A V-TYPE AIRCRAFT ANTENNA

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SUMMARY

An aircraft antenna for use with navigation and communication receiving equipment must meet a number of electrical requirements in regard to gain, bandwidth, field pattern, and polarization, as well as adhere to sound aerodynamic principles in mechanical construction The Civil Aeronautics Administration Type V-109 aircraft antenna, which may be mounted at either a forward position on the fuselage or aft on the vertical stabilizer, was developed for this service and has been used successfully for several years on CAA aircraft This report describes the design, construction, installation, and testing of this antenna

INTRODUCTION

Because of the increasing use of the very high frequencies for landing and navigational aids, and because these facilities emit signals that are horizontally polarized, the development of a suitable receiving antenna for aircraft has assumed considerable importance A study of the requirements for such an antenna reveals that the unit should exhibit broadband characteristics in the frequency range of 108 to 122 Mc, respond to horizontally polarized signals with a minimum of response to vertically polarized signals, provide an essentially nondirectional field pattern without deep minima, compare favorably with a dipole in respect to gain, and present a satisfactory impedance match to standard flexible coaxial cable In addition, the antenna must be of substantial weather-resistant construction, light in weight, and of good aerodynamic design to prevent excessive drag

A survey of the VHF antennas available in 1947 at the time this study was undertaken demonstrated that none of the existing types were completely satisfactory for use with localizer, omnirange, and communications receiving equipment The vertical whip or quarter-wave antenna utilizing the skin of the aircraft as a ground plane, while excellent for communications, provided neither a balanced array nor the correct polarization for reception of horizontally polarized signals

A horizontal dipole, although the simplest form of antenna, had little value in this application because its directive pattern produces nulls along the axis of the antenna

For several years prior to 1944, horizontal loop antennas whose field patterns were essentially circular in shape were used experimentally This type of antenna, while quite useful during the development stages of VHF localizers and radio ranges, possessed several disadvantages which rendered its acceptance on a large scale impractical The inherently low radiation resistance of the loop increased the difficulty of matching, and the high Q of the device necessitated the use of elaborate tuning circuits In addition, the loops were rather bulky structures and offered excessive aerodynamic drag

The familiar AS-27/ARN, a high Q antenna of U configuration, although entirely satisfactory for operation in the localizer band of 108 to 112 Mc, proved to be extremely inefficient at higher frequencies

The V Antenna had been thoroughly investigated by Jasik[1,2,3] and had shown excellent electrical characteristics in addition to reasonably low weight and drag While the V antenna in the original form was not suitable for broadband operation because of the matching system and the small diameter of the elements, the higher radiation resistance of this type of antenna and the very satisfactory field pattern it produced indicated that the device was worthy of serious consideration and further development

It is the purpose of this report to discuss the problems of design, construction, installation, and testing which were conducted on an improved V-type of antenna

[1] Jasik, Henry, "V-H-F 'V' Antenna for Aircraft," Communications, September 1944, pp 33-35, 83-86

[2] Jasik, Henry, "U H F. V Antennas For Use On Aircraft," unpublished memorandum, CAA Technical Development and Evaluation Center, June 1, 1942.

[3] Jasik, Henry, "Experimental Measurements on U H.F 'V' Antennas," unpublished memorandum, CAA Technical Development and Evaluation Center, July 27, 1942

DESIGN CONSIDERATIONS

Earlier studies[4,5,6] of a V antenna for VHF use indicated the superiority of a unit with two horizontal quarter-wavelength elements arranged with an included angle of 80° These particular values were established after theoretical and experimental studies of V antennas formed of elements of various lengths and using apex angles of 60°, 75°, 80°, and 90° It was found that in a V antenna in which the apex angle is large, i e., 80° or 90°, minima of the field pattern are somewhat more shallow than in those antennas constructed with smaller angles, but, that in the 80°-V, for example, the fields at the sides of the antenna were not less than 40 per cent of the maximum field

It was also determined that the radiation resistance of a V antenna increased both as the length of the elements and the apex angle are increased Quarter-wavelength elements with an apex angle of 80° produced a satisfactory field pattern and provided a resistance of approximately 30 ohms, which is sufficiently high to simplify matching problems. The relative gain of an antenna constructed as outlined was calculated to be only 0 95 db below that of a dipole at a given frequency

The elements of the V-109 antenna are slightly in excess of a quarter wavelength. The additional length is required to tune out the capacitive reactance introduced at the center of the V, resulting from the proximity of the elements in the plastic mounting head. A slight improvement also was observed in the minima of the field pattern at the sides of the antenna as a result of the use of longer elements

The V antenna, like a conventional dipole, requires balanced feed In earlier models this was accomplished by connecting the quarter-wavelength elements to RG 22/U balanced cable, and since the receiving equipment which was available at the time required a balanced input, no electrical difficulties were encountered as a result of the use of this cable However, the balanced line was not mechanically strong and proved to be quite susceptible to breakage in air-borne installations On occasions one side of the line would become open-circuited while the other remained intact, and under such conditions unreliable information may be supplied by the receiving equipment As a result of several such experiences, it was decided to resort to a single-conductor coaxial cable Because of its physical strength RG 8/U was selected as the most suitable cable for large aircraft installations, although RG 58/U proved to be entirely satisfactory for light aircraft use

The introduction of this cable presented the problem of properly transferring energy from the antenna to the receiving equipment through an unbalanced transmission line This was accomplished by providing a balanced-to-unbalanced transformer, commonly called a balun A transmission line balun was selected in preference to lumped constants chiefly because suitable operation over greater bandwidths could be obtained without the use of elaborate tuned-circuits. Of the several models tested, a modified Type III balun[7] provided the best balance to the two quarter-wavelength elements of the antenna over a relatively wide range of frequencies The Type III balun is shown diagramatically in Fig. 1 The length "ℓ" of the balun section is one-quarter wavelength at the center of the band of frequencies over which operation is desired It may be seen that whatever the impedance between point 2 and ground, due to the relationship of B and C, there will be a similar impedance between point 1 and ground, due to B^I and C Because the currents entering junctions 1 and 2 from the antenna are equal and 180° out of phase, and because the impedance between junctions 1 and 2 to ground are equal, the dual line to the load will be balanced. The spacing between B and B^I has been kept small in order that the unshielded section of inner conductor of the coaxial cable E will place minimum inductance in series with one side of the balun thereby minimizing unbalance Fig 2 shows the percentage of balance obtained in the quarter-wavelength elements of an antenna when using the Type III balun

The radiation resistance of the V antenna in free space was found to be approxi-

[4] Jasik, Henry, "V-H-F 'V' Antenna for aircraft."

