Standardization of VOR Receiver-Recorder System Response

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STANDARDIZATION OF VOR RECEIVER-RECORDER SYSTEM RESPONSE*

SUMMARY

This report presents the results of tests conducted at the Technical Development Center of the Civil Aeronautics Administration to develop a method for standardizing the VOR receiver-recorder system of flight inspection aircraft in order to provide uniform inspection data

It is concluded that with the use of tantalytic capacitors and a standardized method of adjusting the damping factor of the aircraft equipments, a satisfactory uniformity of flight inspection recordings can be obtained

INTRODUCTION

A major problem in the flight inspection of VOR and TVOR facilities on the Federal Airways is the nonuniform data obtained in different aircraft and with different aircraft equipments with respect to amplitude of course scalloping Scalloping of the course usually is due to the effect of wave reflections from trees, buildings, wires, the earth's surface, and so forth, and appears as low frequency fluctuations on the course deviation indicator (CDI). Most CDI instruments are designed with internal damping for the purpose of reducing the CDI fluctuations, and nearly all aircraft installations have a "wiggle filter" connected across the CDI to reduce the fluctuations further

In CAA flight inspection aircraft, it is necessary that the amplitude and frequency of the voltage fluctuations at the output of the receiver, which are fed to the CDI, be recorded for evaluation and record purposes This usually is accomplished by connecting the input of a microsen d-c amplifier across the CDI terminals and feeding the output to a 2 5-0-2 5 milliampere (ma) d-c Esterline-Angus (EA) recorder This has proven to be a very satisfactory method of recording the information desired, except that the damping factor of nearly every installation is different Tests have shown the amplitude of the recorded course scalloping may vary as much as 6 1 or more, depending on the scalloping frequency and the damping characteristics of the aircraft installation used in making the recordings

The main factors that control the damping of the recorded signal are the source impedance feeding the CDI unit, the capacity of the wiggle filter, and the damping characteristic of the recorder It is known that the CDI source impedance in navigation receivers may vary over 2·1, and in one type of receiver, reactors are used to provide additional impedance as the scalloping frequency increases The wiggle filters are capacitors, usually of the aluminum electrolytic type of the order of 1,250 microfarad (mfd), and these vary in capacity from their specified rating as much as 3·1 Also, the capacity decreases greatly with decrease in temperature Although the EA recorder is a rugged instrument, the damping of the pen depends upon the position of an adjustable counterweight

At the request of the Office of Federal Airways, an investigation was conducted to develop a method of standardizing the VOR receiver-recorder system response of flight inspection aircraft This report describes such a procedure

RECEIVER-RECORDER CHARACTERISTICS

Measurement of System Damping

It was necessary first to devise a method for measuring damping of the receiver-recording system This was accomplished by simulating course scalloping voltages in a VOR receiver, the frequency of which could be controlled and then plotting the frequency versus recorder deflection to produce a receiver-recorder system damping curve

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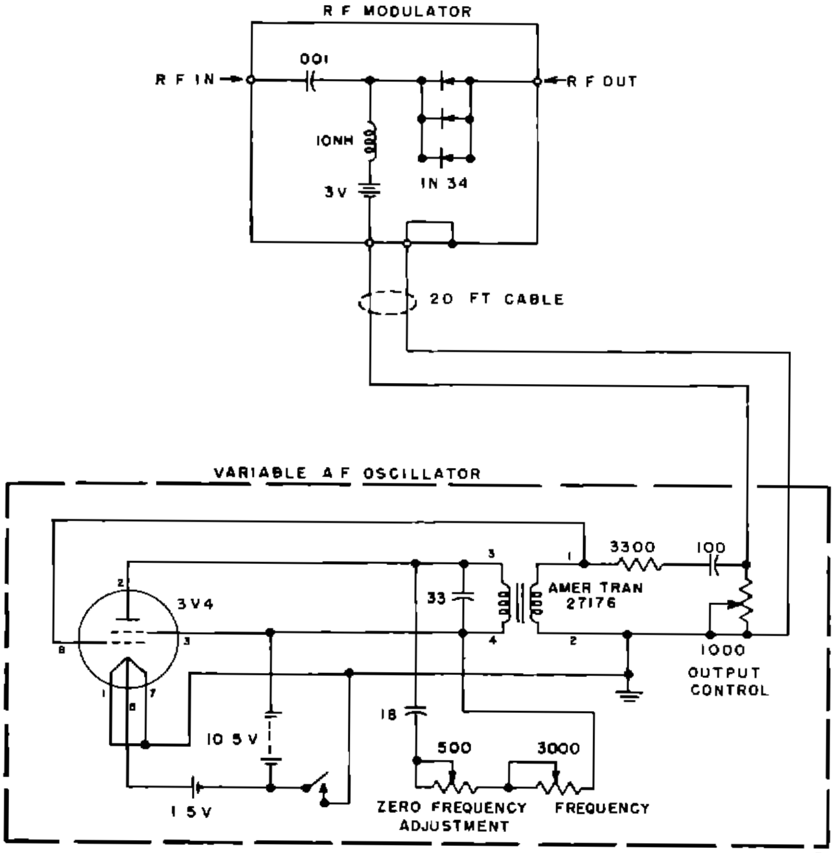

Fig 1 Variable Frequency Oscillator and Modulator Unit

The fluctuation of the CDI was simulated by the use of a transmission line modulator and a variable audio oscillator The transmission line modulator uses three paralleled crystal diodes, a self-contained bias source, and terminals for applying a modulating voltage, as shown in Fig 1 The resistance of the crystal diodes is a function of the voltage across them and this resistance is varied by the output voltage of the variable frequency oscillator When the modulator is inserted in the transmission line between the receiver and a VOR signal generator, the unit produces amplitude modulation by variation of its series impedance A block diagram of the equipment employed to measure the damping characteristics of a receiver-recorder system is shown in Fig 2 The procedure was as follows

With the audio oscillator turned off and the VOR receiver tuned to the test generator frequency, the sensitivity of the microsen d-c amplifier was adjusted to provide a recorder deflection of plus or minus 20 divisions on the recorder chart for a plus or minus 10° change of the OBS unit from the on-course bearing Then with the variable audio oscillator turned on and the calibrated frequency dial set to zero, the zero-frequency control was adjusted to provide a beat frequency with the VOR 30-cps signal, not exceeding 0 02 cps The output control of the oscillator then was adjusted to provide a deflection on the recorder paper of plus or minus 20 divisions for the beat signal, which is nearly zero cps The response of the receiver-recorder system then was obtained from the recorded deflections for frequencies of 0 25, 0 5, 1 0, 1 5, 2 0, 2 5, and 3 0 cps

The receiver-recorder damping curves for the installations in TDC aircraft are shown in Fig 3 The recorded response for these aircraft installations varied as much as 1 65 1 at 0 25 cps, 3 4 1 at 1 0 cps, and 18 1 at 2 0 cps The capacitors used as wiggle filters were of the aluminum electrolytic type purchased under USAF specifications, which allow a tolerance of 750 to 1,750 mfd for a capacitor marked 1,250 mfd These wiggle filters had been in use approximately six years, during which no failures or obvious changes in capacity were reported The wiggle filter capacitor values were measured as listed in Table I

TABLE I

MEASURED VALUES OF WIGGLE FILTER CAPACITORS*

Aircraft	Recorder Position	Measured Capacitance in Microfarads
N-181	1	1770
N-181	2	1800
N-181	3	1830
N-182	1	1510
N-182	2	1400
N-182	3	1820
N-183	1	2820
N-183	2	2680

*All wiggle filters labeled 1,250 mfd.

