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# STUDY OF AIRCRAFT RADAR TARGET SIZE

by

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## SUMMARY

This report describes a method used to determine the relative radar target size of five aircraft types These aircraft were a Twin Beechcraft C-18S, a Douglas DC-3, a Convair 340, a Piper Tri-Pacer, and a Lockheed T-33 The measurements described herein were made to provide FAA flight check personnel with information which will allow various aircraft to be interchanged in the periodic flight check tests of FAA surveillance-type radars Included in the report is a summary of data obtained and the conclusions to be drawn as to the relative detectable range of the various aircraft tested Since the altitude change resulting from flight at different airspeeds had a very significant effect on the effective radar target size, the data presented is not complete Additional tests are, therefore, recommended The report concludes the conversion factors based upon the average of many target size measurements, can not be dependably used to evaluate radar performance on a single aircraft flight

## INTRODUCTION

The FAA has many short and long-range, surveillance-type radars in operation and will expand the number of these facilities in the future Each radar is flight checked at the time of commissioning and at frequent intervals thereafter to assure that adequate performance is being obtained In the past, flight checks normally have been made using a Twin Beechcraft C-18S aircraft, however, with the increase in number of radar installations and the approaching obsolescense of the Twin Beechcraft for this application, it will not be practicable to continue this practice In order that other types of aircraft may be used interchangeably, it is desirable to obtain a target size conversion factor for each aircraft Also, since the target size on L-band and S-band radars differs for a given aircraft, it was necessary to perform tests using both types of radars

Most of the known previous efforts to determine radar target sizes of different aircraft types have dealt with absolute values rather than relative signal strength measurements Some work has been based on calculations and other work on measurements using aircraft models [1] The results of these absolute measurements have been so inconsistent, both in methods of obtaining the data and in the results, that the work has been of little value to the FAA

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[1] Donal E Kerr, "Radar Targets and Echoes", Propagation of Short Radio Waves, Radiation Laboratory Series, Vol 13, p 470

Previous work has indicated that the nature of an aircraft radar target is very complex Variations caused by multiple propagation paths have a great effect on the strength of the return signal Aircraft attidude also, has a profound effect on the return signal In tests which were performed by the MIT Radiation Laboratory it was found that for 1/3 degree change in aspect angle, the return power could change as much as 15 decibels[2] These combined effects result in a rapidly fluctuating return which is very difficult to record and more difficult to analyze.

It is the purpose of this report to describe a method and results for obtaining and analyzing target size data which is believed to be superior to the photographic method described in a preliminary report on this subject[3]

## MEASUREMENT METHOD

To obtain an accurate comparative value of relative target size, it is necessary that a large number of data samples be taken and averaged In this manner the wide variations in signal strength associated with changes in propagation paths and aircraft altitudes will integrated into an "average" difference between aircraft In practice this average difference will be difficult to duplicate on any one occasion, but for a large number of samples it should prove fairly reliable To reduce errors caused by environmental phenomonon or changes in equipment, the two aircraft being compared were in the air at the same time and were measured alternately only minutes apart They were flown at the same altitude on the same course through the same range

During the measurements, the antenna was fixed at one azimuth It was feasible to use at this azimuth a short segment of highway so situated that the extended center lines of the highway segment would pass through the radar site The test aircraft were flown over this highway and were therefore, in the fixed beam of the radar antenna Since

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[2] Louis N Ridenour, "Properties of Radar Targets", Radar System Engineering, Radiation Series, Vol 1 pp 76

[3] Gerald E Dunn, "Preliminary Study of Aircraft Radar Target Size", Technical Development Report No 379

the aircraft's altitude was held constant when flying over this segment, the same test conditions were duplicated for all aircraft

The length of the test path was 1 6 nautical miles (nm) and the midpoint was 20 nm from the radar site The azimuth of the test volume was 359 degrees from the radar site The aircraft were flown at an altitude of 2200 feet above the site (3000 feet mean sea level) The vertical lobe structure of the antenna radiation pattern was calculated[4], and the altitude was selected so that the volume of airspace used for the test was near the maximum of the second lobe of the antenna radiation pattern The aircraft were flown over the test range in both directions, that is inbound and outbound

