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RADAR ENHANCEMENT OF SMALL AIRCRAFT IN THE AIR TRAFFIC CONTROL SYSTEM

Donald H. Turnbull

Federal Aviation Administration
Washington, D. C.

September 1975

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Final Report

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16. Abstract

In response to a National Transportation Safety Board recommendation, an investigation was undertaken to develop and determine the practicality of small aircraft radar enhancement devices. This report discusses the detection capability of present radars as well as an analysis and evaluation of passive radar enhancement devices and active radar enhancement devices. The report concludes that passive enhancement devices are not practical and that active enhancement devices are too costly when compared to the existing Air Traffic Control Radar Beacon System (ATCRBS) transponders. The recommendations are that the ATCRBS should be promoted by the FAA, no further program efforts should be undertaken by the FAA on small enhancement and the development of the Moving Target Detector should be continued.

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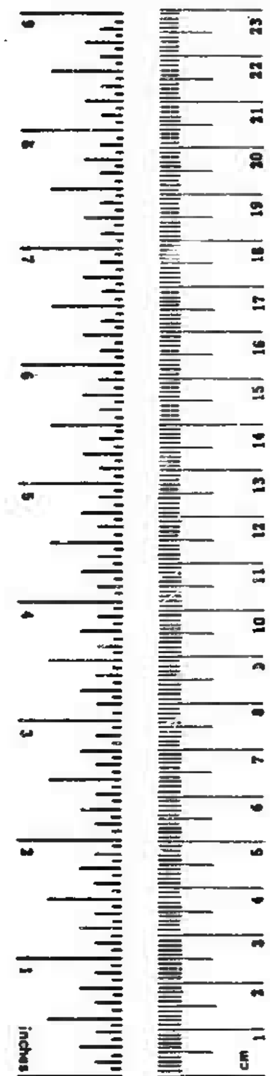
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

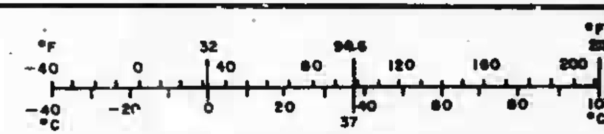
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



EXECUTIVE SUMMARY

In response to a National Transportation Safety Board recommendation, an investigation was undertaken to develop and determine the practicality of small aircraft radar enhancement devices. This report discusses the detection capability of present radars as well as an analysis and evaluation of passive radar enhancement devices and active radar enhancement devices. The conclusions reached are:

a. Passive enhancement of small aircraft is not practical because of the substantial size of enhancement devices required.

b. Amplifier type active enhancement devices have unresolved problems of antenna placement and potential interference with ground radars and will not work with both terminal and enroute radars without doubling the cost. The cost of these systems is a substantial portion of that of an ATCRBS transponder. The operational capability does not approach that of an ATCRBS transponder.

c. Active enhancers utilizing transponder techniques are feasible. The ATCRBS is, in fact, an active enhancer. Development of a new transponder enhancer would actually duplicate the ATCRBS in some modified form.

The report recommends:

a. The Air Traffic Control Radar Beacon System (ATCRBS) is the enhancement system that should be promoted by the FAA since an ATCRBS transponder can be purchased and installed in a small aircraft at a reasonable cost.

b. The FAA should not undertake further program efforts on small aircraft enhancement except to keep abreast of developments in the state-of-the-art that may affect enhancement.

c. The FAA should continue development and evaluation efforts in Moving Target Detector techniques to improve detection of small aircraft.

TABLE OF CONTENTS

I. INTRODUCTION

PURPOSE

The purpose of this report is to document the results of an investigation to develop and determine the practicality of small aircraft radar enhancement devices. This investigation was in response to a National Transportation Safety Board recommendation (Appendix A).

BACKGROUND

The detection of small aircraft by Air Traffic Control radars is difficult especially in the presence of clutter (ground, precipitation, angel) because of the extremely small amount of energy reflected by the aircraft. The detection of these aircraft can be improved by (a) improving the radar antenna pattern, (b) improving clutter rejection circuitry, and (c) increasing the energy returned from small aircraft through the use of enhancement devices. Any further increase in transmitter power or receiver sensitivity will not improve the detection capability of small aircraft since the clutter level will also be increased. The FAA is actively pursuing areas (a) and (b) This report outlines the investigations undertaken by the FAA in area (c), small aircraft enhancement.

II. DISCUSSION

SUMMARY OF DATA ON MIDAIR COLLISIONS (reference 1)

An analysis of past midair collision data gives some indication of the small aircraft radar detection problem. In the period January 1964 through December 1971 there were 271 midair collisions resulting in 556 fatalities. Of these 271 collisions, 50 involved some level of ATC service. These collisions can be separated into three general categories (the number of collisions represented is shown in parentheses):

IFR-IFR	(2)
IFR-VFR	(17)
VFR-VFR	(31)

The two IFR-IFR collisions occurred as a direct consequence of pilot deviation from ATC instructions.

Of the seventeen IFR-VFT collisions, three occurred while the IFR aircraft was on final approach and after radar service had been terminated by the radar approach control facility. In all three cases the local control tower did not have a radar display. In the remaining fourteen IFR-VFR collisions only one VFR aircraft was equipped with an Air Traffic Control Radar Beacon System (ATCRBS) transponder. In seven of these fourteen collisions the VFR aircraft was not seen by the radar controller (details unknown in one case). In the remaining six cases radar traffic advisories were issued to the IFR aircraft.

Of the thirty-one VFR-VFR collisions, twenty-seven occurred at airports not equipped with a radar/beacon facility. In two of the remaining four cases one of the VFR aircraft was receiving radar advisories from an Air Route Traffic Control Center (ARTCC) (long range radar) and the other VFR aircraft was not seen. In one of the remaining two collisions the local controller apparently could not see the primary radar target on his radar display of an aircraft being tracked by the radar approach control facility. In the remaining case the approach controller failed to transfer control of an aircraft to the local controller (who did not have a radar display).

Of the fifty collisions discussed above, three possibly could have been prevented if a VFR aircraft had been seen by the ARTCC controllers, six might have been prevented if a VFR aircraft had been seen by an approach controller, and one might have been prevented if the VFR aircraft had been seen by a local controller on his radar display.

PRESENT RADAR DETECTION CAPABILITY

Before addressing the small aircraft radar enhancement efforts undertaken by the FAA, the present radar detection capability with regard to small aircraft will be analyzed. This analysis will include a discussion of small aircraft radar cross section, free space (theoretical) radar detection, and radar deterioration factors, especially clutter.

RADAR CROSS SECTION OF SMALL AIRCRAFT - The probability of detection of an aircraft with an Air Traffic Control (ATC) radar is dependent among other things upon the amount of energy returned from that aircraft to the radar receiver. The proportion of the energy returned versus the illuminating energy is a measure of the radar cross section (RCS) of the aircraft. The RCS varies as a function of radar frequency and polarization and target characteristics such as size, shape, orientation, and type of material, but is independent of range and radar power. The common unit of measurement for RCS is the square meter. For a given radar a one square meter target

(RCS) is defined as the energy returned to that radar from a conducting sphere with a cross sectional area of one square meter.

The RCS of an aircraft is the result of a vectorial addition of the radar returns from many different points on the aircraft. Because of this vectorial addition, the RCS of an aircraft can vary greatly with a change of only a fraction of a degree in aspect angle. Figures 1, 2, and 3 show the RCS for 0° pitch, 0° roll and 2800 MHz (ASR frequency) for a Piper Cherokee 140, a Cessna 150, and a Piper Super Cub respectively. Both vertical and circular polarization are shown on the graphs. Figures 4, 5, and 6 show the same aircraft at 1350 MHz (ARSR frequency). Median RCS data taken over ten degree intervals was used to plot the RCS of the three small aircraft.

These three aircraft were selected as typical of different small aircraft classes. The Cherokee is a low wing four place, metal covered aircraft. The Cessna 150 is a two place, high wing, metal covered aircraft. The Piper Super Cub is a high wing, four place, fiberglass and fabric covered aircraft. RCS measurements of these aircraft were made at the Air Force Radar Target Scatter Facility at Holloman AFB, New Mexico under a USAF/FAA interagency agreement. Using the plots in figures 1-3, table 1 shows the approximate percentage of aspects that have a radar reflectivity greater than 1 m^2, 2 m^2 and 4 m^2 for each of the three aircraft at 2800 MHz for both vertical and circular polarization. Table 2 shows the same data for 1350 MHz. It should be remembered that the data used was median data and that the instantaneous peaks and valleys vary considerably from the median.

TABLE 1 - MEDIAN RCS DISTRIBUTION AT 2800 MHz

		% Aspects greater than		
	POL	1 m^2	2 m^2	4 m^2
Piper Cherokee 140	LP	100	79	44
Piper Cherokee 140	CP	39	28	12
Cessna 150	LP	92	39	21
Cessna 150	CP	92	43	14
Piper Super Cub	LP	100	85	46
Piper Super Cub	CP	100	67	18

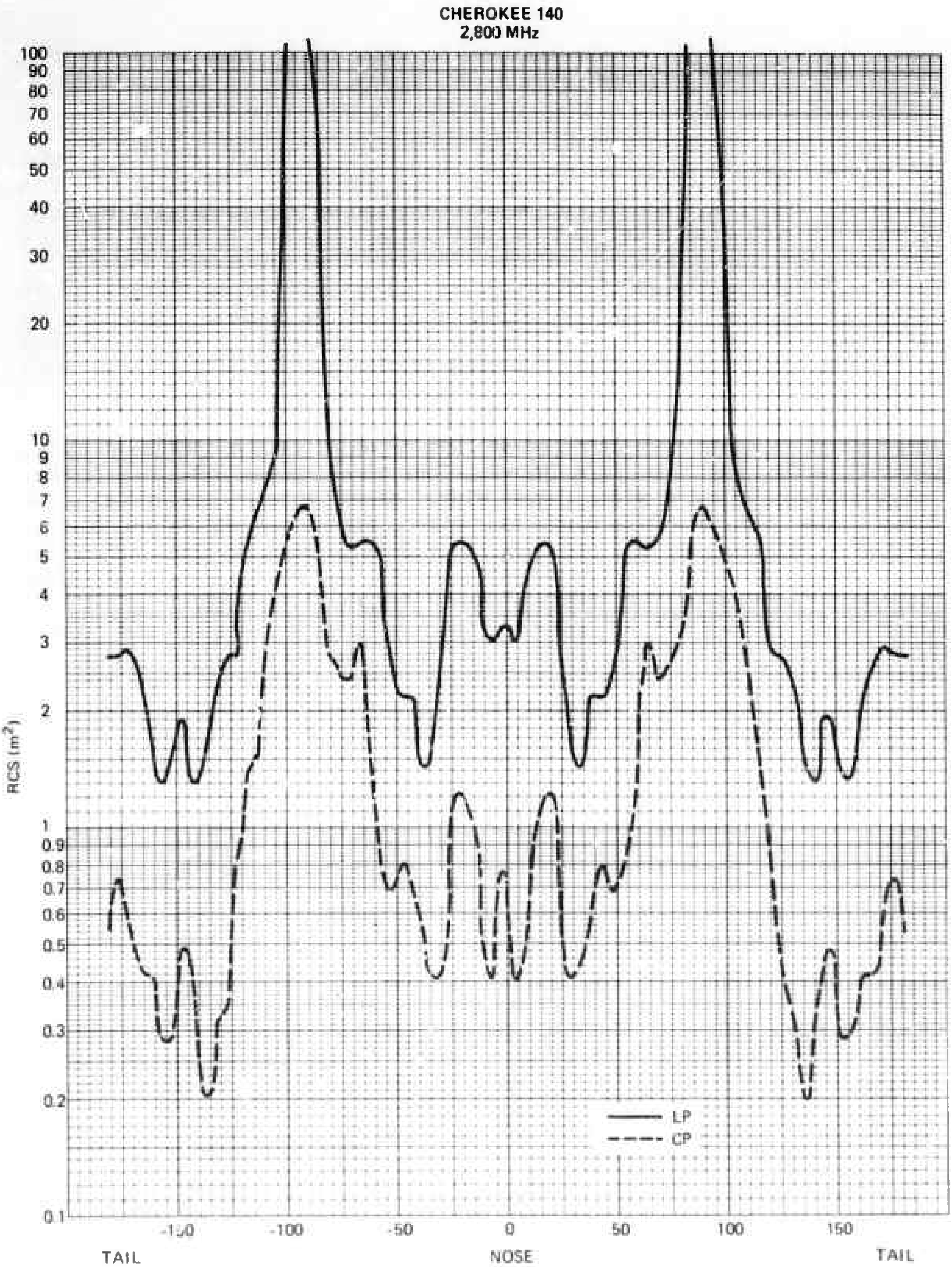

CHEROKEE 140
2,800 MHz
RCS (m²)
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
-150
-100
-50
0
50
100
150
TAIL
NOSE
TAIL
LP
CP