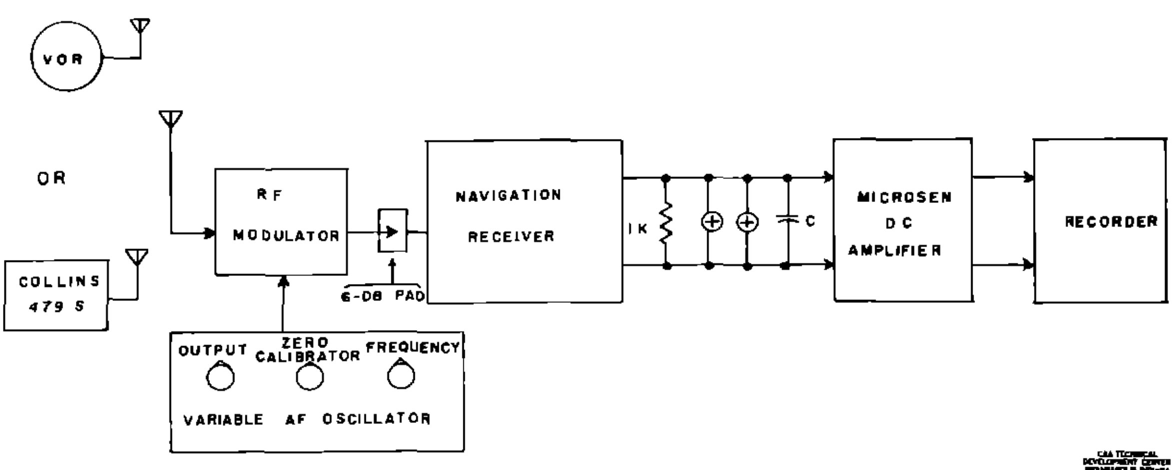

Fig. 2 Block Diagram of Equipment Employed to Measure Damping Characteristics of Receiver-Recorder System

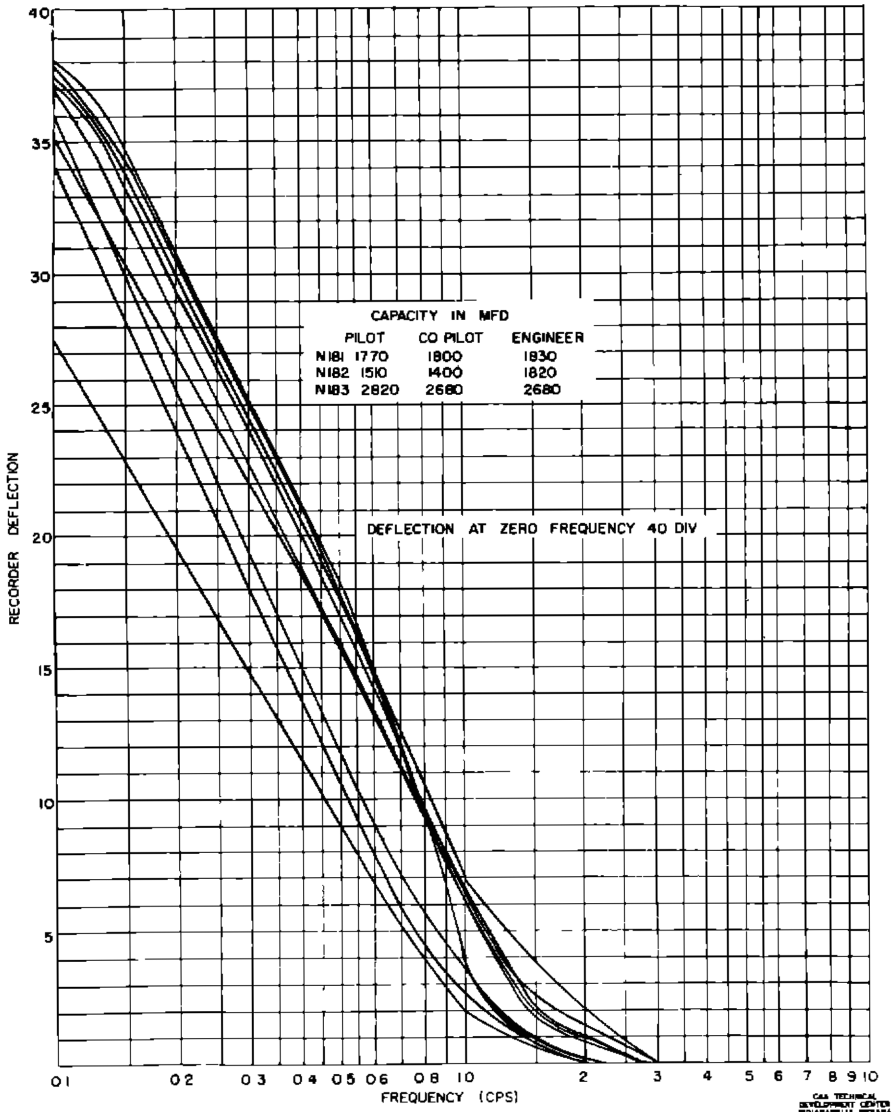

Fig 3 Receiver-Recorder System Response for TDC Aircraft Prior to Standardization

Wiggle Filter Capacitors

The results of the preliminary measurements indicated that the wiggle filter capacitor was a major component of the system requiring investigation Of several different methods, the impedance method of measuring capacity was adopted for these tests Figure 4 is a schematic of the test circuit The unknown capacitor and a decade resistance box were connected in series across a 1-volt a-c power source, and a vacuum tube voltmeter was used to measure the voltage drop across the capacitor and the resistor. The decade resistor then was adjusted until the voltage drop across the capacitor and the resistor were equal The value of capacity in mfd was determined from the equation

$$C = \frac{1{,}000{,}000}{2\pi f R} \qquad (1)$$

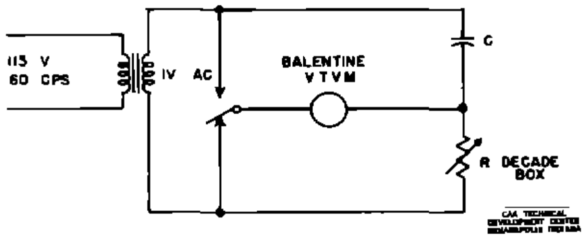

Fig 4 Capacity Test Circuit

where

C = capacitance in mfd

f = frequency in cps

R = resistance in ohms.

Large capacitors were checked by comparing the capacity values measured at 60 cps and at 2 cps Identical values of capacity were obtained at both frequencies. Also, capacitors of about 200 mfd were measured by the impedance method[1] and by means of a capacity analyzer. Both methods gave results which were in very close agreement.

Since the time of installation of wiggle filters in TDC aircraft, there has been considerable development of tantalytic capacitors for certain direct-current, low-voltage applications, where aluminum electrolytic and paper capacitors have not proven entirely satisfactory. Tantalytic capacitors offer greater capacitance per unit volume and their minimum shelf life is many times longer than similar aluminum units. Other features of tantalytic capacitors are their long operating life due to an inherently more stable oxide film, the inert characteristics of the metal tantalum, and the use of a noncorrosive electrolyte which insures protection of adjacent equipment in case of leakage In addition, the tantalytic capacitor has vastly improved characteristics at low temperatures.

Samples of tantalytic and aluminum capacitors of 750 and 1,000 mfd were obtained Two capacitors of each type were subjected to temperature tests. Figure 5 shows their capacity variation with temperature The tantalytic capacitors are much more stable than the aluminum electrolytic type. The capacity of the aluminum condensers was practically zero at minus 40° C., whereas the tantalytic condensers retained approximately 85 per cent of the capacity (measured at plus 20° C.) at the same temperature.

Recorder Characteristics

A series of tests was conducted to determine the capabilities and limitations of the EA graphic recorder, which is used in Federal Airways flight inspection aircraft. Coincident with these tests, a Texas Instrument Company recorder was received with a request from the Office of Federal Airways to evaluate this recorder and determine its suitability for use in flight inspection.

The Texas Instrument (TI) recorder consists of a dual recording milliameter, providing two 2.5-0-2.5 ma movements, each having a nominal input resistance of 365 ohms Independently circuited, these movements are capable of recording simultaneously on a single, continuously moving paper chart The TI recorder is approximately the same size as an Esterline-Angus recorder and the same chart paper can be used with both recorders The heart of the TI recorder is a magnetic-fluid clutch meter movement. Within each meter movement are two magnetic fluid clutches. The output shafts of the individual clutches are held by calibrated springs as the clutch bodies are rotated at constant speed by a 28-volt d-c motor. On the lower end of each output shaft a torque cup extends into a magnetic fluid. A change in drag on the torque cup results when magnetic lines of force from the signal coils

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[1]The impedance method is described and recommended in a P. R. Mallory Co. capacitor manual.