During all measurements one aircraft was compared with another The DC-3, Convair and Tri-Pacer were each compared with the Twin Beechcraft and the Convair also was compared with the T-33 When the DC-3 and Convair were compared with the Beech, all aircraft were flown at approximately 165 mph When the Tri-Pacer was compared with the Beechcraft, both were flown at approximately 130 mph When the Convair was compared with the T-33 both aircraft were flown at approximately 200 knots The test equipment does not require both aircraft to be flown at the same speed, however, this procedure simplifies the reduction of data Most of the reported data was taken, therefore, under these conditions

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[4] J Francis Reintjes and Godfrey T Coate, "Reflection From a Conducting Plane," Principles of Radar, Third Edition, pp 961-964

# TEST EQUIPMENT

An electronic circuit was developed for averaging all received radar returns from the aircraft while they were flying through the given volume of airspace A block diagram of this device is shown in Fig 1

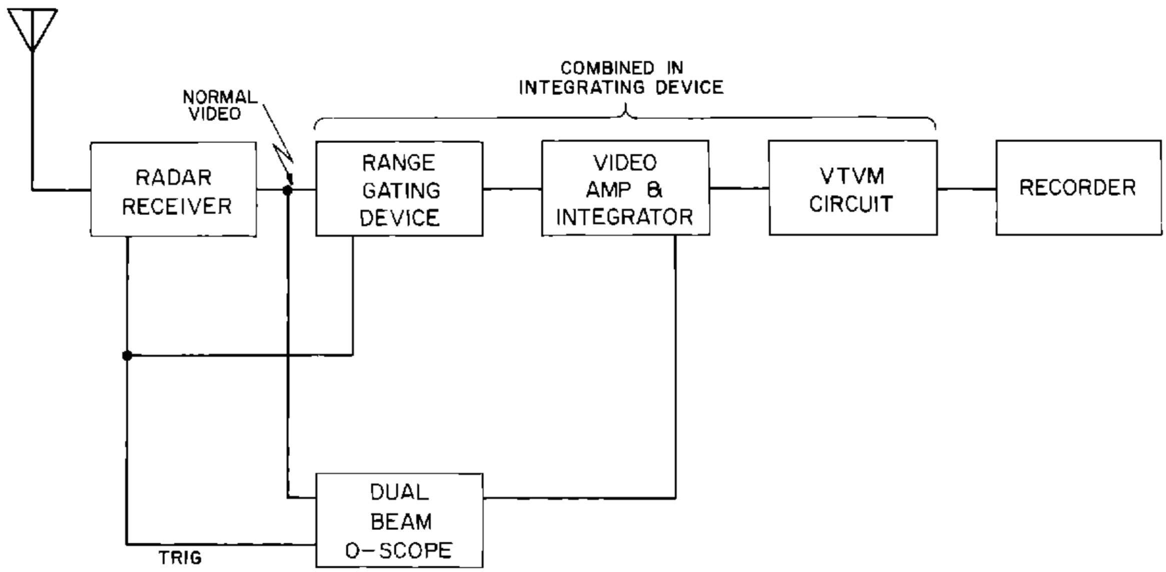


FIGURE 1 - BLOCK DIAGRAM OF TEST EQUIPMENT

The radar normal video from the radar receiver is fed to the integrator device in which the first function is to gate the video in such a manner that only video which occurs in the test gate range is used Following this gating, the video is amplified to yield a 100 volt peak magnitude The video energy is stored in a capacitor with a high leakage resistance The voltage buildup on the capacitor can be calibrated to indicate the average of the total power received during the time that the aircraft was in the range gate A vacuum tube voltmeter circuit is attached to the capacitor, the output of which is connected to an Esterline-Angus 0 to 1 milliampere recorder The recorder provides a permanent record of the measurement for later study A schematic of the system is shown in Figure 2