[5] Jasik, Henry, "U H F. V Antennas For Use On Aircraft "

[6] Jasik, Henry, "Experimental Measurements on U H.F. 'V' Antennas."

[7] "Very High-Frequency Techniques," compiled by Staff, Radio Research Laboratory, Harvard University, 1947, Vol I, pp 86-88

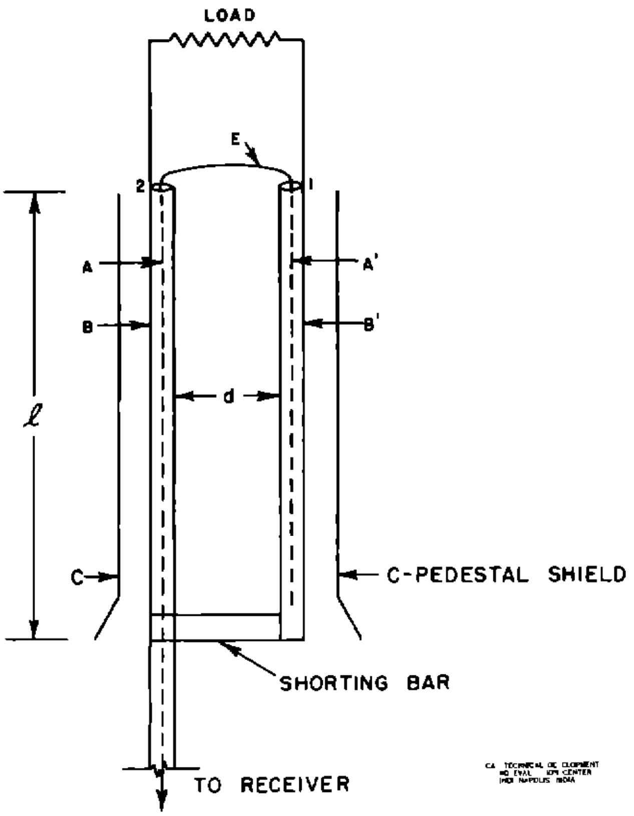

Fig. 1 Diagram of a Modified Type III Balun

mately 30 ohms, but this value is reduced by the proximity of a ground plane at a distance of less than one-half wavelength For reasons discussed in this report under "Tests," a pedestal height of 18 inches was selected as the most satisfactory compromise between optimum electrical performance and aerodynamic considerations. At this distance above a ground plane the radiation resistance of the V antenna measured 25 ohms and a 2 to 1 impedance transformation is required to match the antenna to 50-ohm transmission line.

Since the balun section consisted of quarter wavelengths of coaxial cable, it was found convenient to construct this unit of cable having the proper characteristic impedance to match the antenna to 50-ohm transmission line The impedance of such a matching section may be readily determined by the equation

$$Z_o = \sqrt{Z_c Z_a} \tag{1}$$

where

Z_o = characteristic impedance of the matching section
Z_c = characteristic impedance of the transmission line
Z_a = impedance of the load plus the impedance seen between points 2 and E, Fig. 1. In the case of the V antenna, the proper impedance for the matching section was found to be 35 ohms

Although the balun section, considering the outer conductor of the cables to the shield B to C and B' to C, presents a nearly infinite impedance between load and line at a frequency at which its physical length is equal to an electrical quarter wavelength, the characteristic impedance of the coaxial cable selected to make up the section (conductors A to B) will remain constant, and this cable, therefore, may be used as an impedance matching section

The relationship shown in the equation demonstrates that by the proper choice of

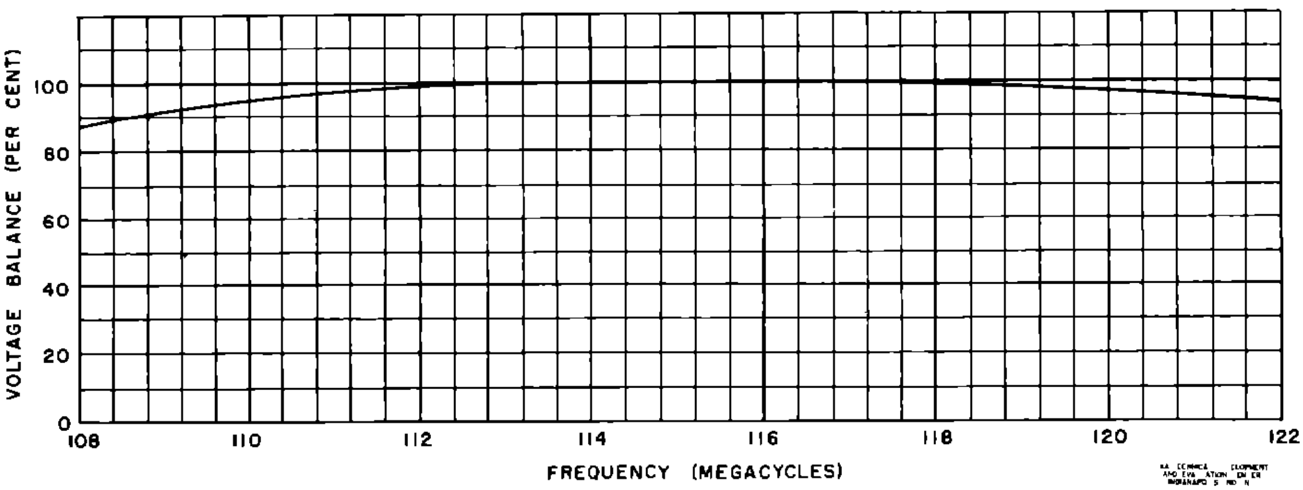

Fig. 2 Voltage Balance Obtained With Type III Balun

Z_o, Z_a can be made to assume the desired value to match the transmission line feeding the antenna at a given frequency If the frequency is varied, but Z_a does not change since Z_o is constant, a match will be maintained It is known, however, that Z_a changes with frequency, but there are two balancing factors that tend to keep this impedance relatively constant These factors are the antenna reactance which becomes negative with a reduction in frequency and the shunting reactance of the balun which is positive under the same conditions of frequency change. The inverse of these reactance changes will, of course, be true if the frequency is raised With these factors tending to maintain a nearly constant Z_a and with fixed values of Z_o and Z_c, it is possible to secure a satisfactory impedance match between transmission line and antenna over the required band of frequencies

