DEVELOPMENT OF A GROUND TO AIRCRAFT RADIOTELETYPE SYSTEM

By

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The Cooperation of the Office of the Chief Signal Officer, United States Army, in furnishing a transport type of airplane for flight tests, and of the United Air Lines Transport Corporation in making available their flight research airplane is greatly appreciated

TABLE OF CONTENTS

FIGURE INDEX

DEVELOPMENT OF A GROUND-TO-AIRCRAFT RADIOTELETYPE SYSTEM

SUMMARY

A ground-to-aircraft communication circuit which will provide a printed message to the aircraft is described A communication circuit of this type will insure greater safety by providing a printed record of weather sequence reports, emergency broadcasts, and traffic reports for the pilot The possibilities of a simultaneous voice and teletype circuit were investigated and the system found to be practicable

The aircraft and ground station equipments are described, together with the results of flight tests in a Waco type N, a Boeing 247-D, and a DC-3 type of transport airplane Perfect copy was obtained at 145 miles from the transmitter at an altitude of 6,000 feet

INTRODUCTION

Two-way radio communication between ground and airplane has become a requisite for the safe dispatching, reporting, and landing of the aircraft, together with the furnishing of complete weather information More especially is this true when the ground is obscured by fog, haze, or clouds, and flights are made "on instruments "

Several improvements have been made which have resulted in a more reliable communication circuit to and from the airplane in flight The most notable improvements are the use of the ultra-high frequencies and the use of a radio typewriter As the airplanes in scheduled air carrier service become larger, the volume of communication to the aircraft will become greater and the duties of the pilots will increase More complete information disseminated to the pilot in the form of a printed record will insure greater safety, since data will be available to him when other duties do not demand his full attention He will thus be relieved of the task of retaining pertinent facts in his mind in the proper relation, as is necessary in the present system of voice transmissions This is particularly true of the sequence weather reports At the same time, the needs of the smaller itinerent aircraft, in which the additional weight and investment preclude the use of a printing system, must not be overlooked

With these requirements in mind, the Civil Aeronautics Administration undertook the development of a communication system which would provide a printed record simultaneously with a voice circuit

The nucleus for this development was the radioteletype system described in a previous Technical Development Report [1] It was considered desirable to combine in one complete system the ground-to-aircraft circuit, the weather collecting, and traffic control systems of the Administration

AIRCRAFT EQUIPMENT

The four units, receiver, audio filter, pulse rectifier-amplifier, and print

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[1] Hromada, J C , and McKeel, P D , "The Development of an Airways Ultra-High-Frequency Communications Circuit," CAA Technical Development Report No 6, February 1938

ing machine, shown in figure 1 comprise the aircraft equipment necessary to provide a voice and printing system. It should be borne in mind that performance was a primary requisite in the development equipment and, as a result, some of the units are much heavier and larger than will be necessary in final equipment.

Receiver

The receiver used on the flight tests was an RCA type AVP-17A, fixed tuned crystal-controlled superheterodyne This receiver, a block diagram of which is shown in figure 2, is provided with a noise-reducing circuit of novel design In this circuit, noise pulses which exceed a predetermined level operate to establish a balance in an audio-frequency bridge in the grid circuit of the first audio-frequency amplifier, thus eliminating the pulse from the signal The level at which the balance is established is a function of the carrier level but in all cases is such that the detector characteristic is linear up to 100 percent modulation Some noise-eliminating circuits operate to compress the detector output when the signal peak exceeds the equivalent of about 60 percent modulation This latter type of circuit is not satisfactory for use on signals where the average modulation is maintained at 80 or 90 percent

The band width of the 4100-kilocycle intermediate-frequency amplifier is 90 kilocycles wide at 6 decibels down from resonance and 240 kilocycles wide at 60 decibels down All spurious responses are at least 40 decibels down from the response at the signal frequency

The receiver is capable of delivering 1 5 watts of audio power to a 250-ohm resistive load The noise is 6 decibels below the signal plus noise output with a carrier (modulated 30 percent with 400 cycles) input of 1 2 microvolts The automatic gain control characteristic of the receiver is shown in figure 3 The total weight of the receiver complete with cables is 23 pounds

Audio Frequency Filter

A standard type BA-189 range filter was used between the receiver output and the pulse rectifier-amplifier unit to provide for discrimination against noise (and voice when used) in the received signal The transmission characteristics of this 1020-cycle band-pass and band-elimination filter are shown in figure 4

Pulse Rectifier and Amplifier

Previous experience gained during the development of the Washington-Baltimore radioteletype circuit[2] indicated that the most satisfactory method of obtaining the pulses to operate the teletype machine would be from a gas discharge relay of the type shown in figure 5

During spacing impulses no audio signal is applied to the pulse rectifier VT_2 In this case plate current flows in VT_3 and VT_4 The plate current of VT_4 through R_1 makes the grid of the thyratron VT_7 negative with respect to the cathode, and the tube is non-conducting The plate current of VT_3 flowing through R_3 biases VT_5 to cut off and, with no current flowing through R_2, the grid of the thyratron VT_6 is at cathode potential, which permits the tube to ionize and conduct current Under these conditions, condenser C is charged to a potential in such a manner that the point A is 15 volts (the drop across the tube) positive with respect to the cathode The point B will then be at the plate potential above the cathode, for example 100 volts

During a marking impulse VT_3 and VT_4 will be biased to cut off, the grid of VT_6 will become negative with respect to the cathode, and the grid of VT_7 will be at

[2] See reference 1, page 1

cathode potential. VT_7 will then ionize and conduct current, instantaneously lowering the potential of point B to 15 volts positive with respect to the cathode. This represents a reduction of 85 volts. The point A will thus be instantaneously lowered by 85 volts or to 70 volts negative with respect to its cathode and the tube will deionize and cease to conduct current. The potential of point A will gradually become 100 volts positive with respect to the cathode. Thus, it is seen that marking and spacing impulses will trigger the two tubes oppositely. The current through the thyratrons is limited by the resistors R_4 and R_5 and is adjusted to the optimum value for best operation of the teletype machine, the magnet of which is connected in the plate circuit of one of the tubes.

The best triggering action is obtained when the control grid current of the gas discharge tube is a minimum. This grid current can be either from cathode to grid or from grid to cathode, depending on the relative potentials of the grid and cathode. To insure that the grid is driven to zero potential in each case, regardless of the amplitude of the signal pulse, a direct-current phase inverter is used. The complete unit consists of a limiting amplifier, pulse rectifier, phase inverter and thyratron relay. Part of the voltage developed across the pulse rectifier filter is fed back to the grid of the limiting amplifier. This grid control, in addition to the limiting action provided through plate regulation resulting from the resistance in the plate circuit of the amplifier, insures relatively constant amplitude pulses at the input of the full wave pulse rectifier. A positive potential is applied to the cathode of the pulse rectifier to act as a noise threshold limiter for the signal pulse.

High voltage plate power is supplied by a dynamotor unit. Ballast lamps of the iron wire in hydrogen type were included in the filament and dynamotor supply circuits to reduce the effects of variations in battery voltage. For best operation of the teletype printer, the current through the magnet coils should be maintained to within plus or minus 10 percent of the normal current value of 60 milliamperes. The magnet coil of the printer is in the plate circuit of one of the thyratron tubes. The plate current of the thyratron is proportional to the plate supply voltage and, therefore, regulation of the plate supply voltage will result in an equivalent regulation of the magnet current. The dynamotor is designed for operation from an 8-volt supply. A ballast lamp, with a nominal voltage drop of 4 volts connected in series with the dynamotor input permits operation from the 12-volt battery of the airplane. A ballast lamp, with a nominal voltage drop of 6 volts, was used in series with the 6-volt heater circuit. The current-voltage characteristics of the ballast lamps are shown in figure 6.

The margin characteristic of the teletype printer used in conjunction with the pulse rectifier-amplifier unit for several battery input voltages and two settings of the noise bias control is shown in figure 7. The number of points of margin are expressed in percent of the normal margin of the machine when it is operated at 60 milliamperes and with the tape distributor directly in the direct-current circuit. For example, 50 percent represents the mean value of the upper and lower margin control lever readings, a reading of 0 to 100 from the curve indicates that the margin through the pulse rectifier-amplifier unit was the same as the direct-current machine margin. The figure shows that under the worst conditions (curve 6) the margin is 80 percent of the direct-current margin over an input signal range of 36 decibels.

The total weight of the experimental unit shown in figure 10 is 18 pounds.