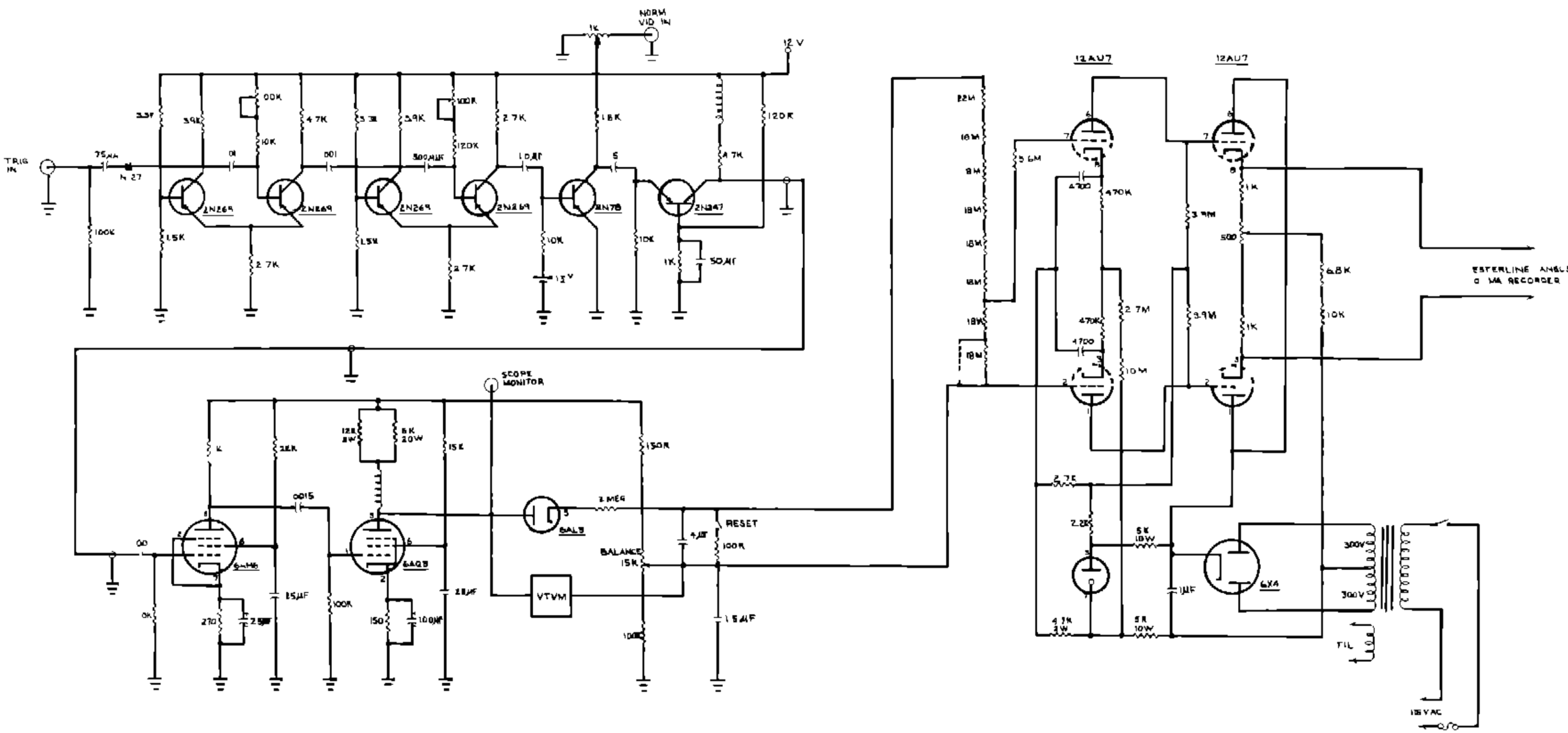


FIGURE 2 - SCHEMATIC OF INTEGRATING DEVICE

The radar receiver, integrator and recorder are linear over a range of approximately 8 db Stronger signals tend to be limited in the receiver and weaker signals are lost in the noise buildup on the capacitor A receiver and video system with a wider dynamic range would improve the measurement accuracy, however, with the IF gain adjusted to keep peak signals from limiting a fairly accurate resultant is obtained with an 8 db range This is particularly true if the measurement path is short and there are no severe lobes in the antenna pattern within the measurement gate Changes of aircraft attitude in the test gate will effect the result, however, if a number of measurements are made, and averaged to obtain the resultant, this effect can be neglected