DESCRIPTION

The Type V-109 antenna consists of four units, viz , the pedestal, the head, the antenna elements, and the balun section

The pedestal, which in a standard installation is 18 inches high, is constructed of aluminum sheet formed into a tube having an airfoil section welded at the trailing edge The top and base plates of aluminum sheet also are welded in position The head is machined from methyl methacrylate plastic similar to Lucite, and the two sections are bonded together with a di-methyl chloride solvent The head is attached to the top plate of the pedestal by means of steel screws which are safety-wired before installation A neoprene gasket is used between head and pedestal for weather-proofing

The antenna elements may be made either of ALCOA Type T-533 streamlined aluminum tubing drawn together, welded, and finished with a rounded tip at the outer extremities or of solid aluminum bar stock machined to similar proportions If tubing is selected, a tapered aluminum slug machined to fit the inner contour of the elements is used for additional strength Brass screws passing through the tapped elements extend through the bottom of the head into the pedestal to provide electrical connections If desired, the elements may be anodized to retard corrosion

The balun section contained within the pedestal is made up of 35-ohm coaxial cable supported in a Bakelite tube. This balancing and matching device is connected to the antenna element terminals in the head and terminates in a Type 82-24 Amphenol fitting at the base

The total weight of the antenna and 18-inch pedestal with balun, base plate, and connectors is 2 pounds 9 1/2 ounces Fig 3, a disassembled view of the antenna, shows the several component parts, and Fig 4 illustrates the general construction of the unit

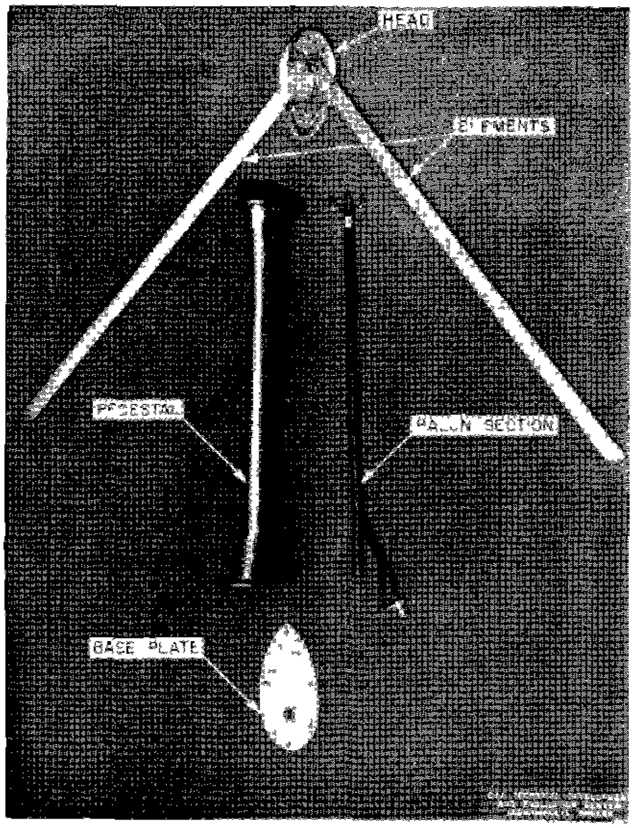

Fig 3 Disassembled View of the Component Parts of the Antenna

INSTALLATION

The V-109 antenna may be mounted in either of two positions on most aircraft forward on the fuselage or aft on top of the vertical stabilizer The forward position offers advantages in ease of installation and the possibility of a very short transmission line to the receiver, but operational difficulties may be encountered in the form of propeller modulation and polarization effects [8]

[8] Hurley, H C , S. R Anderson, and H F. Keary, "The CAA VHF Omnirange," CAA Technical Development Report No. 113, June 1950, pp 56-59