Printer

The typing unit from a standard, 60-word-per-minute Teletype Corporation type 14 printer was mounted on an aluminum chassis and shock mounting. All of the parts which were not essential to the operation of the unit for printing only were removed in order to reduce the weight as much as possible. The weight of the printer (stripped of all non-essential parts) complete with cover and shock mounting was 38 pounds. This weight is considerably more than is desirable for practical application of the system, but for the purpose of determining the practicability of a system of ground-to-aircraft teletype transmission a standard readily available unit was used It is anticipated that in the near future a printer unit will be available which will weigh about 10 pounds The printer, without dust cover, is shown in figure 9

A 12-volt direct-current governor-controlled motor was installed in the printer to provide a constant driving speed for supply voltage variations from 10 to 15 volts The speed characteristic of the driving motor is shown in figure 8

Aircraft Antennas

At different times during the development and testing of the ground-to-aircraft teletype system, installations were made in three airplanes the United Air Lines flight research ship, a Boeing 247-D, a Douglas DC-3 transport type airplane made available through the cooperation of the United States Army, and NC-17, the C A A 's Waco Type N

The antenna used on NC-17 was a horizontal dipole, loaded at the center with a coil of five turns three-fourths of an inch in diameter, mounted 18 inches above the skin over the forward part of the cabin The axis of the antenna was parallel to the wings This installation is shown in figure 11 A flexible coaxial transmission line coupled the antenna to the receiver.

The antenna on the Boeing, figure 12, was a dipole, insulated at the center and stretched between two arms which extended approximately 18 inches below the belly of the ship at about the center of the wings The axis of the antenna was crosswise to the ship A flexible coaxial transmission line coupled the antenna to the receiver

The antenna on the DC-3 was also a half-wave dipole with its axis parallel to the wings The antenna was constructed of a 1/4-inch diameter brass tube strengthened by a rib of balsa wood This structure was mounted on the hatch, about 12 inches above the skin, above the pilot's compartment A flexible coaxial transmission line coupled the antenna to the receiver

All three antennas were, of course, directive forward and backward since they were simple dipoles Greater signals were received when the heading was toward the transmitter in the DC-3 and NC-17 installations, since the antennas in these cases were mounted toward the nose of the ship

The flight tests were to determine the practicability of the system and the distance range that could be expected, consequently, the nulls off the wings were not important provided the ship was flown approximately toward or away from the transmitter In regular practice a non-directive antenna would be used

GROUND STATION EQUIPMENT

The ground station equipment was the regular radioteletype equipment of the Washington-Baltimore experimental radioteletype circuit described in detail in reference 1 Transmissions to the aircraft were made over the Baltimore transmitter, which was located about 2 miles northeast of Logan Field, near Dundalk, Md

The transmitter, a TXK, delivered approximately 100 watts at 65 megacycles to a horizontally polarized directive antenna mounted on top of a 125-foot steel tower The antenna consisted of four 1/2 wave elements spaced 1/2 wavelength apart in a vertical plane, fed in phase, with a similar unit placed 1/4 wavelength behind the radiators used as a parasitic reflector Figure 13 is a photograph of the antenna system

For the ground-to-aircraft radioteletype tests, the usual 4300-cycle tone was replaced by a 1020-cycle tone to take advantage of standard aircraft simultaneous range filters, as described under Aircraft Equipment

A 1020-cycle band-elimination filter in the voice circuit permitted simultaneous voice and teletype transmissions to the aircraft

FLIGHT TESTS

The first flight test was made in NC-17 It was not convenient to have an operator at the Baltimore transmitter for this test, so the equipment was placed in automatic repeat condition[3] and operated unattended Flying was to be done from Bolling Field, Anacostia, D C , and this method of operation provided a very flexible circuit since transmissions could then originate at WWX, Silver Hill, Md , (about 4 miles from Bolling Field) and be relayed through WWII, Baltimore, to the aircraft Since the original WWX, 100-watt transmitter was temporarily out of service, a small transmitter of less than 5 watts output was used With this low output, the received signal at Baltimore was, of course, very low, and with the high automobile ignition interference which was present, some misprinting was experienced The Baltimore-Silver Hill circuit, however, was excellent, and by comparing the transmitted copy originating at WWX with that received back after having been relayed by WWII, the errors in the WWX-WWII link could be isolated Errors which were received on the aircraft copy and on the received copy at WWX were assumed to have come from the WWX-WWII circuit Likewise, those appearing on the aircraft copy which did not appear on the WWX copy were isolated to the WWII-aircraft link

After taking off from Bolling Field, a course toward Baltimore was taken, the equipment was adjusted, and the motor speed corrected The heading was then changed toward Washington and an altitude of 3,000 feet maintained After passing over the Washington range station, the south leg of the range was followed to the Rappahannock River, at which time the ignition interference from the aircraft engine started to cause misprints With the battery ignition shut off and the engine operating from the magneto, perfect copy was received at an altitude of 3,000 feet A descent was then made in the vicinity of King George, Va , (80 miles airline from the transmitter) and the copy was checked at frequent intervals with the battery ignition off Good copy was received at an altitude of 700 feet, below this the signal was too weak to print The heading was then changed to return to Bolling Field Good copy was received at an altitude of 1500 feet with both ignitions on at about Ambar, Va , (75 miles airline from the transmitter) and was good until a descent was made for a landing at Bolling Field

The records were analyzed and it was found that 175 lines of excellent copy were received, starting with the first copy received after the equipment was adjusted and counting all copy received to the point of misprinting near King George There were 15 errors received other than those which were received at WWX from Baltimore Allowing 70 characters per line for 175 lines, 12,250 characters were transmitted This represents one error in 817 characters This was accomplished over an airline distance of 75 miles at an altitude of 3000 feet The only adjustment made to the equipment after the original adjustments were made was to roughly control the audio output of the receiver

The results of this first flight were very encouraging, especially when it was known that the ignition interference in NC-17 was very high

Through the cooperation of the United States Army, an airplane of the DC-3 transport type was made available to the C A A for further tests of the radioteletype equipment

The first flight in the DC-3 was made out the southwest leg of the Washington range at an altitude of 3,000 feet About 10 miles northwest of Quantico, Va ,

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[3] See reference 1, page 1

a distance of 65 miles from the transmitter, a large circle was made to determine the antenna directivity At this distance from the transmitter, the signal was of sufficient strength to obtain perfect printing at all headings, even though the antenna was a dipole and nulls would be expected in line with the axis of the antenna The original course was again resumed and the altitude of 3,000 feet maintained The first errors were received in the vicinity of the Rappahannock River (85 miles from the transmitter), with a heading away from the transmitter With a heading toward the transmitter, however, perfect printing was again obtained, which indicated that the directivity of the antenna favored reception off the nose of the airplane. This would be expected, since the antenna was mounted over the pilot's compartment in the nose of the ship On the return flight, the teletype driving motor gained speed and the printing was poor A landing was made at Bolling Field and the proper speed adjustments were made

A flight was then made to Logan Field, Baltimore, to ferry an operator to the transmitter so that messages could originate at that point instead of at Silver Hill, thus eliminating any errors which might come from the temporary circuit between Silver Hill and Baltimore, which was known to be subject to error Perfect copy was obtained from the take-off at Bolling Field to the landing at Logan Field, and while on the ground On the return flight from Logan Field, simultaneous voice and teletype transmissions were received on the airplane with perfect printing and understandable voice Figure 14 is the aircraft copy received just prior to the landing at Bolling Field The level of the voice circuit was a little low and this level was raised after the landing

The third flight was made out the southwest leg of the Washington range In the vicinity of Woodbridge, Va , a thunderstorm was encountered and it was necessary to bear to the right to go around the storm area Rain static of the "crying" type was observed on entering several cloud formations The effects of the crying static on the printing circuit were practically eliminated by reducing the tone level to the audio filter below the overload point The pass band of the audio filter is sharp and only the 1020-cycle components of the crying static interfered In this test, only a few misprints were received after the levels were adjusted

The storm area was skirted and in the vicinity of Calverton, Va , a southerly course was again taken to Locust Grove, Va , where the original 230° heading was resumed

Occasional errors not caused by static were received which appeared to be due to over-modulation in the voice channel The simultaneous voice channel was then discontinued and the occasional errors were eliminated Figures 15-A, 15-B, and 15-C are three consecutive pages of pasted copy and are included to illustrate this point The errors in the hand-sent messages were checked against the local copy and found to be typographical errors on the part of the operator The errors marked "noise" were the result of turning on the ship's radio transmitter which momentarily lowered the battery voltage to the point where the teletype motor dropped out of synchronism for an instant In a multichannel circuit which combines voice and printing channels or several printing channels, it is essential that the level of each channel be carefully controlled to prevent the total instantaneous modulation of the several channels from exceeding 100 percent In this experimental set-up, no peak-limiting amplifiers were used and occasional overmodulation peaks were expected The test, however, indicated that with proper control of the tone and voice levels, a multichannel circuit was possible

After the voice channel was discontinued, perfect copy was received to the vicinity of Holladay, Va , at an altitude of 7,100 feet, with a heading away from the transmitter This is an airline distance of 110 miles

A large circle was made near Pendletons and Bumpass, Va , and a heading taken toward Baltimore at an altitude of 5,000 feet As soon as the heading was taken toward the transmitter, the copy became perfect and continued as such until the landing was made at Bolling Field.