FIGURE 1

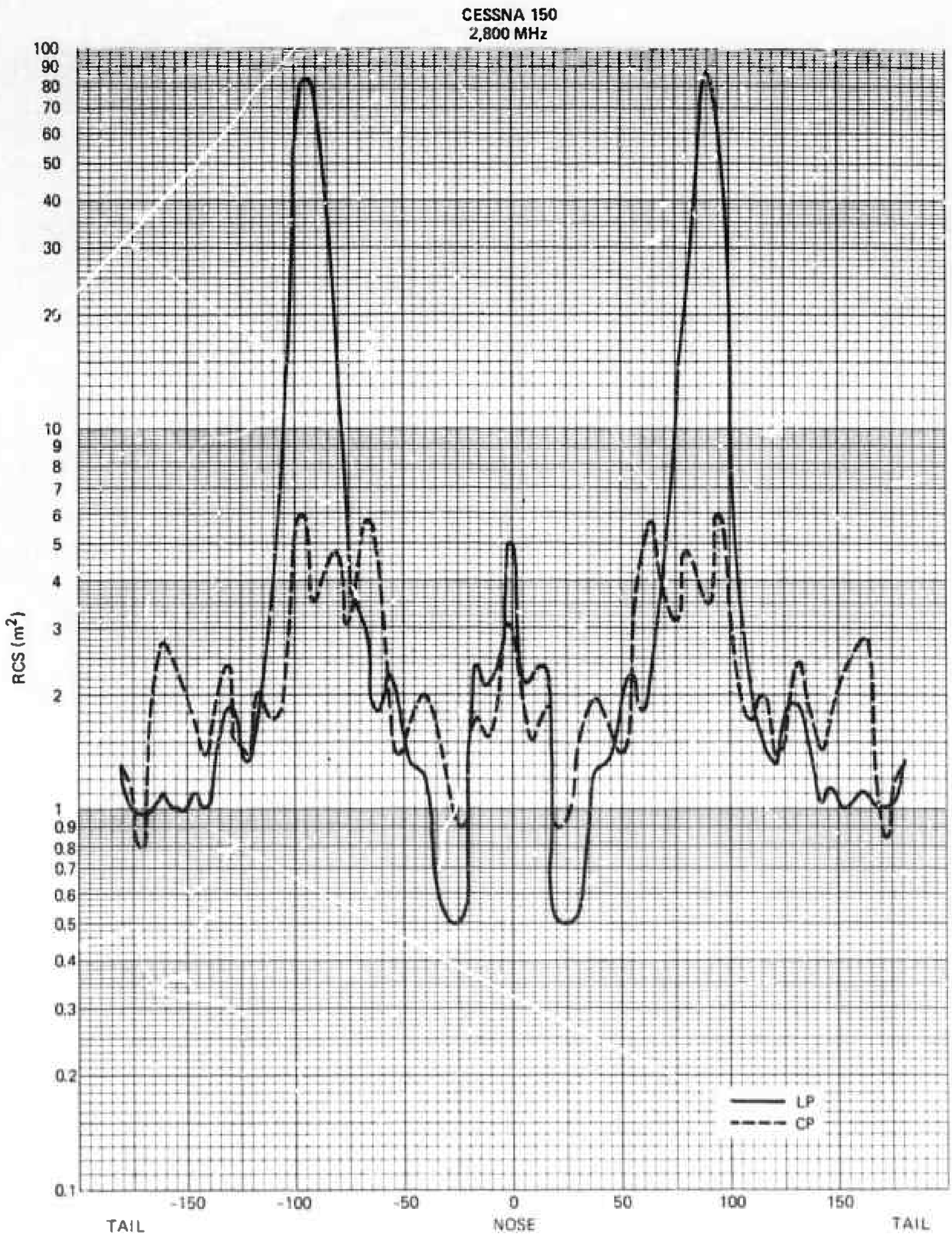

CESSNA 150
2,800 MHz
RCS (m²)
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
-150
-100
-50
0
50
100
150
TAIL
NOSE
TAIL
LP
CP

FIGURE 2

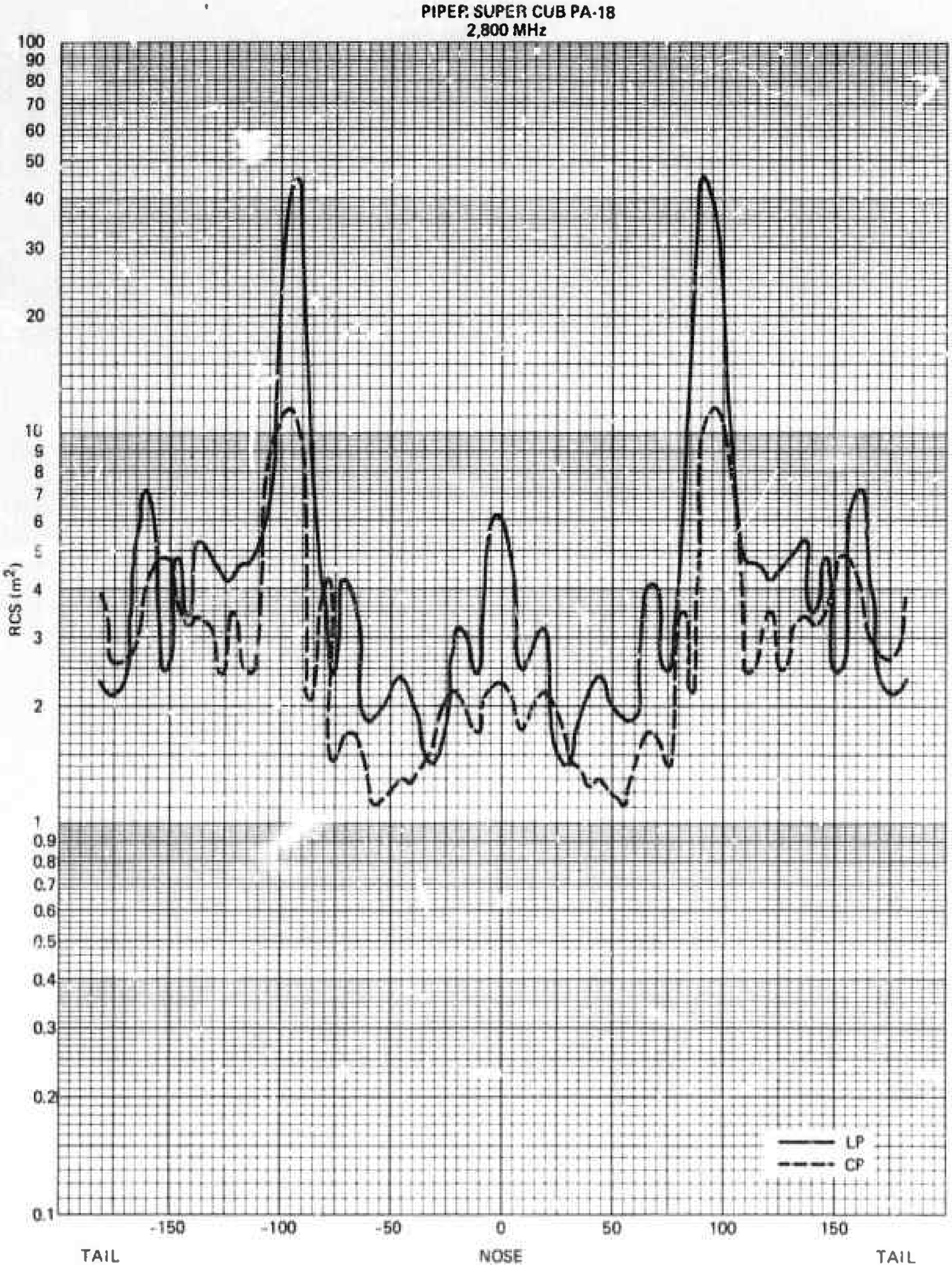

PIPER SUPER CUB PA-18
2,800 MHz
RCS (m²)
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
-150
-100
-50
0
50
100
150
TAIL
NOSE
TAIL
LP
CP

FIGURE 3

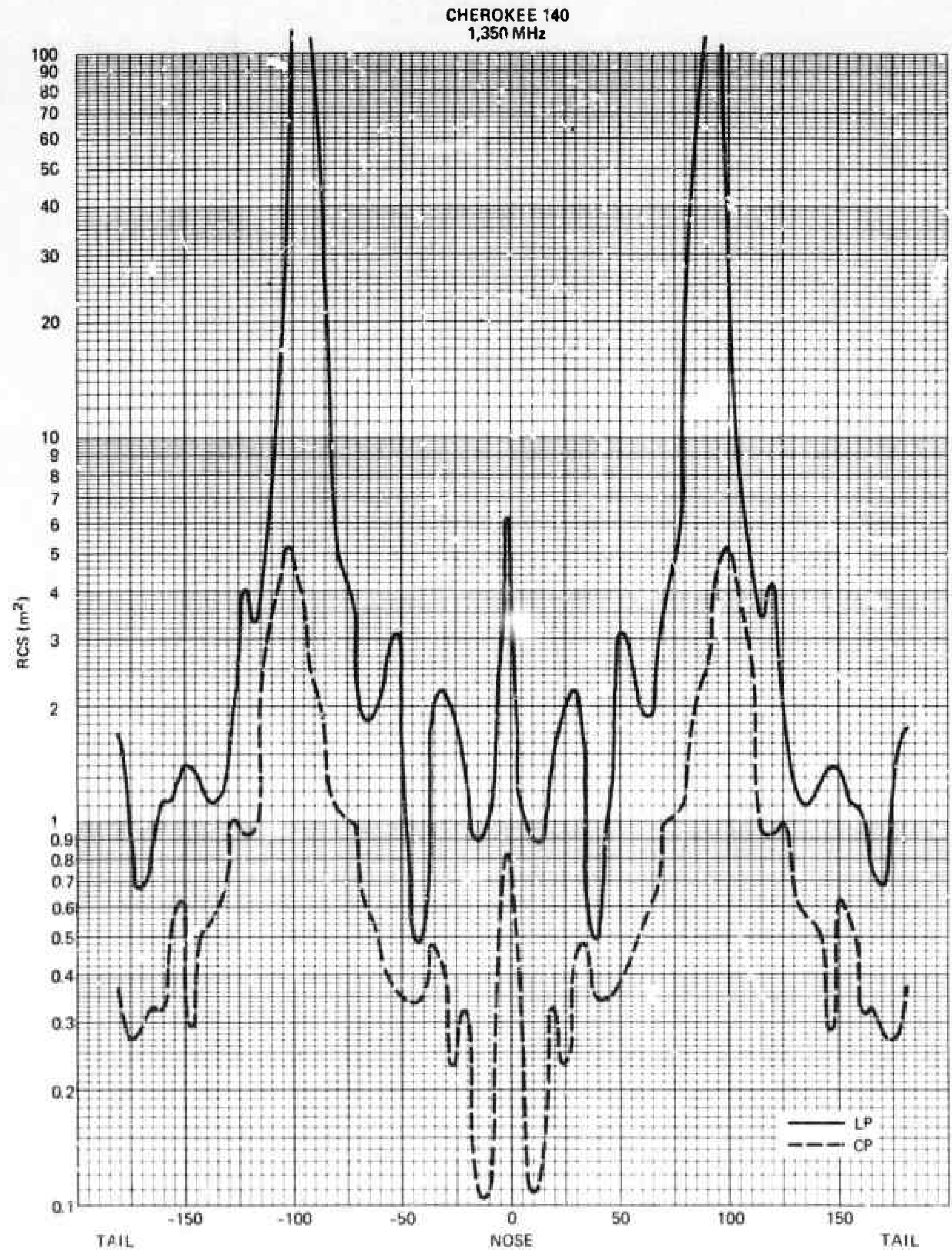

CHEROKEE 140
1,350 MHz
RCS (m²)
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
-150
-100
-50
0
50
100
150
TAIL
NOSE
TAIL
LP
CP