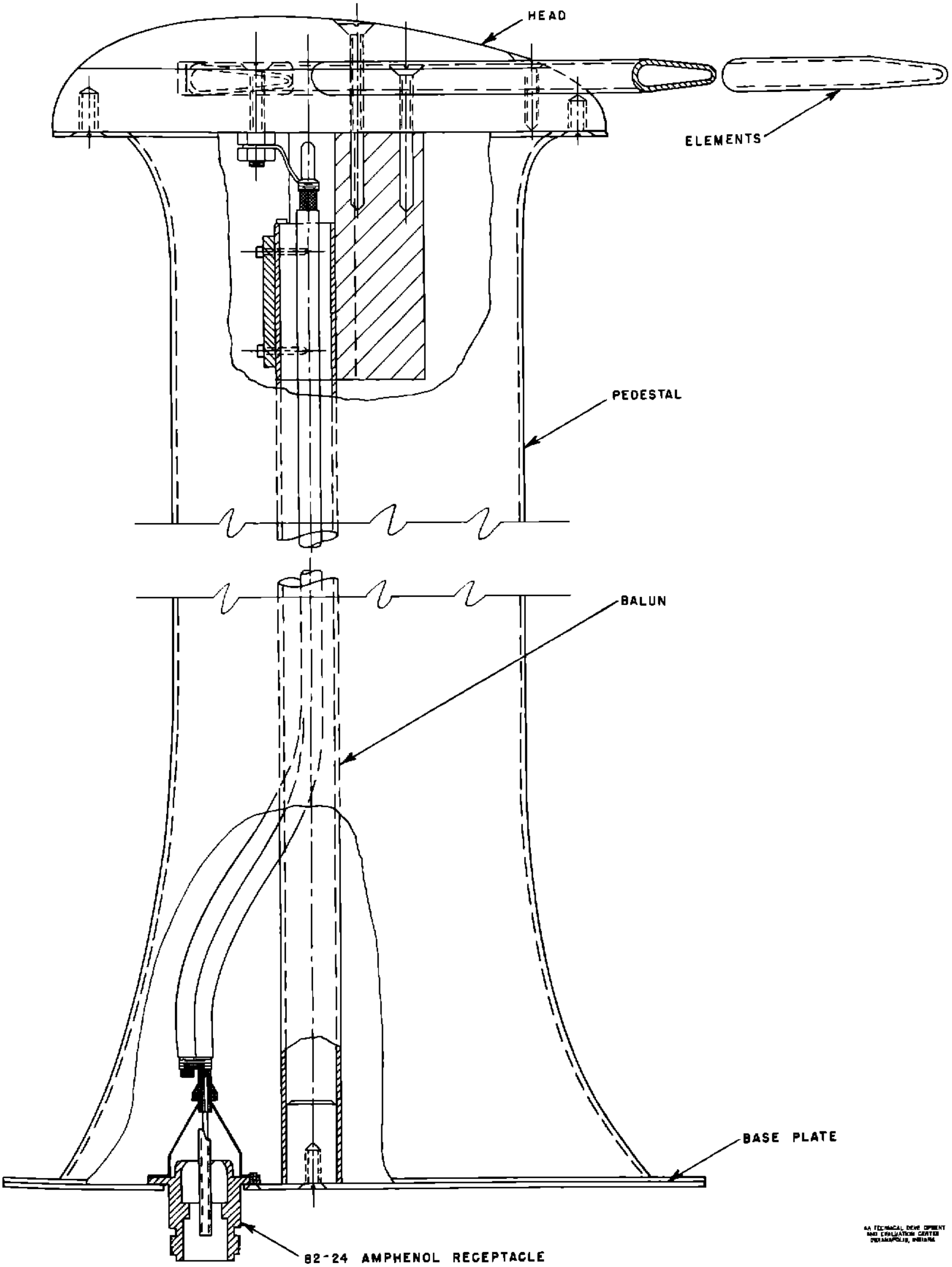

Fig. 4 Main Assembly Antenna V-109

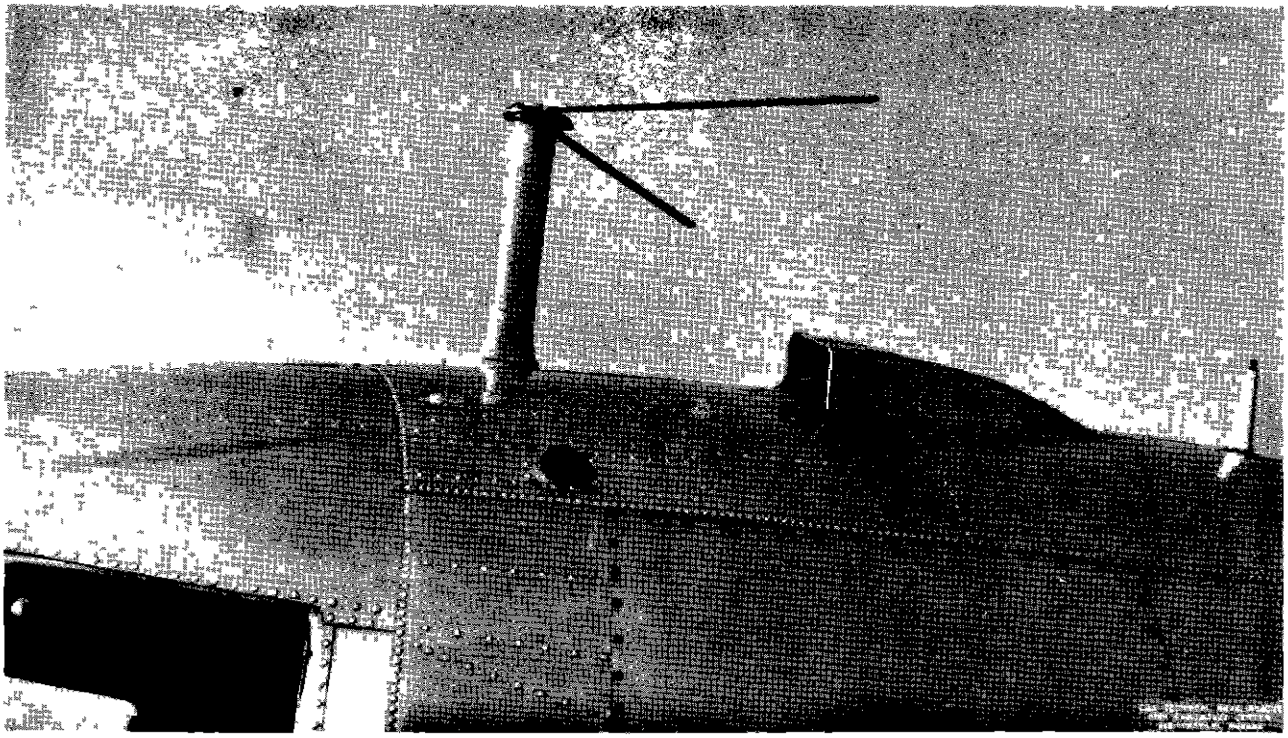

Fig 5 Typical Installation of V-109 Antenna in the Forward Mounting Position on a Douglas DC-3

The tail mounting position on the other hand, constitutes a somewhat more difficult installation problem, necessitates a longer transmission line, and may require some strengthening of the vertical stabilizer assembly It is the most desirable location for a VHF antenna. Essentially free space conditions are obtained in the tail mounting position, and both an improvement in operation with respect to freedom from polarization effects and a considerable reduction in propeller modulation interference will be noted

Fig. 5 shows a typical installation of a V antenna in the forward position on a Douglas DC-3 airplane In this case the V-109 antenna simply replaced an AS-27/ARN-5 U antenna Fig 6 illustrates one method of mounting the V antenna on the vertical stabilizer of a similar aircraft. For light aircraft the usual location for a navigational receiver antenna is in the forward position,[9] although a tail mounting has been used successfully on Ryan Navions and on some Grumman amphibians where a forward position is undesirable Fig 7 shows the installation of a V-109 antenna on a Globe Swift, while Fig 8 shows a modified V-109 antenna with a shortened pedestal mounted on an F-80 turbo-jet type of aircraft

Regardless of the location of an antenna of this type, the installation should be made in such a manner that the antenna elements are in a horizontal plane during level flight.

