PROPAGATION VIA REFLECTIONS FROM AIRCRAFT

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In my article "Enhanced VHF/UHF Signal Levels due to Aircraft", (AR Oct 1985)[1] I explained how the phenomenon known as Aircraft Enhancement[2] could be accounted for by the known effects of passive reflectors. An essential point of my article was that it was a presentation of irrefutable mathematical truths derived from engineering texts. It was not theory. The technical editors of AR may have missed this point because they have subsequently published a contradictory article by Roger Harrison VK2ZTB[3] in which he expounds a theory which purports to explain the phenomenon. The Harrison article is scrutinised in this critique and some points, briefly mentioned in my previous article, are explained in greater detail.

Differing Opinions?

Giving reasons why he doesn't think that direct reflection from the aircraft is the cause of aircraft enhancement, Harrison states "There are widely differing opinions, even in the engineering texts, as to how to calculate the signal levels after reflection from the aircraft." (As a passive reflector.) Is this really the case?

I consulted several engineering texts and compared their formulas for passive reflector gain and path loss via passive reflector links with those given in my previous article, henceforth called "Aircraft Reflectors"[1]. Following is a summary of what I found:

a — Norton's[4] formula for the path loss on a two hop system using a passive reflector in the far field is:

$$Lp(dB) = 171.1 + 20 \log d_1 + 20 \log d_2 - \log a^2$$

The distance is measured in miles and a^2 is the effective area of the passive reflector in square feet. This is the same as in Aircraft Reflectors[1]. The formulas for effective area and passive reflector gain are the same as in Aircraft Reflectors[1].

b — The ITT Handbook[5] editors do not give a formula for path loss being content to simply refer to Norton[4], ie the same as in Aircraft Reflectors[1].

c — Contributors Jakes and Robertson[6] give the total transmission loss for a 'single mirror passive repeater' as:

$$(\text{Loss dB}) = 10 \log \frac{\lambda^4 d_1{}^2 d_2{}^2}{A_1 a_1{}^2 AR}$$

AT, AR, and AI are the effective areas of the transmitting, receiving, and passive reflector antennas respectively and d_1 and d_2 are distances in the same units.

In Aircraft Reflectors[1] AT and AR are isotropic antennas so the effective areas of isotropic antennas must be used in order to compare the results. The effective area of an isotopic antenna is

$$\frac{\lambda 2}{4\pi}$$

When this adjustment is made, the results obtained with this formula are the same as given in Aircraft Reflectors[1].

d — Brodhage and Hormuth[7] give the path loss as:

$$Ap(dB) = 20 \log \frac{d_1 \times d_2 \times \lambda^2}{Sep \times Seu}$$

d_1 and d_2 are in metres, Seu is the reflector effective area and Sep is the effective area of the parabolic reflector used at the terminals. Substituting the effective area of isotropic antennas the formula becomes:

$$Ap(dB) = 20 \log \frac{d_1 \times d_2 \times 4\pi}{Seu\ (Aeff)}$$

This gives the same path losses as given in Aircraft Reflectors[1].

e — Freeman[8] says the path loss a is:

$$GT + GR + GA - a_1 - a_2.$$

Gs are transmitting, receiving and passive reflector antenna gains and a's are path losses, all in dB.

$$GA = 20\log \frac{4\pi A \cos \propto}{\lambda^2}$$

(Passive Reflector Gain)

A is the reflector area (total) and ∝ is half the angle between incident and reflected waves. Watch the signs and you will get the same results as in Aircraft Reflectors[1].

f — Carl[9] states "The gain of an evenly illuminated flat reflector is the same as the gain of a dipole combination with reflector" and:

$$G(dB) = 10 \log \frac{4\pi A}{\lambda^2}$$

(A is Aeff)

Note that this is the one way gain, ie half that given in Aircraft Reflectors[1]. However he also states that the path loss F is:

$F_1 + F_2 - 2G$. (Fs are the path losses)

So he uses G twice anyway. This gives the same results as in Aircraft Reflectors[1].

g — The formula for path loss used by the Lenkurt Electric Co Inc[10] gives the same results as in Aircraft Reflectors[1]. It is formula (27) on page 100 of their publication.

