ENHANCED VHF/UHF SIGNAL LEVELS DUE TO AIRCRAFT

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The anomalous propagation frequently observed on 2 metres and 70 centimetres during Sydney to Melbourne and Canberra to Melbourne contacts was comprehensively described by Doug VK3UM in his article "Aircraft Enhancement of VHF/UHF Signals" in July AR. The fact that enhancement does occur and that it is caused by aircraft is beyond dispute. This article is concerned with how the aircraft does it.

SPECULATION

When strange phenomena are first observed, logical observers will seek to determine whether or not their observations can be adequately explained by known facts.

In the case of Aircraft Enhancement this process was started but received an early setback coincident with an on-air remark (by me I think) to the effect that the levels of signals received could not be accounted for by known radar echoes from the aircraft involved. This either triggered or at least marked the start of a period of speculation about what might cause the signals to be so strong if it wasn't reflections from the aircraft itself.

Hypotheses concerned with possible refraction or scattering from gases ionised by the jet's exhaust or from turbulence in the aircraft's wake or from mini temperature inversions caused by the heat of the exhaust have all been heard. Some of these speculations have been accepted as facts by some amateurs.

The possibility that some truth might lie in some of these ideas cannot be discounted but nevertheless this article shows that the fundamental mechanism of aircraft enhancement lies in reflections from the aircraft itself.

THE AIRCRAFT AS A REFLECTOR

Radar echo calculations are based on an isotropic reflecting sphere of that size which gives the same signal at the radar receiver as the target being considered. An isotropic reflecting sphere scatters an oncoming beam uniformly in all directions and therefore calculations based on this model will result in the erroneous conclusion that the signal level at a distant receiver is the same as that of the back-scattered signal at the radar receiver.

An aircraft is not an isotropic sphere. The large, substantially flat surfaces under the wings and tailplane reflect radio signals in a beam. The reflection efficiency is virtually 100 percent because of the low losses in the aluminium skin of the aircraft and the beam width is inversely proportional to the ratio of the flat area to the wavelength of the incident signal.

When the aircraft is in flight the flat undersides are parallel to the ground and so are in the right position to reflect our signals and thus provide enhanced levels at the receiver by reducing the path loss.

However, Figure 1 illustrates that the whole of the flat area cannot be seen from transmitting or receiving sites in general because of the angle of incidence, which will change as the aircraft's position changes relative to the sites. Furthermore, the undersides of the wings and tailplane are not entirely flat so a more accurate model will be realised if we delete the contribution of the tailplane and any other flat area. The effective area of our reflector will be given by:—

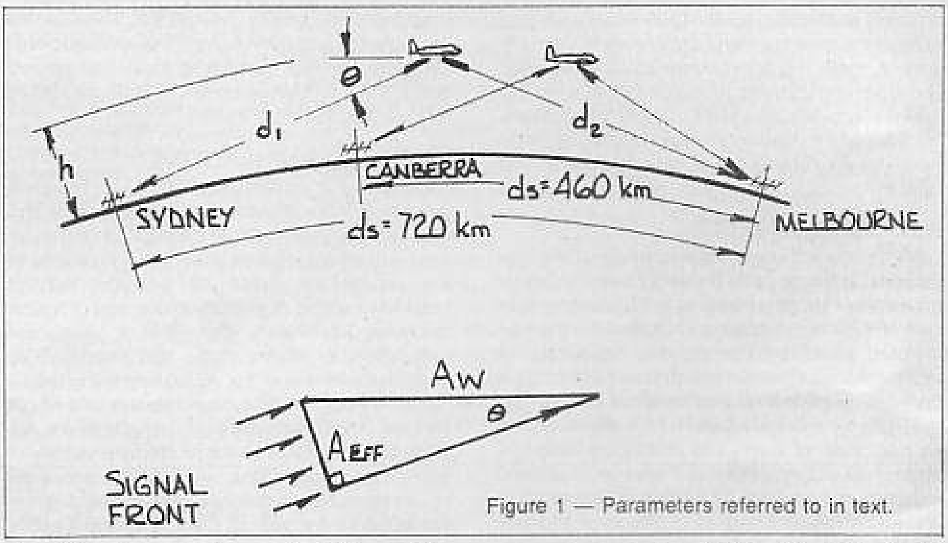

Figure 1 — Parameters referred to in text.

$$Aeff = Aw \sin \Theta \qquad (1)$$

Where:
Aw = Area of Wings in square metres
Θ = Angle of incidence

The effective area has been calculated for various aircraft operating between Sydney and Melbourne assuming that the aircraft is stationary at its nominal operating altitude half way between Sydney and Melbourne and again half way between Canberra and Melbourne. In this case the angle of incidence is given by:—

$$\Theta = 90\text{-}\mathrm{Tan}^{-1} \left[\frac{r \times \sin(4.5ds \times 10^{-3})}{h} \right] \qquad (2)$$

Where:
r = Radius of Earth in km
ds = Distance between sites in km
h = Operating Altitude in km

The distance from Melbourne to Sydney is taken as 720 km and from Melbourne to Canberra as 460 km for these calculations. Note that the angle of incidence is small, being less than 2° for all Sydney to Melbourne paths considered and from 2.5° to just over 3° for all Canberra to Melbourne paths.

