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Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/21273256
Report (National Research Council of Canada. Radio and Electrical Engineering Division : ERB); no. ERB-399, 1956-05

ERB-399

SECRET

NATIONAL RESEARCH COUNCIL OF CANADA
RADIO AND ELECTRICAL ENGINEERING DIVISION

FLIGHT TRIALS OF GROUND-TO-AIR COMMUNICATION USING MARK X IFF

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OTTAWA
MAY 1956

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TEXT

ABSTRACT

Flight trials were conducted with a system whereby emergency ground-to-air communications can be established with Mark X IFF-equipped aircraft. Pulse-frequency modulation is used with a carrier consisting of double pulses (spaced 11 microseconds) at a mean PRF of 6000 pulse-pairs per second. These pulses are transmitted from a ground interrogator (actually a modified airborne transponder) using the antenna of a TPS-1D radar set as a steerable antenna, and the IFF reply for tracking. In the aircraft, a decoder-demodulator circuit employing one tube envelope and weighing less than three pounds in its experimental form, is connected to a video test receptacle already provided on the IFF unit. When the aircraft was within IFF range (the maximum obtained being 115 nautical miles at 10,000 feet), communications of good quality were established with no appreciable interference to the IFF operation of the interrogator associated with the voice transmitter nor to the operation of remote interrogators. Both the reception in the aircraft and the original transmissions were tape-recorded. A composite tape of transmitted and received signals has been prepared for comparison of the two, and this tape may be obtained on loan from the author.

FLIGHT TRIALS OF GROUND-TO-AIR COMMUNICATION USING MARK X IFF

- J.R. Kenney -

INTRODUCTION

In a previous report [1] a system was described whereby the interrogation link of the Mark X IFF equipment might be used for ground-to-air communication in the event of failure or jamming of the existing communication link. At the time of writing the above report, the proposed system had undergone laboratory tests only, but it was suggested that the results were sufficiently promising to warrant flight trials. This report describes the proposed communication system, the flight trials which were carried out during the latter part of May 1956, and the results of the trials.

The abbreviation "CUFF", meaning "Communication Using IFF" became associated with the project, and will be used in this report to designate the system.

GENERAL DESCRIPTION OF THE SYSTEM

The experimental system used pulse-frequency modulation of a ground interrogator associated with a TPS-1D radar set. In practice, an auxiliary ground interrogator would be used for CUFF with a separate antenna, steerable on to the bearing of the aircraft. However, for these trials, the radar antenna, fed through the integrated IFF feed, was used as the steerable antenna. Double pulses spaced at 11 microseconds are generated at a mean rate of 6000 pulse-pairs per second, and this rate is modulated by the voice frequencies to be transmitted. To prevent undue intermodulation distortion with the 6000-cps pulse carrier, voice frequencies are limited to an upper frequency of 2 kc/s. Since the spacing of these double pulses is different from the spacings used for normal interrogations, the transponder trigger circuits are not affected. In the aircraft the pulses appear as video pulses at a low impedance level at a video test receptacle (J-104) on the front of the APX-6 transponder. A coincidence decoder, low-pass filter, and amplifier (using one tube envelope) are then used to recover the voice frequencies. An indicator light is also provided to indicate automatically in the aircraft that CUFF is in use. Thus, in the aircraft, the APX-6 serves as the receiver for this communication system, and requires only the addition externally of a small demodulator, which, without using miniature components, weighs 3 pounds, and occupies a space 3 by 5 by 7 inches.

TRANSMITTING EQUIPMENT

The transmitting equipment employed an APX-6 transponder which had been

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[1] Kenney, J.R. Ground-To-Air Communications Using Mark X IFF, NRC Report ERB-364 (SECRET).

modified by the RCAF to serve as a ground interrogator. When so modified, single trigger pulses into the unit produce an output of radio-frequency pulse-pairs, separated by 3, 5, or 8 microseconds, depending upon the position of a mode selector switch located on a separate power supply unit. For CUFF operation, with high PRF and 11-microsecond pulse-pairs, the following additional modifications were made to the unit:

1) For convenience with an experimental setup, the H.T. voltage from the power supply was made variable by bringing the primary of the H.T. transformer out to a Variac. Separate transformers were added to provide the 5.0 and 6.3 filament voltages originally supplied from windings on the H.T. transformer.

