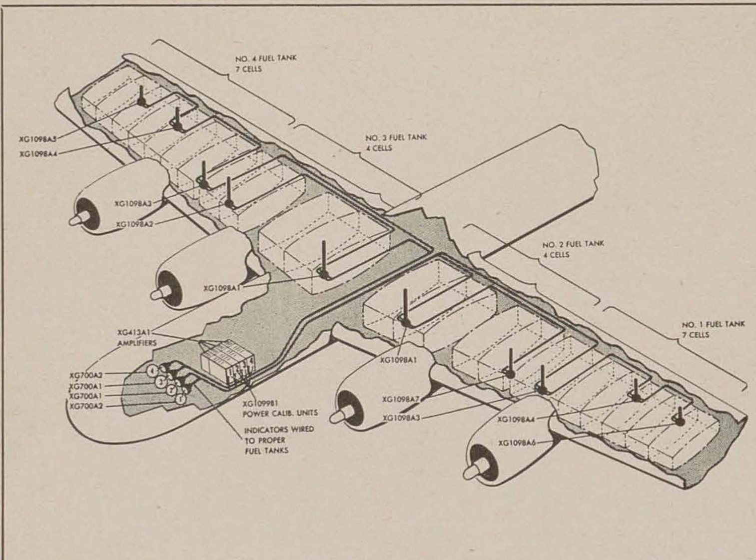

FIGURE 8. Typical Installation of Fuel Quantity Indicating System in B-29

being immune to daylight affects. The tubes must be ruggedly built, mounted in the danger zones and properly protected against mechanical damage.

Still another principle involves the conducting or rectifying action of a flame.

Investigations by others (Review of Modern Physics, 1931, pages 156 to 187, and references therein) indicate that the conductivity of flames is caused by the presence of negative ions or electrons, and positive ions (supposedly due to electron emission in the flame action). The negative ions or electrons are up to 1000 times more mobile than the positive ions. Conduction is comparable with electrical conduction in any gaseous medium.

One theory indicates that with electrodes of equal areas, current flow is equal in each direction with reversal of the applied voltage. When one electrode is made smaller in area than the other, the current flow is greater when the smaller electrode is made positive. The concentration of the potential difference at a point or small area means a concentration of the free electron flow to that point or small area. This concentrated flow means a greater bombardment of the atoms of the gases from which more electrons are dislodged thus increasing current flow. Upon reversal of the applied voltage, the intensity of the charge on the large electrode is less, hence, the free electron density is less near the large electrode, and the concentration of the dislodged electrons is less. Current flow is therefore lower. Operation is therefore a matter of distribution versus concentration of charge.

This performance then satisfies the requirement for rectification when A. C. is applied to the flame electrodes in that the resistance between electrodes is less in one direction than in the other. The engine forms one electrode while a wire may form the other.

No one of these methods is ideal; there are disadvantages in all of them. At present the rectifying-action-of-the-flame system satisfies many of the requirements and shows considerable promise as a detector.

One particular version is shown in Figure 9.

The pick-up or sensing device is simply a single wire of adequate mechanical strength mounted on suitable insulators throughout the danger area. The length and location is practically immaterial so long as the insulation or spacing is adequate for the 300 volts A.C. applied thereto.

Electron tube T1 is the triode which actuates the warning light or extinguisher apparatus through relay R1. Actually in this circuit,