FIGURE 4

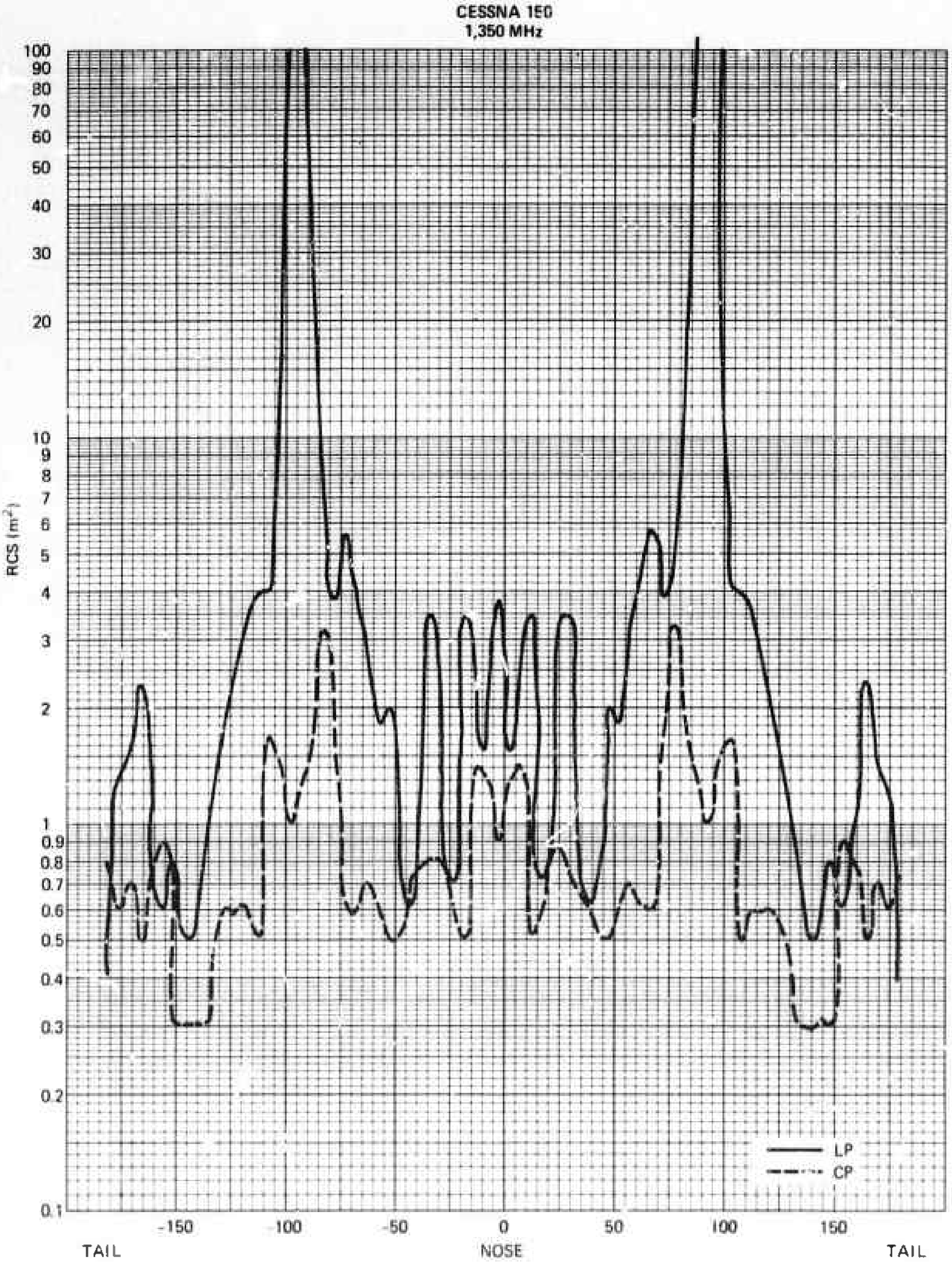
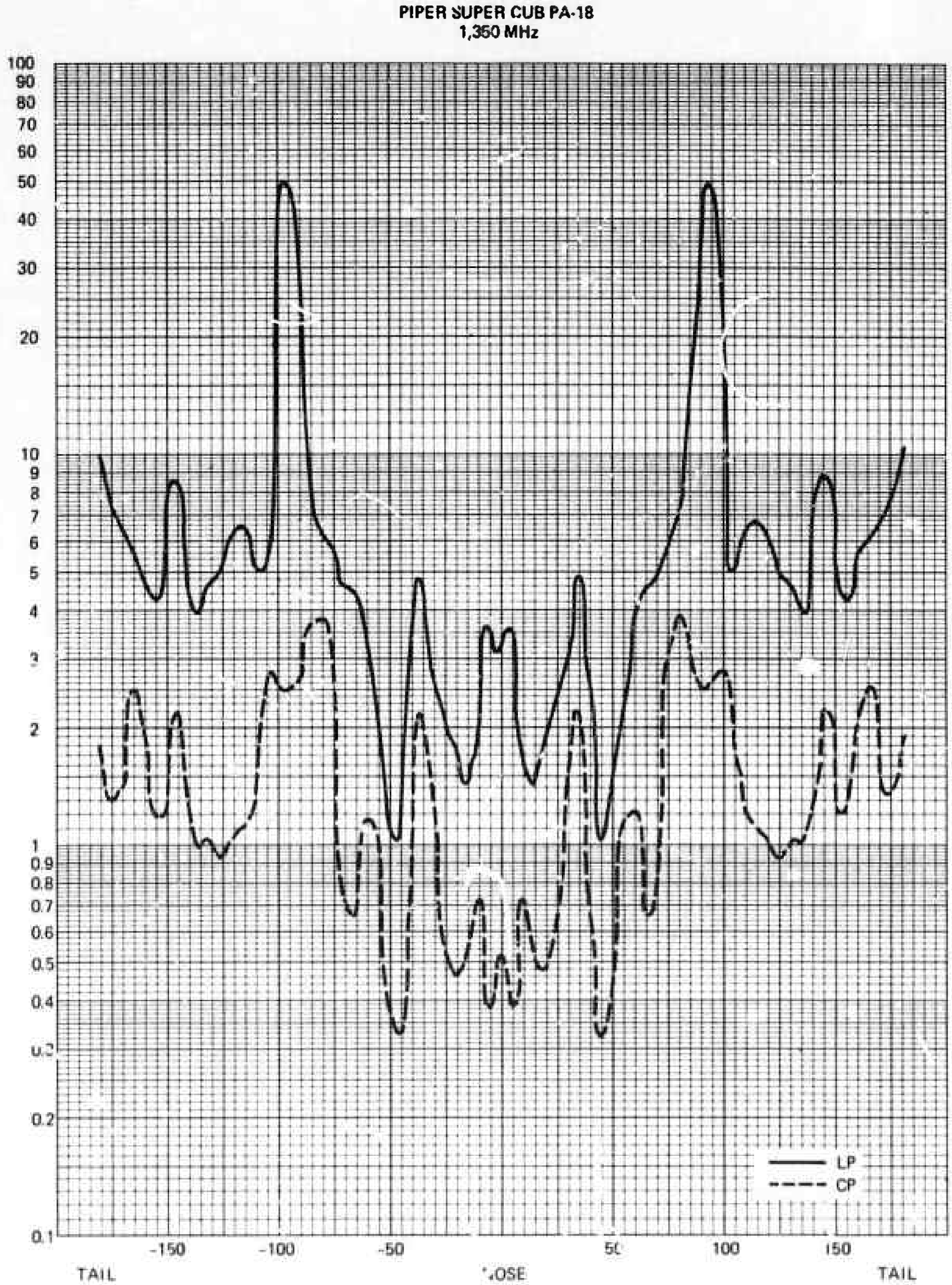

CESSNA 150
1,350 MHz
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
RCS (m²)
-150
-100
-50
0
50
100
150
TAIL
NOSE
TAIL
LP
CP

FIGURE 5



PIPER SUPER CUB PA-18
1,350 MHz
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.2
0.1
-150
-100
-50
100
150
TAIL
TAIL
LP
CP

FIGURE 6

TABLE 2 - MEDIAN RCS DISTRIBUTION AT 1350 MHz

		% Aspects greater than		
	POL	$1\ m^2$	$2\ m^2$	$4\ m^2$
Piper Cherokee 140	LP	82	43	24
Piper Cherokee 140	CP	22	17	6
Cessna 150	LP	75	53	19
Cessna 150	CP	25	4	0
Piper Super Cub	LP	100	85	67
Piper Super Cub	CP	65	28	0

FREE SPACE RADAR COVERAGE - The free space coverage for the ASR-4, 5, 6 radar systems is shown in Figure 7 (reference 2). The 0 dB curve represents 2.2 m^2. Table 3 below indicates the relationship between the curves in Figure 7 (in dB relative to 2.2 m^2) and RCS in square meters.

TABLE 3 - RELATIONSHIP OF RCS IN DB IN FIGURE 7 TO RCS IN M^2

RCS (dB 0dB = 2.2 m^2)*	RCS (m^2)
-16	0.055
-14	0.088
-12	0.14
-10	0.22
- 8	0.35
- 6	0.55
- 4	0.88
- 2	1.39
0	2.2
2	3.49
4	5.53
6	8.76
8	13.88
10	22.00
12	34.87
14	55.26

* A T-33 aircraft with wing tanks viewed nose on is defined as a 0 dB target in the case of Figure 7.

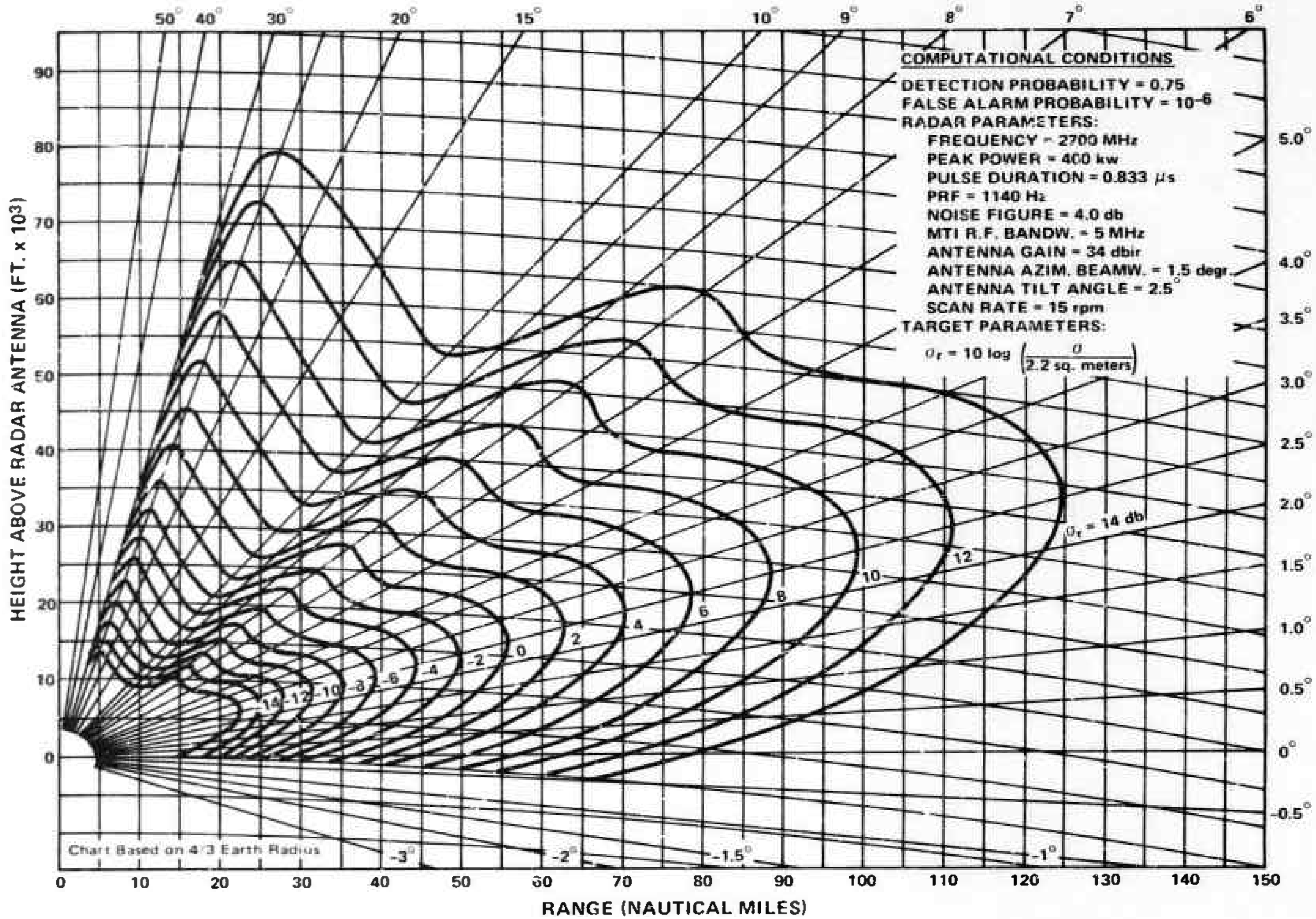


FIGURE 7 ASR-4B, 5, 6 RANGE COVERAGE CAPABILITY—FREE SPACE CONDITIONS

A 1 m^2 target which is typical of small aircraft will fall between the -2 dB and -4 dB curves. This would indicate a maximum range of about 47 miles with a range of 28 miles at the horizon. This coverage would be adequate if the radar could truly provide this detection capability. Unfortunately there are many factors which degrade the performance of the radar from the free space condition, as explained below.

RADAR DETERIORATION FACTORS - Some factors that can degrade the performance of radar are discussed below.

1. Ground Clutter - Returns from stationary objects on the ground such as buildings, mountains, vegitation, etc. can severely degrade the performance of the radar. The strength of this ground clutter can be measured using the equations in reference 2 and the measurements for different types of clutter outlined in reference 3. The radar cross section of the clutter, or σ, is equal to the instantaneous area of clutter seen by the radar times the RCS per unit area of the clutter.

$$\sigma = A_c \quad \sigma_o$$

Where

A_c = area of clutter
σ_o = RCS/unit area of clutter
$A_c = R\theta \frac{c\tau}{2} \sec \psi$

Where

R = range
θ = azimuth beamwidth
c = velocity of light
τ = pulse width
ψ = grazing angle

For the ASR-4, 5, 6 radars at very small grazing angles

$$\sigma = 6057.8 \; R \, \sigma_o$$

Two values of will be used to calculate the RCS of ground clutter at S-band at 20 miles. These values are a) -18 dB which represents a level of clutter in the Rocky Mountains exceeded in only 5% of the cells and b) -32 dB which represents the median clutter RCS for wooded hills (Reference 3). The MTI improvement factor is taken into consideration and has a value of 27 dB.

For case a)

$$R = 20 \text{ miles}$$
$$\sigma = 3.8 \text{ m}^2$$

For case b)

$$R = 20 \text{ miles}$$
$$\sigma = 0.15 \text{ m}^2$$

In order to detect an aircraft the radar must receive a return of sufficient strength to have a signal to clutter (S/C) ratio of approximately 10 dB.

For case a the target must have a strength of 38 m^2 to be detected and for case b the target must have a strength of 1.5 m^2 to be detected.

For the ARSR- 1, 2 radars at very small grazing angles

$$\sigma = 12605.1 \, R \sigma_0$$

The median value of σ_0 for wooded hills (Reference 3) is -35 dB. The MTI improvement factor is 22 dB. (no data is available for mountains at this frequency however there should be no great variation from the S-band data given above)

$$R = 20 \text{ miles}$$
$$\sigma = 0.5 \text{ m}^2$$

For detection with a S/C ratio of 10 dB the required target size would be 5 m^2.

2. Precipitation Clutter - Precipitation deteriorates radar in two ways. The first and least significant is the increased attenuation as the signal penetrates the precipitation. The level of this attenuation increases with increasing frequency but is not operationally significant at the frequencies at which our Air Traffic Control radars operate.

The second way in which precipitation deteriorates radar performance is that back scatter (clutter) from the precipitation is displayed and can mask legitimate targets. Since precipitation moves with the wind, MTI is not very effective in removing it. As with attenuation, the precipitation clutter increases with increasing frequency.

One technique used in our ATC radars to reduce precipitation clutter is circular polarization. In this technique the radar signal is transmitted with a rotating electric field vector. The radar return from a regularly shaped object such as a sphere or flat plate will have the electric field vector rotating the opposite way. The radar will reject the reversed sense of polarization. Because an aircraft is an irregular object only part of the signal will come back in the reverse sense of polarization. Since raindrops are nearly spherical it can be seen that the return from rain will be reduced far more than the return from aircraft.

The magnitude (RCS) of precipitation clutter can be calculated using the equation

$$\sigma_c = \rho \frac{R\theta}{\sqrt{2}} \frac{c\tau}{2} h$$

where

σ_c = RCS of clutter
ρ = precipitation reflectivity per unit volume
R = range azimuth
θ = azimuth beamwidth
c = velocity of light
τ = pulse width
h = height of precipitation

For heavy rain (16 mm/hr) the following values have been determined for reflectivity: (Reference 3)

S-band (2800 MHz) -73 dB
L-band (1300 MHz) -86 dB

For the ASR systems assuming a range of twenty miles and rain height of 10,000 ft the RCS of rain would be 750.3 m^2. The use of circular polarization would reduce this to 23.7 m^2.

For the ARSR systems with the same assumptions the RCS of rain would be 78.0 m^2. The use of circular polarization would reduce this to 2.5 m^2.