2) The 15-ma filter choke in the H.T. supply was changed to a Hammond type-157 choke to accommodate the 50-ma current drain when operating as a CUFF transmitter.

3) Meters were mounted on the unit to indicate H.T. voltage, modulator plate current, and radio-frequency oscillator plate current.

4) To produce 11-microsecond pulse-pairs from the transmitter, trigger pulse-pairs are fed into a second trigger input circuit, for which a single output pulse is produced for each input trigger pulse. For this modification, the grounded grid of the cathode-driven modulator trigger tube (V-121B) was provided with a grid leak, and brought out to a connector on the front of the unit.

CUFF trigger pulses for the transmitter are obtained from a circuit employing a multivibrator with a linear "frequency versus grid-return-voltage" characteristic. The rate of the multivibrator, which functions only when the microphone button is pushed, can thus be frequency-modulated by the amplified voice frequencies from the microphone. The square-wave output of the multivibrator is differentiated to provide frequency-modulated pulses at a mean PRF of 6000 per second with a maximum deviation of ± 2 kc/s. It is explained under "Interference Effects" (see page 4), that if simultaneous interrogation and CUFF transmission is required from the one ground station, it is desirable to eliminate interference between the two functions by gating circuits which suppress interrogation pulses for approximately 68 microseconds before, and 15 microseconds after, the first pulse of a CUFF pulse-pair. Therefore, the pulses obtained from the frequency-modulated multivibrator are used to trigger a 68-microsecond gating pulse. The differentiated trailing edge of this pulse triggers a 15-microsecond gate, as well as a blocking oscillator, with its output driving a cathode follower connected to a 5.5-microsecond open-circuited delay line. The incident and reflected pulses, 11 microseconds apart, are amplified and connected to the grid of the modulator trigger tube in the APX-6 transponder as outlined in modification (4) above.

A second gating circuit in the CUFF trigger generator is used to suppress the output of the ground receiver during the triggering of the transmitter by a voice-carrier pulse. Otherwise, due to leak-through of the CUFF pulses into the receiver of the interrogator, the random voice-carrier pulses would appear on the PPI display as well as the IFF reply pulses.

The CUFF trigger generator and gating circuits employ 15 tubes; no attempt was made to minimize the number of tubes. Seven of these tubes are used for generating the CUFF trigger pulses, five for interrogation gating, and the remaining three for video reply gating. The power supply requirement is 125 milliamperes at 300 volts d-c.

At the mean voice-carrier PRF of 6000 pulse-pairs per second, the type-3E29 modulator tube reaches its limit of peak plate current (2.5 amperes max.) and average plate dissipation (15 watts max.) at a plate voltage of 1000 volts. This is only 10% below the 1100-volt output normally generated by the separate power supply with full line voltage across the primary of the H.T. transformer. With this reduced voltage, the type-2C42 radio-frequency oscillator operates well within its rated average dissipation of 25 watts, and delivers a peak radio-frequency pulse power of about 250 watts.

AIRBORNE DEMODULATOR

An airborne demodulator was described in detail in the preliminary report [Kenney, op.cit.]. However, the unit used in the flight trials was modified somewhat to improve the signal-to-noise ratio at low signal levels, by providing limiting action after decoding. It was found that even for signals strongly limited in the APX-6, the pulse output of the decoding delay line has random amplitude variations, which, without further limiting, produce noise in the output of the unit. Positive video pulses from the transponder are coupled through a crystal diode to a 6-microsecond delay line with a terminating resistor on the input end only. Pulses impressed upon the line are reflected without change in polarity from the open end of the line back to the input, where the pulses "see" only the terminating resistor at the input to the line, and no further reflections occur. If at some point on the line, an incident pulse meets the reflection from a previous pulse, the pulse amplitudes add. For 11-microsecond pulse separation with the delay line used, this addition occurs at a point three sections from the input. This point is connected through a crystal diode, biased so that only the larger pulses from an 11-microsecond pulse pair pass through it to a pulse stretcher. The grid of the following "grounded-cathode" amplifier (one section of a type-12AU7 tube) acts as a limiter, with the plate circuit driving a low-pass (2 kc/s cutoff) filter. The output of the filter contains the voice frequencies with the 6000 cps. carrier suppressed. This output is amplified in the second section of the tube, with the 10K coil of a sensitive relay as a plate load.