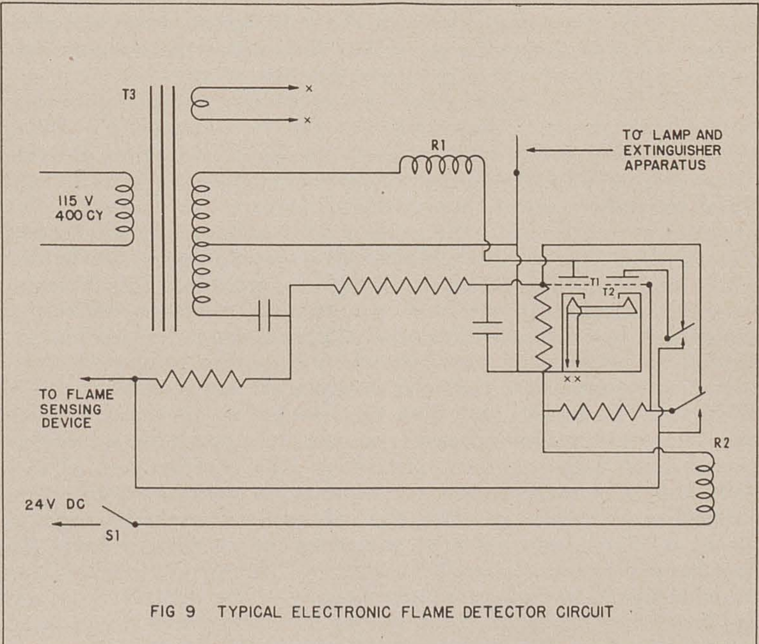

FIGURE 9. Typical Electronic Flame Detector Circuit

in the normal operating position, both triodes are in parallel through the "out" contacts on relay R2, but the principle of operation is perhaps more easily described when one triode only is considered. (These two triodes are contained in a single envelope such as a 12SN7.)

The power is A.C. supplied through transformer T3. In the "no fire" condition there is insufficient bias to prevent R1 from pulling in. This means that while the tube performance is normal, no warning light indication is given. Tube, or other failures cause relay drop out and a warning through the indicator. Power failures are made evident by the warning light if the latter is battery operated. If A.C. operated power failure will result in no warning light indication.

Furthermore, while the tube is heating, the relay is unenergized and therefore the lamp lights. As it warms up, the tube operates the relay and the light disappears. This gives a check on many parts of the circuit every time the system is energized, as well as another check available at will throughout flight, as will be described later.

At such time as fire occurs in the danger zones, the flame rectifies the A.C. normally appearing between the pickup wire and the ground, thus providing a bias on the tube which drops the plate current, thus de-energizing relay R1. This causes the warning light to glow and operates extinguisher apparatus, if any.

Should there be doubt about the resistance path to ground in the pickup circuit, a simulated fire can be obtained by closing switch S1. The action is as follows: Closing S1 energizes R2 thus disconnecting T2 from its normal parallel connection with T1, and simultaneously connects the grid and plate of T2 together. This provides a rectifier with the sensing wire voltage applied thereto. This rectifier thus applies a bias to T1 as would appear in the case of fire and the relay R1 drops out giving warning. This checking action is affected adversely if the ground resistance, pickup to the engine, has decreased materially. This feature gives added protection in proving the condition of most of the components.

It is very important that the electrode or flame sensing wire be adequately insulated, and that this insulation does not decrease with time. An excessive decrease in resistance results in insufficient bias through flame rectification to drop R1 out. Inasmuch as various kinds of flames introduce resistances to ground varying from about 2 megohms for gasoline, through approximately 10 megohms for an oil flame, and up to 20 megohms for an alcohol flame, the resistance between electrode and ground should not be less than 30 megohms. The insulators are usually of the ceramic type and are treated so that the surface does not "wet" well. Such treatment encourages the moisture to form in drops rather than in a complete path to ground. Cleaning the surfaces of the insulators periodically with some suitable solvent reduces the chances of the collection of oil or dirt decreasing the leakage resistance to ground.

CATHODE RAY COMPASS

A suitable means of continuously indicating accurately the direction of movement of aircraft in flight has long been sought. Many adaptations of the basic principles of the magnetic needle compass have been designed and constructed but the majority possess some inherent disadvantage. Their slowness in response to changes, caused by damping provisions incorporated to make practical readings possible, requires that the observer wait to get his direction until oscillations have completely died out. In banking, the effects of the compensation, added to offset the dip introduced by magnetic declination, make readings often quite meaningless.

Ordinarily, also, magnetic compasses must be mounted near the observer in which case individual calibration is required to compensate for the effects of stray or distorted magnetic fields in the immediate vicinity. Any attempts to install the usual pickup or sensing devices on such a compass to permit placing it in some isolated location in the plane (with remote indication of the direction of flight placed before the observer) accentuates the basic disadvantages because such additions involve greater mechanical loading.

The cathode ray compass is one of the newer types that shows considerable merit in that it does not possess many of the undesirable characteristics of the conventional types. Since it is an electrical device, it can be mounted in some remote spot, free from stray fields, such as out in a wing. Furthermore, the electron beam which is acted upon by the earth's field, possesses no inertia hence its response is immediate.

A standard cathode ray tube for oscilloscope use consists of a source of electrons properly focused so as to impinge in a spot upon a fluorescent screen. Deflection of this beam is possible by either electrostatic or electromagnetic means. In the former case, deflection is parallel with the field existing between plates straddling the beam. Deflection by the latter method is at right angles to the field produced by electromagnets mounted around the beam. In normal use the beam is fixed in intensity and centered by the proper choice of adjustable voltages. During operation, its position on the screen is determined by controlling voltages applied to either or both of two sets of electrostatic plates, or to electromagnets to perform the equivalent action.