The fourth flight was made to determine the distance range of the circuit After taking off from Bolling Field, a southwesterly course was taken, climbing to an altitude of 9,500 feet near Holladay, Va The first errors were received at this point, 112 miles from the transmitter with a heading away from the transmitter The printing was perfect, however, for headings toward the transmitter A south-southwest course (210°) was then resumed. This heading was not directly away from the transmitter, and the null off the tail was avoided Errors again came in at the James River at 8,000 feet altitude, but the copy was perfect with headings toward the transmitter A large circle was made over the James River, 145 miles from the transmitter, at an altitude of 8,000 feet, to determine the antenna directivity Good copy was obtained for headings approximately 45° either side of the nose and also for headings 30° to the left of a heading directly away from the transmitter The turn was made to the left, which would account for the reception to the left of the tail and not to the right since part of the fuselage would be between the antenna and the transmitter for reception to the right of the tail

The course was continued away from the transmitter and the altitude reduced to 6,000 feet A turn was made near Buckingham, Va , where it was estimated no signal would be heard with the heading toward the transmitter The heading was taken toward Baltimore and an altitude of 6,000 feet maintained Signals were first heard near Dillwyn, Va , a distance of 160 miles from the transmitter The signals, however, were too weak to print The first copy was received about 5 miles west of Cartersville, Va , 145 miles airline distance from the transmitter Perfect copy was received from that point to Bolling Field and on the landing down to about 150 feet above the ground Figures 16-A and 16-B are sections of the copy received at the various points on the fourth flight

The third group of flights was made with the equipment installed in the United Air Lines flight research ship and was for the purpose of demonstrating the system to the members of the Radio Technical Commission for Aeronautics Several flights were made to the vicinity of Quantico, Va , 65 miles from the transmitter, with results equal to those obtained in the DC-3 This installation is shown in figure 17

DISCUSSION OF RESULTS

On two occasions difficulty was experienced from variation of speed of the driving motor This was traced to high resistance contacts in the governor control The original tungsten contacts were replaced with platinum contacts and the trouble was eliminated

Frequently throughout the description of the flights, the received copy is referred to as perfect It should be kept in mind that the type of messages which will eventually be handled on a ground-to-aircraft circuit will be, to a large extent, coded weather and ship movement information There is no indication on the present teletype message to show whether the character received is the one transmitted or whether an extra impulse has been picked up or, conversely, one dropped, to print a different character Perfect copy, then refers to copy without errors, and good copy refers to one error in 500 to 800 characters

In all of the copy received on the airplane one characteristic is predominant The transition period between perfect copy and complete misprinting covers a very short time Figures 18-A, 18-B, and 18-C have been included to illustrate this point The copy which immediately preceded that shown and also that which followed was perfect copy with no errors This copy was received during the third flight in the DC-3 and covers the last perfect copy on the outgoing flight in which misprinting started in the vicinity of Holladay and continued through the turn until the heading was again toward the transmitter The recovery was, of course, hastened by the greater pick-up off the nose of the ship, but in the outgoing flight, the copy went from perfect to zero in less than 500 characters, or about $1\frac{1}{2}$ minutes In the fourth flight in the DC-3 after the heading was taken toward the transmitter in the vicinity of Buckingham, Va , the first signals were heard near Dillwyn, 160 miles from the transmitter, and perfect copy was obtained at about 145 miles This short transition period can be attributed to two things (1) the rapid attenuation of ultra-high-frequency waves beyond the horizon, and (2) the limiter action of the amplifier feeding the pulse rectifier, the noise bias voltage on the pulse rectifier, and the positive triggering action of the thyratron type of relay

CONCLUSIONS

The ground-to-aircraft radioteletype development is a continuation of the radioteletype development reported in detail in a previous Technical Development Report[4], to extend the system to make available on an airplane a printed record of weather conditions, flight information, and such other data as may be necessary for the safe operation of the airplane Although the standard teletype printer was not designed to operate under the vibration encountered in aircraft, on only one occasion did the machine misprint because of a violent movement of the ship, and in that instance the accelerometer indicated a bump of 1 6 G Other printers of a different type which use the same five-unit Baudot code have been designed They have fewer reciprocating parts and therefore are less susceptible to shock

The results obtained in the numerous flights indicated that a ground-to-aircraft teletype system is entirely practicable, and if this system is combined with the proposed radioteletype system used to collect and disseminate the weather and ship movement information, a communication system will be available to simultaneously collect the necessary information, dispatch it to the itinerant over a voice channel, and provide on the larger airplane a printed record

[4] See reference 1, page 1

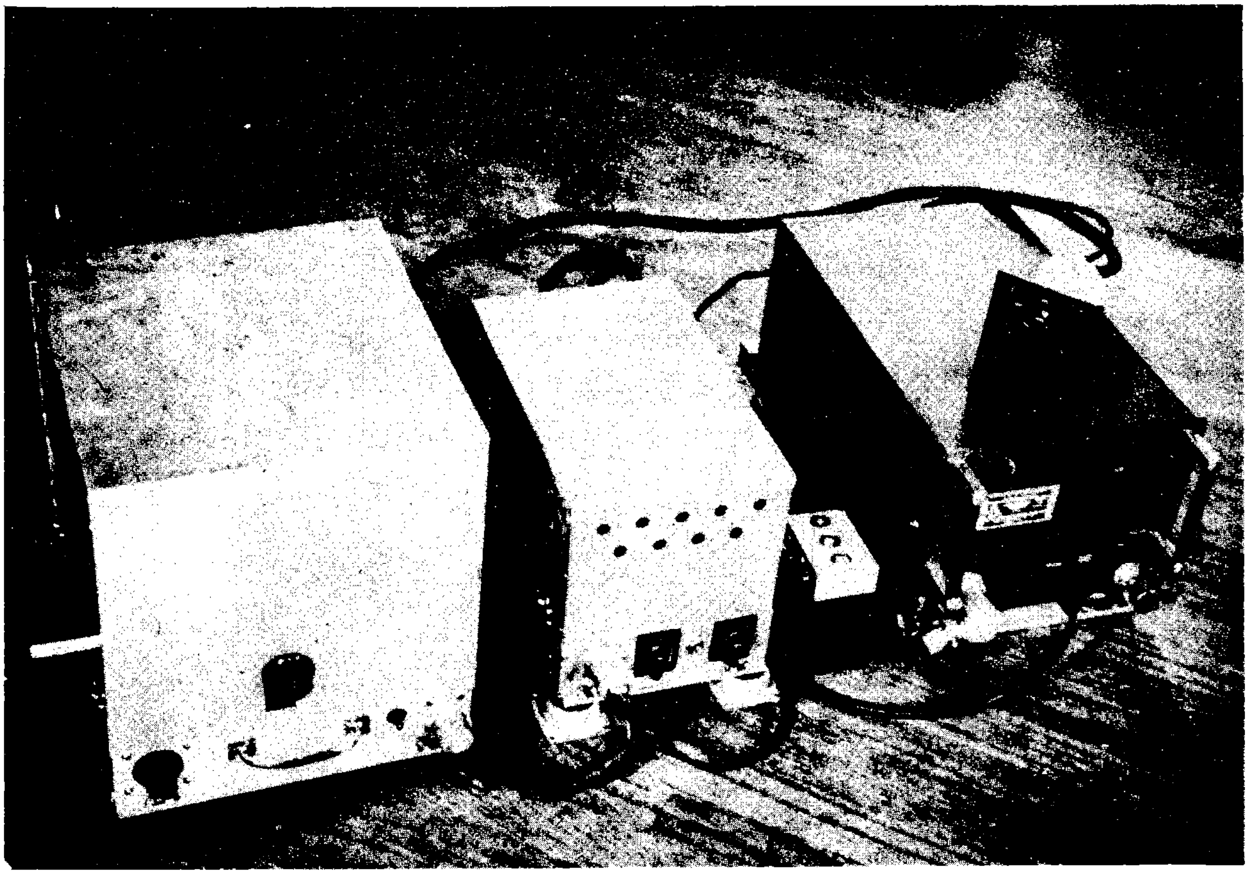

Figure 1. Aircraft Equipment Used in Tests.