Owing to the presence of a crystal diode across the input to the low-pass filter, a positive d-c bias is obtained at the filter output as well as the audio frequencies when the CUFF carrier is present. This positive bias causes the plate-circuit relay to close, which in turn lights an indicator bulb, to show that the system is in use. The audio output from the plate of the audio amplifier is coupled through a volume control to a small audio output transformer (33 : 1 impedance ratio) so that the output of the unit can be connected to the 500-ohm inter-communication system of the aircraft.

The B+ power for the CUFF demodulator is obtained from the 110-volt a-c 400-cps aircraft supply, with a selenium rectifier, while the filament power is obtained from the 26-volt d-c aircraft supply with a suitable dropping resistor. The a-c power requirement is about 2 watts, and the d-c consumption is 4 watts.

INTERFERENCE EFFECTS

Preliminary laboratory tests indicated that even with a decoding circuit in the airborne demodulator to reject all but 11-microsecond pulse-pairs, the presence of random interrogation pulses would degrade the CUFF reception by introducing noise. This action can be attributed to the presence of an echo-suppression circuit in the transponder, by which the sensitivity of the receiver is decreased for a few microseconds following a received pulse, or following a reply pulse from the transponder. The time constant of the suppression circuit is 5 microseconds, but the actual suppression time depends upon the relative strengths of the pulse producing the suppression, and the pulse following it. Thus, a voice pulse-pair may be missed and a noise spike produced in the CUFF demodulator, if either pulse of the pair follows within a few microseconds of an interrogation pulse or a reply pulse. For interrogators remote from the CUFF transmitter, the CUFF operator has, of course, no control over the interrogations. However, unless the aircraft is quite close to the remote interrogator, such interrogations are present for only a fraction of a second for each revolution of the radar antenna, and the noise introduced into CUFF reception is negligible.

Interrogations originating from the CUFF transmitter are triggered in synchronism with the radar set, but these pulses occur at random times with respect to the CUFF pulses, and interference to CUFF reception would occur at all times unless preventive steps are taken. Although voice transmissions are still quite intelligible with this noise background present all the time, it is a source of noise which is under the control of the operator, and can be eliminated. Suppressing all interrogation pulses during a CUFF transmission would be the simplest way to accomplish this. However, if it is considered necessary to have simultaneous interrogation and CUFF transmission from one site, the interference can be eliminated by suppressing only those interrogation pulses occurring at times relative to the voice pulses which would cause interference to CUFF. The worst condition is with "mode three" interrogation and emergency reply, in which case the last reply pulse occurs 58 microseconds after the first interrogation pulse. Furthermore, it is undesirable to have the first of a voice pulse-pair follow within 10 microseconds of the last reply pulse, to prevent these pulses forming a chance interrogation pulse-pair. Thus, a 68-microsecond gate (58+ 10 microseconds) suppressing interrogation pulses for this period preceding each voice pulse-pair would be needed to eliminate interference in the worst situation. Since it is also undesirable to have an interrogation pulse occur within a voice pulse-pair, the interrogation pulses should also be suppressed for about 15 microseconds after the first voice pulse. This was the system used in the flight trials. Interrogation pulses are suppressed for a total of 83 microseconds for each voice pulse-pair, which on the average are separated by $10^6/6 \times 10^3 = 167$ microseconds. As a result, about half of the interrogation pulses are suppressed during a CUFF transmission, but this did not prove to be serious with a normal interrogation rate of 400 cps.

GROUND SETUP

The radar set used in conjunction with the CUFF transmitter was a trailer-mounted TPS-1D L-band radar, on loan from the RCAF and located at the NRC Radio Field Station, a few miles south of Ottawa. This radar has complete provision for operation with an IFF interrogator, including interrogation trigger pulses, reply video input, and IFF feed to the antenna. However, instead of the normal direct connection between the radar and interrogator, the interrogation pulses and video reply were gated by circuits in the CUFF trigger generator, as described above. The radio-frequency output of the CUFF transmitter was connected directly to the IFF feed of the TPS-1D radar reflector. This antenna has a gain of about 25 db at the interrogation frequency of 1030 mc/s, with a beam width of 5 degrees.