The ASR-7 and ARSR-1/2 systems have precipitation suppression circuitry that will remove the precipitation clutter from the display and permit detection of those aircraft that have a radar return at least 10 dB stronger than the precipitation return. This means that in very heavy rain at twenty miles an aircraft must have an RCS of

237 m^2 to be detected by an ASR-7 and 25.0 m^2 to be detected by an ARSR.

3. Angel Clutter - Angel clutter appears on the radar display as large masses of discrete targets. The predominant cause of angel clutter is birds although it can also be caused by large swarms of insects or by convection cells. The type and concentration of angels at a particular site depends upon geographic location, season, time of day, and westher and is most severe during the Spring and Autumn bird migration season. Because the angels are returns from moving phenomena, MTI will not eliminate them from the display. The maximum range for angel clutter is approximately 10-15 miles.

   In moderate angel clutter, it is usually possible for a controller to visually track an aircraft it his workload is light enough to permit adequate concentration. Detection of unknown aircraft in moderate angel clutter is much more difficult. Severe angel clutter can result in taking the radar off the air. (Reference 4).

4. Anomalous Propagation(AP) (Reference 2) - Electromagnetic waves traveling through the earth's atmosphere do not travel in a straight line but are curved due to the variation of the velocity of propagation with altitude. In a standard atmosphere the index of refraction (the ratio of velocity of propagation in free space to that in the medium in question) decreases with altitude causing radar waves to bend downward. Changes in the standard atmosphere due to moving air masses, rsin, fog, tempersture inversions, etc. can cause changes in the nominal index of refraction and can result in radar waves being bent further downward or in some cases upward.

   The bending of waves further downward during AP results in an extension of the ground clutter area and reduced coverage in the airspace above the extended surface coverage. When the westher is cold, rough, stormy, windy, or cloudy the atmosphere is well stirred up and propagation is likely to be normal.

RADAR FLIGHT CHECK- Flight checks of three small aircraft were made using the ASR-5 system at the Nstional Aviation Facilities Experimentsl Center (NAFEC). Procedures were in conformsnce with the U.S. Standard Flight Inspection Manual used in commissioning rsdar systems. The results of these flight checks are documented in Appendix B. In general, the results of these flight checks showed that the maximum detection range of these aircraft at higher altitudes (about 8000 ft.) was approximately equal to that predicted under free space conditions, while the maximum range at lower altitudes (about 2000 ft.) was approximately 5-8 miles less than that predicted under free space conditions.

SMALL AIRCRAFT RADAR ENHANCEMENT

In an attempt to increase the radar return from small aircraft and thereby improve radar detection of these aircraft, the FAA undertook an investigation of enhancement techniques. The results of this investigation are discussed below and are separated into passive enhancement and active enhancement sections. Independent analyses were undertaken by MITRE and Lincoln Laboratory. These analyses are documented in reference 9 and Appendix C respectively.

PASSIVE ENHANCEMENT - A passive enhancement device returns the electromagnetic signal in the direction from which it arrived rather than scattering it in all directions. As the name implies, a passive device has no energy source and can only return as much energy as it intercepts. The ideal passive device is a flat plate aimed directly at the radar. The RCS of this "ideal" passive enhancer follows the following equstion.

$$\sigma = 4\pi A^2/\lambda^2$$

where

σ = RCS
A = intercept area
λ = wavelength of the singal

Whereas the flat plate will return energy in the direction of the radar only if it is aimed precisely at the radar, a passive enhancer, or retrodirective device, haa an effective angle, usually about 45 degrees, in which it will return a large portion of the energy intercepted back in the direction from which it arrived. A retrodirective device is not 100% efficient and has an inherent loss of about 3 dB. An additionsl 3 dB loss is incurred at the limits of the enhancer's effective angle. Thia 6 dB loss would require that an enhancer have double the intercept area of the theoretical flat plate to obtain the same RCS.

Types Of Passive Enhancement Devices

a. Trihedral Corner Reflector - A trihedral corner reflector consists of three conducting planes whose intersections are mutually perpendicular. The corner reflector will not work for circular polarization since the returns are in the wrong sense to be received. Modification to corner reflectors to permit them to work with circular polarization increse the losses and may make the devices highly frequency sensitive. (Reference 5).

b. Dihedral Corner Reflector - A dihedral corner reflector consists of two conducting surfaces perpendicular to esch other. These reflectors will return both linear and circular polarization, however they have very limited elevation coverage.

c. Luneburg Lens - A luneburg lens is a sphere with a varying dielectric - constant that focuses an incident signal to a point on its surface. This signal can then be reflected and re-radiated back in the direction of the original signal. This device will not work with circular polarization unless modified. The required modifications add to the losses of the device.

d. Van Atta Array - A Van Atta array is an array of dipoles interconnected in pairs with equal lengths of transmission line so that incoming signals are re-radiated in the direction of their origin. The array can be arranged so that alternate dipoles are at right angles to each other so that the array will work with circular polarization.

Passive Enhancer Physical Size - Because the effective angle of a passive enhancer is limited to about forty-five degrees, four to six enhancers would be required to be mounted on a small aircraft. To be practical these enhancers must be physically small enough to permit this multiple installation without adversely altering the aerodynamics of the small aircraft.

As was presented previously, the equation for the RCS of an idealized passive enhancer (or a flat plate) viewed head on is:

$$\sigma = 4\pi A^2/\lambda^2$$

where

A = effective intercept area
λ = wavelength of signal

Using this equation, the area of an idealized passive enhancer can be calculated for a given RCS and wavelength. An operational enhancer would have to take into consideration an approximate 3 dB loss inherent to all retrodirective devices and another 3 dB loss at the edges of the effective angle. This means that an operational (or real-world) enhancer must have twice the area of an idealized enhancer.

Tables 4 and 5 below show the physical areas required in both m^2 and in^2 for an idealized enhancer (flat plate) and an operational enhancer for three levels of RCS. Table 4 gives this information for the ASR and Table 5 is for the ARSR. (Note - the m^2 used in the units for RCS is not the same unit as the m^2 used for physical size.)

	Ideal Enhancer (flat plate)		Operational Enhancer	
RCS(m^2)	m^2	in^2	m^2	in^2
2	.04	62	.08	124
1.5	0.345	53.5	.690	107.0
33.3	.175	270.6	.350	541.2

Table 4 ASR Enhancer Physical Size

	Ideal Enhancer (flat plate)		Operational Enhancer	
RCS(m^2)	m^2	in^2	m^2	in^2
2	.092	142.6	.184	285.2
5	.145	224.75	.29	449.5

Table 5 ARSR Enhancer Physical Size

Work Previously Done

a. Van Atta Array Evaluation - A Van Atta array system developed by Mac Dowell Associates was evaluated at NAFEC. This system consisted of four 10" by 7" arrays mounted in the plastic wingtips of a Piper Cherokee aircraft.

The arrays were positioned so that they faced at angles of forty-five degrees to the centerline of the aircraft. (See Figure 8). The aircraft was flown on prescribed courses and tracked by the ASR-4 at NAFEC.

The conclusion reached was that although the Van Atta arrays resulted in some increase in radar sensitivity to the test aircraft, the increase was not operationally significant.

b. Dipole Enhancement Evaluation - Tests were conducted at NAFEC in coordination with the Air Force to determine the radar enhancement capability of dipoles taped to the canopy of a fighter aircraft. The effect of these dipoles on radar reflectivity was negligible.

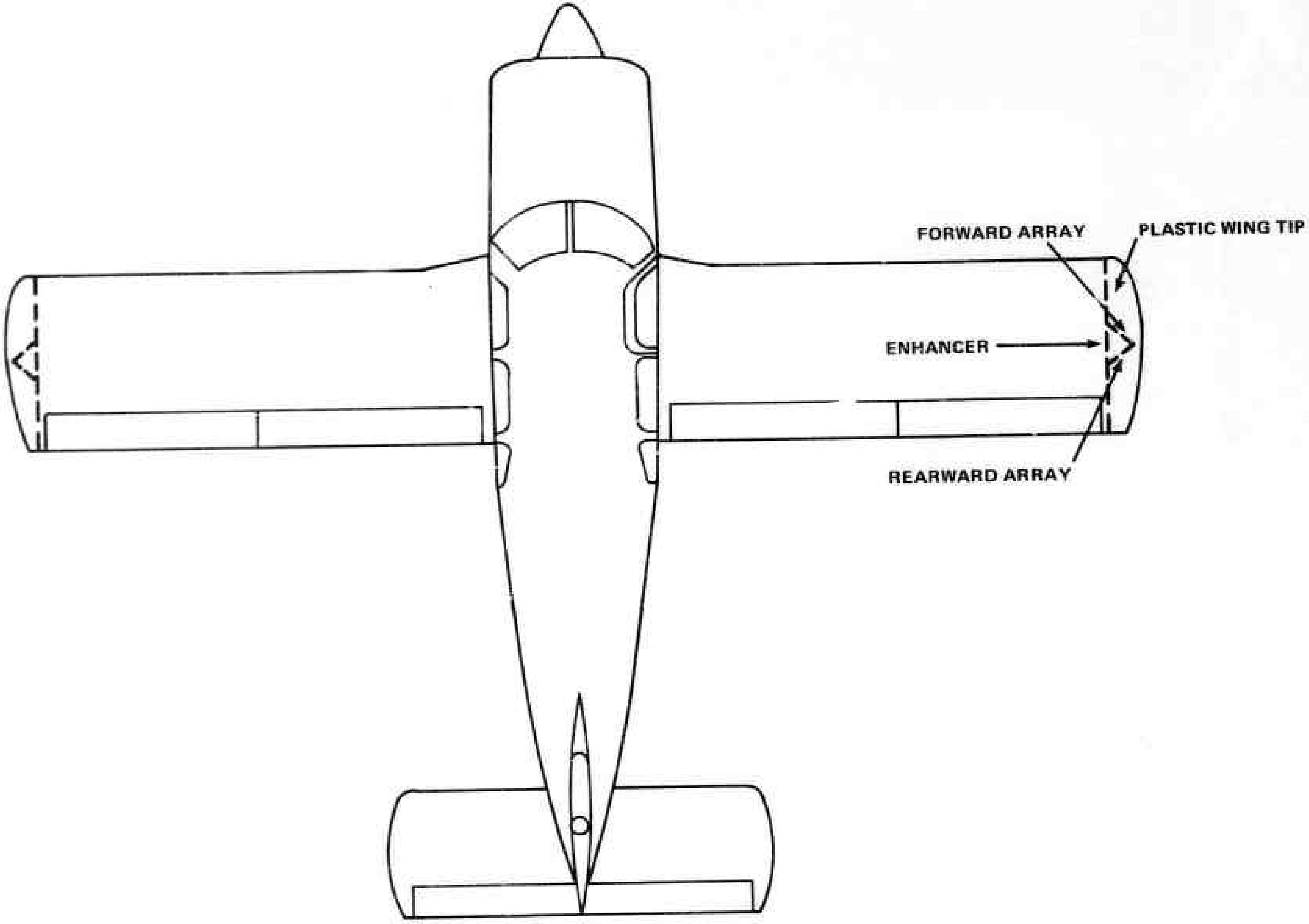


FIGURE 8 ILLUSTRATION OF ENHANCERS INSTALLED IN TEST AIRCRAFT

ACTIVE ENHANCEMENT - There are basically two types of active enhancement techniques. These are (a) amplifier enhancement whereby the received radar signal is amplified and returned, and (b) transponder enhancement whereby the received radar signal is used to trigger an airborne transmitter. The Air Traffic Control Radar Beacon System (ATCRBS) utilizes transponder techniques. The FAA has explored enhancement systems utilizing both of these techniques. The ATCRBS and these techniques are discussed below.

Air Traffic Control Radar Beacon System (ATCRBS) - The Air Traffic Control Radar Beacon System (ATCRBS) was developed for the specific purpose of improving surveillance of aircraft. Initially beacon transponders had 64 discrete codes. All transponders sold today are required to have 4096 discrete codes. Some advantages of the ATCRBS are:

a. reinforcement of radar targets without competition with clutter (ground, precipitation, angel, etc)

b. rapid target identification and initiation of tracks in the automated system.

c. unique display of selected codes to aid controllers

d. alerting of controllers to emergency situations

e. reporting of altitude for those aircraft equipped with transponders and encoding altimeters.

The FAA actively encourages the installation of transponders in all aircraft and is expending considerable effort to improve the ground portion of the ATCRBS.

Since the ATCRBS is in effect an "enhancement system" already implemented by the FAA this system should form the baseline for comparison with any new enhancement system.

The minimum cost of an ATCRBS transponder is $595.

Amplifier Enhancement - This class of active enhancement devices receives a signal from the radar, amplifies this signal, and returns it. The FAA and U. S. Air Force (Rome Air Development Center) participated in a joint effort to develop and test such a device. RADC had the primary responsibility for the development effort and awarded a contract to Stanford Research Institute (SRI). The FAA had the primary responsiblity for test and evaluation.

Initial efforts centered upon the development of an active Van Atta array that would operate in the 2700-2900 MHz frequency band. Reflection type amplifiers were added to the transmission lines connecting the elements of the array. It was anticipated that this device would have the retrodirective characteristics of a passive Van Atta array and would also have sufficient signal amplification to allow a reduction in the size of the array sufficient to permit a practical installation on a small aircraft. This device could not be made to function over the full frequency band of 2700-2900 due to a lack of isolation between elements of the array.

When it became evident that an active Van Atta array would not provide the required performance SRI initiated development efforts on an active corner reflector. This configuration consisted of a circular array of four reflection - amplifier terminated dipoles centered around a cross of barrier strips forming a 90 degree corner reflector behind each dipole (Figure 9) (Reference 6). The corner reflector increased the isolation between dipoles. Even with the increased isolation the performance over the full frequency band of 2700-2900 MHz was not adequate.

A third configuration proposed by SRI was a target enhancing linear relay (TELR) system. This system consists of a pair of dipole antennas, a 40 dB S-Band amplifier, and interconnecting cables (see Figure 10). The radar signal is received on one antenna, is amplified, and is re-radiated at the same frequency from the other antenna. The dipole antennas must be placed at least eight feet apart to provide proper isolation. Both antennas must be visible for the system to function. In the flight tests at NAFEC (Reference 7) the antennas were installed on the belly of a Piper Cherokee 180 aircraft with the amplifier and a battery pack mounted in the baggage area.