On page 99, referring to 'billboard' type metal reflectors the author states "With surfaces of adequate flatness it is close to 100 percent efficient, as compared to about 55 percent efficiency for antennas".

Furthermore, the passive reflector acts as both a receiving antenna and a retransmitting antenna, and it's 'gain' is therefore applied twice," ie the same as stated in Aircraft Reflectors[1].

h — What about Picquenard[11]? Harrison implies that his opinion, at least, differs. The truth is that Picquenard doesn't address the matter of radio links using passive reflectors at length.

However he does give a nomogram for path loss via a passive reflector. It is Figure 184 on page 287. The distance scale will cover the Canberra to Melbourne path and the passive reflector effective area scale, which he calculates in the same way as in Aircraft Reflectors[1], will cover the Aeff of a 747 at 37 000 feet half way between those two cities.

The path loss scale is a little short as it finishes at 200dB but an easy extrapolation will result in the same path loss as given in Aircraft Reflectors[1] for the conditions considered, ie approx 208dB.

The foregoing clearly indicates that Harrison's assertion about differing opinions is wrong. In fact, all authorities agree that the passive reflector has gain, they agree on how much gain a reflector of a given size has and as a result they all agree on the path loss to be expected from a given link with a passive reflector in it. Their methods differ slightly but the end results are invariably the same.

Furthermore Harrison's calculation of path loss between VK3UM and VK2ZAB is also wrong simply because it does not include the gain of the passive reflector.

The foregoing also clearly indicates that the methods used in Aircraft Reflectors[1] are correct for passive reflectors and also for aircraft because there is surely no doubt that the performance of a flat piece of metal as a reflector is not dependant on the nature of the supporting framework behind it even though this may the rest of an aeroplane.

Observations

Harrison's summary of reported observations contains several which require comment. Are they accurate? Are they reported in an unbiased manner? Let us examine a few of them:

a — "Signal level 'lift' observed is estimated to be 30-60dB." Signal level lift from what? Where is this observed? Is it the same everywhere? One thousand to one million times is a fair degree of uncertainty! It is difficult to imagine this observation being of any use to anyone.

b — "Signal level lift and period of enhancement are **dependant** on upper-air wind conditions, etc".

This is not an observation; it is a conclusion. Is it couched in this manner because Harrison needs it to support his hot air theory?

In fact, all it amounts to is that Canberra amateurs claim that when aircraft enhancement is poor from them to Melbourne, aircraft report turbulence. It has not been clearly related to Sydney to Melbourne contacts and it is not clear whether or not turbulence is always reported when aircraft enhancement is always poor when turbulence is reported.

In any case signal conditions vary for a quite different reason and at best there is only a coincidental relationship to turbulence. This is explained in more detail in the next section of this article.

c — "Stations in Frankston (Melbourne) hear stations in Sydney some two to three minutes earlier than VK3UM, who is located about 40km closer to Sydney".

This is a misleading half truth. Whereas stations in Frankston have been observed to hear Sydney stations earlier than VK3UM hears them, the estimate of two or three minutes relates to how much earlier the Frankston stations hear Canberra[12] and the estimate was made early in the aircraft enhancement experiment when VK3UM was active on two metres rather than 70cm as he is now.

In the case of Sydney stations, although they are heard in Frankston earlier than VK3UM, the time difference has not been clearly established.

VK3UM is located 40km closer to Sydney than Frankston, however he is also located about 16km north-west of a line between Frankston and Sydney and about 15km north-west of a line between Frankston and Canberra. Later in this article I will show that this is more significant than the 40km mentioned by Harrison.

d — "Backscatter propagation is noted between Canberra and Sydney stations ... This phenomenon is only noted during exceptional 'lift' conditions".