The CUFF microphone was located in the radar trailer, where the noise level from blower motors was quite high. Two systems were tried to obtain transmissions without this noise background:

1) A tape recording was made by several different people, male and female, reading lists of words used in intelligibility tests, and giving typical commands. This tape was played back into the CUFF trigger generator. However, since the recorder available for playback was somewhat lacking in fidelity, this system was used for only one flight trial.

2) A second microphone was located in a building some 100 feet away from the trailer, and so arranged that it was automatically cut out when the trailer microphone was in use.

A VHF communication set was located in the same room as the remote microphone, as well as a dual-channel tape recorder, which recorded all CUFF transmissions on one channel, and on the other channel, all VHF transmissions to, and receptions from, the aircraft.

AIRBORNE SETUP

The aircraft used in the flight trials was an RCAF "Dakota", equipped with Mark X IFF equipment, and flown by Central Experimental and Proving Establishment, Rockcliffe. The AN/APX-6 transponder was located in the tail compartment of this aircraft with a flush-mounted antenna on the underside of the rear fuselage; the CUFF demodulator was located about 15 feet away, outside the tail compartment, so that the "in use" indicator light could be seen from the main cabin. Also located in the main cabin was an airborne tape recorder (Presto, type RC-12), on loan for these trials from the Department of Transport. This recorder has an automatic tape-reversal feature. After reversal, the recording is done on a second track, and thus, 64 minutes of uninterrupted recording time can be obtained with 7-inch reels (1200 feet of tape) at a tape speed of 7.5 inches per second. The remote control panel for the recorder was placed in the radio-navigation compartment, where the operator monitored the CUFF reception. The monitor output of the recorder was also fed into one channel of the aircraft inter-communication system, so that several persons could listen to the actual reception.

The only adjustment necessary to the CUFF demodulator is a bias setting, which is made to eliminate interrogation pulses. It should be noted that this adjustment was made in the laboratory, prior to any of the flight trials, and with a different transponder than that used in the flight trials. This procedure proved to be satisfactory, and therefore the setting of the bias control appears not to be too critical, and would rarely require adjustment.

FLIGHT TRIALS

In all, five flight trials were conducted, all following radial paths from the ground station; three flights were made eastward to Montreal, and two westward toward the radar site at RCAF Station Foymount, 70 miles west of Ottawa. On the ground, the IFF reply was used for tracking. To aid in identification, mode 2 interrogation was used, since few aircraft have their transponders switched to this mode. With a rotating antenna the IFF reply forms an arc on the PPI, and for CUFF transmissions the antenna was stopped with the PPI trace bisecting the arc so formed. At regular intervals of about 10 miles, or if the IFF reply became intermittent, CUFF transmissions were stopped while the antenna was swung a few degrees on each side of the aircraft bearing, so that the complete reply arc would be re-painted on the PPI for re-orienting the antenna. Admittedly, the radial paths flown minimized the need for this procedure, but it should be remembered that in the complete system as proposed, a separate steerable antenna would be used for CUFF, and therefore bearing information would be continuously available from the rotating antenna.

Details of each flight are given below:

Flight No. 1: Friday, May 18, 1956. Take off at 0930 hours, heading east toward Montreal at 5000 feet. At this altitude CUFF reception was readable up to 62 miles, with several fadeouts due to lack of experience in orienting the antenna. After losing CUFF as well as IFF contact at 62 miles, 5000 feet, the aircraft circled and started to climb. Contact was established again at 76 miles, 6200 feet, and out to 90 miles at 8850 feet. At about 95 miles CUFF was lost completely and the aircraft turned back toward Ottawa. CUFF was re-established at about 65 miles at 8750 feet. Several CUFF fadouts were experienced on the return flight, due to an insufficient number of antenna re-orientations to compensate for the aircraft drifting off course. The tape recording for this flight has a much higher background noise than later CUFF recordings. This is partly because all transmissions were made from the radar trailer microphone, but the main reason was faulty airborne tape-recorder technique with the CUFF output undergoing unnecessarily high attenuation followed by amplification.