Figure 3 is a typical recording of the voltage buildup across the integrating capacitor during a target size measurement The time of the buildup is the time the aircraft is in the gate The maximum reached is the averaged result of all received power during the time the aircraft was in the gate Figure 4 is a typical calibration recordings It was obtained by feeding a calibrated signal generator into the directional coupler of the radar system By inserting a known power level signal of the same pulse width and prf as the radar, and adjusting the pulse delay to fall into the range gate, the integrating capacitor will build up as shown The time allowed for the calibration buildup is made longer than it would take the slowest aircraft to fly through the measurement gate thereby making one calibration usable for all aircraft tested

To find the average power level of a received signals, it is necessary to first determine the length of time over which the measurement took place This is the time for the beginning of the voltage rise to the start of the fall The peak rise and the time of the measurement is then compared to the calibration curves When a curve is found where, for the same length of time, the calibrated source had an equivalent voltage rise then the average power received during the measurement was the same as the calibrating source

Since the test was to determine relative aircraft target size the sensitivity or power output of the radar does not enter into the accuracy of the measurement Calibrations were made with the same IF gain and receiver performance as during the measurements The Normal video receiver was used for all tests Calibrations were made before and after each series of measurement which ordinarily took from one to three hours to make

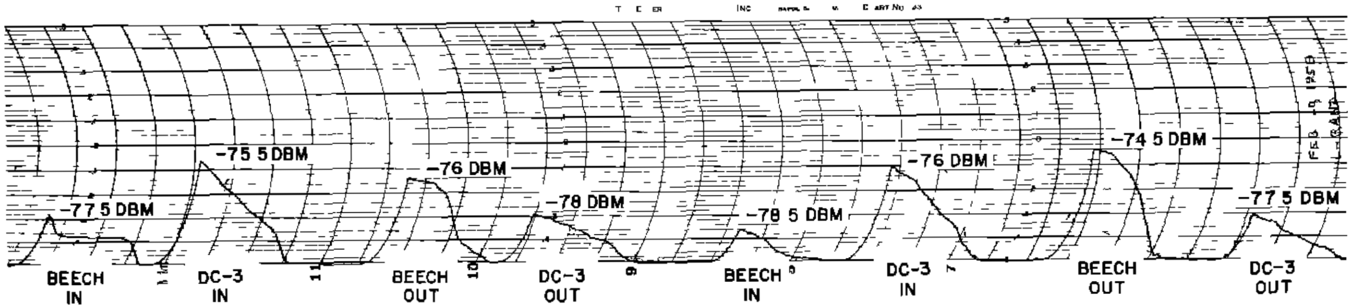


FIG 3-TYPICAL MEASUREMENT DATA

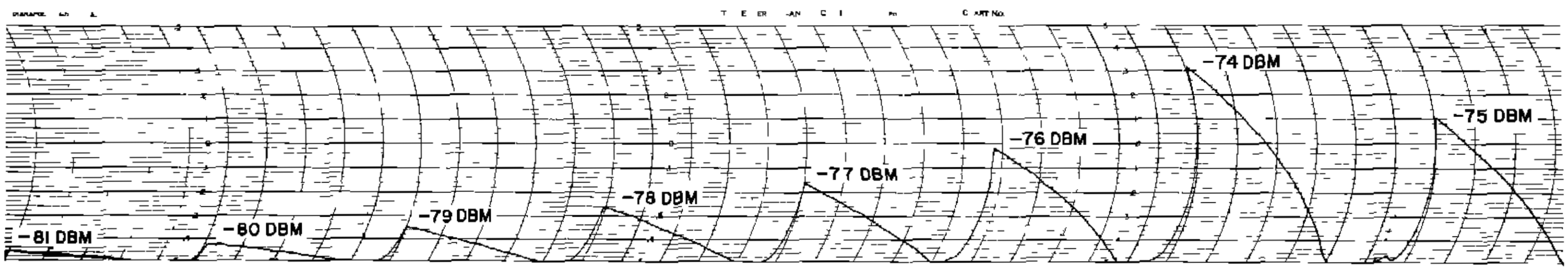


FIG 4 - EQUIPMENT CALIBRATION RECORDING

Tests were made using a FPS-8 L-band radar This set had a 3 degree half power azimuth beam width and had previously been modified to a 600 PRF, two microsecond pulse width The S band tests were made using a standard ASR-2 radar This set has a 2 2 degree half power azimuth beam width It has a 1200 PRF and a one microsecond pulse width