The NAFEC flight tests indicated that the TELR provided significant improvement at long ranges in a tail-on aspect. The TELR did not provide significant enhancement nose - on and during terminal area maneuvers. Perhaps one reason for this was shielding of one or both of the antennas except in a tail-on aspect.

A solid state S-Band amplifier forms the major equipment cost of the TELR. This system used an Amplica Model No. 2544SS amplifier. Cost estimates obtained from Amplica for this amplifier are: (See Appendix D).

QUANTITY	PRICE
1-4	$725
100	$350
500	$300
1000	$260

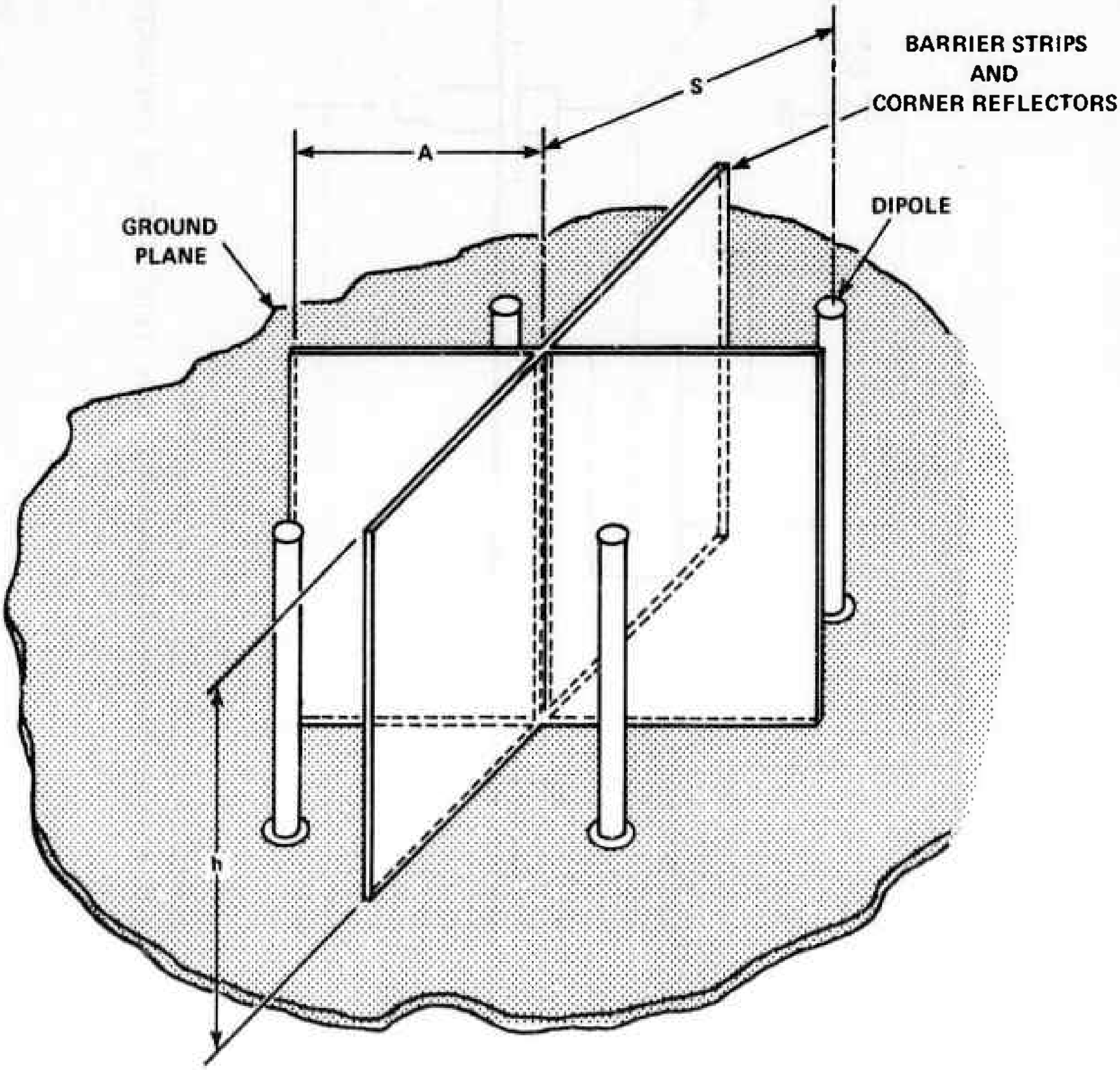


FIGURE 9 ACTIVE-CORNER-REFLECTOR TARGET ENHANCER

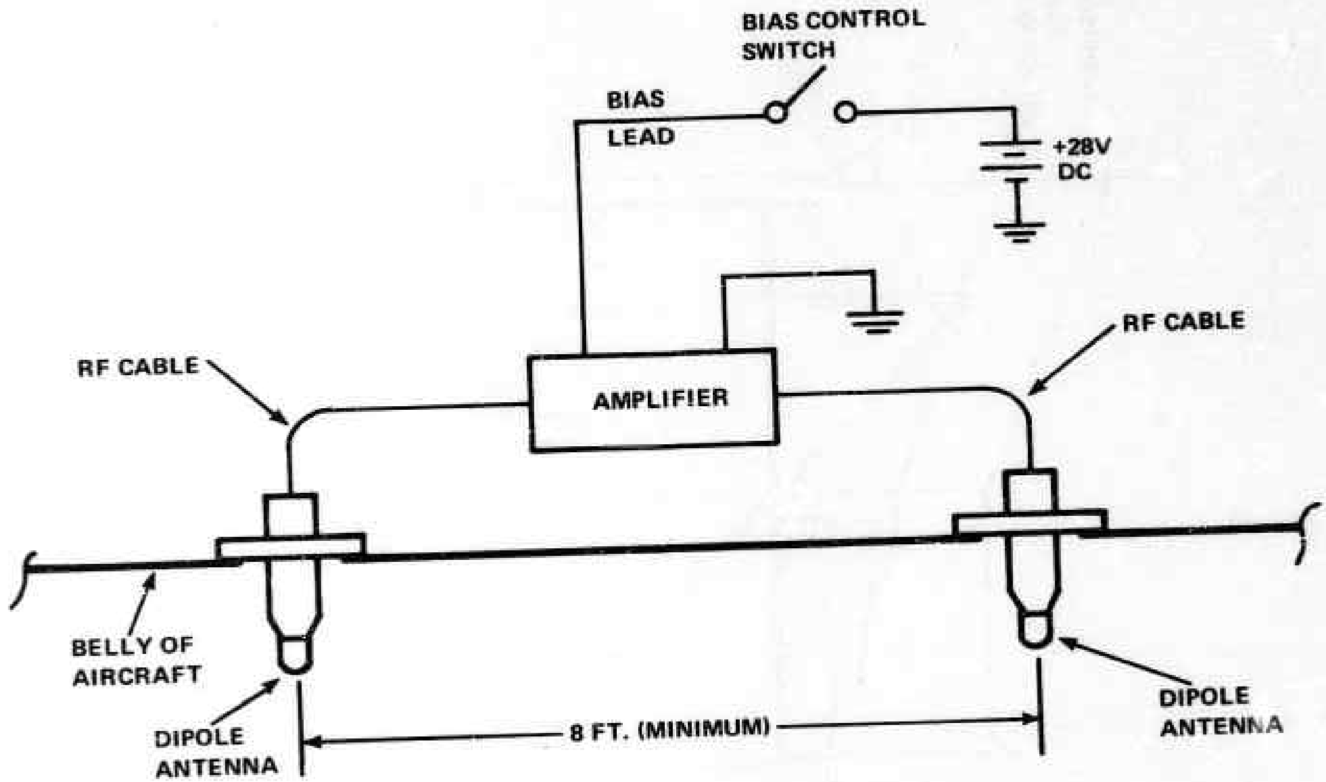


FIGURE 10 TARGET ENHANCING LINEAR RELAY (TELR) SYSTEM SCHEMATIC DIAGRAM

It is estimated that a complete TELR system would cost more than $300 even in large quantities. This would not include installation charges. The $300 represents half of the cost of a beacon transponder without offering such features as discrete codes, emergency codes, and altitude reporting capability. If capability to operate with the ARSR systems was added, the price would double.

An area that was not explored at NAFEC was a determination of the additional interference caused by this system.

Transponder Enhancement - The other form of active enhancement uses the transponder technique. In this technique a signal is received from the radar by an airborne unit which then generates a reply. The FAA leased and evaluated an enhancement system developed by Vega Precision Laboratories that utilized the transponder principle. This system is known as the Vega Aircraft Radar Enhancing System (VARES). (Reference 8)

The VARES is a cross-band beacon system consisting of a ground receiver and airborne unit. The overall equipment configuration and principles of operation are shown in Figure 11.

The system is designed to operate with a standard airport surveillance radar/ air traffic control beacon interrogator (ASR/ATCBI) terminal facility. The airborne unit responds to interrogations from the radar transmitter in the 2700 to 2900 MHZ frequency range and replys on the existing beacon interrogation frequency of 1030 MHZ.

A ground receiver, which is connected to the beacon antenna through a circulator for isolation purposes, processes the VARES replies for display. The receiver and airborne unit block diagrams are shown in Figures 12 and 13 respectively.

The evaluation indicated that the VARES provided an increased radar target detection capability. The maximum range of the VARES was about 55 miles. The system performance did not deteriorate when the ASR frequency was changed from 2710 MHZ to 2790 MHZ or when the polarization was changed from vertical to circular.

Since the VARES operating principles are the same as the Air Traffic Control Radar Beacon System (ATCRBS) it faces many of the same problems. One of these problems is fruit. This would require that a defruiter be installed in all ground equipment.

Another problem is ring around which occurs when the airborne unit responds to sidelobes. The introduction of Sensitivity Time Control (STC) might help filter out the extraneous returns in the ground receiver however, if the system was widely deployed Side Lobe Suppression (SLS) might become necessary. SLS would be more effective than STC since it actually prevents the airborne unit from replying to sidelobes rather than just preventing

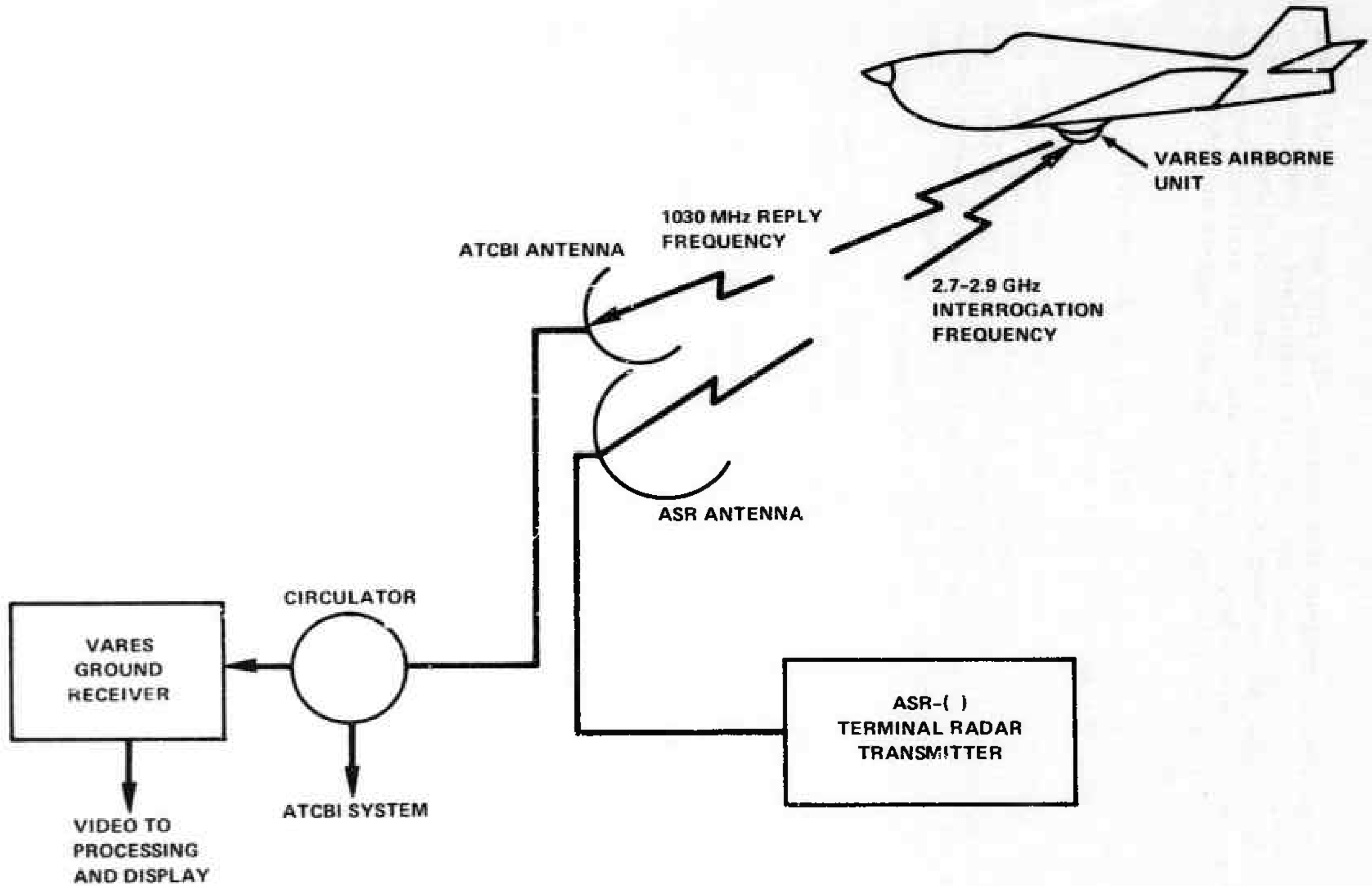


FIGURE 11 VEGA AIRCRAFT RADAR ENHANCING SYSTEM (VARES)