The results are given in Table 1:

GAIN OF AIRCRAFT AS A REFLECTOR

As a reflector the aircraft behaves in the same way as two identical, back to back, antennas. Its gain, as an antenna, can be defined in the same way as the gain of any other antenna:—

$$G = \frac{4\pi A}{\lambda^2} \qquad (3)$$

Where:
A = The effective area
λ = Wavelengths in the same units

Converting λ to frequency and expressing G in decibels we get:—

$$G_a = 20 \log f + 10 \log A - 38.55 \qquad (4)$$

Where:
f = Frequency in MHz
A = Effective Area in square metres

This gain is realised when the reflecting aircraft receives the incident signal and when it retransmits it so that the total reflector gain is twice that given in equation 4. ie:—

$$Gr = 40 \log f + 20 \log A - 77.1 \qquad (5)$$

Using this formula and the effective area from Table 1 the reflector gain on 432.2MHz of a 747 at 37,000 ft. half way between Canberra and Melbourne is 56.58dBi!

SPACE LOSS WITH AIRCRAFT AS REFLECTOR

Free space loss between isotropic antennas is:

$$Ls = \left[\frac{4\pi d}{\lambda} \right]^2 \qquad (6)$$

Aircraft Type	Altitude (ft)	Wing Area (m^2)	Aeff (m^2) Syd/Melb	Aeff (m^2) Can/Melb
Airbus A310.200	33,000	219	6.116	9.565
Boeing 727.200	35,000	144.92	4.292	6.712
Boeing 747.200B	37,000	528.15	16.54	25.86
Mcd/D DC10	35,000	364.3	10.79	16.87
Boeing 767.200	40,000	283.3	9.59	14.99

TABLE 1 — See Text.

Aircraft Type	Lar (dB) Syd/Melb	Lar (dB) Can/Melb	SR (dBm) Syd/Melb 2 Metres	SR (dBm) Can/Melb 70 cm
Airbus A310.200	226.5	216.8	– 132.5 (S2)	– 113.1 (S5)
Boeing 727.200	231.6	219.9	– 135.6 (S1)	– 116.2 (S5)
Boeing 747.200B	219.9	208.2	– 123.9 (S3)	– 104.5 (S7)
Mcd/D DC10	223.6	211.9	– 127.6 (S3)	– 108.2 (S6)
Boeing 767.200	224.6	212.9	– 128.6 (S3)	– 109.2 (S6)

TABLE 2 — See Text.
NOTE: "S" Units are taken to the next lower place.

Converting λ to frequency and expressing Ls in decibels we get:

$Ls = 32.44 + 20 \log f + 20 \log d \quad (7)$

Where:

f = *Frequency in MHz*
d = *Distance in km*

There are two "spaces" to be considered where we have a reflector in the middle of the path so taking the loss for each space from equation (7) and combining these with the reflector gain (5) we will get a formula for the space loss between isotropic antennas with an aircraft reflector in between, i.e.:

$Lar = 141.98 + 20 \log d_1 + 20 \log d_2 - 20 \log A \quad (8)$

Where:

d_1 = *Distance from site 1 to aircraft*
d_2 = *Distance from site 2 to aircraft*
A = *Aeff (Table 1)*

Note that the frequency factor has cancelled out because the increasing space loss with increasing frequency is exactly matched by the increasing gain of the reflector with frequency.

Lar's for the various aircraft considered are listed in Table 2.

SIGNAL LEVELS VIA AIRCRAFT REFLECTIONS

The signal power at the receiver in dBm is:

$S_R = P_T + G_T - L_T + G_R - L_R - Lar \quad (9)$

Where:

P_T = *Transmitter power output in dBm*
G_T = *Gain of transmitting aerial in dBi*
L_T = *Transmitter feeder loss in dB*
G_R = *Gain of Receiver aerial in dBi*
L_R = *Receiver feeder loss in dB*
Lar = *Space loss via aircraft reflector in dB*

Examples:

1 I run 400 W PEP on 2 metres, my antenna gain is 20.65dBi, feeder loss 0.65dB and there is a clear path from me to a Boeing 747 at 37,000 ft just east of Tumbarumba. I call CQ VK3 and Melbourne stations located in an area centred roughly on Dandenong and who have similar antenna gains and feeder losses along with a clear path to the same 747 must receive my signal at a peak level of:

$$S_R = 10 \log 400 \times 10^3 + 20.65 - 0.65 + 20.65 - 0.65 - 219.9$$
$$= -123.9 \text{ dBm}$$

which, assuming the "S" meters are calibrated according to the IARU standard for VHF/UHF is one dB short of S4.