TESTS

Tests of the V antenna included measurements of voltage standing wave ratios, field patterns, gain, polarization and propeller modulation effects, drag, and ice accretion

Voltage standing wave ratios plotted against frequency are shown for both free space and ground plane conditions in Fig 9 These measurements were made with an Andrew Co Type 3100 slotted line and associated traveling voltmeter, in conjunction with a Ferris Model 18-C Microvolter signal generator The standing wave ratio of the slotted line when operated into a purely resistive dummy load of 52 ohms measured 1 05 A correction factor, to

[9] Gehres, F , E C Gregory, and James O Martin, "The Development of Techniques for the Utilization of VHF Radio in Light Aircraft," CAA Technical Development Report No. 116, June 1950

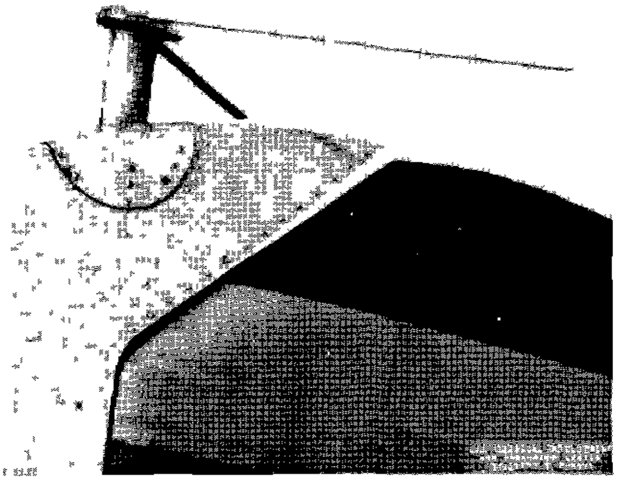

Fig 6 V-109 Antenna Mounted on the Vertical Stabilizer of a Douglas DC-3

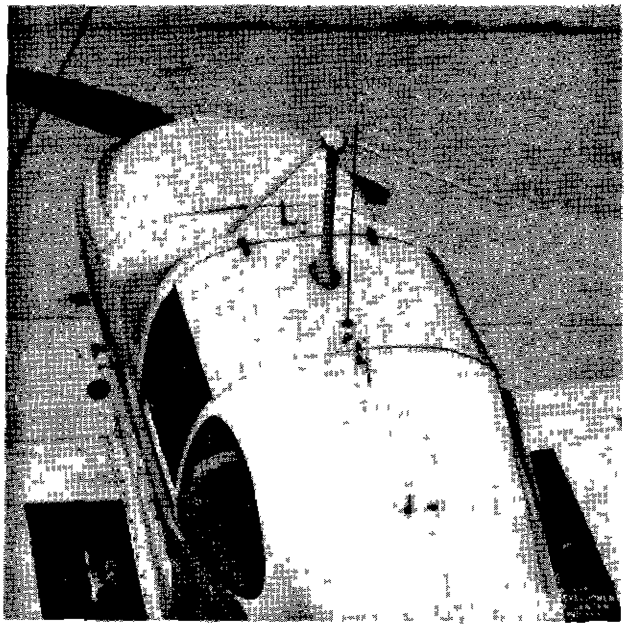

Fig 7 V-109 Antenna Mounted on a Globe "Swift" (18-inch Pedestal)