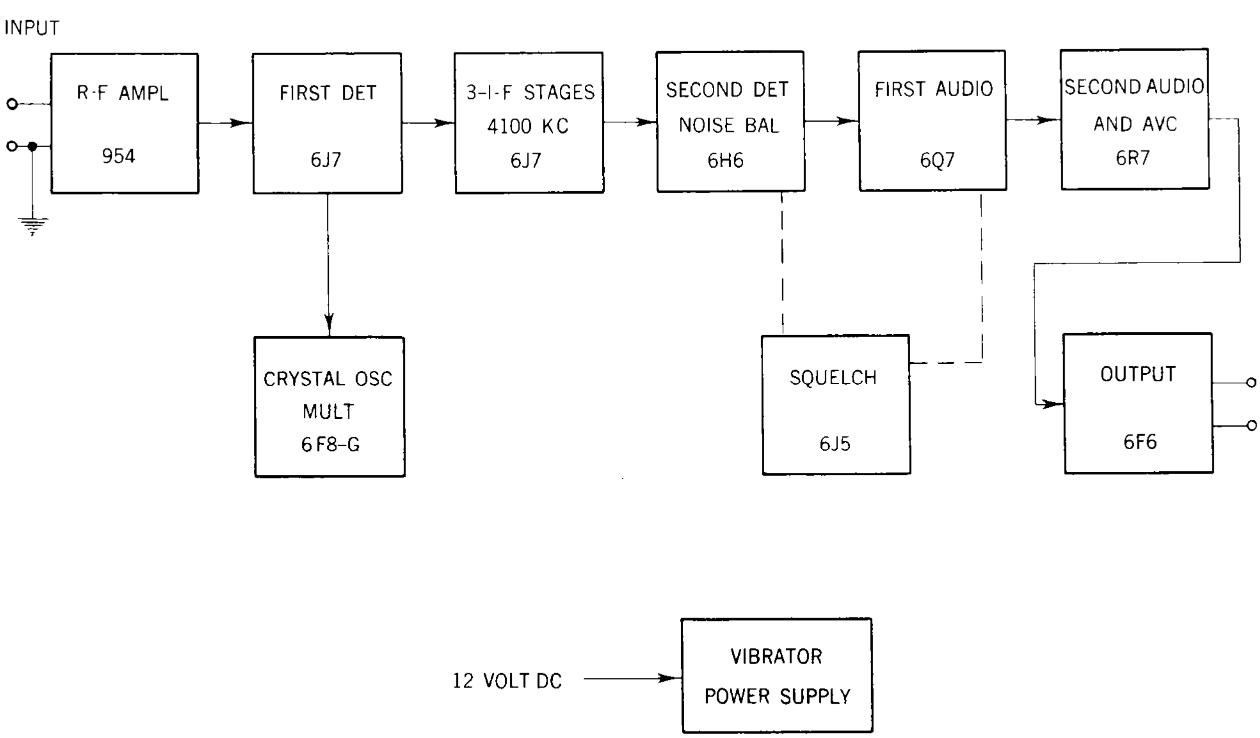

Figure 2. Block Diagram of the RCA AVR-17A Receiver.

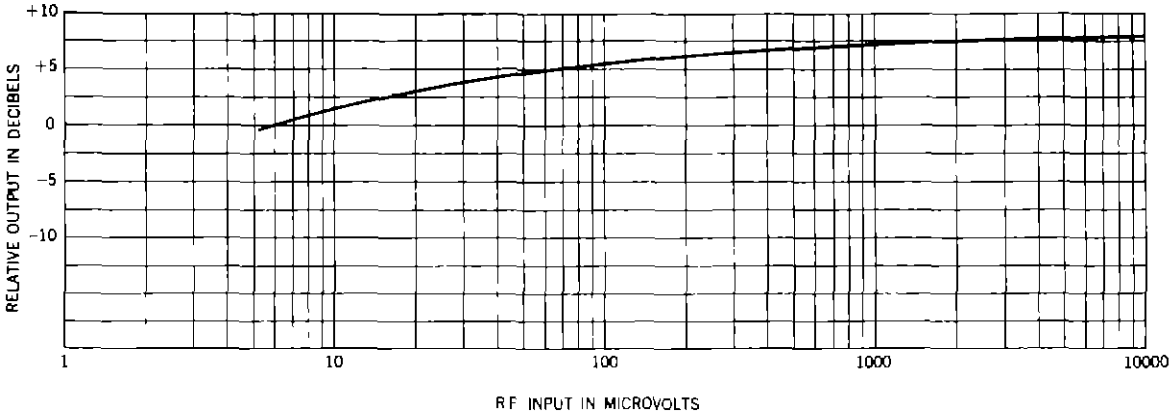

Figure 3 Automatic Gain Control Characteristics of the RCA AVA-17A Receiver

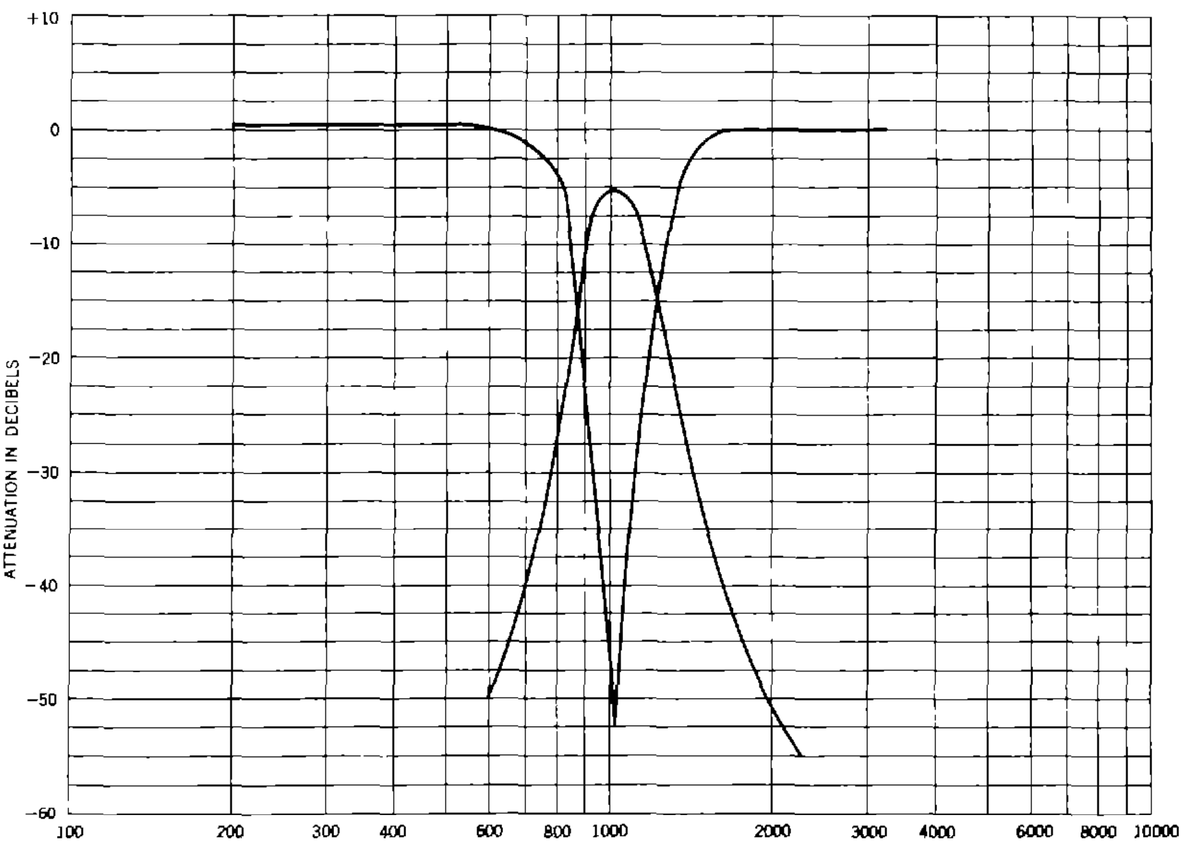

Figure 4 Transmission Characteristics of the 1020-Cycle Band-Pass and Band-Elimination Aircraft Filter (BA-189)