## TEST RESULTS

The S band tests were run at 165 miles per hour with the DC-3 and Convair being compared in each case with the Twin Beechcraft The averaged data is shown in the following table

### TABLE I

### DIFFERENCES BETWEEN AIRCRAFT ON S-BAND

| Aircraft | Direction | No of Trials | Average DB Difference | Range Multiplier |
|---|---|---|---|---|
| | | (Compared to Beechcraft) | | |
| DC-3 | Outbound | 41 | +2 3 | 1 14 |
| DC-3 | Inbound | 41 | +1 5 | 1 09 |
| Convair | Outbound | 27 | -0 8 | 0 96 |
| Convair | Inbound | 27 | +1 4 | 1 08 |
| | | (Each Aircraft Compared to Its Own Outbound Attitude) | | |
| Beech | Inbound | 68 | +0 6 | 1 03 |
| DC-3 | Inbound | 41 | -0 4 | 0 98 |
| Convair | Inbound | 27 | +2 6 | 1 16 |

Figure 5 is a plot of all measurements made to determine the inbound and outbound differences between the DC-3 and Beechcraft The inbound difference measurements vary from +5 db to -2 db, outbound differences vary from +5 db to -1 db Similar variations were found in the Convair/Beechcraft comparative measurements

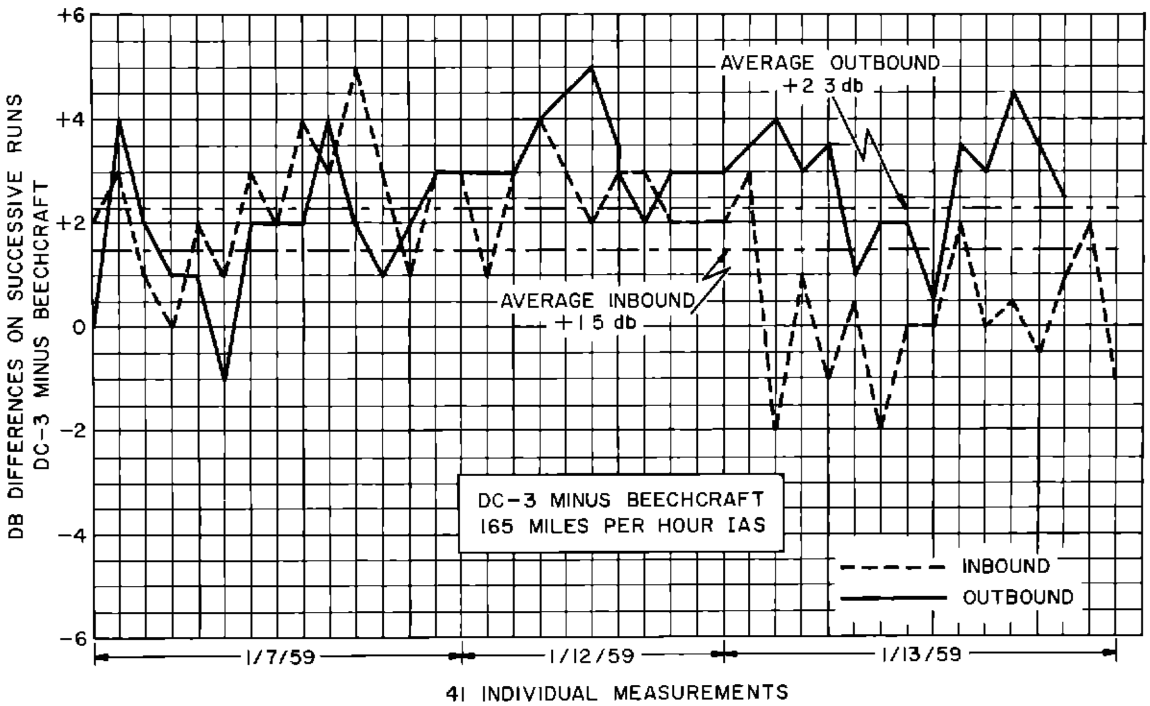


FIG 5 - S-BAND DB DIFFERENCES INBOUND AND OUTBOUND

The comparative L band data for the DC-3, Convair and Twin Beechcraft were run at 165 miles per hour The averaged data for these three aircraft are as shown in the following table

TABLE II

DIFFERENCES BETWEEN AIRCRAFT ON L-BAND

| Aircraft | Direction | No of Trials | Average DB Difference | Range Multiplier Based on Average |
|---|---|---|---|---|
| | | (Compared to Beechcraft) | | |
| DC-3 | Outbound | 40 | -0 4 | 0 98 |
| DC-3 | Inbound | 40 | +2 1 | 1 13 |
| Convair | Outbound | 30 | -2 8 | 0 85 |
| Convair | Inbound | 30 | +5 3 | 1 36 |
| | (Each Aircraft Compared to Its Own Outbound Attitude) | | | |
| Beech | Inbound | 70 | -3 7 | 0 81 |
| DC-3 | Inbound | 40 | 0 0 | 1 00 |
| Convair | Inbound | 38 | +2 9 | 1 18 |

Figure 6 is a plot of all measurements made to determine the inbound and outbound differences between the DC-3 and Beechcraft The inbound difference measurements vary from + 5 db to +0 5 db, the outbound differences vary from +4 db to -5 db Similar measurement variations were found in the Convair/Beechcraft comparative measurements