Flight No. 2: Friday, May 18, 1956. Take off at 1455 hours, heading west toward RCAF Station Foymount at 5000 feet. The recorded tape was played intermittently into the CUFF transmitter for this flight, along with announcements from the trailer microphone. CUFF reception was good out to 32 miles, but several fadeouts were experienced between 32 and 39 miles. Reception and IFF contact was lost at this range, and the aircraft started to climb. At 57 miles and 7200 feet CUFF and IFF contacts were established again for a few minutes, but the CUFF background noise was fairly high. On the return flight, contact was obtained at 45 miles, and maintained with intermittent noise bursts from there in. The ranges for both CUFF and IFF contact on this flight were poor, and subsequent investigation to determine the cause revealed the TPS-1D antenna to be tilted upwards about 1.5 degrees in the westward direction. This condition was corrected before the next flight. Although it had no direct bearing on the CUFF and IFF system, a further difficulty in conducting this flight trial was caused by a nearby auroral radar set, which produced interference in the VHF receiver to such an extent that air-to-ground VHF communications were reduced to about a 25-mile range.

Flight No. 3: Tuesday, May 22, 1956. Take off at 1400 hours, heading east toward Montreal. Weather conditions limited the altitude on this flight to 3000 feet. The remote microphone setup was used, and although the modulation was somewhat lower with this microphone than with the trailer microphone, both CUFF and IFF contacts were maintained out to 63 miles. However, the tape-drive of the airborne recorder slowed down during this flight, and consequently the recording was poor.

Flight No. 4: Wednesday, May 23, 1956. Take off at 1430 hours, heading east for 10 miles and then turning west toward RCAF Station Foymount at 5000 feet. The remote microphone circuit was changed to provide the same signal level as the trailer microphone. Shortly after this flight began, the radar set failed and interrogation trigger pulses were obtained instead from a 60-cps trigger generator. Tracking was more difficult at this low PRF, and as a result both IFF and CUFF contacts became poor after 48 miles. The air-to-ground VHF communications again suffered interference from the auroral radar set.

Flight No. 5: Thursday, May 24, 1956. Take off at 1315 hours, heading east toward Montreal and then northeast toward Quebec City, climbing to 10,000 feet. Both IFF and CUFF contacts were maintained to 115 miles on the outbound trip, and contacts were re-established at 110 miles on the inbound trip. CUFF was off the air briefly on two occasions during this flight. The radar set again failed, but this time interrogation trigger pulses were obtained from a 400-cps trigger generator, so that IFF operation was normal. A further interruption of six minutes occurred when the gasoline powered motor-generator set ran out of fuel. Interference to the VHF communications was eliminated for this flight.

DISCUSSION OF RESULTS

The flight trials indicated that as long as a reasonably good IFF reply was obtained from the aircraft, male-voice CUFF transmissions from a properly oriented ground-antenna were received with high intelligibility and adequate quality for voice recognition. Only one female voice was used in the tests, but the intelligibility of the transmission was much lower, due to the relatively low cutoff frequency (2000 cps) of the CUFF demodulator. The best results for consistency of reception at shorter ranges, as well as for maximum range, were obtained on the last flight trial. The consistency of reception is attributed to experience gained in orienting the antenna, and the greater range of 115 nautical miles for intelligible reception on the outbound trip was due, of course, to the higher altitude (10,500 feet) for this flight. This range is very close to the expected line of sight range of 124 miles at this altitude. Also, on this flight, the maximum range of 110 miles for the inbound trip was only slightly less than that obtained while outbound. Greater discrepancies than this had been obtained on previous flights and had been attributed to a poorer head-on aspect for the airborne IFF antenna, since it is mounted on the sloping part of the rear fuselage, and is somewhat shielded from the front. However, the results of the last flight trial indicate that the discrepancies for the earlier flights were probably due less to antenna aspect than to the fact that it is more difficult to pick up an inbound aircraft than to follow an outbound one. The CUFF ranges obtained on the other two eastward flights at lower altitudes were also close to expected line-of-sight ranges. Such is not the case for the westward flights towards the radar station at Foymount. It was anticipated that noise would be introduced into the CUFF reception for an aircraft flying close to a ground interrogator, but distant from the CUFF transmitter, just as interrogations originating with the CUFF transmitter caused interference unless a gating circuit was used. However, such interference was not the fundamental reason for the poor westward CUFF ranges, since even the interrogation ranges were low. For the first westward flight the poor performance was attributed to a tilted antenna pedestal, with an upward tilt to the west. For the second westward flight the radar set failed, and interrogation trigger pulses were obtained from a 60-cps trigger generator. With this low PRF, the IFF range was greatly reduced. In spite of these troubles, CUFF reception was obtained at 57 miles (13 miles from Foymount) at 7200 feet. At this distance from Foymount, the transponder would be interrogated through the full 360° revolution of the Foymount antenna. As a result, there was a higher noise background to the CUFF reception, but it was still intelligible. Since voice pulses are lost for a period following a transponder reply, the interference from a remote radar interrogation increases with the number of reply pulses. Thus, a mode two reply (two pulses) to a remote interrogator would result in more noise in CUFF reception than would a mode one or mode three single pulse reply under the same conditions, and an emergency reply (four pulses) would be even noisier. During these trials, the transponder was switched to reply to all three modes, but it is understood that the remote interrogator was operating on mode three. It should be noted that proper orientation of the CUFF antenna is most important in such a case, since the number of voice-pulses missed, and hence the noise level, depends upon the relative strengths of the interfering interrogation signals and the CUFF signals. The CUFF signals should therefore be as strong as possible, which requires good antenna orientation. This was not obtained on the westward flights. On the other hand, in the more usual situation, with a remote radar station interrogating only for a fraction of a second during a revolution of its antenna and not "ringing-around", the CUFF signal-to-noise ratio remains the same as long as the voice-pulses are at a level sufficient to limit in the APX-6 receiver. Consequently, within limits depending upon the range, exact antenna orientation is less important in this case.