For television applications, an additional variable is included to provide the proper shading effects in the picture through modulation of the beam intensity by means of a control grid. In either case, visible reproduction of electrical changes is the objective.

In the cathode ray compass tube, however, the location of this beam on the screen or target is the objective. The physical location is made possible of electrical interpretation by dividing the target into four quadrants. The intensity and the focusing of the beam is fixed and remains unchanged throughout operation. Movement of the beam is the result of the action of the earth's field in a manner comparable with the electromagnetic deflection principle referred to in the foregoing.

Figure 10 shows a cross-section of the cathode ray compass tube.

Figure 11 shows the appearance of the tube.

In our particular location on the earth, the magnetic dip or declination is about 70°. The field then can be resolved into a vertical component and a horizontal component. By mounting the cathode ray compass tube in a vertical plane, the electron beam will be acted upon only by the horizontal component of the earth's field because the vertical field will be parallel with the electron beam.

If completely shielded, this beam is centered within the four-quadrant target. If not shielded, the beam will be deflected from the normal position and thus impinge on some off-center spot on the screen or target. By voltage adjustment, this beam can be restored to some convenient spot near center for a given physical position of the tube.

If this tube and its accessory equipment is set up for true north direction spot calibration, deviations from this position will result in beam deflection. When installed in a plane, then, any deviation from true north flight will result in beam movement at an angle proportional to the deflection off course.

For a given beam deflection, the new target spot location can be resolved into two components with respect to the north-south, east-west reference lines. The magnitudes and directions of the components identifies the new spot location and hence the angle of deflection of the beam with respect to true north.

Figure 12 indicates how this principle is translated into output signals for indicating purposes or for maintaining a plane on course in actual flight.

Opposite pairs of plates are connected to opposite ends of two center tapped primaries of the two transformers shown. The positive potential required for the target of the cathode ray tube is applied to these center taps. The control grid of this tube is modulated with a 400 cycle signal.

Normally when the beam is near center among the four quadrants, the voltages appearing across the transformer outputs are relatively low. When acted upon by the earth's magnetic field, the beam deflects towards or into one of the quadrants or along the dividing line between two quadrants. This immediately results in a larger potential differential of a given magnitude and direction, across each primary and hence across the secondaries. These in