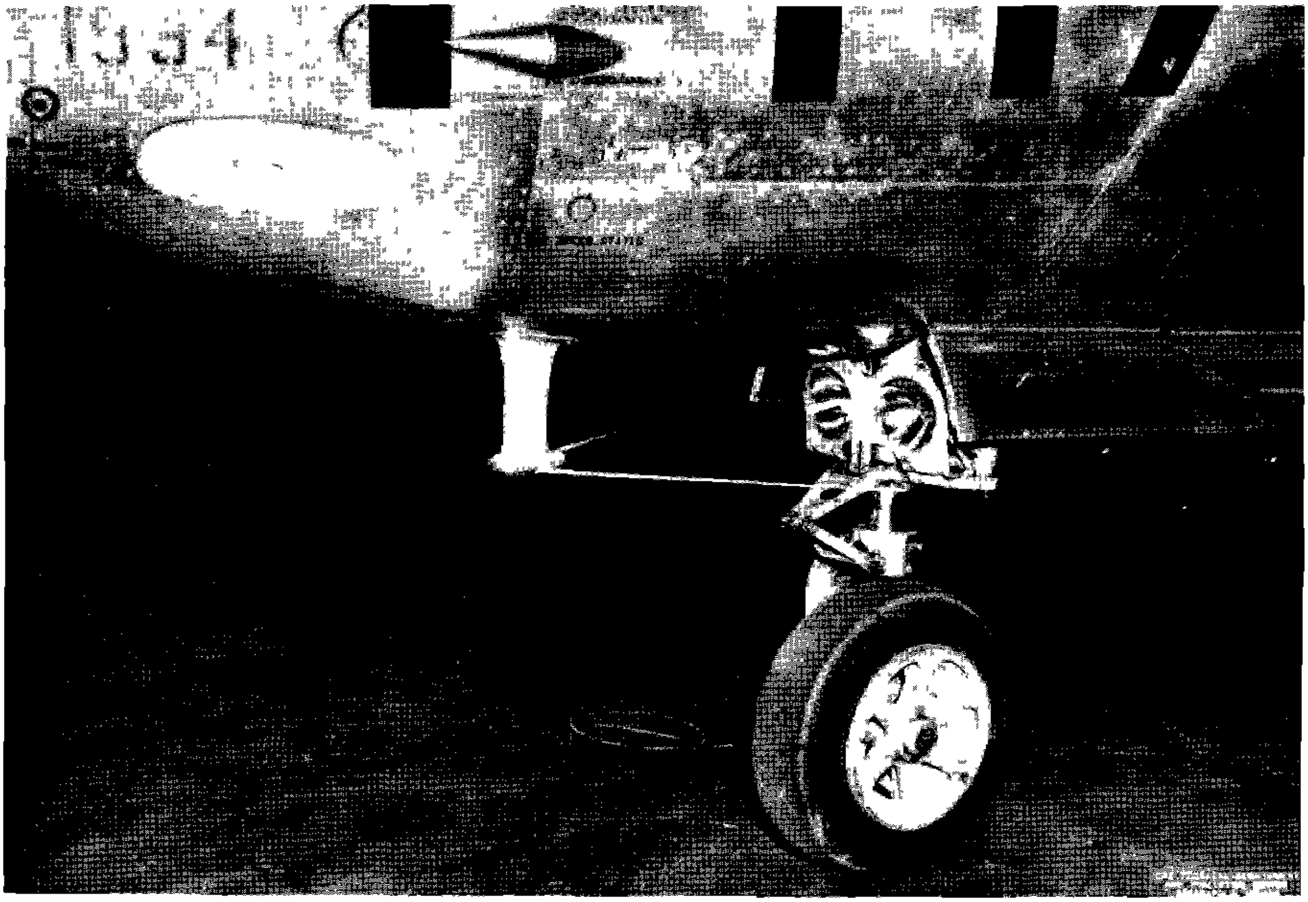

Fig 8 Modified V-109 Mounted on an F-80

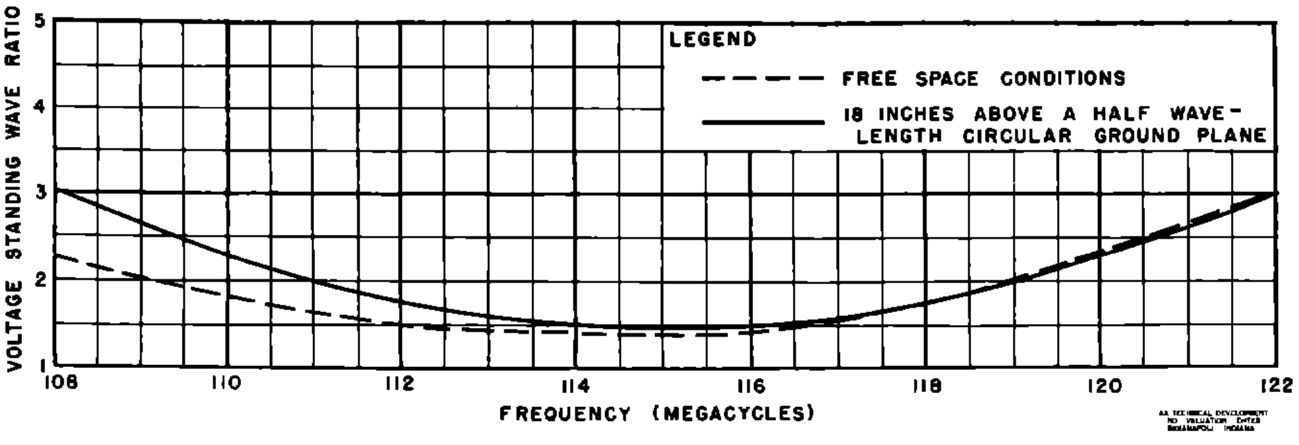

Fig 9 Voltage Standing Wave Ratios V-109 Antenna

compensate for attenuation of the reflected wave in the length of coaxial line connecting the slotted line to the antenna, has been added to all measurements to show true standing wave ratios

Both laboratory and flight techniques were employed in determining the horizontal field pattern of the antenna In the laboratory measurements, the antenna was mounted on a calibrated rotatable platform, with a signal source located several hundred wavelengths away The field strength was measured with a Stoddart Aircraft Radio Co. Model NMA-5 field intensity meter Measurements of signal level were taken each 10°, while the antenna was rotated through 360° of azimuth The field pattern shown in Fig 10A was obtained in this manner Flight tests to investigate the field patterns of both the forward and tail mounted V antennas on a Douglas DC-3 airplane were conducted by flying circles of small radius about a point 40 miles removed from a signal source. As in the laboratory method, measurements of signal level were taken every 10° in azimuth, utilizing the same field intensity measuring equipment Figs 10B and 10C show the field patterns obtained in the flight tests.

Comparing Figs 10B and 10C, it may be seen that in a flat circle, a condition in which the antenna elements remained in a horizontal plane, the field pattern of the antenna mounted on the vertical stabilizer of the aircraft resembles that obtained by laboratory measurements, while the forward V exhibits a more nearly circular pattern When the tests were repeated with the aircraft in a 30° bank, the pattern of the tail mounted antenna still retained a similarity to the calculated pattern, whereas the pattern