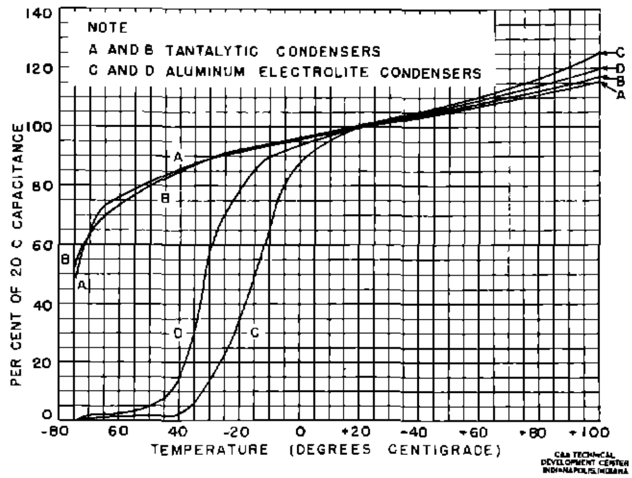

Fig. 5 Capacity Variation with Change of Temperature

change the fluid viscosity. With the rotation and polarity of the two clutches in opposition, the total mechanical effect produced by each meter movement is comparable to an electronic push-pull amplifier.

The frequency response and linearity of the EA and TI recorders were measured when operated from the output of a microsen d-c amplifier. Figure 6 is the test circuit used to obtain the response data shown in Figs. 7 and 8. In these tests, data were obtained on recorder pen deflection versus frequency, with and without a 1,250-mfd wiggle filter. Also included in Figs. 7 and 8 are graphs of the recorder input level (microsen d-c amplifier output voltage). This voltage was measured with a cathode-ray oscilloscope From these figures, it is seen that the input impedance of the EA recorder varies considerably with frequency Figure 7 also shows that if the EA recorder pen is held so that it cannot move, the microsen output voltage is essentially constant. Figures 9 and 10 show the response and linearity characteristics of the EA and TI recorders, respectively It will be noted that the EA recorder has a nonlinear response. An example of the problem created by recorder nonlinearity is presented as follows

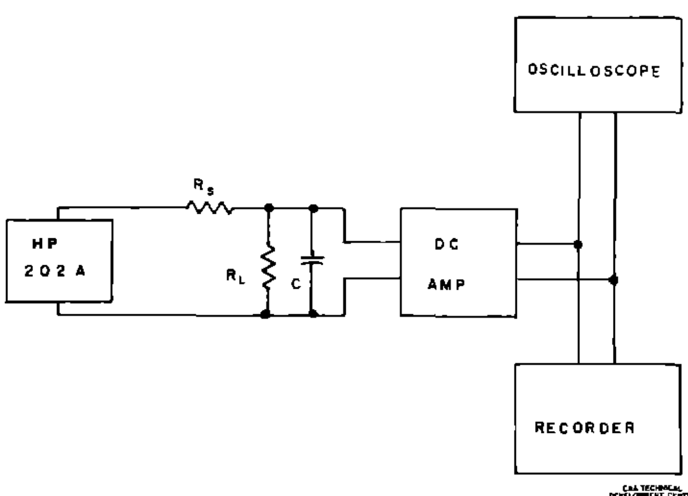

Fig. 6 Test Circuit for Determining Frequency Response and Linearity of Recorders

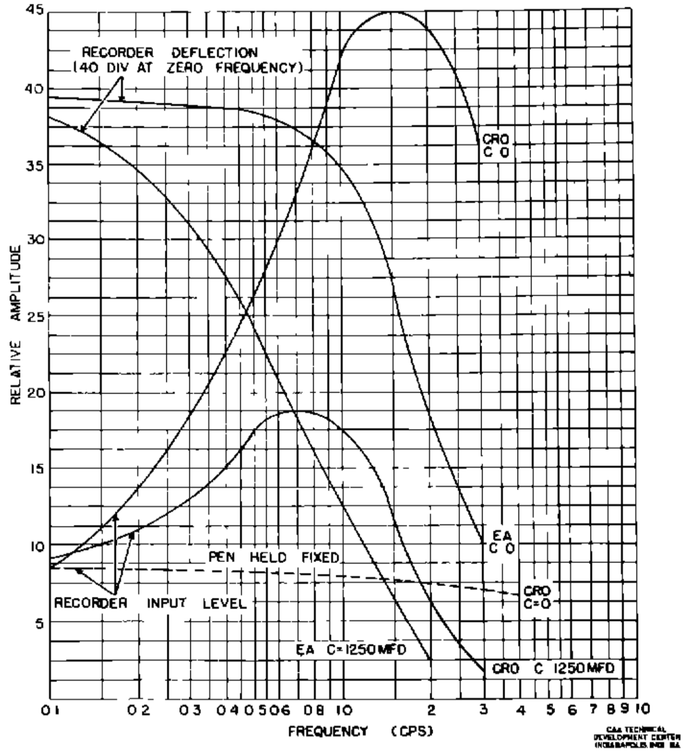

Fig 7 Esterline-Angus Recorder Input Level and Deflection Versus Frequency and Capacity

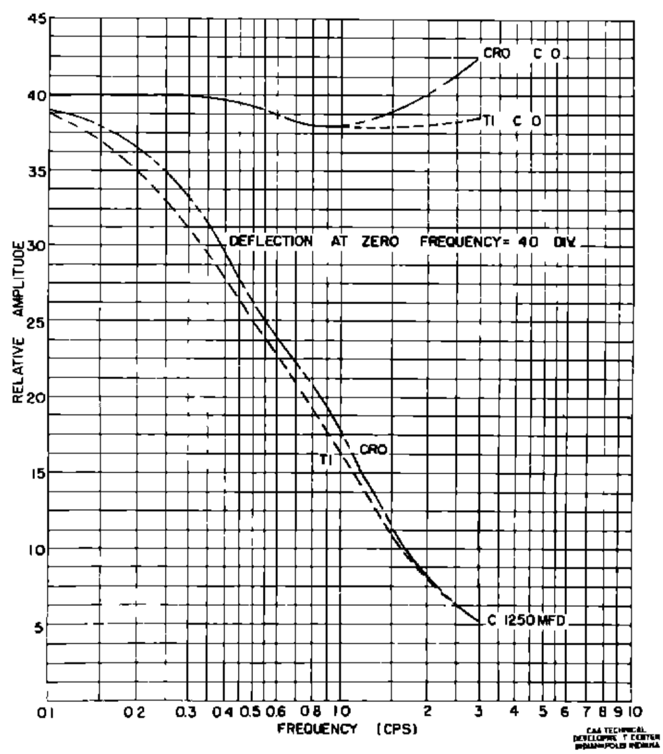

Fig. 8 Texas Instrument Recorder Input Level and Deflection Versus Frequency and Capacity

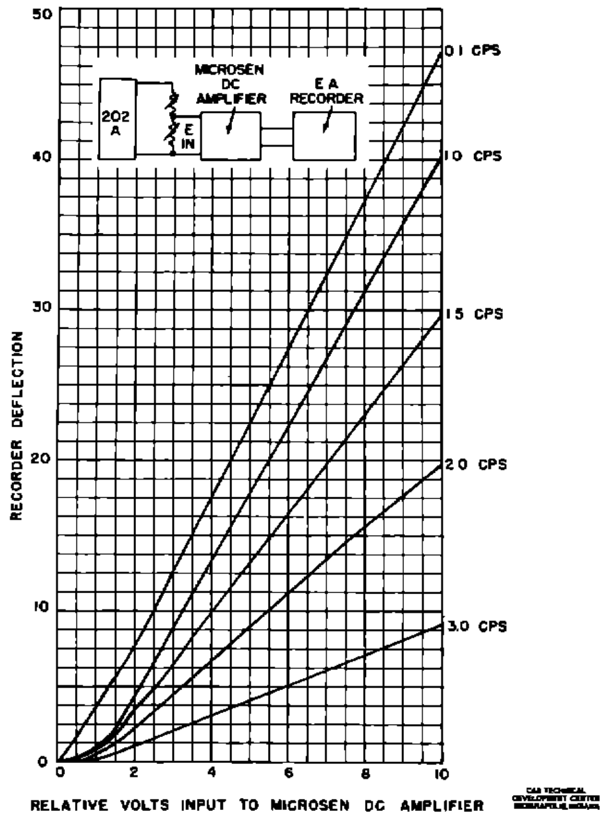

Fig. 9 Volts in Versus Deflection for Various Frequencies of Microsen D-C Amplifier and EA Recorder

A flight inspection aircraft assigned to flight-check a given VOR radial encountered two sectors of uniform rhythmic course scalloping. The scalloping frequency in both of the sectors was 1.5 cps, however, the VOR CDI output voltage in the first area was 4 units, whereas the output voltage in the second area was 8 units. At the conclusion of the flight, the recorded scalloping was converted to degrees of course displacement in the two sectors. Assuming a recorder sensitivity of plus or minus 10° equal to 40 small chart divisions, by reference to Fig. 9 it is evident that the first sector of scalloping (4 units of voltage) produced a recorder deflection of 10 divisions, equivalent to plus or minus 2.5° of course scalloping. However, due to recorder nonlinearity, the second sector of scalloping (8 units of voltage) produced a recorder deflection of 23 divisions, equivalent to plus or minus 5.75° of course scalloping. The nonlinearity of the EA recorder in this example results in the 115 per cent increase in recorded scalloping, when the scalloping voltage is doubled. The same data recorded on the TI recorder would produce a 103 per cent increase in recorded scalloping. Figure 11 shows the variation in response for different levels of scalloping signal when using the EA recorder

Measurements of the damping characteristics of several identical EA recorders tested did not produce the same results. The difference in results was due to differences in pen pressure on the chart. The effect of pen element balance on recorder response then was investigated.