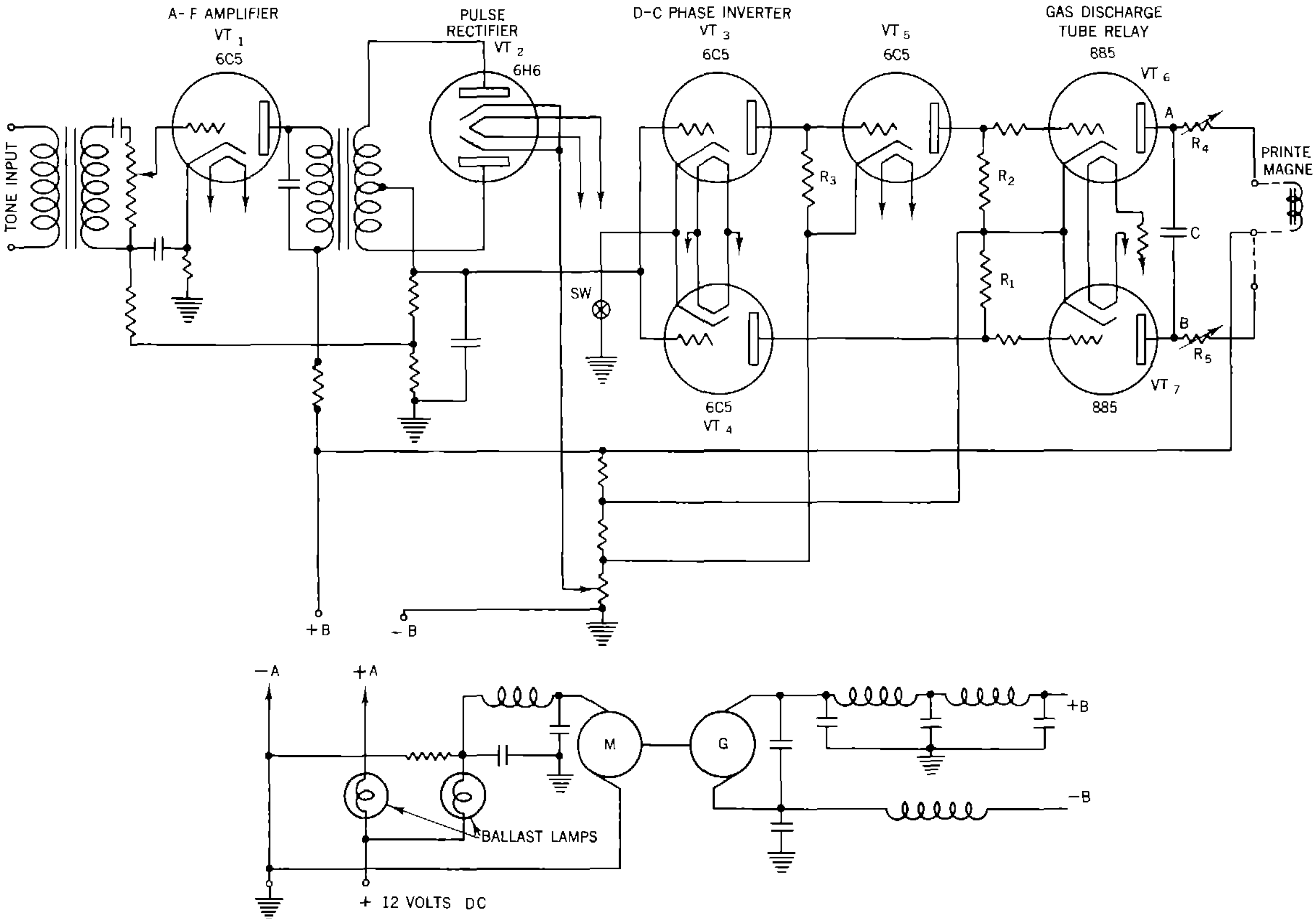

Figure 5 Schematic Diagram of the Pulse Rectifier and Amplifier

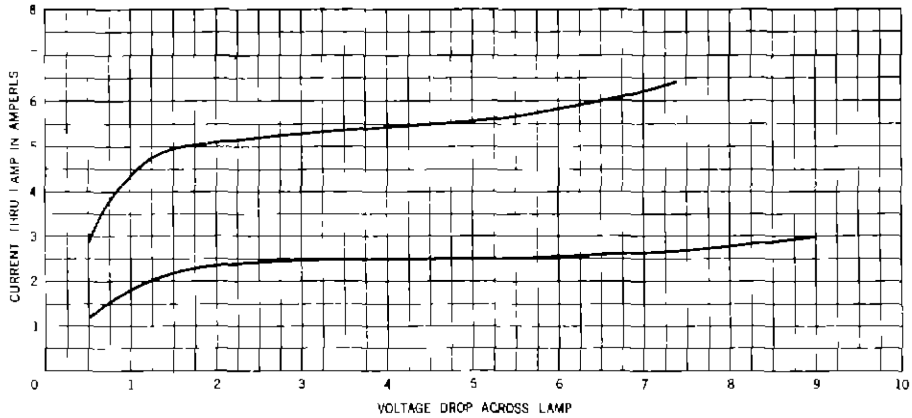

Figure 6 Current Voltage Characteristics of Ballast Lamps Used in the Pulse Rectifier Amplifier Unit.

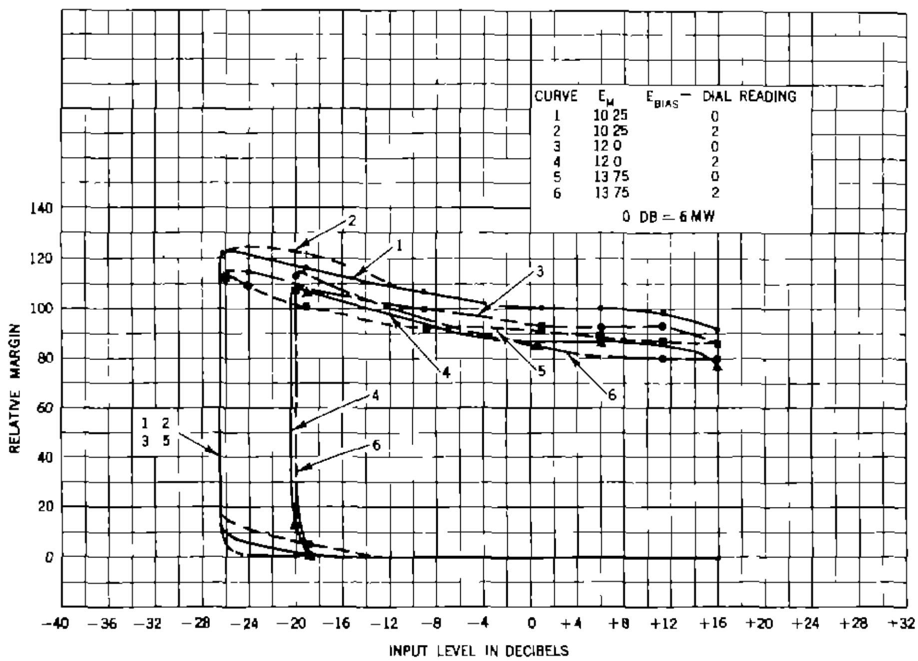

Figure 7 Margin Characteristics of the Teletype Printer Used With the Pulse Rectifier-Amplifier of Figure 5 for Several Battery Voltages, and Two Settings of Noise Bias Control

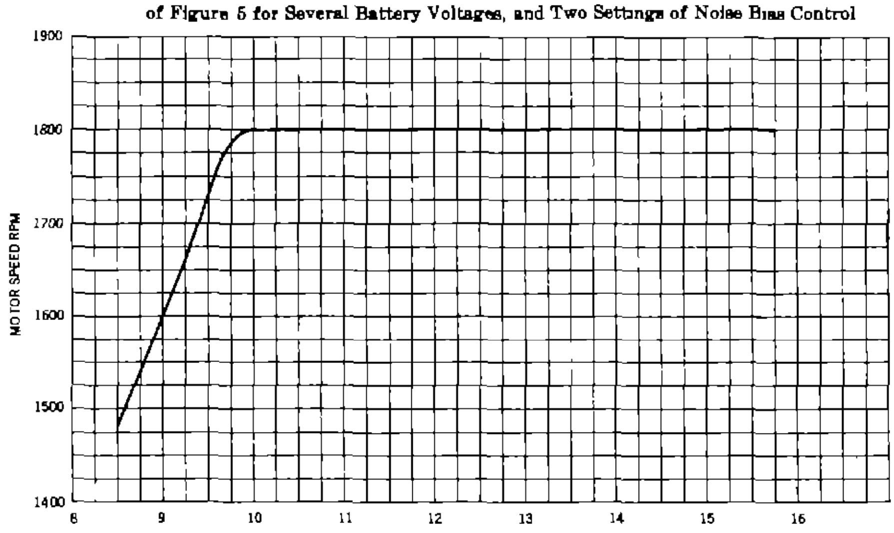

Figure 8 Speed Characteristic of the 12-Volt DC Governor-Controlled Motor Used to Drive the Aircraft Printer