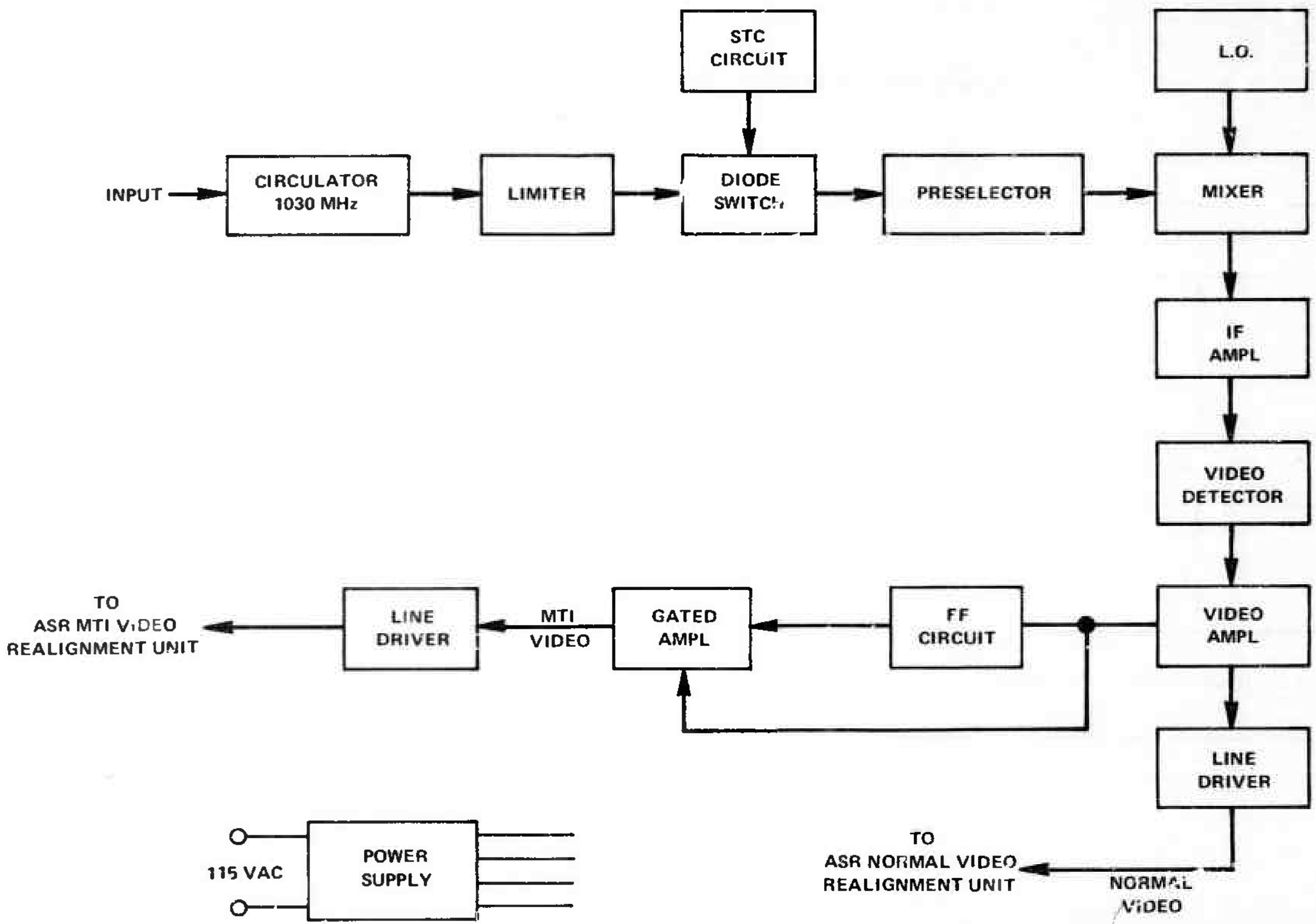


FIGURE 12 BLOCK DIAGRAM OF MODEL 641-1 L-BAND RECEIVER

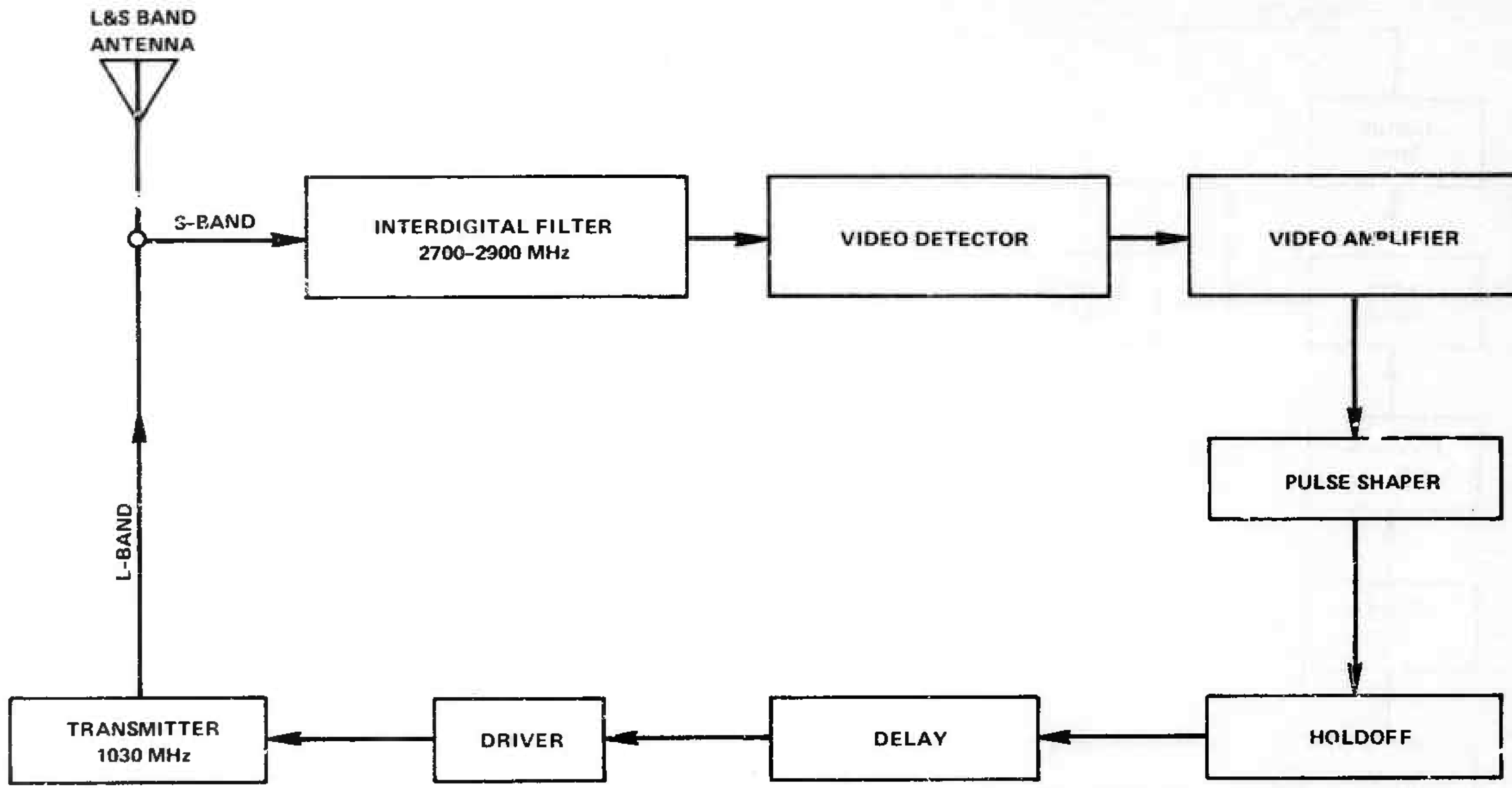


FIGURE 13 BLOCK DIAGRAM OF MODEL 641-2 AIRBORNE ENHANCER

the display of extraneous replies. SLS significantly reduces the generation of fruit. (Reference 9).

Another potential problem is transponder overload. The ATCRBS transponder has the capability of reducing its receiver sensitivity if it receives too many interrogations. This has the effect of eliminating those interrogations from the furthest distance. The VARES as tested did not have automatic overload control.

The VARES responded on 1030 MHZ, the beacon interrogator frequency. Tests at NAFEC indicated that a VARES return would be above the receiver threshold of an ATCRBS transponder within a range of 10 miles. If the VARES was widely deployed, it would significantly increase the level of interference on the ATCRBS interrogator frequency and thereby increase the probability of ATCRBS false replies and suppressed replies. This could be especially crucial when the Discrete Address Beacon System (DABS) is implemented, utilizing the same (1030 MHZ) interrogator frequency.

Vega Precision Laboratories estimated in 1971 that the VARES airborne unit would sell for about $100. Since this system was leased from Vega for the FAA evaluation and the design was proprietary, the FAA could not verify this cost estimate.

RADAR IMPROVEMENTS

The detection of small aircraft can be improved through the improvement of primary radar systems. The FAA is currently procurring new improved terminal and enroute radar systems. In addition the FAA is procurring new antennas for use in existing terminal radar systems.

A processor called the Moving Target Detector (MTD) shows great promise in improving the detection of small aircraft. The MTD was developed by the FAA and is presently being evaluated. This system will permit the tracking of small aircraft at low altitudes, over heavy ground clutter, through precipitation clutter, and is not subject to the loss of targets due to the tangential blind speed as is the case with our present radars utilizing MTI.

III. CONCLUSIONS

A. Passive enhancement of small aircraft is not practical because of the substantial size of enhancement devices required.

B. Amplifier-type active enhancement devices have unresolved problems of antenna placement and potential interference with ground radars and will not work with both terminal and enroute radars without doubling the cost. The cost of these systems is a substantial portion of that of an ATCRBS transponder. The operational capability does not approach that of an ATCRBS transponder.

C. Active enhancers utilizing transponder techniques are feasible. The ATCRBS is, in fact, an active enhancer. Development of a new transponder enhancer would actually duplicate the ATCRBS in some modified form.

IV. ALTERNATIVES

A. Periodically review the state-of-the-art in active enhancers.

B. Continue the development program to design a practical active enhancement device.

C. Undertake no further work on investigation of enhancement devices.

D. Encourage the installation of ATCRBS transponders in all aircraft.

E. Require all aircraft to install ATCRBS transponders.

F. Initiate development effort on an ultra low-cost ATCRBS transponder.

V. RECOMMENDATIONS

A. The Air Traffic Control Radar Beacon System (ATCRBS) is the enhancement system that should be promoted by the FAA since an ATCRBS transponder can be purchased and installed in a small aircraft at a reasonable cost.

B. The FAA should not undertake further program efforts on small aircraft enhancement except to keep abreast of developments in the state-of-the-art that may affect enhancement.

C. The FAA should continue development and evaluation efforts on Moving Target Detector techniques to improve detection of small aircraft.

REFERENCES

1. "Civil Aviation Midair Collisions Analysis," Report No. FAA-EM-73-8, the MITRE Corporation, dated May 1973.

2. "Primary/Secondary Terminal Radar Siting Handbook" (Draft), FAA, dated January 31, 1974.

3. Nathanson, F. E., "Radar Design Principles," 1969.

4. "Angel Clutter and the ASR Air Traffic Control Radar," Report No. FAA-RD-73-158, Johns Hopkins University Applied Physics Laboratory, February 1973.

5. "Feasibility Study of Radar Reflectors for Light Aircraft," Report No. 6109-3, Radiation Inc., April 1957.

6. "Beacon Target Enhancement," Report No. RADC-TR-74-146, Stanford Research Institute, May 1974.

7. Offi, D. L., "Flight Tests of the Rome Air Development Center Target Enhancing Linear Relay System, "Report No. FAA-RD-74-141, FAA, October 1974.

8. Offi, D. L., "Tests of the Vega Aircraft Radar Enhancing System (VARES)," Report No. FAA-RD-73-38, FAA, April 1973.

9. Spencer, N. A. "Radar Enhancement of Small Aircraft in the ATC System," Report No. MTR-6428, MITRE, June 8, 1973.

10. "Airman's Information Manual," FAA, November 1974.

APPENDIX A

FAA/NTSB CORRESPONDENCE

DEPARTMENT OF TRANSPORTATION
NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C. 20591

January 30, 1970

OFFICE OF
THE CHAIRMAN

Honorable John H. Shaffer
Administrator
Federal Aviation Administration
Washington, D. C. 20590

Dear Mr. Shaffer:

Recent investigations into the facts and circumstances concerning two midair collisions which occurred in radar terminal areas between large, high-performance air carrier aircraft and small general aviation aircraft have revealed, among other things, the following:

The small aircraft was not detected by the air traffic controllers on radar in one case, and was detected and subsequently lost from the radar in the other.

The small aircraft, with low radar cross sections, were operating in radar tangential effect during a portion of the controllers' available detection time. The radar cross sections of the small aircraft were considered marginal.

Safe and effective air traffic control expanded radar service cannot be provided unless aircraft possess adequate radar cross section to ensure that usable primary radar returns are received on the controller's display equipment.

Suitable passive radar reflectors are available for small aircraft which will increase the aircraft's radar cross sections, thereby enhancing their reflective capability to the desired level. Reflectors can be designed to eliminate the tangential effect.

The cost of the simple reflectors, with 2 square meters of reflective augmentation, is within the financial means of most operators who desire to use the available expanded radar service in terminal areas. The cost of reflectors with the capability of eliminating the tangential effect is somewhat greater.

We believe that it would be appropriate to modify Parts 21 and 23 of the Federal Aviation Regulations to require all aircraft under 12,500 pounds, manufactured after some appropriate date, to possess a radar cross section suitable for primary target detection by FAA radar at ranges up to 125-150 miles. This cross section augmentation should be accomplished during manufacture, using passive reflectors.

We also believe that the regulations should require a minimum level of radar cross section for present-day aircraft before permitting them to operate in certain expanded radar service environments such as the high-density areas indicated in your recent rule making proposals.