The EA recorder pen element is approximately 6 inches long with a glass penpoint on one end and a pair of adjustable balance weights on the other end. The pen element is supported by knife edges seated in the slots of a meter movement fork. The pen element is supported below its center of gravity, therefore, the pen does not operate in the balanced state In order that the penpoint can write on the chart, the balance weights must be adjusted properly.

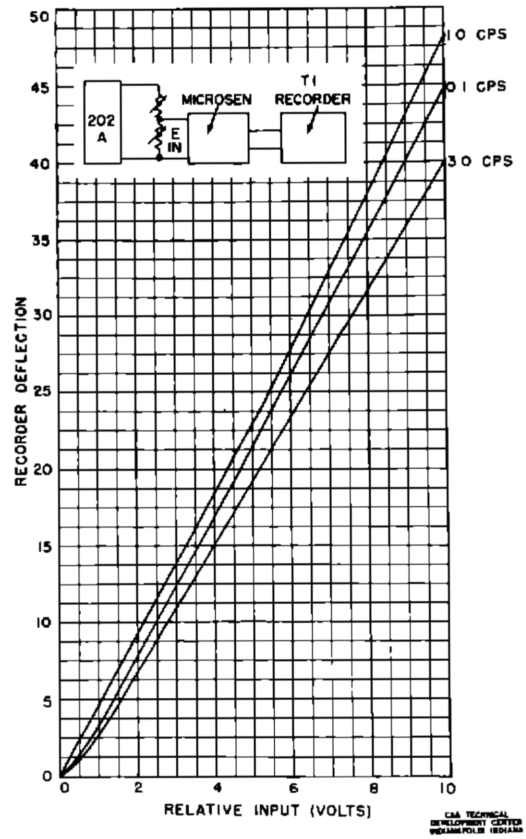

Fig. 10 Volts in Versus Deflection For Various Frequencies of Microsen D-C Amplifier and TI Recorder

The need for standardization of penpoint pressure on the recorder chart is clear, by reference to the damping curves, Fig. 12, which were plotted with the balance weights adjusted to provide minimum and maximum penpoint pressures. Another test, the results of which also are shown in Fig. 12, showed that the recorder response at 1 cps with the pen weight at maximum and using a 1,340-mfd wiggle filter was the same as when the pen weight was adjusted at minimum, but using a 1,973-mfd wiggle filter. At 1 cps, the adjustment of the pen weight balance had an equivalent effect of an additional 633 mfd. The shape of the response curve as a whole, however, shows that a change in wiggle filter capacity alone will not compensate for the difference in pen weights. It became necessary, therefore, to devise a method of measuring penpoint pressure.

A laboratory working model of the pen pressure measuring device developed at TDC is shown in Fig 13 This measuring device consists of a piece of 0 003-inch spring steel 7 inches by 3/32-inch anchored at one end to a rotatable vernier-driven shaft mounted at the edge of the recorder case The unit is operated by placing the recorder penpoint at one end of the steel spring and applying a torsional force on the vernier end until the pen is raised off the recorder paper The penpoint pressure then is read from a graduated scale on the vernier drive unit. The vernier drive scale was calibrated against a laboratory balance. Figure 14 shows the response curves of six different recorder pens, each of which had been adjusted to provide 0 09-gram of penpoint pressure

It was desired to determine if it would be possible to obtain equal penpoint pressures on all EA pens by adopting a standard method of setting the balance weights to a predetermined position The two balance weights are screwed on the threaded end of the pen element First, the balance weights were screwed to the limit of travel toward the knife edge support, and the penpoint pressure was measured. The balance weights then were moved five complete turns in the direction away from the knife edge, and again the penpoint pressure was measured. This procedure was repeated for each five turns of the balance weights until the penpoint

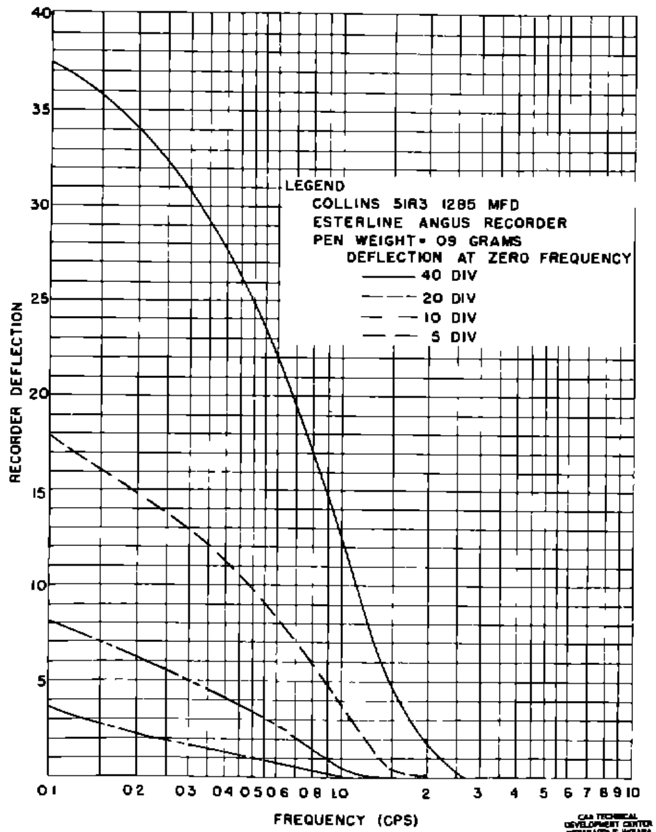

Fig. 11 Variation in Response for Different Levels of Signal

pressure was reduced to zero A plot of the pen weight versus the number of turns of the balance weights is shown in Fig 15 for two pens. These two curves represent the extremes of 15 pens tested They showed that the method described is not satisfactory for obtaining standard pen pressures, and that a pressure measuring device must be employed

It also was necessary to select a standard penpoint pressure As previously shown, the lower the pen pressure, the better the response characteristics of the recorder. However, in airborne usage, rough air conditions result in the bouncing action of a lightly weighted pen. Tests were conducted with various penpoint pressures while the recorder was subjected to simulated rough air vibration. It was determined from these tests that a pressure of 0.09-gram on the recording paper when inking is satisfactory

It was desired to determine the zero stability of the recorders with zero input The pens of both recorders were adjusted carefully to zero, and the chart drive mechanisms were allowed to operate for three hours with no input to the meter movement As shown in Fig. 16, the TI recorder zero-signal stability is not satisfactory for use in flight inspection. In actual usage, this instability could be interpreted as plus or minus 1.25° of VOR course error.

CDI Damping.

Tests were conducted to determine the relationship between the damping characteristics of the course deviation indicators (ID-48 and ID-249) and the recorders Figure 17 shows the response curves of two CDI instruments and two recorders It is evident that considerable difference exists between the amplitude of a given wiggle as observed by the pilot on a CDI instrument, and that recorded on the chart.