As far as interference to normal IFF operation was concerned, the interrogation and reply link associated with the CUFF transmitter operated normally during a CUFF transmission, except for a slight decrease in effective range due to the suppression of about half of the interrogation pulses. For remote interrogators, it was anticipated that chance coincidences between voice-pulses and the interrogation pulses from the remote station, might cause about 4% of interrogations to result in premature or wrong-mode replies. However, this causes negligible degradation of IFF replies, since, during the flight trials, Pinetree radar stations tracking the aircraft reported no abnormal IFF replies, even though the operators were specifically instructed in advance to look for such replies.

Although difficulties of one kind or another were encountered on each flight, no failures occurred with the CUFF equipment itself, and the only modification made during the trials was provision of a remote microphone.

CONCLUSION

The flight trials demonstrated that it is entirely feasible and practical to provide emergency communication from ground to air by utilizing the receiver in the airborne IFF transponder, while meeting the requirements of negligible interference with normal IFF operation, minimum added airborne equipment, and no modification of the APX-6 airborne transponder.

Within IFF range, the intelligibility of the system is high, even though the audio bandwidth of the system was limited to 2 kc/s in a compromise between bandwidth and pulse-carrier frequency. The bandwidth could be increased to improve the reception of higher pitched female voices, at the expense of using a higher pulse-carrier frequency.

As it is difficult to assess intelligibility quantitatively tape recordings have been prepared from the air and ground tapes recorded during the trials, and authorized persons may obtain these recordings on loan from the writer.

Normal IFF operation of the interrogator associated with the CUFF transmitter would not be affected if a separate, steerable antenna were provided for CUFF, except possibly for a slight decrease in IFF range. Interference to remote interrogators is not operationally significant, and in general, such interrogators cause no appreciable interference to CUFF transmissions.

Sufficient pulse carrier power for the ground transmitter can be obtained from a modified APX-6 transponder to provide line-of-sight communication at 10,000 feet (115 nautical miles), so that adequate power for normal operational ranges should be obtainable from the usual higher powered ground interrogators.

ACKNOWLEDGMENTS

The suggestion that the interrogation link of the Mark X IFF system might be used for ground-to-air communications on an emergency basis originated with S/L D.L. Dudley, CD, RCAF. The cooperation of members of the RCAF concerned with the project is much appreciated, and thanks are especially due to F/O H.C. Baker, DRW/RW4-3-2, for negotiating equipment loans, and for advice and assistance given during the whole program, and in particular during the flight trials. The loan of the airborne tape recorder from the Department of Transport greatly simplified the flight trials. Dr. F.R. Hunt was responsible for mounting the TPS-1D radar in the trailer, and for putting it into operation. He further assisted in its operation during the flight trials. The ground recording, VHF communications, and at times remote CUFF microphone operation, all were handled by Mr. N.A.C. Lewrey. Thanks are also due to Dr. R.S. Rettie, who did the initial work on the project, for his continued guidance, and for the benefit of his experience in conducting flight trials.