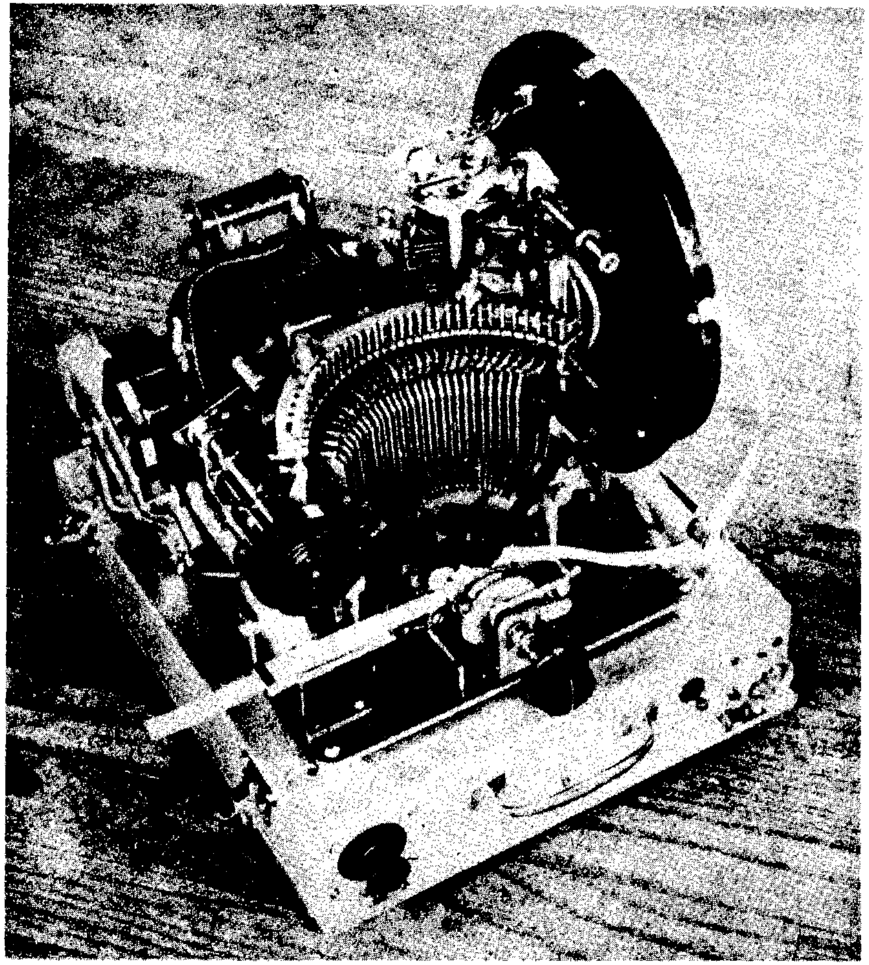

Figure 9. Aircraft Printer With Dust Cover Removed. A Standard Teletype Corporation Type 14 Printer with Non-Essential Parts Removed to Reduce Weight to a Minimum.

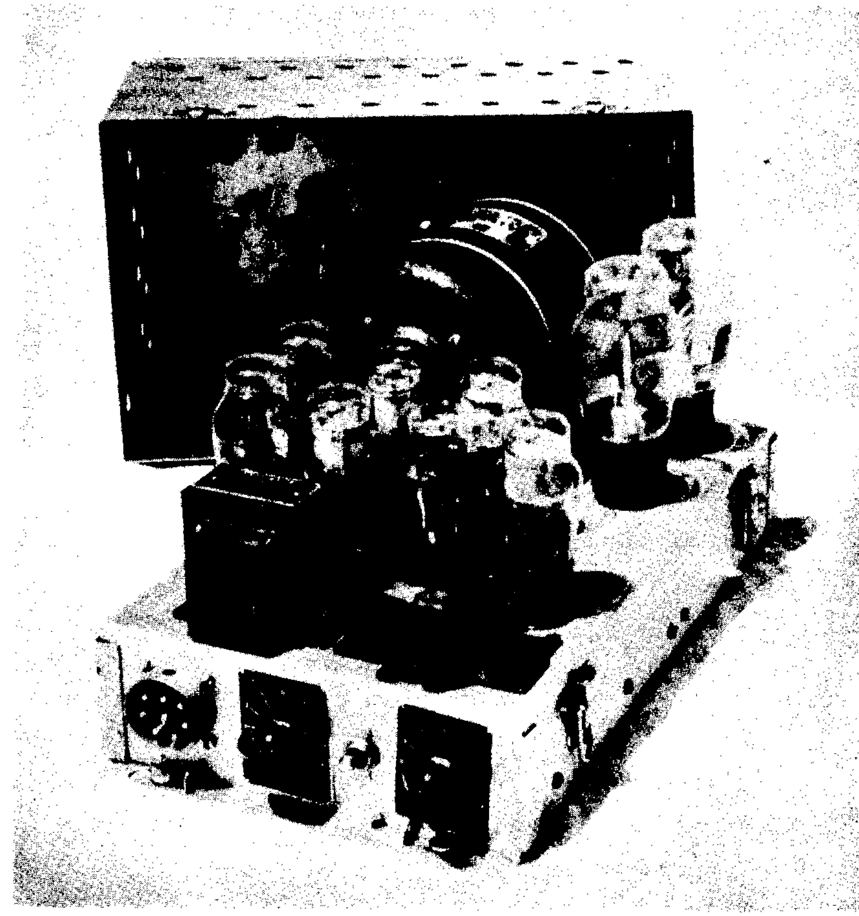

Figure 10. Pulse Rectifier-Amplifier Unit.

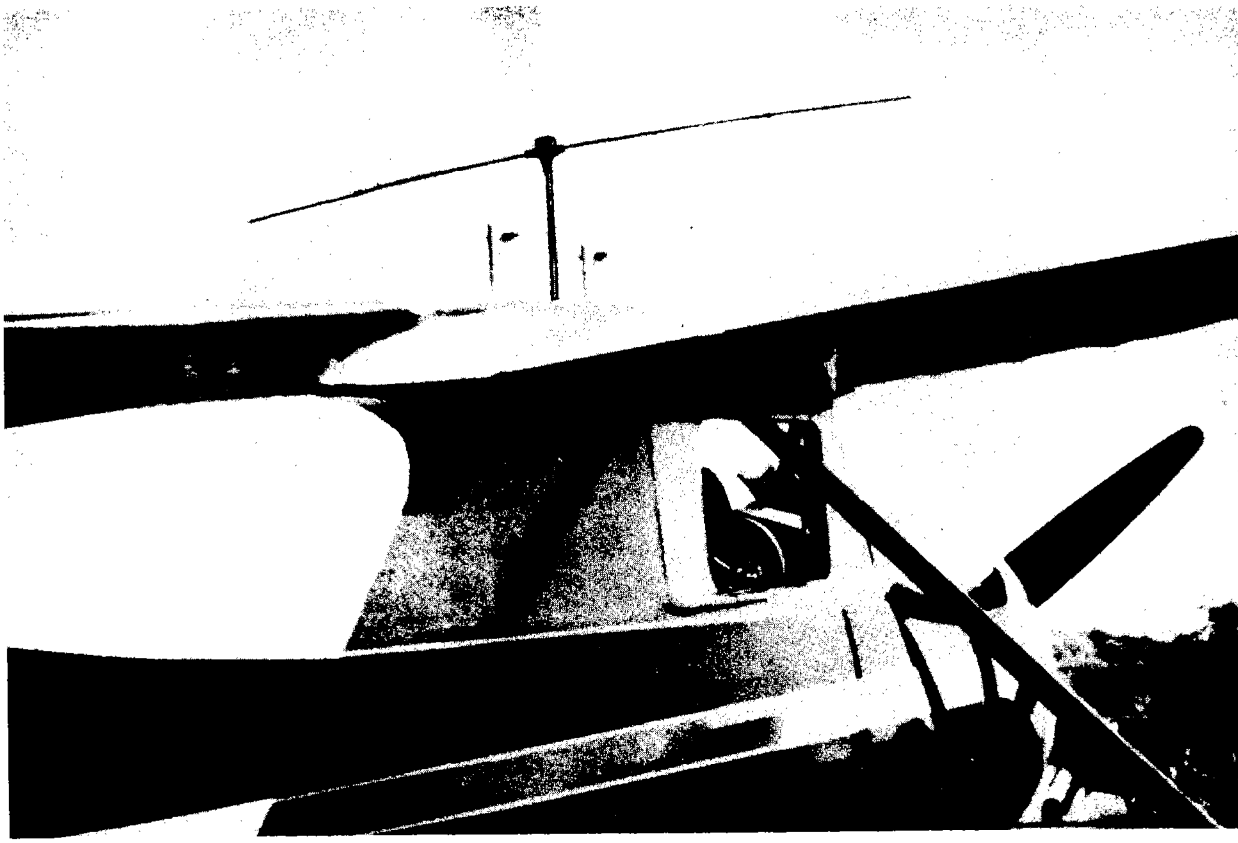

Figure 11. Antenna Installation on NC-17.