2 Doug VK3UM runs 375 W PEP and about 28 dBi of antenna gain after deducting feeder losses on 432.2 MHz. The same 747 as in example 1 has now arrived over Mitta Mitta still at 37,000 ft. A Canberra station equipped with 20 dBi of antenna gain after feeder losses and who has a clear path to the 747, as Doug has, will receive Doug's signal at:

$$S_R = 10 \log 375 \times 10^3 + 28 + 20 - 208.2$$
$$= -104.5 \text{ dBm}$$

which, on an IARU calibrated meter, is better than S7 peak.

3 If I had been listening on 432.2 MHz when the 747 was over Tumbarumba I would have heard Doug at – 115 dBm which is better than S5 and he would have heard my 10 Watts PEP at almost S3.

The stations used in examples 1 and 2 are used for all examples listed in Table 2.

VARIATIONS FROM EXPECTED LEVELS

Variations can and do occur for a variety of reasons, some of which could be categorised as "normal" variations. eg:

(a) The aircraft can be "seen" by the transmitting and receiving sites for periods up to several minutes either side of the time the aircraft reaches the centre of the path. However the signal level will vary over this period simply because the power density in the beam from the transmitter varies spatially, as it also does in the beam reflected by the aircraft.
This means that the length of time that the signals are enhanced will be decreased as the frequency increases even if the beam widths of the ground sites remained constant because the beam width of the reflected signal will get narrower as the ratio Aeff to λ increases.
Aircraft off to one side of the direct site to site path may expose a greater area of reflecting surface to both sites during banking turns. The signal levels will increase accordingly.

(b) Anomalous propagation other than aircraft enhancement occurs at some time almost every day. Ducting and subrefraction can trap or divert the beam from the transmitter or aircraft so that it is not intercepted by the aircraft or receiving site as "normally" expected. In Sydney, it has been observed that signals due to aircraft enhancement are either weak or not present at all during periods when signal levels are high over direct paths from Sydney to Canberra and Adaminaby indicating the presence of superrefraction.

(c) Perhaps the most obvious reason for variations lies in power outputs, antenna gains and particularly "S" meter calibrations not being what they are thought to be. It is not possible to come to any sensible assessment of path losses unless you know exactly what the fellow at the other end means when he says you are S4 or whatever.
The IARU has set a logical, absolute standard for "S" meters. It is that S9 is 5 microvolts input to the receiver at VHF/UHF. 5 microvolts equals – 93 dBm for 50 ohms input and the "S" units are 6 dB apart. S4 then is –123 dBm input to your receive system — preamp in circuit or not.

MISCELLANEOUS THOUGHTS ON REFLECTIONS

There is no doubt that this mode of propagation will be evident at 1296 MHz and above, however the length of time that the signal will be available at a given receiving site will be quite short because the beam will be very narrow.

In the unlikely event that a signal is reflected from one aircraft to another before being intercepted by the ground station the path loss will be quite different. It will also decrease with increasing frequency.

Someone might like to derive a formula for the maximum distance which can be covered by aircraft reflections from say a 747 at 40,000 ft to give an S2 signal from a 400 W PEP transmitter with 20 dBi antennas at both ends.

CONCLUSIONS

The signals received during Melbourne/Sydney and Melbourne/Canberra contacts on 2 metres and 70 cm can be accounted for by reference to the known effects of passive reflectors. The aircraft itself is a passive reflector.

Observations made by myself on 2 metre signals in Sydney correlate closely with the levels predicted in this article. My 70 cm observations did not correlate well with these predictions until the "S" meter was properly calibrated. Correlation is now close. In the case of observations made in Canberra and Melbourne any lack of correlation with the levels predicted in this article will have to be explained by the observers but I strongly recommend that they carefully consider the possibilities listed under the paragraph "Variations from Expected Levels" in this article.

Acknowledgements:

Lance May VK2ZLM who acted as a sounding board for these ideas.

Doug McArthur VK3UM who started the ball rolling.

Ian Cowan VK1BG who cleared up a doubt relating to clearance angles from Canberra.

References:

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VK75A

Among the many cards received for contacts with VK75A was this one from Nancy Dietrich KA6WJI of Santa Barbara, California. The front of the QSL is stitched very decoratively with embroidery.