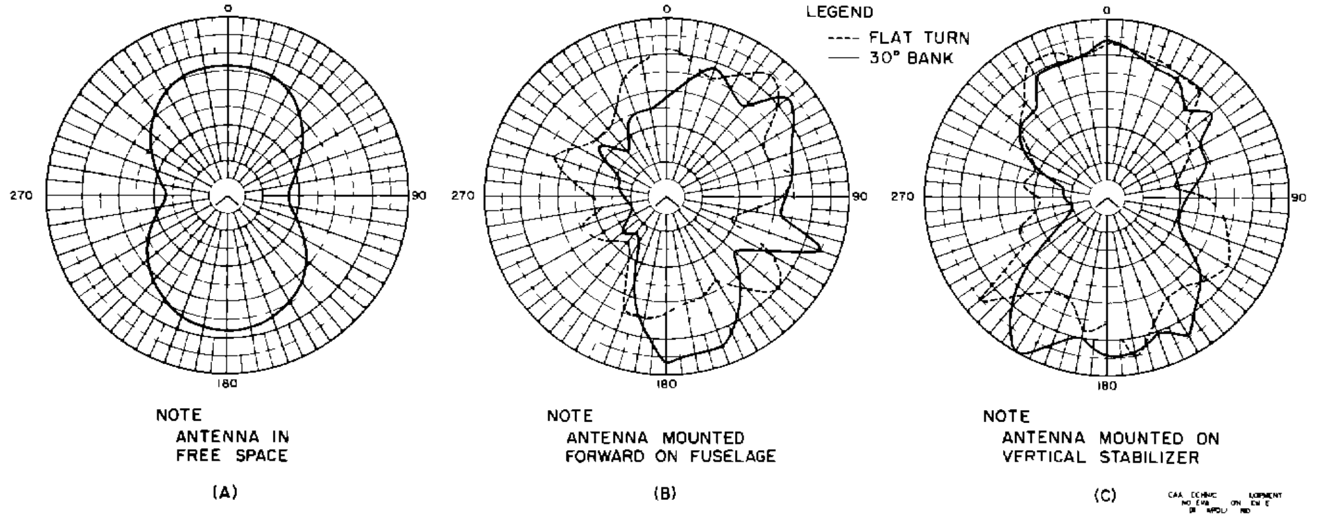

Fig 10 Field Patterns in Horizontal Plane of V-109 Antenna

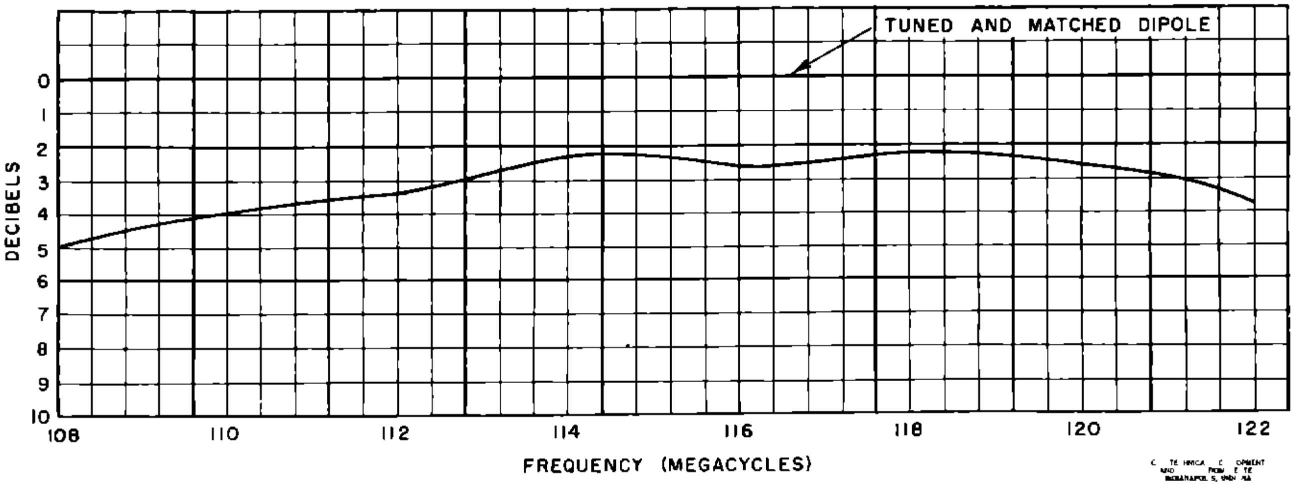

Fig 11 Gain of V-109 Antenna Relative to Tuned Dipole

obtained with the forward antenna was considerably distorted It should be noted that all measurements of flight field patterns are relative and should not, therefore, be used as comparative gain measurements

To determine the gain of an antenna the signal strength obtained at a receiver from the antenna under test can be compared with that secured when utilizing a one-half wavelength dipole, the elements of which have been adjusted to proper length for each operating frequency to be investigated Such tests revealed that the gain of the V-109 antenna is slightly more than 2 db below that of a dipole at midband, and approximately 5 db below that of a dipole at the extremities of the band 108 to 122 Mc Fig 11 shows the relative gain of the subject antenna at several frequencies

The relative gains of V antennas mounted forward on the astro-dome and aft on the vertical stabilizer of a Douglas DC-3 were measured 1,000 feet above a ground check point 26 4 miles from a VOR station Pedestal heights of 9 and 18 inches were used in the forward position and 5 inches in the vertical stabilizer position The aircraft was headed to the station and each antenna, in turn, was connected to a field intensity meter An average number of these trials revealed that the forward antenna on an 18-inch pedestal delivered approximately 6 db lower signal level than the tail mounted unit, while the forward antenna on a 9-inch pedestal was 12 db below the tail antenna

Omnirange and localizer facilities radiate horizontally polarized energy, but currents induced on the surface of vertical objects in the immediate field, such as the pedestals supporting the sideband loops in the omnirange antenna system,[10] will radiate some energy that is vertically polarized The presence of this vertically polarized energy in the received signal can produce course errors, and for this reason it is essential that the receiving antenna be comparatively insensitive to the reception of any but horizontally polarized energy Early tests indicated that the magnitude of these polarization errors in a well-balanced air-borne antenna system is largely determined by the location of the antenna on the aircraft and its height above the conducting surface (skin) of the aircraft

In order to study further these polarization effects, a V-109 antenna was mounted on a 5-inch pedestal on top of the vertical stabilizer of a Douglas DC-3 and used as a reference to check similar antennas on 9- and 18-inch pedestals located on top of the forward astro-dome of the same airplane The following polarization tests were conducted 20 miles from the Indianapolis VOR station at an altitude of 1,000 feet

A 30° Wing Rock

Headed toward the station the aircraft is banked ±30° The course deviation indicator current was recorded and converted to degrees of course displacement

B Eight Ways Over a Ground Check Point

While recording the course deviation indicator current, the aircraft was flown on eight different headings over a specific

[10]Hurley, H C , S R Anderson, and H.F Keary, "The CAA VHF Omnirange "

TABLE I

Flight Polarization Errors

Flight Test	Tail V Degrees(±)	Forward V-109 9-inch Pedestal Degrees(±)	Forward V-109 18-inch Pedestal Degrees(±)
360° Circle	0 53	1.85	0 7
Eight Ways Over a Point	0 25	1 25	0 25
±30° Wing Rock	0.25	0 25	0.25

ground check point The recorded bearing was marked and the indicated bearing was compared with the magnetic bearing. The zero reference point in each case was that obtained while flying over the point headed to the station

C. 360° Circle

Starting from a heading toward the VOR station, a 360° circular pattern was flown at a constant 30° bank The course deviation indicator current was recorded during the circle and converted into degrees of error from the azimuth course being flown at the beginning of the circle Since the aircraft in the 360° circle was changing azimuth slightly with respect to the VOR, this deviation was computed in degrees and subtracted from the indicated course deviation error, resulting in the numerical value of polarization error

Maximum errors observed in the three tests are shown in Table I

During this investigation, it was considered feasible to examine the effects of propeller modulation as a source of error by using the antenna mounting positions and pedestal heights previously described. This test was made while flying a radial toward the VOR with the aircraft engine speed adjusted to 2, 133 rpm. The oscillation of the course deviation indicator due to propeller modulation was measured in degrees of course displacement Maximum errors are shown in Table II.