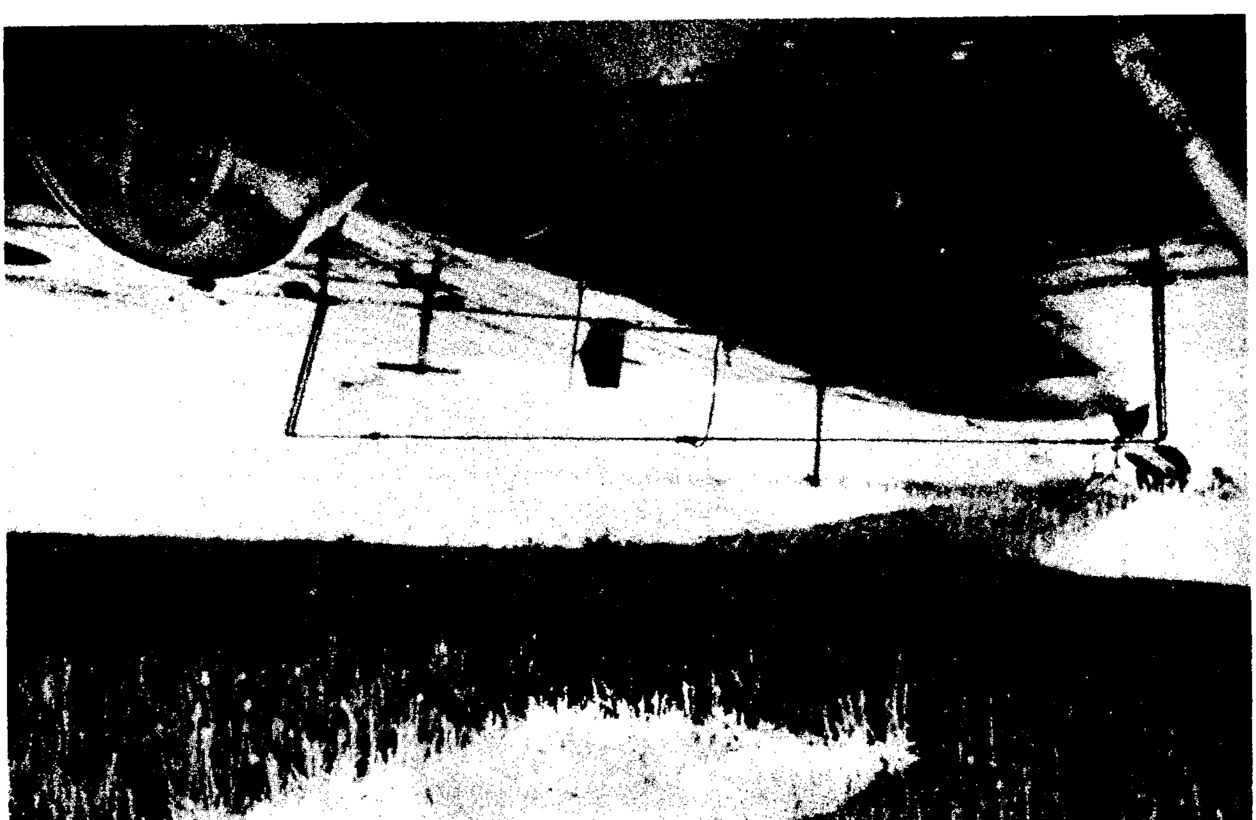

Figure 12. Antenna Installation on the United Air Lines Flight Research Ship, a Boeing 247-D.

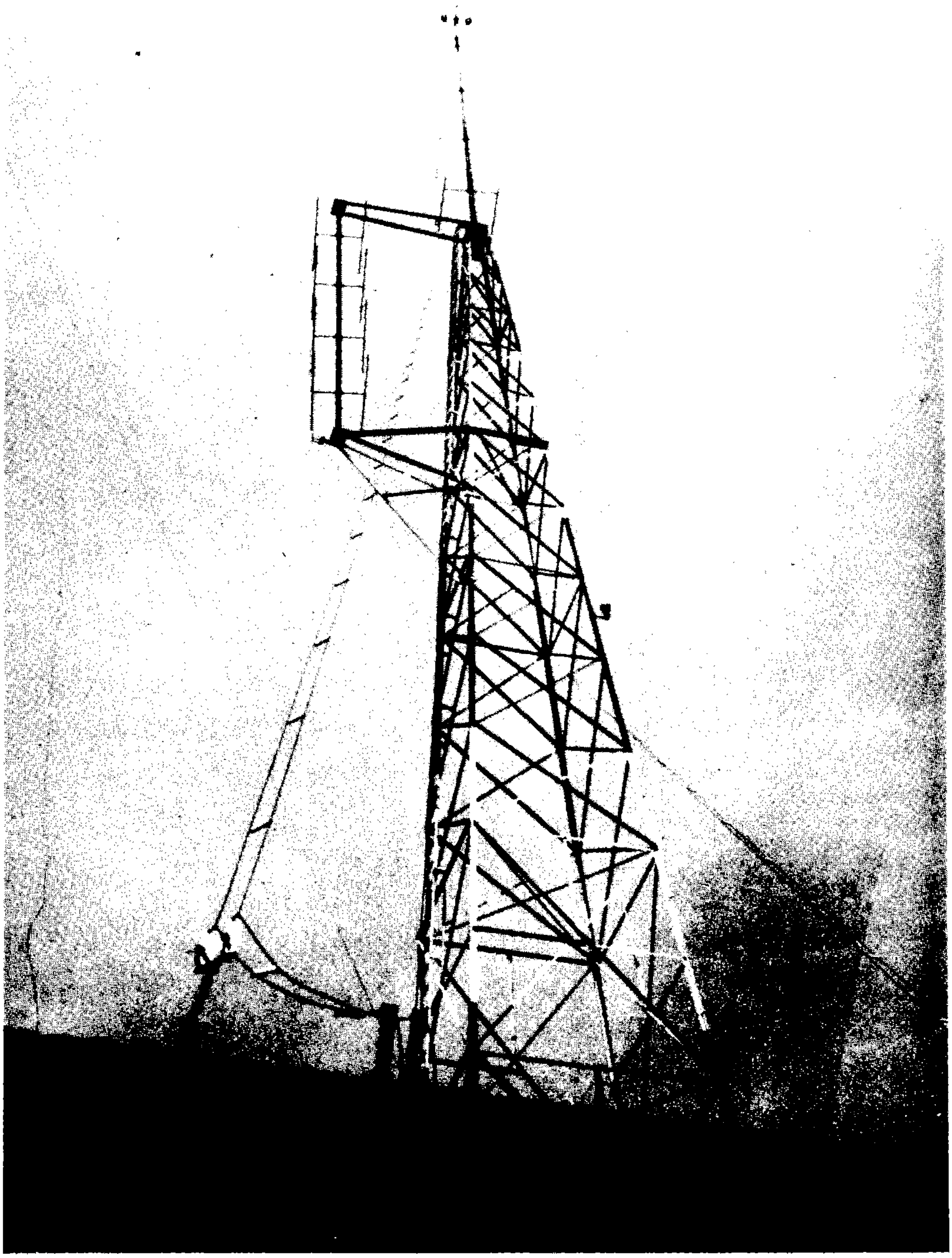

Figure 13. 65-Megacycle Transmitting Antenna on Top of 125-Foot Steel Tower. Station WWII Near Dundalk, Md.

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...NOW IS THE TIME FOR,........OK   MAC   IM HERE
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Figure 14. Aircraft Copy Received on the DC-3 Just Prior to Landing at Bolling Field After Second Flight Test.