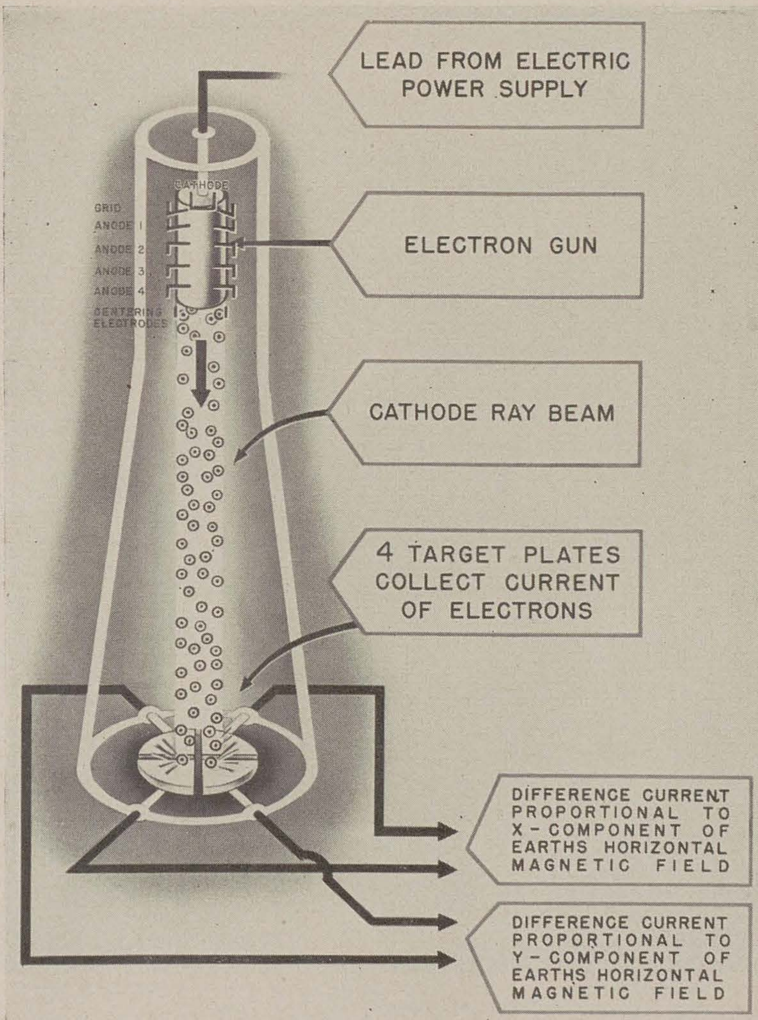

FIGURE 10. Cathotrol Compass Tube Cross-section

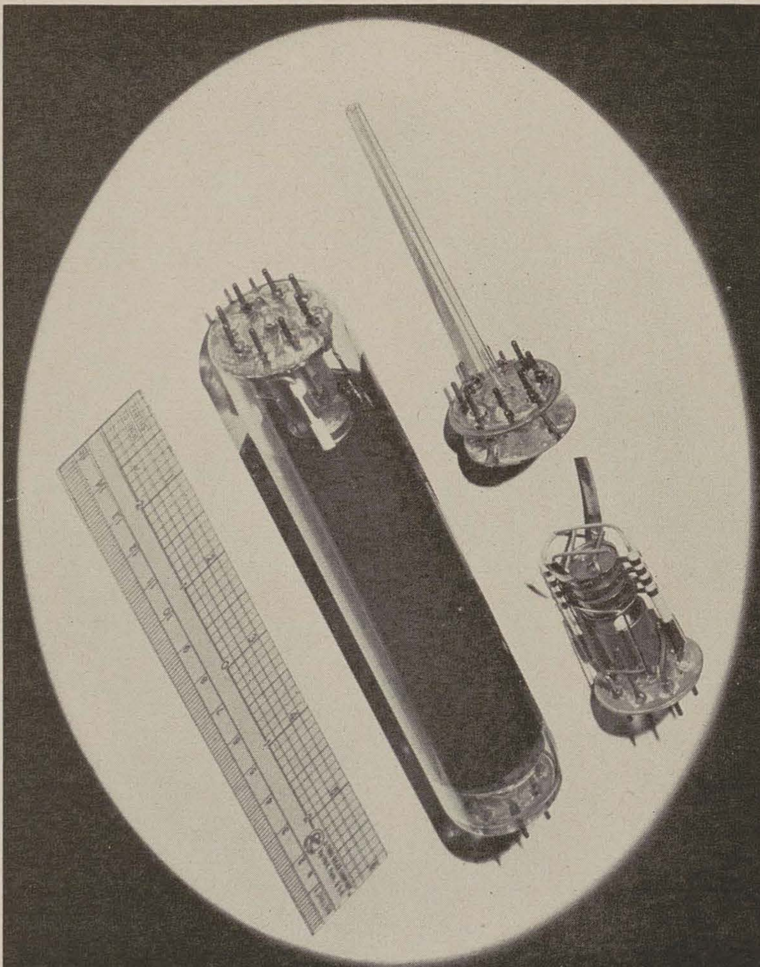

FIGURE 11. Typical Cathotrol Tube

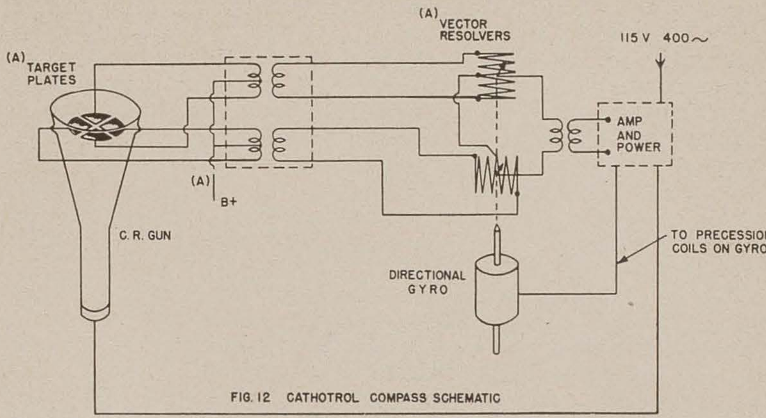

FIGURE 12. Cathotrol Compass Schematic

turn feed the two potentiometers shown. These consist of two flat cards wound with fine resistance wire, over each of which a contact arm can rotate. If one considers the relative positions of the two potentiometer windings, it will be seen that in one case the voltage will increase from zero to maximum as the arm moves 90°, and in the other, from maximum to zero as the arm moves through the same angle. As the two arms are mechanically connected there will be simultaneous changes in voltages in the orders indicated throughout all four quadrants in a 360° turn.