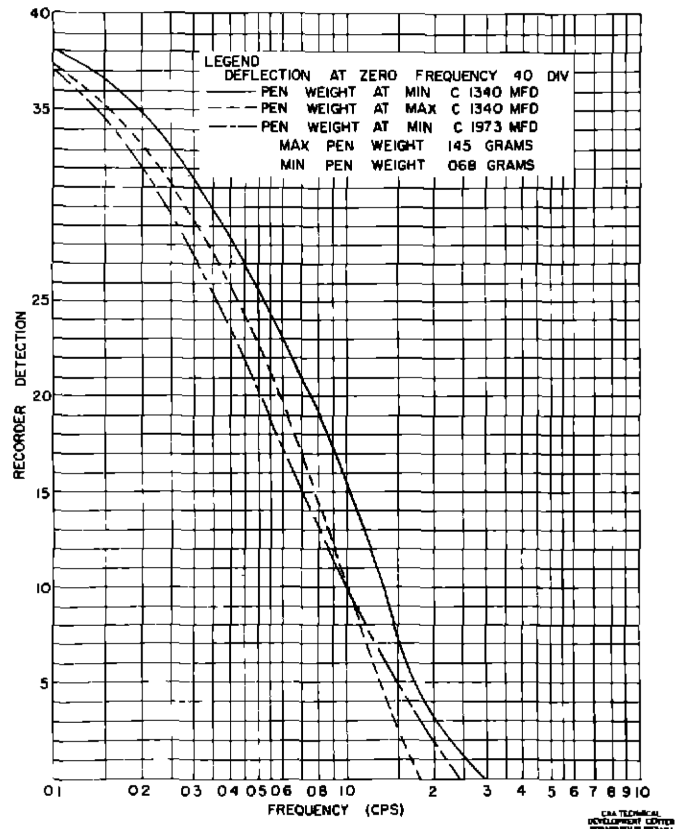

Fig 12 Esterline-Angus Recorder Response Versus Pen Weight and Capacity

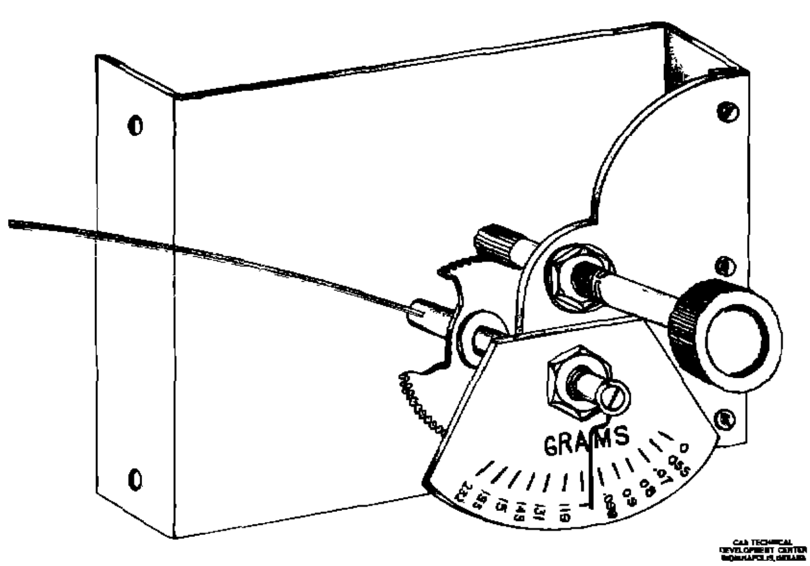

Fig. 13 Pen Pressure Gauge

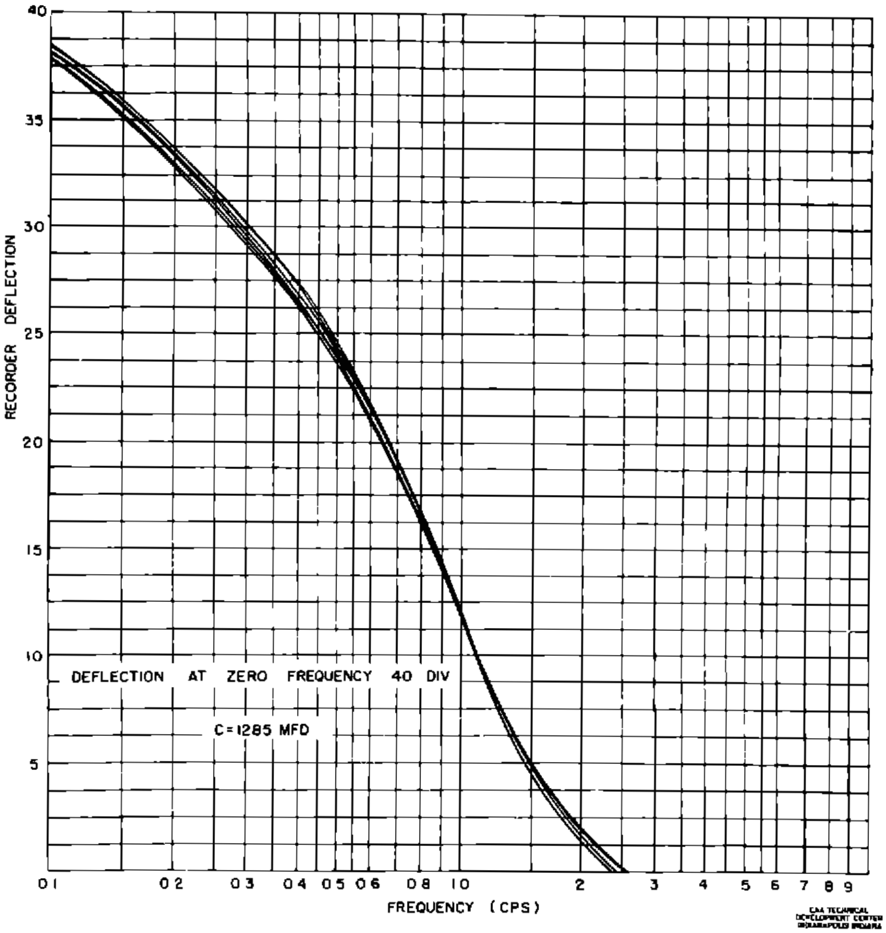

Fig 14 Esterline-Angus Recorder Response for Six Different Pens Having Same Pen Weight of 0 09-Gram

The significance of Fig. 17 can be explained best by an example. An EA recorder, adjusted for a course sensitivity of plus or minus 10° equal to 40 chart divisions, records a 1-cps course wiggle 12.5 chart divisions The amplitude of the course displacement due to this wiggle is computed to be plus or minus 3 12°. Now if the amplitude of this same wiggle is computed by using the CDI (ID-48), an entirely different result is obtained. If the CDI scale is graduated in 40 divisions and adjusted to the same sensitivity as the recorder, the same 1-cps wiggle with amplitude unchanged would deflect the CDI plus or minus 2.37 divisions. This deflection represents plus or minus 1 80° course displacement to the pilot, in contrast to the plus or minus 3 12° measured on the recording By examination of the CDI and recorder response curves, shown in Fig 17, it can be seen that for wiggles of varying frequency, there is no "factor" that can be applied to convert recorded data to CDI data It also can be seen that the amplitudes of wiggles as computed by the flight test engineer from recorded data always will be in excess of those observed by the pilot on the CDI.

RC Filter Frequency Response.

Rapid VOR course deviations are highly damped by a simple resistance-capacitance (RC) filter, whose frequency response is affected by the source impedance, the filter capacitor, and the load impedance. While the load impedance is standardized at 33 ohms (3 instrument load), and the capacitor is standardized at 1,250 mfd, the source impedance remains variable These variations are caused by the variable resistors used to adjust the CDI sensitivity in both the Collins and Bendix VOR receivers.