This needs to be clarified quite a lot. In fact at least two Canberra amateurs who regularly take part in aircraft enhancement contacts have been in the habit of referring to signals heard via the back of their beams as 'backscatter'. How can genuine 'backscatter' be correlated to 'exceptional lift conditions' under these circumstances?

In any case what exceptional lift conditions? Between Canberra and Melbourne? Both? Or between Sydney and Canberra perhaps?

In spite of these uncertainties, backscatter does occur and when it does doppler shift also occurs. The magnitude and direction of the doppler shift is consistent with back reflections from an aircraft retreating from both Sydney and Canberra, ie past Canberra on its way to Melbourne. Harrison does not mention this, probably because he didn't know about it. However, it does not help his hot air theory much either.

Incidentally, while on this subject, some amateurs have expressed concern about the lack of doppler shift on Sydney-Melbourne and Canberra-Melbourne contacts.

Doppler shift only occurs when there is a change of path length, transmitter to receiver. This happens in the backscatter case but does not happen, or strictly speaking, only happens marginally when the aircraft is near the terminals, during the Sydney- Melbourne and Canberra-Melbourne contacts. Hence there is no doppler shift on those paths.

e — "The size and type of aircraft seemingly has little bearing on the enhancement characteristics, etc".

This is simply not true. It would help the Harrison theory if it was, but it clearly is not. I know of no observers anywhere who would agree with this.

The signal levels are clearly proportional to the size and operating altitude of the aircraft. This has been confirmed many times over the Sydney-Melbourne and Canberra-Melbourne paths as well as in local reports of overseas observations, albeit somewhat sloppy observations[13].

Furthermore, dozens of aircraft enhancement contacts between VK2ZAB and VK4s AUR, AGQ, KJL, and others less frequently on 144.300MHz, together with some contacts between VK2ZAB and VK4AGQ on 432.300MHz have been made at signal levels consistent with the size of the aircraft operating between Brisbane and Sydney at the times when the contacts were made.

The facts are clearly consistent with the path loss and signal level calculations made on the basis of the aircraft as a passive reflector as set out in Aircraft Reflectors[1]. Harrison's summary of observations is clearly biased toward his hot air theory. The omission of the doppler shift in the backscatter observation and the false suggestion that the aircraft size is unimportant, together with the lack of comment on operating altitude clearly show this bias.

However, why does the enhancement mode fail sometimes and what is this about the footprint moving backwards? Let us examine these matters further.

Radar Holes[14]

In Aircraft Reflections[1] I drew attention to the fact that anomalous propagation, other than aircraft enhancement, occurs at some time almost every day[15].

When a group of amateurs are participating in regular scheduled operations, as the aircraft enhancement fraternity are, the laws of chance dictate that other forms of anomalous propagation must sometimes coincide with the aircraft enhancement time slot.

Tropospheric temperature inversions occur frequently causing super-refraction of radio waves and tropospheric ducts[14]. This should be well-known to all VHF/UHF enthusiasts because it gives rise to enhanced signal levels at distant locations and hence 'troppo' contacts.

When ducts coincide with aircraft enhancement schedules it may be thought that the combination would result in even bigger and better signals and indeed sometimes it does. My first 70cm contact with Angus VK4AGQ, in Brisbane, was undoubtedly aircraft assisted troppo.

However, perhaps more frequently than not, the coincidence of ducts and aircraft results in poor aircraft enhancement signal levels.

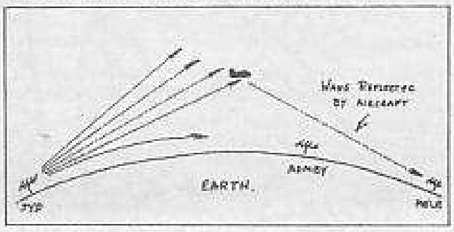


Figure 1a — Normal Aircraft Enhancement Situation. Note: Some low angle waves refracted in normal troposphere provide contact between Sydney and Adaminaby.