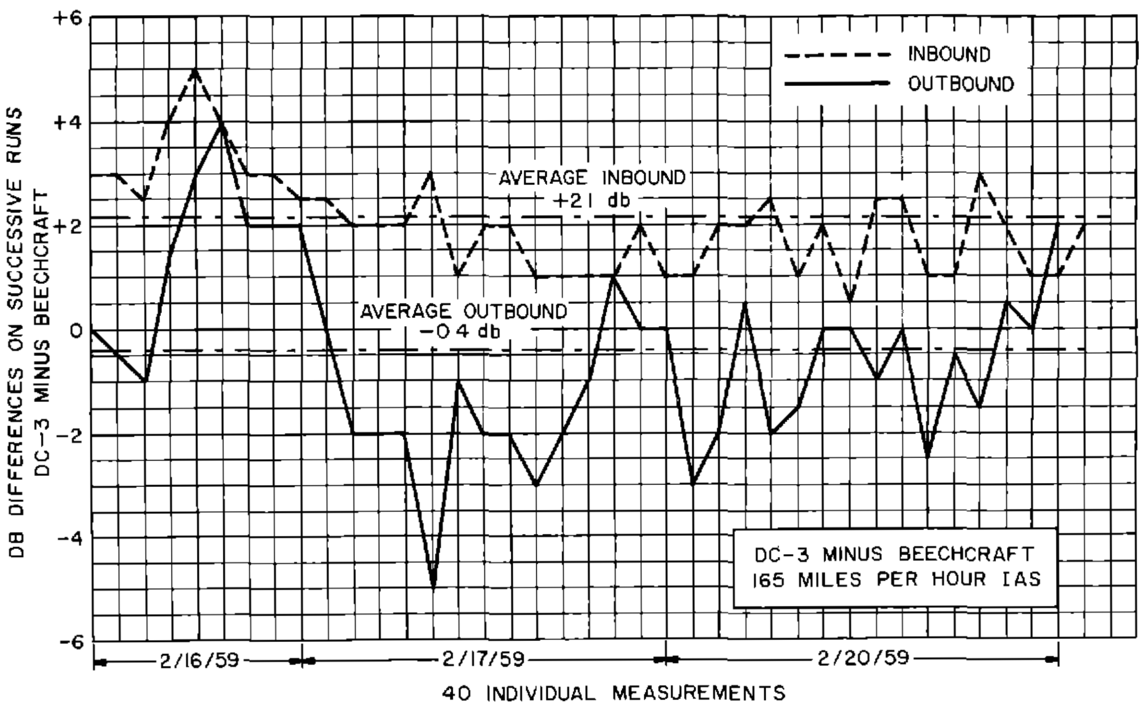


FIG 6 - L-BAND DIFFERENCES INBOUND AND OUTBOUND

Figure 7 is an analysis of all alternate L-Band Beechcraft measurements taken to show differences in inbound and outbound measurements at 165 miles per hour It shows variations from -1 db to +10 db There is a definite variation between readings of one day as compared to readings on other days While not recorded at the time it is definitely known that cross winds existed on the test range on certain days and these undoubtedly explain the range of variations shown

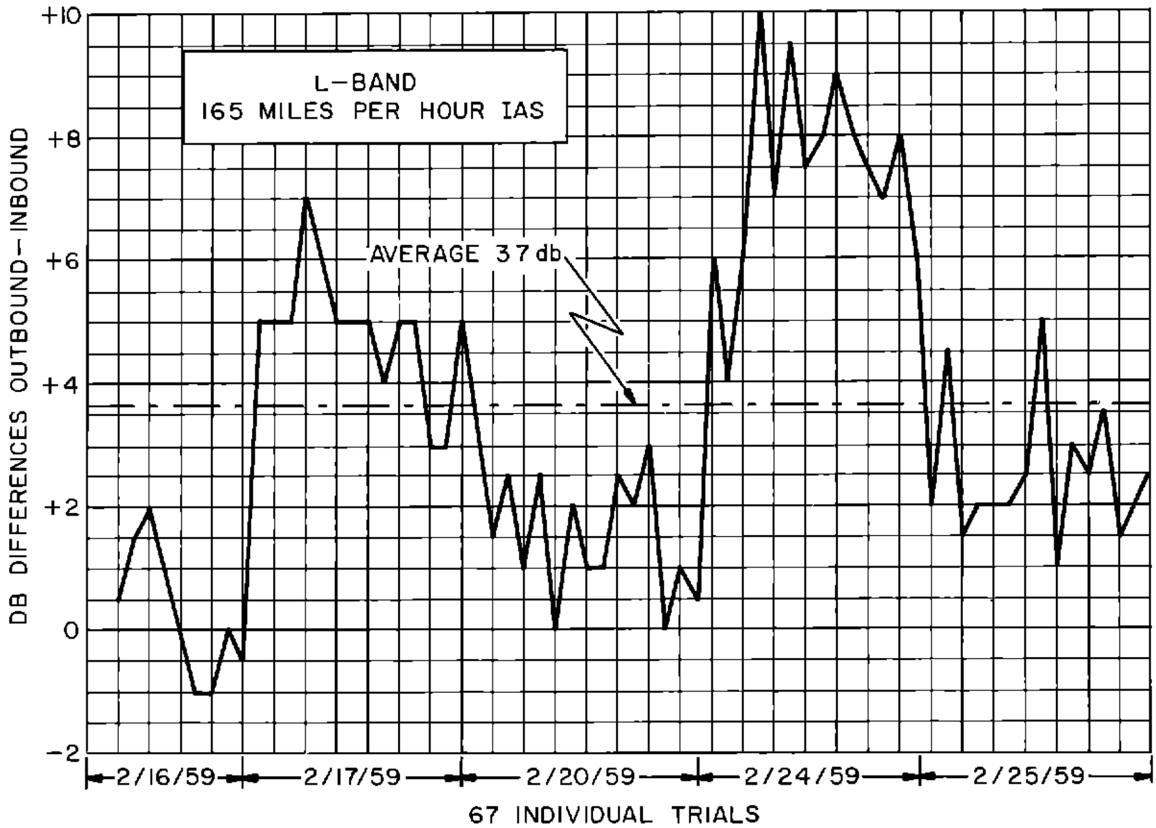


FIG 7 - DB DIFFERENCES IN ALTERNATE OUTBOUND MINUS INBOUND MEASUREMENTS OF TWIN BEECHCRAFT

The comparative L-band data for the Twin Beechcraft and the Tri-Pacer were run at 130 miles per hour In 12 comparisons, the Tri-Pacer averaged -4 8 db outbound (76 per cent range) and 1 7 db inbound (110 percent range) as compared to the Beechcraft The Tri-Pacer averaged 3 4 db (121 per cent range) stronger inbound than when it was outbound Random variations of individual tests can be expected to vary in the same order of magnitude as shown in Figures 6 and 7 for other aircraft types

