Defence Science Journal, Vol.1, No.2, January 1950, pp. 131-137

GENERAL FEATURES OF AIRCRAFT INSTRUMENTS

By Sq./Ldr. Satgursaran Singh, Electrical and Instrument Specialist, Air H.Q.

General Requirements.

The aircraft instruments distinguish themselves from those used in other spheres of industry by their ability to operate under more severe conditions of service. For instance when an aircraft is on the tarmac on a hot summer day in the tropics the temperature in the vicinity of the aircraft may be anything upto 120°F. As soon as it takes off and gains height the temperature starts decreasing rapidly until at a height of 40,000 ft., it may be as low as—20°F. Similarly on a long distance cross-country flight the aircraft may have to pass through many zones of high and low temperatures. Not only that, the humidity may also vary as rapidly.

2. Another striking point of distinction is the power to withstand the heavy strain put on the bearings of the working parts by the vibrations of varying intensity. For instance when the aero-engine is first run-up at the start of the flight the vibrations set up by the engine are of longer amplitude and smaller intensity. As the engine revolutions are increased the amplitude of vibration decreases while the intensity increases. Therefore during a normal flight the vibrations keep on changing as the engine revolutions change. To enable the instrument to withstand such vibrations it is necessary that it be robust in construction.

3. In addition to the points mentioned above the effect of forces of gravity when the aircraft is undergoing aerobatics cannot be overlooked when designing an aircraft instrument. To ensure that the instrument does not disintegrate under the forces of "g" it is necessary that the moving assemblies be as light as possible. These assemblies should be well balanced to give accurate readings under all conditions.

4. A few other points of interest which can be enumerated are as follows:—

(a) The instrument should have suitable damping arrangements so that the instrument pointer takes up its position quickly and gives a steady reading.

(b) The pivots should be frictionless to ensure high standard of accuracy.

(c) The instrument should be as light as possible to ensure high efficiency of the aircraft and to obtain maximum amount of pay-load.

(d) The natural vibration period of the moving parts must not bear a simple relation to the natural frequency of the vibration of the engine, otherwise its pointer will oscillate violently, making it impossible to obtain a steady reading.

(e) The instrument should be so designed that the markings on the dial are not cramped and that there is no uncertainty to the actual reading.

(f) The indications of the instrument must be reasonably correct under various altitudes of the aircraft.

(g) The materials used should be those which offer maximum resistance to corrosion. It should not produce a large deviation in the aircraft compass readings.

4. These are a few of the requirements which all aircraft instruments irrespective of their function are required to fulfil. You may call these as the "Basic" Requirements.

Classification of Instruments.

5. There are many instruments which are used in the aeronautical industry which find no place in the normal equipment of aircraft. These are used for determining measurements in the study and practice of aviation, either on the ground or in the air, and may be broadly classified under the following headings:—

(a) Meteorological instruments.
(b) Laboratory instruments.
(c) Calibrating instruments.
(d) Performance testing instruments.
(e) Aircraft instruments.

At the present moment we are only dealing with instruments used in the normal equipment of aircraft and those specific to the role of its performance.

6. Broadly speaking the aircraft instruments can be sub-divided under the following sections:—

(a) Engine performance instruments.
(b) Aircraft performance instruments.
(c) Navigational instruments.
(d) Instrument for bombing and gunnery operations. These depending upon the role of the aircraft.
(e) Instruments for Oxygen Equipment.

Following is an example of various instruments falling under each section:—

(a) *Engine performance instruments.*
 (i) Engine Speed indicator.
 (ii) Fuel Pressure indicator.
 (iii) Oil Pressure indicator.
 (iv) Boost Pressure indicator.
 (v) Fuel-air ratio indicator.
 (vi) Oil temperature, thermometers, radiator thermometer, cylinder head temperature indicator. Free air temperature thermometers.

(b) *Aircraft Performance Instruments.*

- (i) Air Speed Indicator.
- (ii) Artificial Horizon.
- (iii) Turn and bank indicator.
- (iv) Altimeter.
- (v) Automatic controls.

(c) *Navigational instruments.*

- (i) Turning indicator.
- (ii) Various compasses.
- (iii) Air Position Indicator.
- (iv) Ground Position Indicator.
- (v) Drift meters.
- (vi) Watches.

(d) *Instruments for Bombing and Gunnery Operations.*

- (i) Various types of Bombsights.
- (ii) Various types of Gunsights.
- (iii) Bomb release units.

(e) *Instruments for Oxygen Equipment.*

- (i) Flow indicators.
- (ii) Oxygen economisers.

In addition to a few different types of instruments mentioned above, there are other instruments used on aircraft for various purposes such as fuel flow indicators, fuel contents gauges, rate of climb indicator, mack meters, etc.

The Past.