Consider Figure 1a: This is the normal aircraft enhancement situation. The signals in Melbourne and Sydney are enhanced by reflection from the aircraft and the signals from Adaminaby are normal in Sydney. There is no duct.

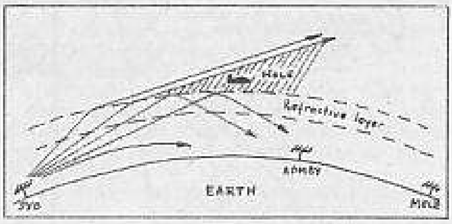
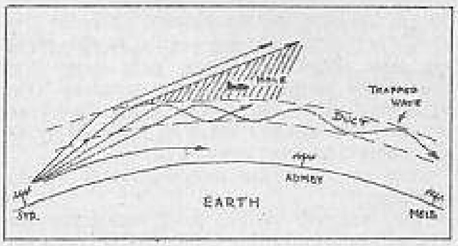


Figure 1b — Aircraft Enhancement Sydney to Melbourne is poor because Aircraft does not intercept signal from Sydney. However, Sydney to Adaminaby signals are good.

In Figure 1b a refraction layer of air caused by a temperature inversion has formed and the aircraft is above it. This results in a decrease in the power density available at the aircraft and aircraft enhancement signals are poor. Signals from Adaminaby are good in Sydney.

In Figure 1c the degree of inversion is such that a duct has formed and the signal has become 'trapped' in the duct. Aircraft enhancement signals are poor. Signals from Adaminaby are normal in Sydney.

The reduction in power density at the aircraft also results in a reduction inthe level of the back-scattered signal so the aircraft may disappear off radar screens. The aircraft is said to be in a 'hole'. It is a well-known and understood phenomenon.



Duct traps wave so that Sydney to Adaminaby signals are back to normal but still no Aircraft Enhancement Sydney to Melbourne.

It is clear that this mechanism is a more likely cause of reduced aircraft enhancement signals than having the hot air blown away in the wind.

Nevertheless, it may be that the meteorological conditions, which give rise to ducts, also give rise to turbulence, as reported by the aircraft, so the observations made by Canberra amateurs may be, coincidentally, valid.

There are diurnal and seasonal variations in the prevalence of inversions so there will also be diurnal and seasonal variations in their coincidence with aircraft enhancement conditions.

Path Geometry and Footprints

Harrison says that: a — The fact that Sydney (or Canberra) stations are heard in Frankston before they are heard at Chirnside Park (VK3UM) indicates that the signal footprint on the ground moves backwards, ie towards the aircraft; and b — That direct reflection from the aircraft would require that the footprint moved forward at twice the speed of the aircraft. Thus, he says, the two are contradictory.

This is nonsense. Proposition a is wrong, proposition b is irrelevant and the contradiction would only apply in a one dimensional world.

The signal footprint on the ground is in the form of a long ellipse modified by terrain irregularities. The long axis of the ellipse lies along the continuation of a line joining the transmitting station with the reflecting aircraft. This pattern may be simulated with a torch (flashlight) resting on the floor of a darkened room so that its beam is at a slight positive angle to the floor, ie the floor is not directly illuminated but the circle of light falls on a wall about 500mm up from the floor and say four metres from the torch.

Now hold a small (75-100mm diameter) mirror face down and parallel to the floor. Lower it into the beam 300 to 400mm in front of the torch and observe the pattern of illumination on the floor.

The shape of the mirror will change the pattern somewhat, as will the shape of the aircraft change the footprint. However, our purpose will be served without considering the complexities introduced by this factor or diffraction effects at the edges, departures from flatness or the earth's curvature. The footprint will be generally elliptical with the long axis along the signal path.