## ATTITUDE STUDIES

The comparative L-band data for a T-33 type aircraft was taken with reference to the Convair The measurements were made with both aircraft flying at 230 miles per hour The T-33 was equipped with wing tip fuel tanks At the time the measurements were made, it was felt that, since comparisons had already been made between the Beech and Convair, that the T-33/Convair comparisons could be used to calculate the target size relationship between the Beechcraft and T-33 However, when the Convair data was analyzed, it was found that at 230 miles per hour the Convair averaged 1 0 db stronger out than in, whereas the previous L-band data at 165 miles per hour showed the Convair averaged 2 9 db stronger inbound than outbound Although only limited data was taken it was suspicioned that the difference in longitudinal attitude between 165 and 230 mph caused the Convair to present a different effective target area For this reason it does not appear valid to relate the 230 miles per hour Convair data to the Beechcraft size at 165 mph

Eight measurements were made to compare the Convair with the T-33 at 230 mph The average of these show that the T-33 is 4 8 db weaker inbound than the Convair and 6 9 db weaker outbound than the Convair Compared with itself, the T-33 is 1 1 db stronger (106 per cent range) inbound than outbound

The speed phenomena found with the Convair suggested that additional investigations should be made into attitude effects Unfortunately the time allotted to the project did not permit a lengthy study However, a quick study was conducted, to see if the speed effect could be better understood The only aircraft available for this part of the study was the Twin Beechcraft

The Beechcraft was flown over the previously described course and measured in the same manner Two inbound and two outbound measurements were made at each airspeed on L-Band only The airspeed was controlled by the longitudinal attitude of the aircraft, i e nose higher or lower The results were as shown below

| Indicated Air Speed (mph) | Inbound (dbm) | Outbound (dbm) | DB Difference Outbound with Respect To Inbound |
|---|---|---|---|
| 100 | -77 5 | -78 | -0 5 |
| 110 | -78 | -77 3 | +0 7 |
| 120 | -76 3 | -78 | -1 7 |
| 130 | -75 5 | -73 | +1 5 |
| 140 | -74 | -67 | +7 0 |
| 150 | -76 | -68 3 | +7 7 |
| 160 | -77 | -66 | +11 0 |
| 170 | -78 | -69 5 | +8 5 |

Since there were only two samples at each speed some inconsistencies in the data can be expected Nevertheless, it can be definitely seen that the inbound signal is about the same at all speeds The outbound signal on the other hand is approximately 10 db weaker at 100 mph as compared to 170 mph Although a different crab angle may have been required to hold the test course over the range of speeds involved it would seem that, since a large crab would be required at lower speeds, that low speed should have had the larger target signal strength Also, since there is little change in the inbound signal the crab angle apparently wasn't a big factor The only remaining point appears to be that different longitudinal attitudes have a large effect on outbound signal strength, but obviously this needs further evaluation

## CONCLUSIONS

1 The tables in this report which compare DC-3 and Convair aircraft to the Twin Beechcraft are the averages of a number of measurements and therefore, represent an average difference which can be expected when the aircraft are operating at 165 mph, indicated air speed

2 Wide fluctuations from the average can be expected on any individual test

3 Speed and crab angles will have large effects on the signal strength of any particular flight

# RECOMMENDATIONS

The only feasible conversion factor which can be used to compare aircraft is the average of a large number of measurements It is recommended that a new series of tests be conducted based on the measurement principles described in this report The aircraft should be operated at their normal cruising speed and the resultant data be used as an average conversion factor Instructions to operating personnel should emphasize the wide variances from the average can be expected on any particular flight