As a result of the polarization and propeller modulation tests, it was concluded that the most suitable mounting position for a navigational receiver antenna was on top of the vertical stabilizer of the aircraft However, if conditions dictate a forward mounting position, very satisfactory operation may be obtained if the V antenna is supported by a pedestal 18 inches in height, and this value was adopted as standard in the final model

Drag measurements of the V-109 antenna mounted on an 18-inch pedestal were conducted in the wind tunnel of the Polytechnic Institute of Brooklyn, N Y These tests revealed a measured drag of 0 59 pound at a dynamic pressure of 27 pounds per square foot, equivalent to a velocity of 105 mph Extrapolation indicates that a drag of 2 36 pounds might be expected at 210 mph The head and elements of the antenna, without the pedestal, exhibited a measured drag of 0 18 pound at 105 mph and an estimated drag of 0 72 pound at 210 mph The latter figures are of special interest in the application of the antenna to a mounting position on the vertical stabilizer of aircraft, for in this type of installation the pedestal height may be reduced to only four or five inches with a resultant reduction in the total amount of drag of the unit Since the velocities obtainable in this wind tunnel were of limited magnitude, further investigations of the antenna at increased airspeeds were considered advisable

Vibration and icing tests at velocities to 300 mph were later conducted in the icing research tunnel of the NACA Lewis Flight Propulsion Laboratory In these studies special emphasis was placed on mechanical design considerations, and in this connection two types of antenna elements as well as two kinds of material for head construction were

TABLE II

Propeller Modulation Errors

Flight Test	Tail V-109 Degrees(±)	Forward V-109 9-inch Pedestral Degrees(±)	Forward V-109 18-inch Pedestal Degrees(±)
Propeller Modulation	0 25	3.25	2 5

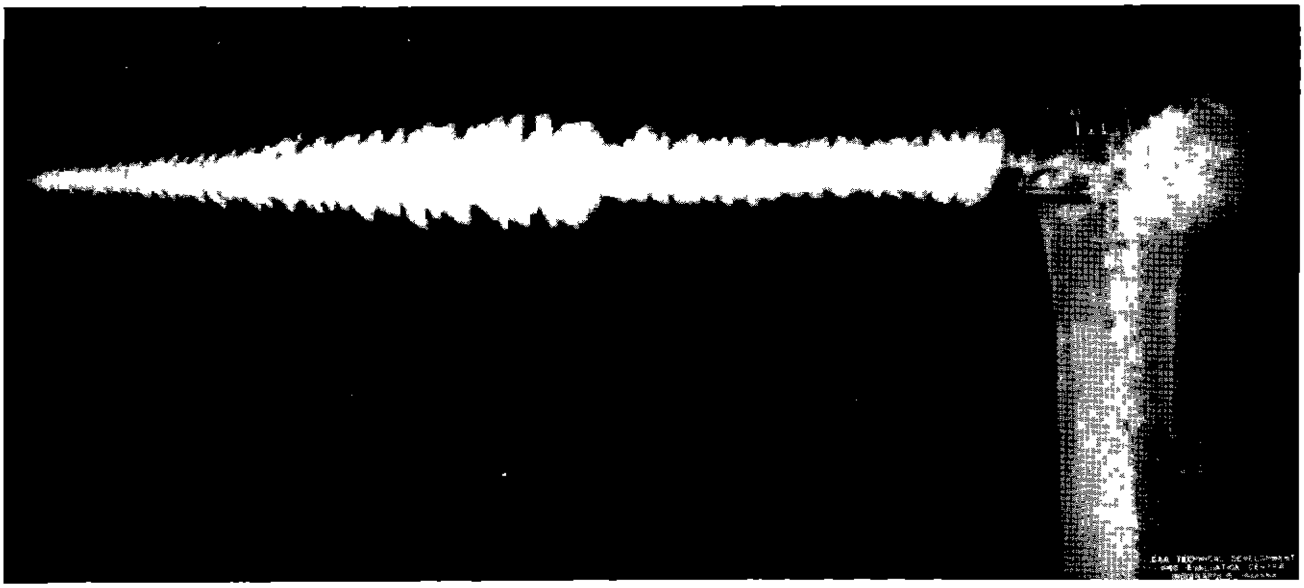

Fig. 12 V-109 Antenna After Severe Icing and Air Speeds to 300 mph

examined One of the sets of antenna elements tested consisted of hollow streamlined aluminum tubing, while the other was similar except for the addition of solid aluminum inserts machined to fit the inner contour of the tubing Materials tested for head construction were linen-based Bakelite and methyl methacrylate (similar to Lucite)

These wind-tunnel tests conducted with and without ice and at air velocities from 100 to 300 mph demonstrated conclusively that antenna elements containing the insert were highly superior to the hollow tube type with respect to vibration and fatigue failure Tests of the head materials were not so conclusive as those of the elements, but results indicated some superiority of the methyl methacrylate over the Bakelite in that the plastic retains a degree of elasticity even at low temperatures and tends to damp out vibration of the elements. Fig 12 is a reproduction of a photograph taken after extended tests in the icing tunnel The antenna employed a plastic head and elements with solid inserts

Because of lack of access to wind tunnels in which air velocities of 500 to 600 mph are produced, very little laboratory data has been secured on the aerodynamic performance of the modified jet type of V-109 antenna However, one of these units installed on an F-80 (see Fig 8) was subjected to more than 200 hours of flight time over a period of approximately one year without developing either mechanical or electrical difficulty This experience demonstrates the worth of the antenna at altitudes up to 45,000 feet and airspeeds to 610 mph.

CONCLUSIONS

1 The antenna exhibits broadband characteristics over a frequency range extending from 108 to 122 Mc

2 The antenna compares favorably with a dipole with respect to gain

3 The field pattern of the antenna shows minima which are at least 40 per cent of the maximum field.

4. The antenna responds primarily to horizontally polarized signals with a minimum of response to vertically polarized signals

5. The antenna is light in weight but of substantial weather-resistant construction.

6. The design of the antenna is such that drag is reduced to a low value

7 The antenna is equally adaptable to a mounting position forward on the fuselage or aft on top of the vertical stabilizer of the aircraft

8 With only minor modifications the antenna can be mounted on either light or heavy types of aircraft

9 The antenna is so matched and balanced that single coaxial cable may be used as a transmission line to the receiver

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