Now consider Figure 2. This illustrates the general case encountered in practice. The flight path of the aircraft crosses the signal paths from transmitter to receivers at an angle.

The signal footprint illuminates receiving site 'A' at a medium distance from the transmitter, it then illuminates site 'B' somewhat further away from the transmitter and then sites 'C' and 'D' simultaneously even though 'C' is closer to the transmitter than 'B' and 'D' is further from it.

The time between illumination of successive sites depends upon the speed of the aircraft, the location of the receiving sites relative to the transmitter and the angle the flight path makes to the signal paths.

The case cited by Harrison where the **whole** signal footprint moves forward at twice the speed of the aircraft, requires the flight path to coincide with the signal path from the transmitter to each observing receiver. This situation would be rarely encountered in practice and doesn't apply to the Sydney or Canberra to Melbourne situation.

Note also that the footprint never moves backwards.

Still referring to Figure 2, consider the transmitter is located at Canberra and receiver B and C are at Frankston and Chirnside Park respectively. The length of time between illumination of these two sites will be that time taken for the aircraft to get from point X to point Y.

I plotted the site locations and signal paths on radio navigation chart AUS RNC 2, available from the Department of Aviation, along with the flight path of large aircraft such as 747s, which leave Sydney on a noise abatement heading which takes them east over Botany Heads to a point, about 13km from the coast, where they turn right and track directly for Eildon Weir. This track takes them between trunk routes which leave Sydney on headings of 195 and 220 degrees (magnetic) and which may be used by domestic aircraft not equipped with inertial navigation systems.

Assuming a nominal speed of 650km/h the aircraft will cover the 33.36km from point X to point Y in 2.35 minutes. This is the time between signal 'peaks' at Frankston and Chirnside Park (VK3UM) for that aircraft reflecting a signal from Canberra. For signals originating at Berowra Heights (VK2ZAB) the geometry is different, points X and Y are 80.61km apart and the time difference is 5.69 minutes for a 747 on that flight path.

These are nominal acquisition time differences only because factors which will result in small variations in acquisition times have not been taken into account. These include terrain factors, differences in Lar, the space loss via the aircraft reflector[1], and differences in receiver thresholds at the two sites.

Signal Strengths

Harrison observes that amateur 'S-meter' reports are meaningless, and I agree with him, but he then goes on to take them more or less at face value. Furthermore, his suggestion that says VK1BG's signal on 432MHz can traverse the gap between Canberra and Melbourne, be backscattered from the ground, traverse the gap between Melbourne and Sydney and then retain such power that I can receive it at readable level, all with the aid of a ball of hot air, is simply mind boggling.

Nevertheless, I have been told that amateurs, particularly some located in Melbourne, have difficulty accepting the signal levels predicted in Aircraft Reflectors[1] because their 'S-meters' indicate higher levels at times.

I am still inclined to the view that this is **primarily** due to bad calibrations and that if I had said that say -105dBm was equal to 10dB over S9 instead of the IARU standard S7, there would have been no problem. There is also some evidence to indicate that the aircraft enhancement fraternity does not take into account phenomena like elevated ducts and temperature inversions which may reduce the path loss from the aircraft to the terminal sites under some circumstances.

There is no doubt that the signal levels received due to aircraft enhancement on its own is determined by the transmitted power, transmitting aerial gain, receiver aerial gain, cable losses and the path loss with the aircraft as a passive reflector. It may be that this last factor is not properly understood.