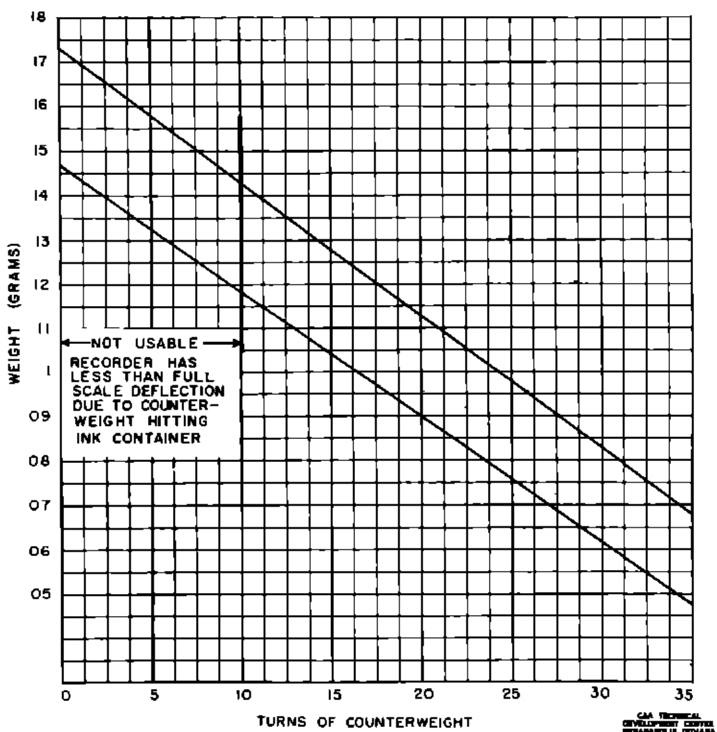

Fig. 15 Pen Weights Versus Turns of Counterbalance Weights

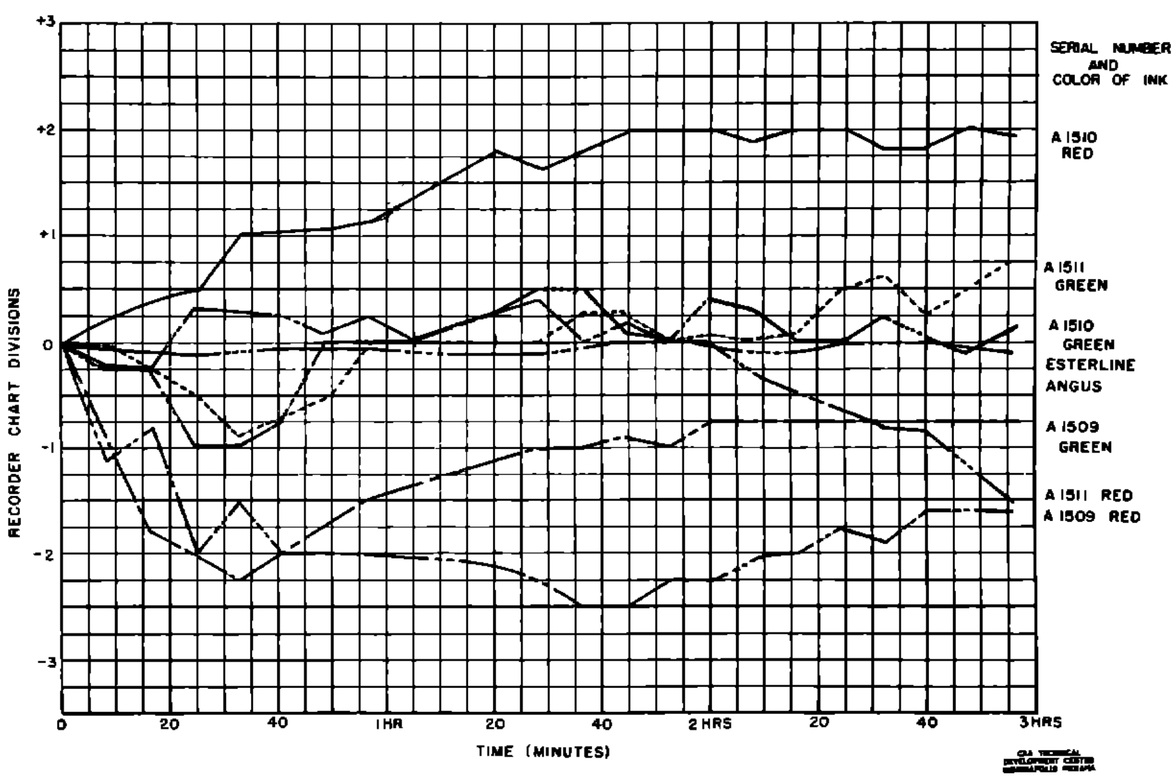

Fig. 16 Variations in Zero Setting of Three TI and One EA Recorder Versus Time

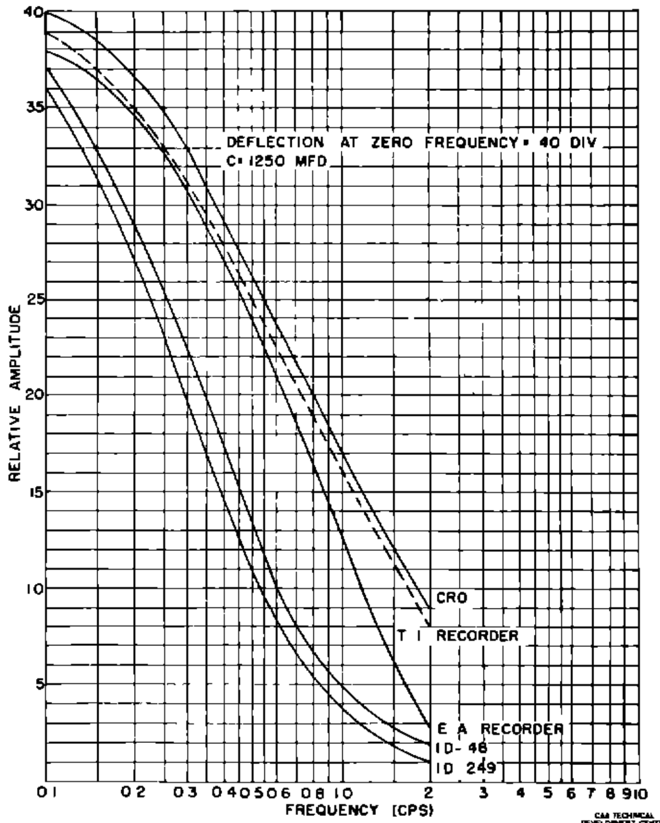

Fig. 17 Deflection Amplitude Versus Frequency of Recorders, CDI's and CRO

Calculated and measured frequency response curves of RC filters for various capacitors and source impedances are shown in Fig. 18. The test circuit is shown in Fig. 19. The signal generator used was a Hewlett Packard Type 202A with the output level held constant during the testing period. Filter output was measured with a DuMont 304H oscilloscope, which was operated with the Y amplifier switches in the d-c position

Damping curves of Collins and Bendix VOR receivers were plotted with the course sensitivity controls set at minimum and maximum resistance These curves are shown in Figs. 20 and 21. It can be seen that the change in damping between minimum and maximum settings of the course sensitivity controls is not large enough to be of major importance in the solution of the receiver-recorder standardization problem.

MISCELLANEOUS OBSERVATIONS

1. The zero-signal instability of the TI recorder rules out its use for flight inspection. However, this recorder possesses a number of excellent features that should be noted and, if possible, incorporated in any future recorder to be considered for VOR flight test work.

   a Chart speeds are changed by turning a chart speed selector knob. The true value of a gearshift-type chart speed-changing system will be appreciated by flight test personnel who have had to spend much time on their hands and knees searching for gears dropped during a rough air gear-change operation.