Normally a directional gyro maintains its position in space unless acted upon by certain forces. These forces usually cause deflection of the gyro, or "precession." If now the potentiometer windings are physically mounted on the gyro case and the wipers are linked with the gyro rotor, any precession will result in wiper displacement and hence a voltage output from the two potentiometers, or "vector resolvers." These "resolvers," then, translate unto electrical signals both as to magnitude and polarity the relative points at which the potentiometer wipers contact the two windings at any instant.

Any tendency of the directional gyro to precess because of, for example, friction, then causes a signal from the vector resolver, which in turn actuates the amplifier shown. The output of this amplifier is fed to precessing coils on the gyro which return the gyro to its original position.

Corrections continue as long as the system is not satisfied, and it is not satisfied unless the gyro is in normal position, and no voltage appears across the output of the resolvers. As long as the plane has not changed its direction of flight, the cathode ray beam is in normal position, there is no call for correction of flight and all components are in balance.

When flying manually, then, the pilot can observe whether or not he remains on the chosen course. If the plane deviates, the beam is deflected, the resolver output changes, and the gyro is precessed until balance is realized. This new balance indicates to the pilot that he is off course whereupon he makes corrections in the rudder and aileron control surfaces to bring the plane back on course. The cathode ray beam thus returns to the original location on the target and the gyro is precessed back to its original heading indication.

This operation can be made automatically by a tie-in with the automatic pilot through the medium of another voltage from a separate potentiometer. This is shown at A in Figure 13, and is connected into the autopilot circuit so as to result in servo operation for changing control surface positions.

Consider a plane going off course. The beam is deflected, the gyro precessed and simultaneously a voltage is applied into the autopilot circuit from A, which results in control surface movement and return of the plane to normal flight direction. In so doing,

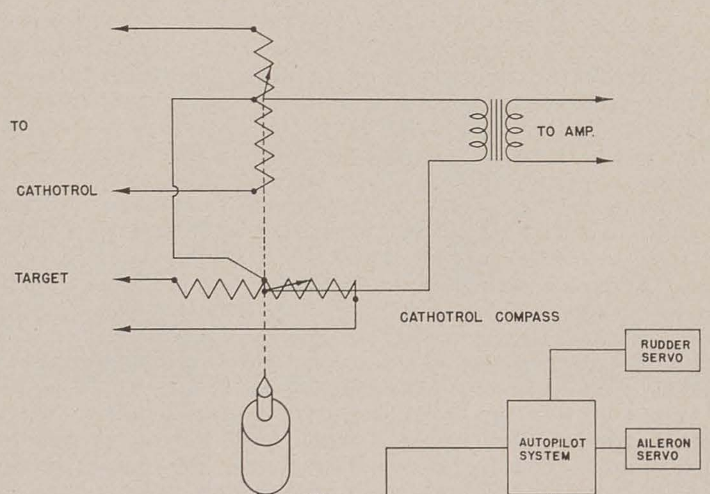

FIG. 13 COMPASS TIE-IN WITH AUTOMATIC PILOT

FIGURE 13. Compass Tie-In With Automatic Pilot

the beam is returned to normal thus restoring the gyro to its original position and in turn restoring the output of A to zero. Further corrections are unnecessary until the next deviation occurs.

Should the pilot desire to change his course, he can manually change potentiometer A a chosen amount. This means that a correction will be introduced into the autopilot circuit thus altering the course of the plane. This will mean that the beam will be deflected, and the resultant signal from the resolvers will call for a gyro position change. This change will be in the direction and of an amount sufficient to bring the gyro to the electrical balance position with respect to the chosen setting of potentiometer A. The plane continues on the new course, then, until a deviation calls for a new change.

The successful bidding for world air supremacy by our nation, and the ability of the airlines to compete with other forms of transportation requires the development and use of aircraft components and accessories that will improve operations in both fair and foul weather with a minimum of hazards. This calls for the maximum possible ratio of hours in the air to hours on the ground, with minimum time consumed in flight for given point to point distances covered with maximum pay loads.

The three devices described herewith are just a few of many electronic instruments that are aiding in achieving the desired goal in airborne carriers.

MAN AND THE TEMPERATURE OF HIS ENVIRONMENT

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