The formula for the path loss via an aircraft reflector is:

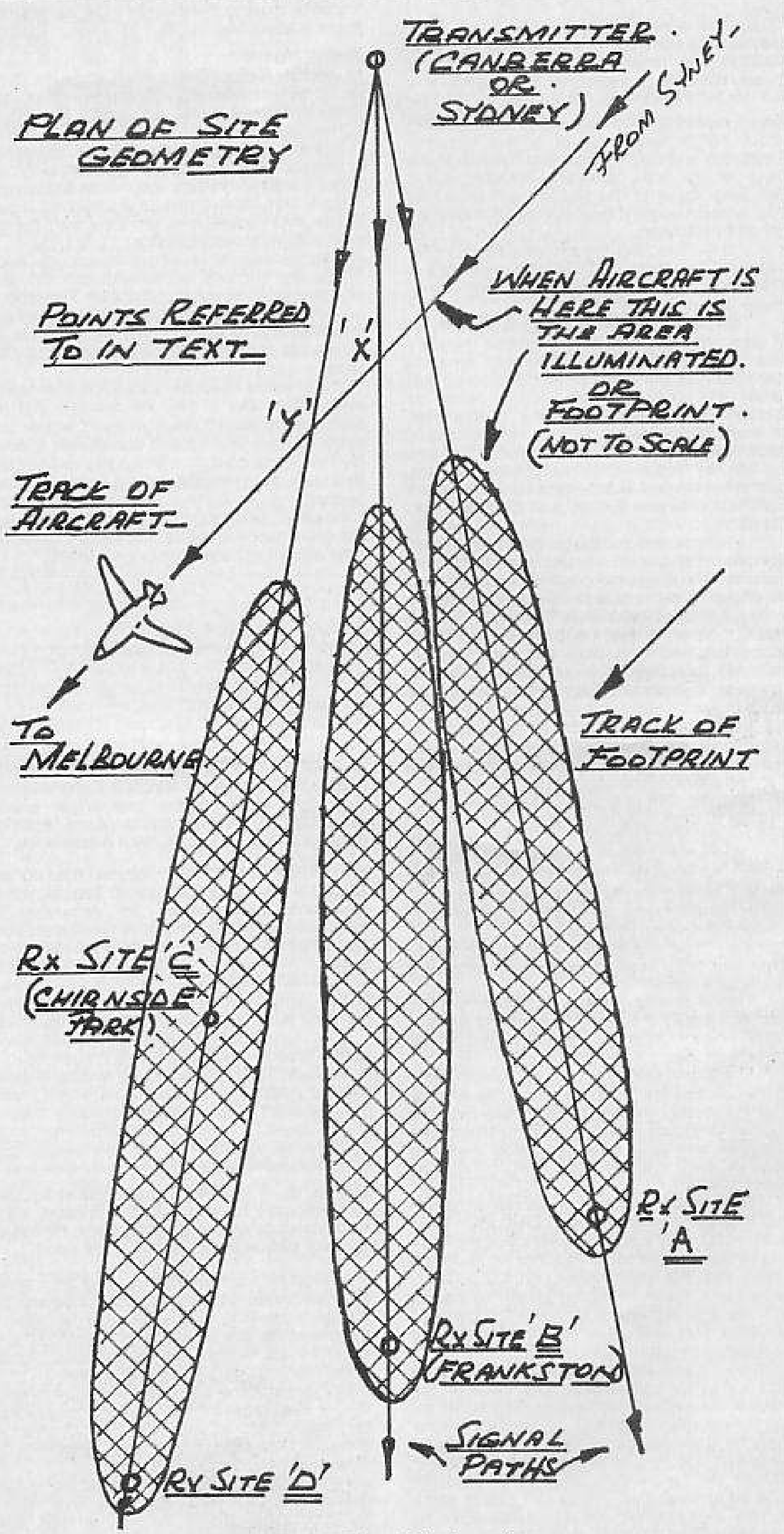


Figure 2 — Plan of Site Geometry.

$\mathrm{Lar(dB)} = 141.98 + 20 \log d_1 + 20 \log d_2 - 20 \log \mathrm{Aeff}$[1]

Where d_1 and d_2 are the distances in km from the terminal sites to the aircraft and Aeff is the effective area of the aircraft reflector in square metres. For a flat sheet:

$\mathrm{Aeff} = A \sin \theta$

Where A is the reflector area in square metres and θ is the angle of incidence of the signal.