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.KOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ..
.NOW IS THEHTIME FOR ALL GOOD MEN TO COME TO THE AID OF HHEIR PARTY ,
,.NOW IS THE TIME FOR ALPIGOOD MBNITM COME TO THE AUD MF HHEIR PACTY
.NGNOW IS THEHMUME FOR ALLSGOOD MZN TX COME TO THEHAID GF OHEIR PARTY ,
N.NOW IS THE TIME FOR ALLHGOMD MENHTC COME TO THE AID OF THEIR PARTY ..
.NGW IS THEITIME FORNALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ..
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ..
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ..
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIC PARTY ..
.NOW IE THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIV PARTQ ..
.NOW IU THE HIVE FOR ALLIGOOD MEN TO COME HO THE AI3 OF LHEIR PARTYN..
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ..
```

8

Figure 15-A. Consecutive Copy Received During the Third Flight of the DC-3 Illustrating Errors Caused by Over-Modulation in the Voice Channel. (Uninterrupted Copy Continued on Figure 15-B).

Occasional errors in copy which were apparently for no reason. No noise crashes were heard when listening with headphones. Probably errors due to over-modulation of voice channel. Voice modulation removed and the copy became perfect indicating that it was over-modulation.

Alt. 7500 ft. Lignum, Va. .NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE [illegible] THE TRS[illegible]T FT.

.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AI

........TO SHIP I HEARD EVUR MESSAGE

TO SIPXXX CUNARD TN 6210 WILL NOT..USE VOICE ANY MORE ......

.TO CUNARD THEY WILL CALL U ON PHONE IN FEW MINUTES TO TELL U TO.

.TELL ME NOT TO USE VOICE ANY MORE I HAVE THE MESSAGE AND U NEED .

.NOT CALL ME UNLESS I HAVE IT WRONG......D OF THEIR PARTY ..

..NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ..

.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ..

.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ..

Noise .NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF ZESDX SNFL..

.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY

...NOW IS THOK

SEE U LATER....E TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ..

9

Figure 15-B. Consecutive Copy Received During the Third Flight of the DC-3 Illustrating the Elimination of Errors Which Were Caused by Over-Modulation in the Voice Channel. (Uninterrupted Copy Continued on Figure 15-C).

.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ..

.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ..

.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ..

.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ..

..NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ..

.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ..

..NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY

...NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ..

Locust Grove, Va. Alt. 10,200 feet .NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ..

.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ..

.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ..

.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ..

Volume changed on ship .NOWNIS THE TIMEIFOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ..

.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ..

..NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ..

.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ..

10

Figure 15-C. Consecutive Copy Received During the Third Flight of the DC-3 Illustrating the Perfect Copy Received After Discontinuation of the Over-Modulated Voice Channel.

Demonstration flight of Civil Aeronautics Authority Ground-to-Aircraft Radio Teletype, May 12, 1939.

Ground transmitter located at U.S. Airway Experimental Radio Station, about 2 miles NE of Logan Field, Baltimore, Maryland.

.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,

2 Miles NW of Accotink, Va. Altitude 3000 feet. 53 miles from transmitter.

.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,

12 miles WSW of Quantico, Va. Altitude 6500 feet.
80 miles from transmitter.

.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,

Nearing Gordonsville, Va. Altitude 9180 feet.

Figure 16-A Sample of Copy Received During the Fourth Flight of the DC-3.

.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,

4 miles West of Holiday, Va. Altitude 9500 feet.
112 miles from transmitter.

TO COME TOTMS ,U D OF THE R PARH ,..NOW IE THE TIME FOR ALL GOOE MEN TO

Louisa , Va. headed from Baltimore.
118 miles from transmitter.

.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,

6 Miles North of James River - Heading 210 degrees. Altitude 8000 feet.
140 miles from transmitter.

.NOW IS THE T ME JOR ALLGOTD OEN TOROME TO THE IDOFLTHEIP PARTY ./,

Near Cartersville, Va. headed toward Baltimore. Altitude 6000 feet. 145 miles from transmitter.

.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,

Louisa, Va. 118 miles from transmitter.

.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,

10 miles South of Fredricksburg, Va. Altitude 6000 feet. 95 miles from transmitter.

.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,

Over Rappahannock River 5 miles East of Fredricksburg, Va. Altitude 6000 feet.

.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,

Mason Springs, Va. Altitude 6000 feet. 58 miles from transmitter.

Figure 16-B Sample of Copy Received During the Fourth Flight of the DC-3.

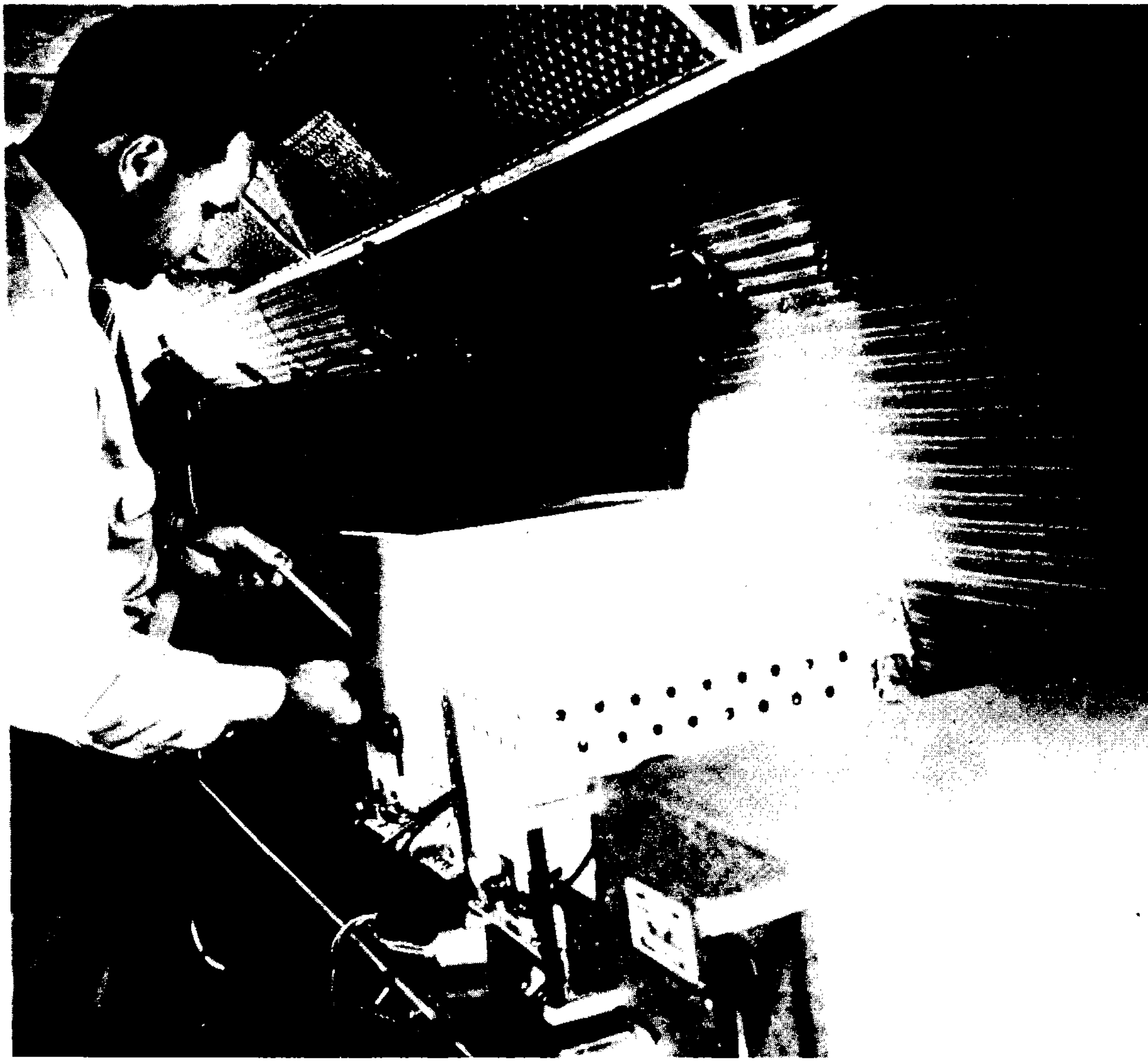

Figure 17. Ground-to-Aircaft Radioteletype Equipment Installed in the United Air Lines Flight Research Ship.

.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,
Belmont,Va. Alt. 9500 ft. .NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,, Belmont 9500

12

Figure 18-A. Consecutive Copy Received During the Third Flight of the DC-3 Illustrating the Perfect Copy Received at a Distance of Approximately 100 Miles from the transmitter. (Uninterrupted Copy Continued on Figure 18-B).

.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,
Alt. 8000 ft. .NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,, 8000'
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,
.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY ,,

13

Figure 18-B. Consecutive Copy Received During the Third Flight of the DC-3 Illustrating the Perfect Copy Received at a Distance of Approximately 105 Miles from the Transmitter. (Uninterrupted Copy Continued on Figure 18-C).

.NOWHIS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY .,

.NOW IS OHE TPME FOR ALLPGOOD VEN TO COME TO THE AIDPOF TMEQV PARTY M,

.NOW IU THE TQVE FO ALLN99↗ MENHTO COVE TO THE AID OF THEIR PARTY .,

Holladay, Va. Alt. 7100 ft (110 miles)

NOW IS THE TIME FOR ALL GOOD MEMPTO Holladay 7100 THE JNOF THEIC PARTY ,O.

NMW IS TME TIME FOR ALL GOODUVSNPTM COMEPTO TVZ AIX OF THEIV PARTY .,

.NOW IU THE TWME FOR AWL GOOB MENITO COME TO

THE AID OF THEIR PARTY ...NMW IS THEMTIME XUIBIOV←VVQQQXXXMMJPU←2ZBIQM

XQVV↘1→↘QGCVXPVUU/VXQ1→KQVVXQWYQWC011XPQVXQV26VFQVQKXQQQFXQ17K11QXQQB\

/KUQQVXMXVXUQXKKWKC JQXKJXUVKXKXQX/XBYQVKQPQBJQFQVB/XXJKQKWKXVKKBXPKM(

Turning around near Pendletons or Bumpass, Va to head back at alt. 5000 ft.

)XQVQKKXVVXXXX Turn around head back at 5000

XKKFXWAUV1K.ZVOCMMDVQPIIIDMOD MZN TO COMA TO THE AID OX THEIR PARTY ,

,RNMW UQ THE TUME FOR A↖ GMOGLMOVLTO COMYPTM THENAID MF THSIR PARTY .,

.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY .,

.NOW IS THE TIME FOR ALL GOOD MEN TO COMEPTO THE AID OF THEIRNPARTY .,

.VOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY .,

.NOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR PARTY .,

14

Figure 18-C Consecutive Copy Received During the Third Flight of the DC-3 Illustrating the Rapid Transition from Perfect Copy to Complete Misprinting.