7. During the early days in the history of aviation a very limited number of instruments were used on aircraft as the engines used were not so highly developed as today and the flying was limited to day—flying only within a prescribed area. The pilot had to do his navigation with the aid of his compass, map and the visible pin-points on the ground. As the engine power rating went on increasing it became more and more necessary to feel the "pulse" of the engine for which purpose additional instruments were produced and introduced. Also with the increase in engine power it became possible to carry more fuel and thus increase the range of flying per sortie. This necessitated the development and introduction of aircraft instruments and navigational instruments. With the increase in range it also became necessary to find means by which the pilot could fly through all weather conditions. This led to further investigations which resulted in what we have today as "The Blind Flying Panel".

8. All these developments also led to the idea of "high altitude flying" which required various navigational aids such as Astro-Compasses to enable proper navigation in the absence of ground pin-points as the case would be if the aircraft were flying above clouds. At the same time it was found that the ceiling of aircraft would be limited if the supply of oxygen remained as would be under the normal atmospheric conditions. Oxygen equipment was therefore developed for use during high altitude flying.

9. With the development in the general performance of aircraft it was felt that the usual course-setting bombsight and ring-and-bead gunsight could not continue to give an effective value to the weapons employed as the human-error was always present which lead to inaccurate bombing and firing. To increase the effectiveness of the weapons much research work was carried out and today we find that such computors are available which automatically make allowance for various factors such as gravity drop, wind drift, speed and direction of the target, etc.

10. At the same time the size of the aircraft went on increasing which necessitated the development of remote-indicating instruments as it was neither desirable nor practical to bring pipes from the engines to the dash-board for the purpose of indicating oil pressure, boost pressures, engines revolutions, etc., to the pilot.

The Present.

11. Today we find that most of the engine instruments except those used on single-engined trainer aircraft are remote indicating comprising of the transmitter, indicator, and the connecting medium such as electrical wires or capillary tubes. Dealing with each type of major instruments used on present day aircraft according to the country of origin the following is a brief description of events leading to it:—

(i) *Engine Speed Indicators.*—In the early days mechanical engine speed indicator based on the action of centrifugal force on fly-weights were used. The indicator was driven by a flexible shaft which received its rotation from the engine. Normally the speed of the shaft was reduced to 1/4th the engine speed by means of a gear box. This was done to reduce the wear and tear of the flexible shaft and its casing. The speed was again stepped-up by means of a gear box forming an integral part of the indicator. The main limitation to the use of this type of instrument was the maximum length of the flexible drive which could be used without any decrease in the efficiency of the complete instrument. The other drawback was the excessive length of wearing surface. To replace this a direct current generator with the characteristic of one volt per every hundred revolution along with a voltmeter suitably calibrated and marked to indicate r.p.m. direct was developed. The drawback in the use of this engine speed indicator was the maintenance and cost of the commutator brushes which were made of silver and plated with gold. Moreover, it required a well matured permanent magnet which must not change with use. Also the maximum speed reading which could be obtained from it was limited. A new r.p.m. indicator was therefore thought of and produced. This instrument worked with alternating current and had no commutator trouble. The transmitter is more robust and can withstand higher temperatures as the windings and fixed on the stator and the insulating material used is the one of greater heat resisting qualities. A small flexible drive is used for connecting the transmitter to the engine without the use of any intermediate gears. The indicator which is connected to the transmitter by means of three wires is a self-synchronous three phase motor having a permanent magnet connected to the armature. Around the magnet is a copper sleeve which tied to follow the permanent magnet as the eddy currents get induced in it. This follow up movement is geared up to the pointer to indicate the revolutions per minute. It should be noted that no calibration is needed for the generator as its sole function is to provide a varying periodicity according to the engine speed. The indicator keeps in step and reproduces the speed. This is the type of engine speed indicator as used today on modern aircraft.

Fuel Pressure, Oil Pressure, Boost Pressure Gauges.

12. The earlier types of fuel and boost pressure gauges had a capsule made of corrugated sides which expanded or contracted as soon as the pressure between the inside and outside the capsule changed. One side of the capsule was normally fixed while the other side moved inwards or outwards due to differences in pressure. This movement of the side-wall operated the pointer through a chain of gears. These instruments were all direct reading types and were mostly used on single-engined aircraft.

The oil pressure, hydraulic pressure, pneumatic pressure gauges operated on the principle that a tube bent into a circular shape has a tendency to straighten out when a pressure is applied to it. Such a tube is known as the Bourden tube. One side of this normally oval and circular tube made of a suitable metal is fixed while the other end is free to move. Through pinion and gear arrangement the movement of the free end is amplified and calibrated to indicate the desired pressures. The material, shape and size, and suitability are selected to give the desired range.