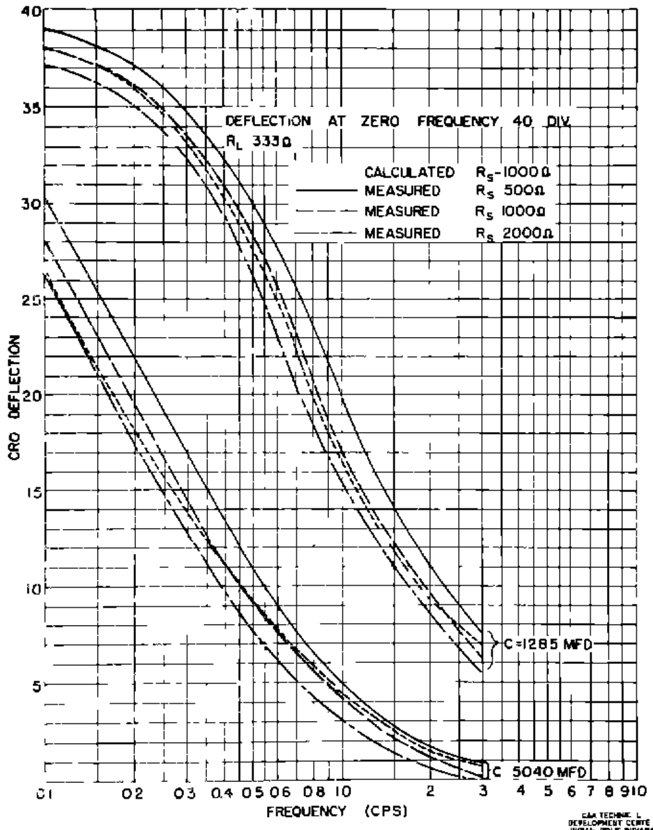

Fig. 18 Filter Response for Variation in C and Source Impedance R_S

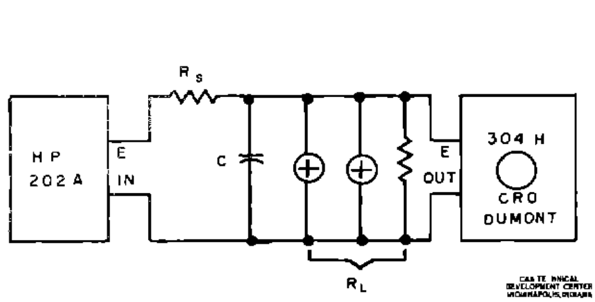

Fig. 19 Filter Response Test Circuit

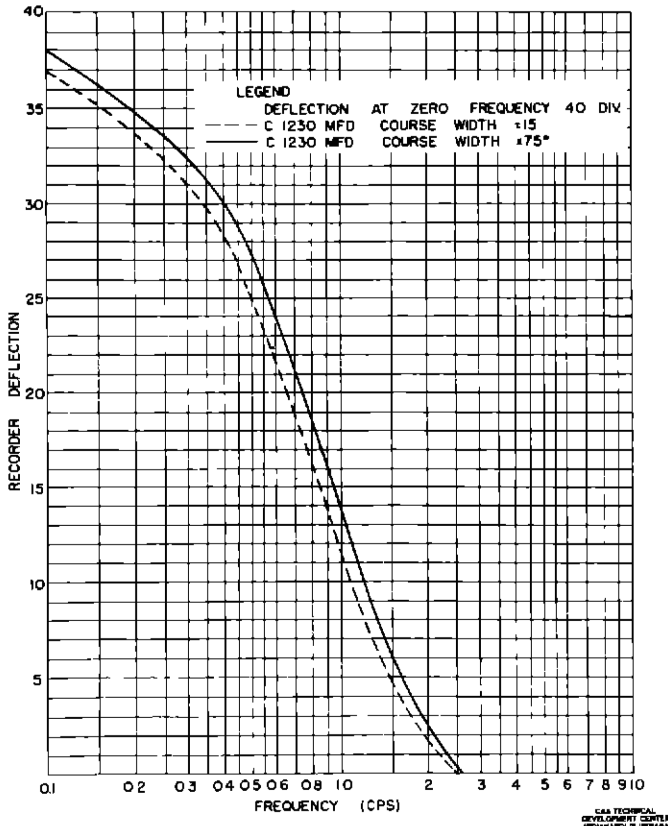

Fig. 20 Variation in Response for Different Course Sensitivity Adjustment of Collins 51R3 Receiver

b. The ink reservoirs of the TI recorder are so designed that evaporation is practically eliminated. The ink trace of a TI recorder dries as rapidly with fresh ink as with ink which has been in the reservoir six months. This is in contrast to the EA open reservoir where most of the volatile liquid in the ink evaporates in a week, after which the trace drys very slowly

c. The dual-pen, single-chart system provides a dual information presentation which is more effective than the use of dual charts.

d. In view of the many excellent features of the TI recorder, an inquiry was made to the manufacturer regarding the possible improvement of the zero-signal stability. The manufacturer stated that ". . . this drift is a characteristic of the temperature curve for the magnetic fluid clutch and cannot be completely eliminated. This is the basic characteristic which limits the over-all accuracy of plus or minus 5 per cent."

2. The effects of a full or partially full inkwell, using either fresh ink or ink that had been exposed to evaporation for a month, were negligible on the response of an EA recorder.

3. The Bendix VOR receiver incorporates an inductive-type filter in the CDI output circuit. It was found that the filter has practically no effect below a frequency of 1 cps, but that it does improve the efficiency of the wattmeter circuit In one test, this filter was shorted and the course sensitivities before and after the short circuit were compared. The course sensitivity was much greater with the filter in the circuit. An installation using a Bendix receiver will require a different response curve than an installation using a Collins receiver.

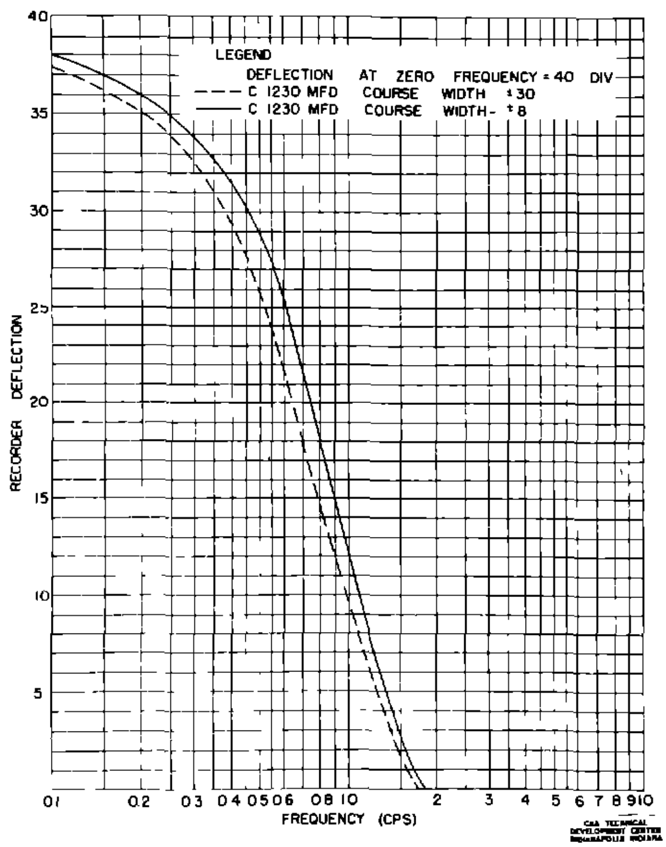

Fig 21 Variation in Response for Different Course Sensitivity Adjustment of Bendix MN85BA Receiver

4 The damping curves of all receiver-recorder installations in TDC aircraft were plotted Each EA recorder pen was adjusted to 0.09 plus or minus 0.01-gram pressure, and wiggle filter condensers were adjusted to identical values of capacity. All damping curves were in close agreement with one exception, this particular receiver-recorder damping curve was entirely different from all the others. On closer examination, it was discovered that the three-meter load in this installation consisted of two course deviation indicators and the 1,000-ohm input impedance of a Bendix autopilot, which was highly inductive. The input impedance was 800 ohms (d-c), but increased rapidly with frequency until the effective load impedance more than doubled The standardization of receiver-recorder response will require special attention in such cases, and will require either the substitution of a 1,000-ohm resistor in lieu of this type of autopilot circuit, or the use of a different response curve.

5. The critical damping of the EA recorder was investigated, and it was found that within the limits of the d-c amplifier, improvement in response curve could not be obtained by the addition of series or parallel resistances to the recorder.

6. It was observed that, when recording an on-course signal, the EA recorder pen would deflect from the zero centerline of the recording paper one to two divisions when the recorder was tilted 30° either to the left or right The deflection was less than 0.1 division when the recorder was tilted 30° either forward or backward. When recording a 1-cps signal, it was observed that the amplitude of deflection would decrease as much as 50 per cent when the recorder was tilted 30° in any direction This characteristic of the EA recorder must be taken into account when analyzing recordings One flight test in particular, which is affected by this characteristic, is the plus or minus 30° wing rock polarization test. This test should be performed twice, once with no signal, and a second time with VOR signal. The difference between the two tests will represent a more realistic value of polarization error.