Sincerely yours,

John H. Reed

John H. Reed
Chairman

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

WASHINGTON, D.C. 20590

OFFICE OF THE ADMINISTRATOR

11 February 1970

Honorable John H. Reed
Chairman, National Transportation Safety Board
Department of Transportation
Washington, D. C. 20591

Dear Mr. Chairman:

This is in reply to your letter of 30 January 1970 in which you recommended that the Federal Aviation Administration take regulatory action to require specific radar cross sections on light aircraft when operated within certain radar service environment.

We are actively working with industry to develop methods or devices to enhance radar detection of light aircraft. The evaluation of target enhancers is in addition to our transponder program.

We have no knowledge of suitable passive radar reflectors which are now available for small aircraft. To our knowledge, an acceptable application of passive reflectors has not been demonstrated on existing metal skin small aircraft. Your letter indicates you may have information that has not been made available to us. We would appreciate your informing us so that we may contact anyone with a promising proposal. We would like to use our facilities to test and evaluate active or passive radar enhancement devices.

As soon as an acceptable approach to radar target enhancement is found, we will be in a position to consider regulatory action making radar enhancement devices a requirement in addition to requirements for transponders under specific operation.

Sincerely,

G. S. Moore

G. S. Moore
Acting Administrator

DEPARTMENT OF TRANSPORTATION
NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C. 20591

OFFICE OF
THE CHAIRMAN

March 19, 1970

Honorable John H. Shaffer
Administrator
Federal Aviation Administration
Department of Transportation
Washington, D. C. 20590

Dear Mr. Shaffer:

Thank you for your response dated February 11, 1970, to our recommendation concerning modification of the Federal Aviation Regulations to insure adequate radar cross section of aircraft weighing under 12,500 pounds.

We were pleased to learn that you are actively engaged in the development of "methods or devices to enhance radar detection." While we now have considerable data, we have decided to invite industry representatives to present a briefing, in the near future, on the state of the art. In that way we hope to be able to furnish you with more complete information concerning passive radar reflectors.

As soon as the date for this briefing has been established, we shall advise you and would welcome attendance by representatives of the Federal Aviation Administration.

Sincerely yours,

John H. Reed

John H. Reed
Chairman

DEPARTMENT OF TRANSPORTATION
NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C. 20591

OFFICE OF THE CHAIRMAN

July 7, 1970

Honorable John H. Shaffer
Administrator
Federal Aviation Administration
Department of Transportation
Washington, D. C. 20590

Dear Mr. Shaffer:

In our letter of January 30, 1970, we recommended action designed to enhance aviation safety through the use of passive reflectors on small aircraft for the purpose of augmenting primary target returns on FAA radar.

Your response of February 11, 1970, stated that you had "no knowledge of suitable passive radar reflectors which are now available for small aircraft."

Consequently, we decided to convene an industry briefing on the subject and invited FAA representation at the briefing. You accepted the invitation by letter of April 3, 1970, and your representatives were in attendance at the briefing held at the Safety Board on April 28, 1970.

Based upon the presentations at the above-mentioned briefing, we have concluded that the state of the art has evolved to such a degree that due consideration should now be given to its practical application on an expedited basis. The various business concerns have indicated that they are capable of providing the necessary equipment to accomplish this end.

We feel a sense of urgency inasmuch as the circumstances which originally directed our attention to this matter remain unchanged. The potential for catastrophe through collision is still a reality within the ATC system. Small aircraft are difficult and sometimes impossible to detect with present day radar.

In our earlier recommendation dated January 30, 1970, it was suggested that action be taken modifying parts 21 and 23 of the Federal

Aviation Regulations to require that all aircraft under 12,500 pounds, manufactured after some appropriate date, possess a radar cross section suitable for primary target detection. We now believe that a more appropriate regulatory approach would be to amend part 91 of the Federal Aviation Regulations to require that all aircraft have a minimum level of radar cross section in order to operate in radar service environments. Such action would make it possible for some operators, never operating in radar environments, to avoid the necessity of reflective augmentation. At the same time, it would achieve the goal of assuring adequate primary target returns on ATC radar at ranges of 125-150 miles.

Sincerely yours,

John H. Reed

John H. Reed
Chairman

COPY

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

Washington, D.C. 20590

Office of
The Administrator

13 AUG 1970

Honorable John H. Reed
Chairman, National Transportation Safety Board
Department of Transportation
Washington, D. C. 20591

Dear Mr. Chairman:

This is in reply to your letter of 7 July 1970 relative to the use of passive reflectors and acknowledges participation in the 28 April 1970 briefing to which you refer.

In a practical manner, there was no passive device presented at that briefing that would achieve your stated goal of adequate primary target returns on ATC radar at 125-150 miles range. We will expedite our R&D efforts in this matter hoping to develop a practical enhancement device.

In a related action to improve radar detection of small aircraft in terminal areas, FAR 91.90 as amended by Amendment 91-78, effective 25 June 1970, requires operable transponders on all airplanes operating VFR or IFR within the Group I designated terminal control areas. FAR 71 as amended by Amendment 71-6, effective 25 June 1970, defines the list of the nine Group I designated terminal control areas. The requirement for transponders was implemented at Atlanta effective 25 June 1970 and is scheduled for implementation at Washington, D. C., and Chicago O'Hare on 20 August 1970.

Sincerely,

/s/ K. M. Smith

K. M. Smith
Deputy Administrator

APPENDIX B

NAFEC ASR-5 FLIGHT CHECK

DATA

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

DATE: 19 April 1973 WASHINGTON, D.C. 20591

IN REPLY REFER TO: ANA-120

SUBJECT: Aircraft Crosa Section Measurements, Activity No. 022-241-040

FROM: Program Area Leader, ANA-120

TO: K. E. Coonley, ARD-243

NAFEC ASR-5 coverage flight tests were completed on 14 March. A Piper Cherokee 180, Cessna 172, and Piper Super Cub were flown consecutively over a two-week period, following the procedures for determining horizontal and vertical coverage characteristics outlined in the U. S. Standard Flight Inspection Manual.

The data resulting from these tests have been reduced and the resulcs are forwarded for your use. The raw data, in the form of video tape, 35 mm. film, and accompanying log sheets will be retained at NAFEC and will be made available upon request. This letter completes the subject activity.

Original Signed by

W. F. HERGET

Enclosure
cc:
ARD-240

ANA-120:WFHERGET:lbc:x2196:4/19/73
Original Retyped

DATA ATTACHMENT

The aircraft were flown over the ACY 230° radial at various altitudes for outer fringe coverage evaluation, and directly across the radar site on approximately the 250° radial for inner fringe measurements. In addition, each aircraft flew a 15-mile radius orbit around the radar site, at 2000' altitude, to obtain horizontal coverage information.

Normal video was recorded (by photographic and magnetic tape) and displayed for the outer fringe and horizontal runs, and MTI video for the inner fringe runs. Radar parameters are nominal, with the antenna circularly polarized except for several repeat radial runs made to spot check linear polarization coverage.

The data were reduced and vertical pattern results are presented on the attached coverage diagrams. Horizontal information was not presented because there was no apparent difference between aircraft, with solid coverage obtained for the entire orbital run.

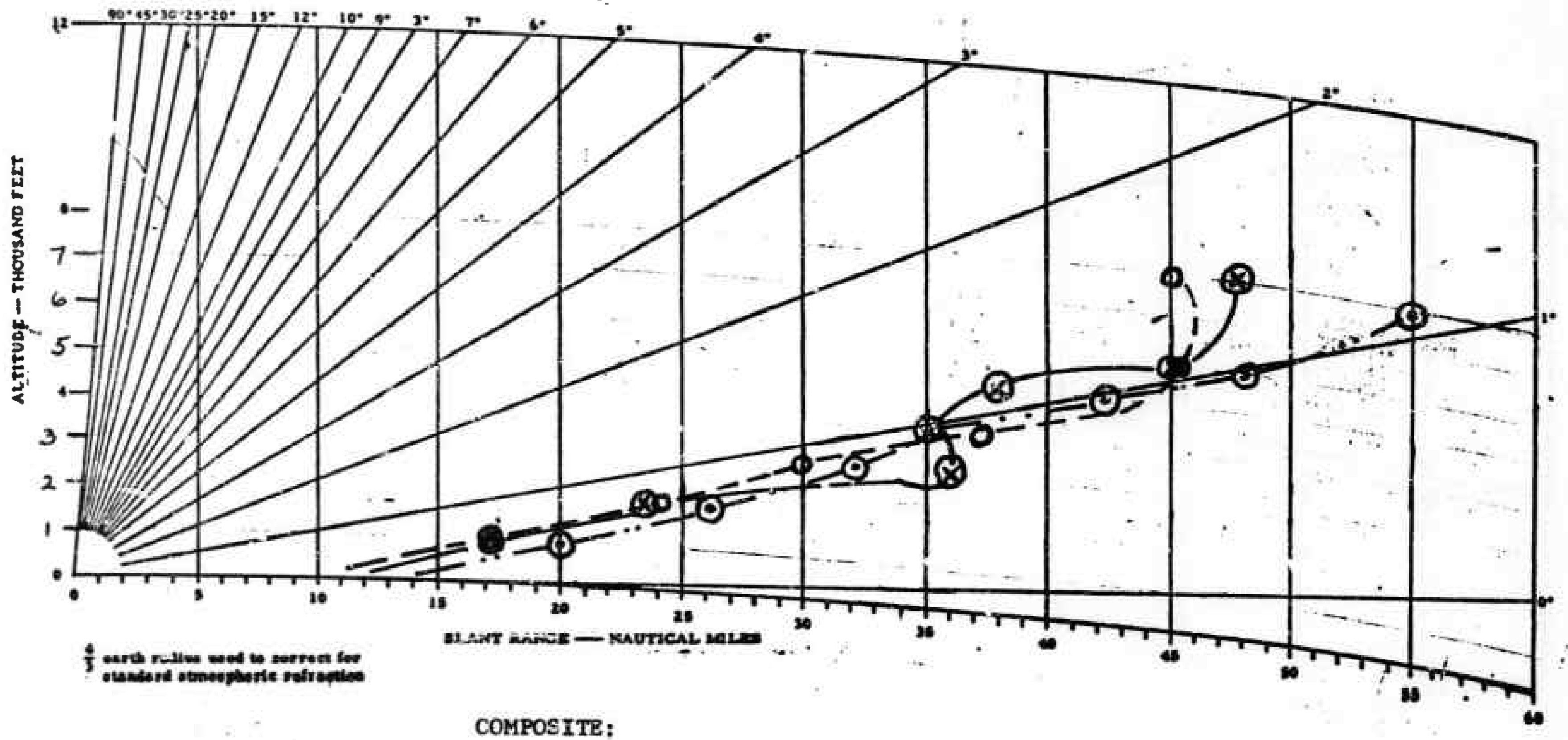
The data points on the diagrams are the average inbound/outbound run information.

Each aircraft was photographed from various aspect angles to illustrate structural differences.

Copies are enclosed.