With the development of multi-engined aircraft these instruments had to be suitably improvised and converted into remote-reading type. In United Kingdom this was done by the use of a capsule enclosed in an outer case and a capillary tube connected the transmitter and the indicator. The three components, i.e., the transmitter, capillary tube, and the indicator capsule or bourden tube as the case may be were filled with suitable non-freezing fluid and permanently sealed together to form one instrument. No repairs were possible in service once the sealed portion of the instrument had failed. In America the conversion of direct reading into remote-reading instrument was accomplished by making use of electro-mechanical arrangements. The mechanical movement was converted into electrical impulses which were transmitted by the autosyn system to the indicator. The electrical portion of the complete instrument worked from a 26 volt 400 cycle single phase A.C. supply.

Basically two identical motors were employed and by suitable connections the angular movement of the rotor of one motor was transmitted to the second meter. On the transmitter side a capsule was suitably linked with the rotor. Any movement of the capsule wall produced an angular displacement of the rotor. The displacement was repeated in the indicator by the autosyn system and was suitably converted back into an angular movement which operated the pointer. The advantage of this system is that the distance between the transmitter and the indicator did not matter at all and the wiring could be done very neatly. There was a danger of inaccuracy in the reading due to the compressibility of the fluid as used in the British type instrument.

Oil temperature, radiator temperature, cylinder head temperature and free air thermometers.

13. The cylinder head temperature has not changed its type except for the use of various metals to form the bi-metal transmitter couple for giving the various ranges. The reason for this being that the indicator has been able to meet all the requirements satisfactorily.

The original oil temperature and radiator temperature thermometers were operated by the bourden tube, similar to pressure gauges except that the transmitter was in the form of a bulb and the fluid used in the capillary tube was mercury. This type of instrument had similar limitations as other instruments using the same principle. During the last world war II a new type of instrument was developed. This thermometer employs an Electrical Wheatstone Bridge circuit, three sides of which are in the shape of coil inside the indicator while the fourth side is in the form of a bulb which replaces the bulb of the mercury filled thermometers. The advantage of this type of bulb is the reduction in cost and the increase in the distance between the transmitter and the receiver. The principle utilised is the relation between the resistance of an electrical wire to the temperature. Although this instrument is not much favoured by the British Industry it is quite popular with the American, French and German Aviation.

Air Speed indicators.

There has been no radical change in the design of the instrument except for the minor alterations required for the increase in the range of the instrument.

Artificial Horizon.

Ever since the first instrument was designed no radical change took place until the last war when the Germans and the Americans produced an Electrically Driven Gyro instrument which had a greater operating range. It was also established that at high altitudes where the density of air becomes low the air driven gyros do not remain sufficiently accurate and become sluggish in operation. In United Kingdom the Electrical Artificial Horizon is now being experimented upon to check its suitability for universal use. As soon as the experiments are over this item is likely to get in general use in U.K. as well due to its superior performance.

Auto controls.

The auto controls were conceived when it became possible to increase the range of Flight and the endurance of aircraft in the air. It was felt that on long range steady flights it was unnecessary for the pilot to stay on his seat till the completion of flight. It was also found necessary to relieve the pilot to attend to other duties such as navigation. To meet this requirement an hydraulic-cum-air pressure devise was produced. This devise became a standard equipment till early 1939 when the world war II broke out. During operational sorties it was found undesirable to have high pressure oil pipe lines running right through the fuselage and wings. Experiments were therefore carried out and a new type of auto control was produced. This new auto control had the gyro units operated by air suction of 4½ inches of mercury and suffered from the same defect as other air driven instruments such as the artificial Horizon. Moreover, the control was not suitable for very heavy aricraft. Further investigations were carried out and in early 1943 an electrically operated auto control was manufactured in America by the Mennipo.es—Honnival Company. This equipment was tried and it was found successful in service. The main reasons for its success can be enumerated as follows:—

(a) Easy to maintain.

(b) Parts and cables damaged by enemy action easily replaceable as complete item or a complete harness of electrical cables.

(c) No hydraulic or pneumatic leaks.

(d) Total weights less than other types of auto-controls.

Similarly Navigational equipment as well as instruments for bombing and gunnery operations were similarly developed from their simple form into complicate and more efficient instruments. In the early type of instruments a lot of mental calculation work was left for the crews handling the equipment. This resulted in a greater wastage due to errors and variation in human judgment. Efforts were therefore made to reduce this error to a bare minimum.

The Future.

The experiments undertaken before and during the world war II were performed under heavy strain and in many cases equipment produced was not tried under continuous operation of long duration. There was a general shortage of materials and time was short. Therefore much work remains for testing the equipment produced under war time conditions. Furthermore, many new ideas were put into practice without trials and standardisation. Some instruments working on Electrical bridge system, selsyn system, desynn system, telegon system etc., were produced by certain manufacturers when the others were concentrating on mechanical remote reading instruments operated by various fluids and based on various principles. In addition to this it is necessary to concentrate on electrically driven instruments as electrically operated systems are more promising than any other systems. The various points in its favour are (a) reliability (b) lesser weight with greater efficiency (c) easy maintenance (d) Less vulnerable to enemy action (e) ease of operation (f) easy manufacture and installation.