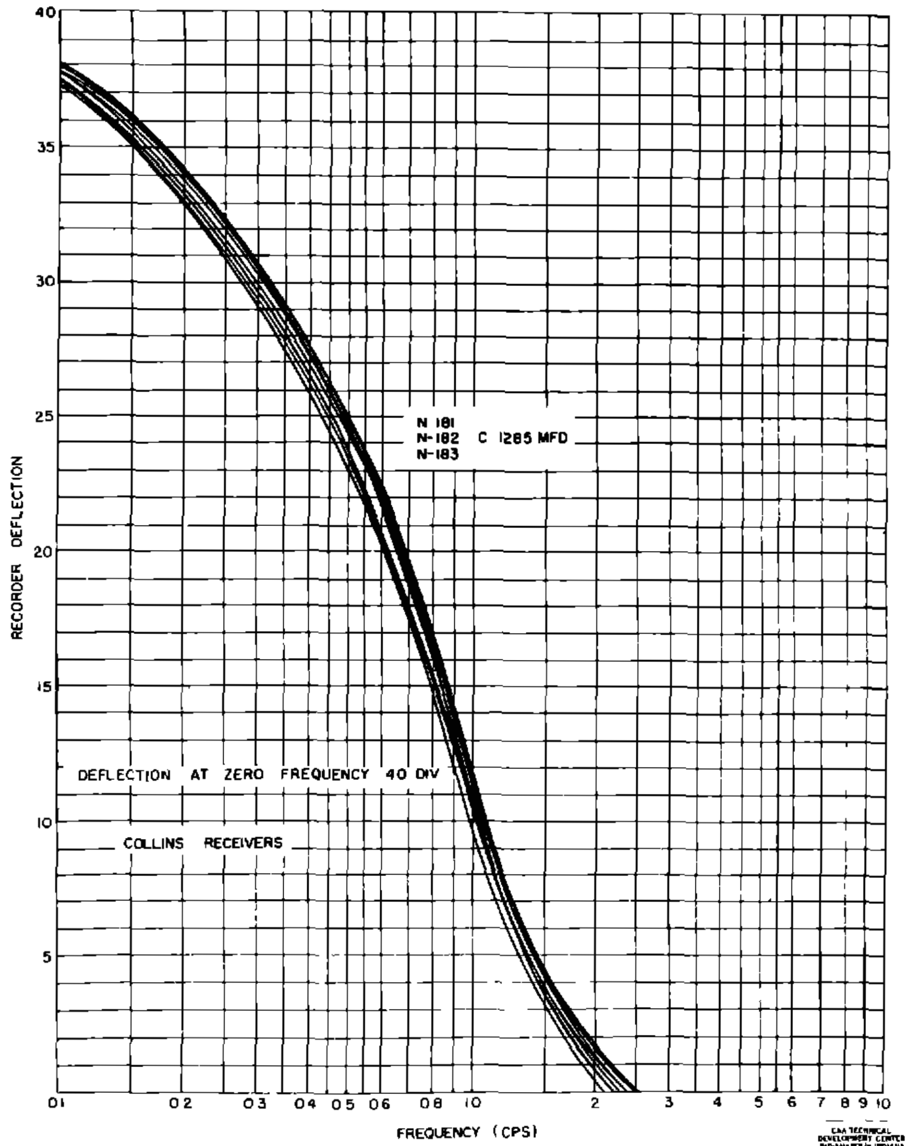

Fig 22 Receiver-Recorder System Response for TDC Aircraft with Fixed Capacitor after Standardization

7 Although no tests were conducted to determine glide path receiver-recorder damping characteristics, it is believed that the use of low-tolerance 1,250-mfd tantalytic filter capacitors in the CDI circuit will provide acceptable standardization for glide path recordings

8 In view of the wide experience already obtained in flight testing VOR's with various aircraft installations having filter condensers which vary between 1,400 and 2,800 mfd it is recommended that a value of 2,500 mfd be selected for VOR operation and 1,250 mfd for ILS operation

STANDARDIZATION PROCEDURE

Standardization of receiver-recorder system response may be accomplished satisfactorily by adoption of the following procedure

1 For VOR operation, the wiggle filter should consist of two 1,250-mfd tantalytic capacitors connected in parallel Only one 1,250-mfd condenser should be used for ILS operation The capacity tolerance should be held to 1,250 mfd plus or minus 50 mfd

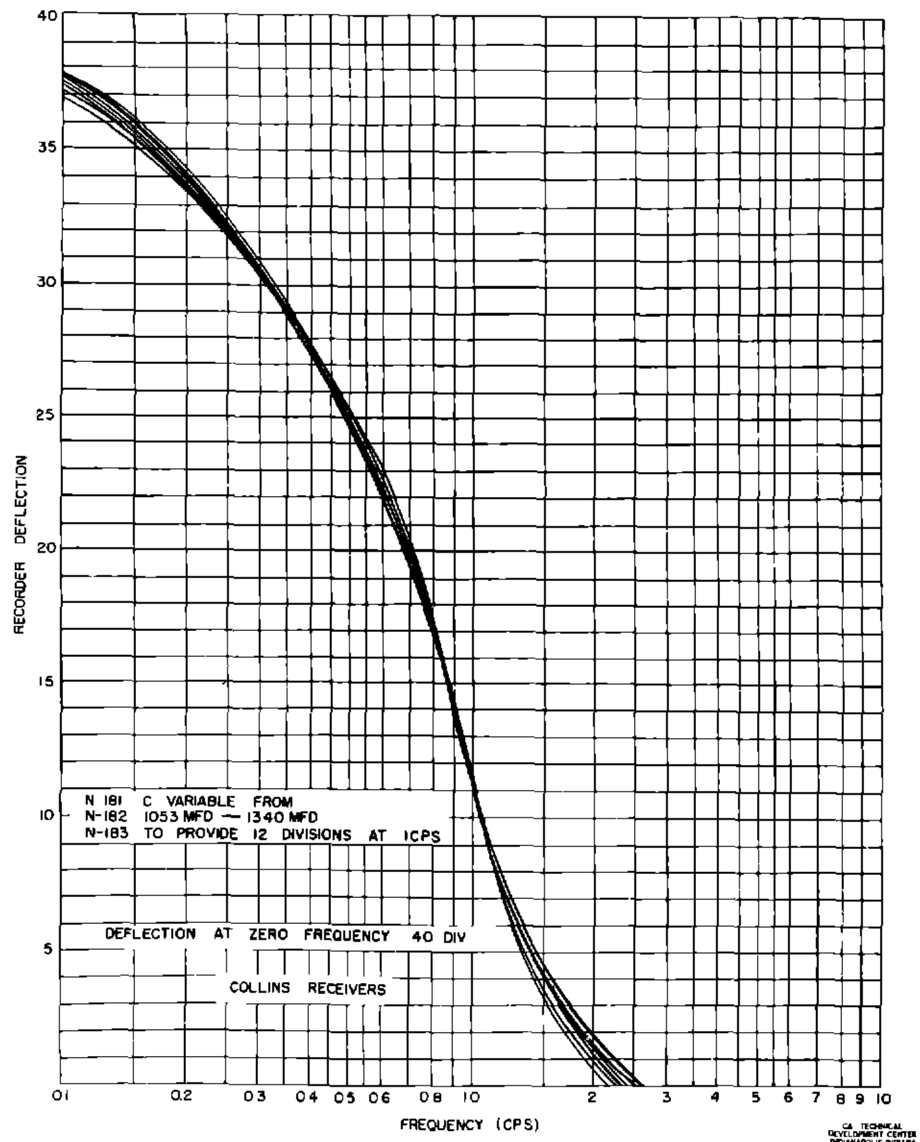

Fig. 23 Receiver-Recorder System Response for TDC Aircraft with Variable Capacitor after Standardization

2 The EA recorder pen balance weights should be adjusted to provide a penpoint pressure of 0.09 plus or minus 0.005-gram when inking. This will require the use of a penpoint pressure gauge similar to the type described in this report.

3. The receiver-recorder system should be calibrated with a VOR signal and transmission line modulator using the procedure described in detail in this report. From these calibration data, a damping curve may be drawn. The system should be recalibrated periodically, and whenever any equipment changes are made

This standardization procedure was applied to the six receiver-recorder systems in TDC aircraft. The damping curves are shown in Fig. 22. The small differences between these damping curves represent a large improvement in standardization when compared with Fig. 3, which shows the damping curves prior to standardization.

A further refinement of the standardization procedure was tested. A variable wiggle filter capacitor in the form of a decade box was used to adjust the recorder deflection to a standard value at a given frequency. Figure 23 represents the damping curves of the six

TDC receiver-recorder systems when the variable wiggle filter was adjusted to provide 12-division deflection at 1 cps. The damping curves in Fig. 23 are superior to those in Fig. 22, but the improvement is not sufficient to warrant the purchase of wiggle filter decade boxes

CONCLUSIONS

A standardization procedure has been developed that will greatly improve the uniformity of data obtained in flight inspection of ILS and VOR stations. The standardization procedure includes

1. Installation of two low-tolerance 1,250-mfd tantalytic capacitors which are connected to provide 2,500 mfd for VOR operation and 1,250 mfd for ILS operation.
2. Adjustment of the EA recorder penpoint pressure to 0.09 plus or minus 0 005-gram.
3. Calibration of the receiver-recorder system.

The testing of the various equipment components and circuits which contribute to the over-all response of the receiver-recorder system revealed among other things that the EA recorder now in use in flight inspection is not ideally suited for the purpose for which it is used. However, it is rugged and reliable, and no suitable replacement is presently available.