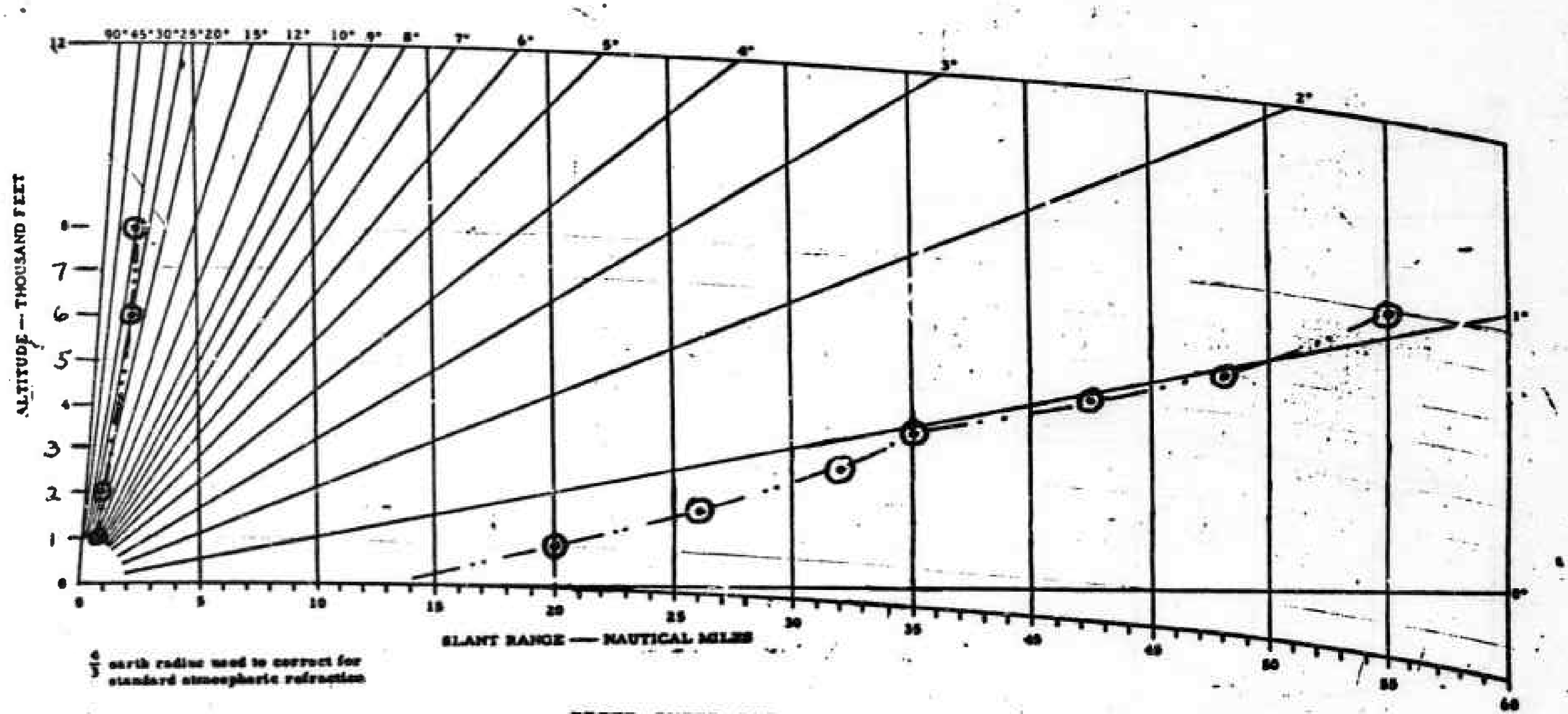
Enclosures

Original Retyped

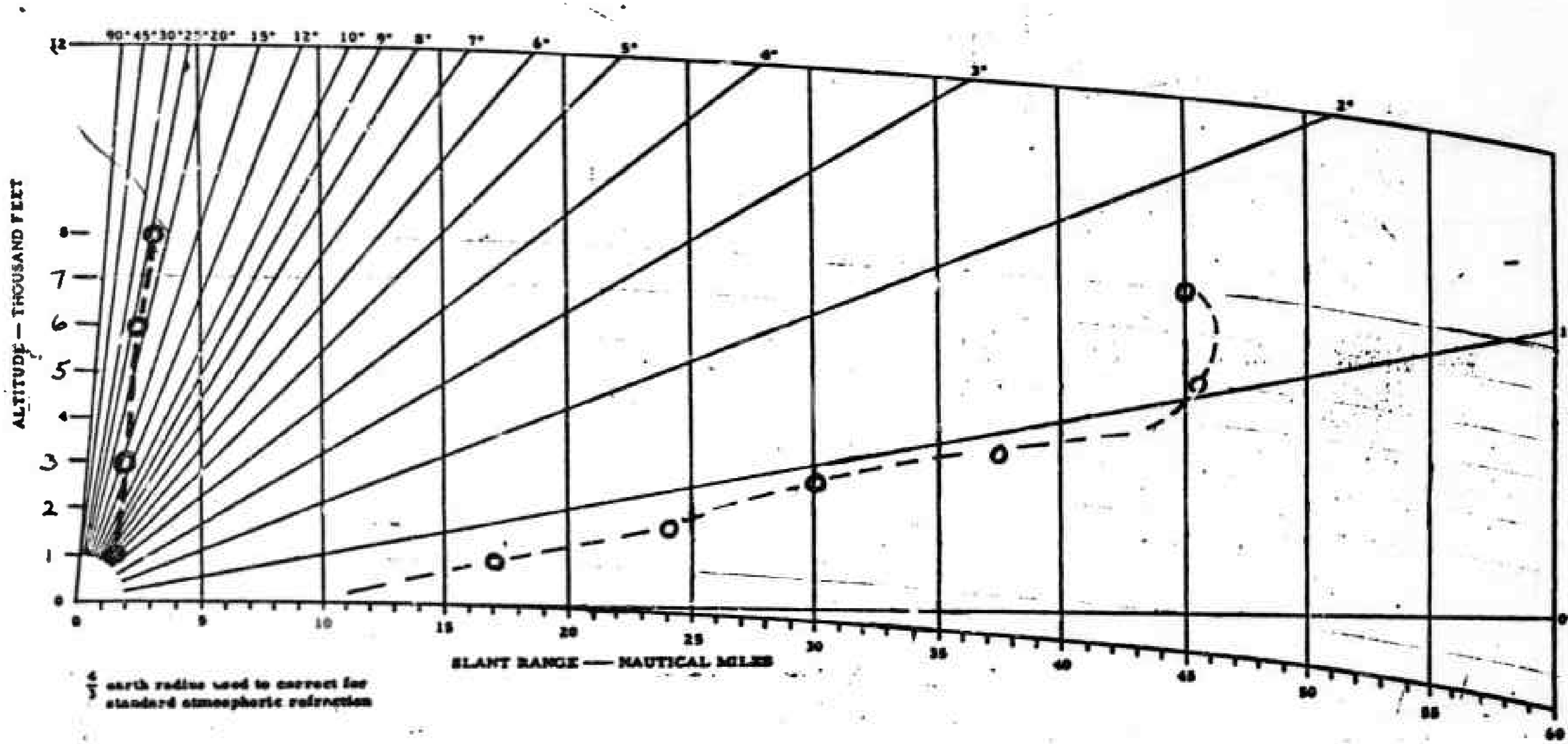


COMPOSITE:

- - - - CESSNA 170
- ..- PIPER SUPER CUB
——— PIPER CHEROKEE 180



PIPER SUPER CUB



CESSNA 170

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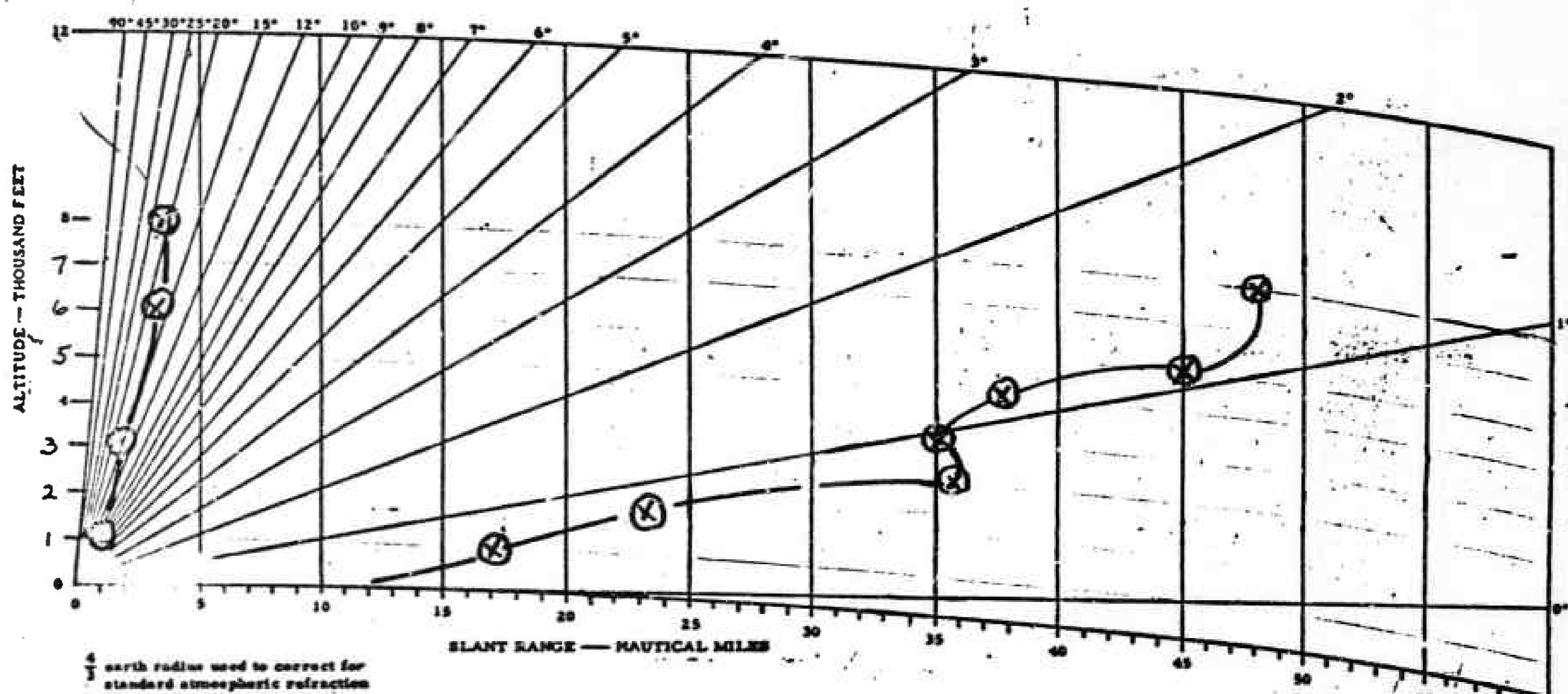

PIPER CHEROKEE 180

APPENDIX C

AMPLIFIER COST ESTIMATE

Amplica, Inc.

730 LAKEFIELD ROAD • BUILDING F • WESTLAKE VILLAGE • CALIFORNIA 91361 • TEL. (213) 889-8700

January 24, 1975
In Ref: 04-176

Federal Aviation Administration
2100 2nd St., S.W.
Washington, D.C. 20590

Attention: Oon Turnbull
Code: ARO 243

Reference: Our telecon of 1/23/75

Subject: S-Band Solid State Amplifier

Dear Mr. Turnbull:

In connection with the reference, Amplica, Inc. is pleased to provide the following quote for your review and consideration.

S-Band Solid State Amplifier Model 2544SS, the same as previously built for Stanford Research Institute in December, 1973.

1-4 Piece Price:	$725.00 each
5 Piece Price:	650.00 each
10 Piece Price:	575.00 each
25 Piece Price:	500.00 each
50 Piece Price:	425.00 each
100 Piece Price:	350.00 each
500 Piece Price:	300.00 each
1000 Piece Price:	260.00 each

Delivery could start 90 days ARO at a rate to be negotiated.

Thank you for allowing us to be of service. In the event you require additional information or clarification, please do not hesitate to contact the undersigned.

Sincerely,

James A. Cole
Vice President

JAC:ls
cc: Vanguard Eng. Sales
Enclosure: 1) Catalog
2) Test data sheet on 2544SS

APPENDIX D

SMALL AIRCRAFT ENHANCEMENT
ANALYSIS, LINCOLN LABORATORY

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LINCOLN LABORATORY
LEXINGTON, MASSACHUSETTS 02173

Area Code 617
862-5500

43C-66 26 June 1973

Mr. Kenneth Coonley
Federal Aviation Administration
ARD-231, Room 719
800 Independence Avenue, S. W.
Washington, D. C. 20591

Dear Ken,

This letter is in response to your memo of 16 May 1973 concerning possible radar enhancement devices for small aircraft. After review of the subject, I can only echo your thoughts and those expressed in the attachments to your letter.

I took this opportunity to consult with F. S. Holt of AFCRL since he has been studying the subject off and on for years and did a review this spring for ESD with respect to Air Force terminal control systems. Attached are his comments.

The conclusions I reached are that there are three possible solutions to the problem of detecting small aircraft, (1) passive reflecting device, (2) active enhancement device and (3) improved primary radar.

(1) The passive device, through many studies, is not viable because it is too difficult and costly to provide enough cross section over 360 degrees even at one frequency (S-band).

(2) Any active device will suffer all the faults of the present ATCRBS beacons. Therefore, if an active device is chosen as the solution it ought to simply be a cheaper beacon since so much money and effort has already been and is being expended in improving the beacon system.

(3) The third alternative is to improve the primary radars so they can easily detect small aircraft in heavy clutter. This is the objective of the ASR Improvement Program at Lincoln Laboratory. There appears to be no reason why the S-band radar being developed will not give 20 to 30 dB greater clutter rejection and, if our assumptions concerning radar cross sections are correct, this should solve the small aircraft detection problem. (The RATSCAT cross section test should confirm our assumptions.) A UHF radar using the same principles has already demonstrated this capability.

I hope the above is responsive to your inquiry.

Best regards,

Charles E. Muehe

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Group Leader

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Attachment - Comments by F. S. Holt

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Comments on Program to Develop

Passive Enhancement Devices for Small Aircraft

F. S. Holt

Starting with RCS measurements on typical small aircraft, then proceeding to considerations of the feasibility of various passive and active enhancement devices, and finally negotiating contracts to develop the most promising of the devices seems to be a most reasonable plan of attack on the small aircraft enhancement problem.

The following comments are primarily concerned with passive enhancement devices:

1. The tests at NAFEC surprised me in that they used such small Van Atta arrays (7" x 10") and that they used four at once on just the wing tips. The expected RCS (radar cross section) for a 7" x 10" Van Atta array at S band is only about 1.3 m^2. Hence, for certain aspects the return from the aircraft itself was surely large enough to interfere with the return from any illuminated array and produce deep RCS nulls. If by any chance more than one array was illuminated at a time then interference certainly occurred between array returns. I think that poor results could have been predicted for this test.

2. Return from an ordinary triple corner reflector or Luneberg lens reflector illuminated by a CP (circular polarization) signal will be in the same CP sense as the return from rain drops and hence will

not be accepted on reception. However these reflective devices can be modified for effective operation with CP. Also the Van Atta array can be modified to operate with CP as well as with LP (linear polarization) but there is still an inherent 3 dB loss.

3. The use of a 45^{o} grid belt around a Luneberg lens could produce a reflector with 360^{o} azimuth coverage and probably $\pm 30^{o}$ elevation coverage. (To my knowledge this device has not been built.) The grid would cause a loss of 3 dB with CP or with horizontal or vertical LP. Assuming a 0.5 dB loss due to attenuation in the lens material and a 3 dB loss due to the presence of the grid, a lens diameter of about 15.4" would be needed to produce an RCS of $8\,m^2$ at S band.

4. A Luneberg lens reflector could be modified to operate with little loss with CP and LP. Coverage over a 120^{o} sector in azimuth and probably $\pm 30^{o}$ in elevation could probably be obtained with a single lens. Assuming a 0.5 dB attenuation loss in the lens material an RCS of $8\,m^2$ could be obtained with a lens diameter of about 13.2". Full 360^{o} azimuth coverage could be obtained by rotating the lens or by using a cluster of three.

5. A word of caution about the above devices. At S band even the largest of the Luneberg lens reflectors discussed above has a diameter of less than four wavelengths. With so few wavelengths in aperture there is some question as to how well these lenses will focus. However, some experimental results with constant dielectric spherical

lenses of diameters about 2 λ have indicated surprising focussing effects, and it is reasonable to assume that the Luneberg lens will perform as well as these constant dielectric spheres.

6. Even with no losses any passive reflector must present an aperture of area at least 125 in^2 to produce an RCS of 8 m^2 at S band. This is an appreciable area and for fast moving aircraft requires recessed or flush mounting. Van Atta arrays on the sides and a Luneberg lens reflector in the nose seems a possible configuration. For slower moving aircraft an exterior mounted Luneberg reflector possibly in a streamlined radome could be considered.

7. At L band the only passive reflector with any possibilities would seem to be the Van Atta array and even its practicality is doubtful because of the large surface area required. Active systems have significant advantages over passive systems at these lower frequencies. With an active system it should be possible to make the exterior configuration very simple and compact. The interior associated electronics creates expense and complexity but these are problems that perhaps can be treated more successfully than the large exterior configuration requirements of passive systems.