Consider the following:

a — Obviously, if the distances decreases the path loss will decrease. Signals from Canberra are stronger in Melbourne than signals from Sydney.

b — The examples given in Aircraft Reflectors[1] assume $d_1 = d_2$. If d_1 does not equal d_2 the path loss will decrease. The 747 on track for Eildon Weir crosses the Canberra to Frankston line much closer to Canberra than to Frankston. Therefore, provided it isn't counteracted by any other factor, the signal from Canberra will be about 5.5dB or one 'S' point better in Frankston than that indicated in Aircraft Reflectors[1].

c — If the aircraft flies higher than the nominal altitudes given in Aircraft Reflectors[1] θ will increase, Aeff will increase and the loss will decrease, but not by much. Work it out for yourself.

d — In Aircraft Reflectors[1] the examples of signal levels were based on aircraft as reflectors equivalent in area to the aircraft's wings. This is the only uncertain parameter in the formula.

Obviously bigger aircraft are bigger reflectors and cause lower path losses but is the area 'A' of a given aircraft equivalent to a flat sheet of the same area as its wings?

Persistent claims by amateurs who claim to have properly calibrated 'S-meters' indicate that the signal levels might be slightly higher than those given in the Aircraft Reflectors[1] examples.

Furthermore theory indicates that the forward scatter cross section of even a sphere is greater than the backscatter cross section[16], so it may be that parts of the aircraft other than the flat undersides contribute to the equivalent area and hence to Aeff resulting in a reduction in path loss beyond that given in the Aircraft Reflections[1] examples.

Nevertheless, even if the equivalent flat sheet area of the aircraft is twice that assumed in Aircraft Reflectors[1], the path loss will be reduced by no more than 6dB or one 'S' point on the examples given.

History

Reflecting objects such as ships and aircraft have been causing enhanced signal levels at receivers a considerable distance from the transmitter for almost as long as radio has existed. Reflections from aircraft were recorded in 1931 and a series of experiments were carried out, using among other things, a Ford trimotor and a transmitter on about 72MHz.

These early observations led to a system for the radio detection of ships using 'wave interference' equipment which later became known as "Bistatic Radar"[16].

Bistatic Radar uses transmitters and receivers a considerable distance apart (comparable to the target range) instead of at the same location (Monostatic Radar).

The system had disadvantages which caused it to be dropped in favour of Monostatic Radar, but not before it had been noted that one of its advantages was the dramatic increase in signal level which obtained when the transmitter, target and receiver were all in line (180 degrees Scattering Angle).

The system was investigated again in 1955, but again shelved.

The point is that "Aircraft Enhancement" is Bistatic Radar. It is not new. The system parameters were worked out long ago and it all happened before the jet age. There is not much of a ball of hot air behind a ship or a Ford trimotor.

Conclusion

The Harrison article has been shown to be inaccurate, misleading and illogical. The enhanced signal levels, due to aircraft, are caused by reflection from the aircraft itself. Harrison's article fails to provide an alternative to this historical, well-documented, engineering fact.

NOTE: The forgoing arguments are clear and convincing, but do not eliminate the possibility of a hot air refraction mechanism also taking place. Clarification of the debate as to the relative magnitudes of reflection and refraction can only occur with the provision of much more carefully recorded data, particularly as regards absolute signal levels. Go to it, chaps! — Ed.

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AR

YOUTH RADIO

One of the latest amateur radio stations in China is BY1SK, located at the Xuanwu Youth Technical Centre, in Beijing.

The Centre, which was set-up three years ago, is an after-hours institute where about 1 000 students pursue subjects in extra- curricular classes ranging from oceanography to model ship-building.

One BY1SK operator is 13-year-old Zhou Ti, a