AIRCRAFT ENHANCEMENT

Another view

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For some years now, VHF amateurs in Sydney, Canberra and Melbourne, and more recently elsewhere, have been making regular use of the Aircraft Enhancement (AE) mode of propagation of VHF signals to establish contact on 144 and 432 MHz.

Results have usually been good, and sometimes even spectacular, with, for example, 5 x 9 signals being exchanged between Melbourne and Canberra on 432 MHz.

There have been several articles in this magazine in recent years about this mode of propagation. The most notable have been by Doug McArthur VK3UM (who was the first to exploit this mode regularly), Gordon McDonald VK2ZAB, and Roger Harrison VK2ZTB. These articles are more fully indexed in the reference list below. In addition, VK2ZAB and the writer engaged in personal correspondence over a period of some months between May and September 1987. As readers of his contributions to AR on this subject will know, Gordon has very firm views regarding the mechanism responsible for the AE mode of propagation. I found the exchanges with him to be forthright, but otherwise very helpful to my developing an understanding of how it works.

None of the above authors offers a full explanation of the AE mode as I have observed it from my VK1 QTH. Gordon's calculations didn't fit and Roger's backward moving footprint didn't work either. As a result of my own observations and of my dialogue with VK2ZAB, I have concluded that, although there is likely to be a good deal of truth in the explanation provided by him concerning metallic reflection, there is also a mode of hot gas supported propagation which gives very good results indeed when the conditions are right. A favourable set of conditions would comprise:

(a) A baseline distance of, say, 450 kilometres (eg VK1 to Melbourne).

(b) Air reasonably still and stable (ie pilots do not report turbulence or strong winds).

(c) Ground-wave propagation is normal - big temperature inversions are unhelpful to AE, although they may be a blessing in other ways.

(d) The aircraft track is nearly parallel to the radio wave path, and the intersection of the two is close to the mid-point of the radio path.

(e) Both stations have line of sight to the aircraft.

(f) Both stations have sideband equipment; better than 20 watts transmitter power, reasonable antenna gain, and low noise receiver preamplifiers. It can work on FM, but the average FM operator lacks the necessary ERP and receiver sensitivity.

What does an aircraft do??

There are two important characteristics of the wake left behind an aircraft which make it potentially a very good refractor of VHF signals. Firstly, the aircraft delivers a large amount of heat to the atmosphere which creates a temperature anomaly, and second, the geometric shape of its wake is very like a two dimensional copy of the temperature inversions produced in nature which provide so much fun for serious VHF operators. Each of these properties will be considered in detail below.

Aircraft heat delivery

The following discussion makes use of a number of different information sources. In the text these are referred to by the surname of the source, except that WBE is used in lieu of World Book Encyclopaedia. A complete list of references is given at the end of this article.

The mixing of imperial and metric units is done for the sake of simplicity, given the variety of the source material.

Probert advises that the fuel consumption of a B747 aircraft in level flight, at cruising speed and at 35,000 feet, is between 0.016 nautical miles per pound (fully loaded) and 0.016 nautical miles per pound (fully loaded) and 0.026 nautical miles per pound (lightly loaded). A typical value could reasonably be taken as 0.02 nautical miles per pound. This corresponds to 50 pounds per nautical mile.

50lb/NM = 50/1.852 lb/km, ie 26/lb/km

Now the cruising speed of a B747 is about 870 kilometres per hour, or 14.5 kilometres per minute. Thus the fuel consumption of the aircraft is about 27 x 14.5 pounds per minute, which equals 391.5 pounds per minute. Since the aircraft is in the level cruise equilibrium mode, all the heat of combustion of this fuel is released to the atmosphere, where it causes a temperature rise.

From Low, the lower calorific value of kerosene is 10,200 CHU/lb. Thus the heat liberated by the combustion of 391.5 pounds of fuel each minute by the aircraft is 391.5 x 10200 CHU, ie 3, 990, 000 CHU/minute. For those unfamiliar with these units, this corresponds to about 126 megawatts. Note that no vapour condensation is allowed for in this case. (Should condensation occur, the heat liberation would be greater, since the latent heat of vapourisation would then also be released.).

Atmospheric Heating

From WBE, the air pressure at 35,000 feet is about 3.45 PSI. The air temperature at this height varies quite a bit but -35 degrees Celsius (238 degrees Kelvin) may be taken as a typical value.

Low (p25) gives the volume of one pound of air at 14.7 PSI and 0 degrees Celsius (273 degrees Kelvin) as 12.39 cubic feet.

Using the universal gas law P1.V1/T1 = P2.V2/T2.

V2 = 14.7 x 12.39/273 x 238/3.45
= 46.02 cubic feet or 1.303 cubic metres.

That is, one pound of air at 35 000 feet and at -35 degrees Celsius, occupies approximately 1.303 cubic metres.

Low shows that the specific heat of air at constant pressure (Kp) may be calculated from:

Kp = 0.230 + 0.000038.t

where t is the temperature in degrees Celsius.

Thus at -35 degrees Celsius,
Kp = 0.230 - 0.00133
= 0.2287

Now it is possible to calculate the amount of air heated by a given amount per minute by the passage of the above B747. Let us work it out for, say, a 10 degree Celsius rise.

Weight of air so heated = CHU/Kp x 1/10
= 3,990,000/0.2287 x 1/10
= 1, 745, 000 pounds

The volume of this air at 35,000 feet is 1,745,000 x 46.02 cubic feet. That is 80 300 000 cubic feet. This equals 2, 274, 000 cubic metres of hot (10 degrees Celsius rise) air generated for each minute of passage of the aircraft.

Now, if the aircraft was producing a uniformly heated volume of air at 10 degrees Celsius temperature rise, and its speed is 14,500 m/minute, then the cross sectional area of the volume so produced (as seen from the tail of the aircraft) must be 2,274,000/14,500 square metres, ie 157 square metres.

As it happens, the aircraft is not producing a uniformly heated volume of air; obviously the efflux is hotter close to the aircraft than it is further away. However, there will be some point behind our B747 at which the efflux is 10 degrees Celsius above ambient, and the cross sectional area of the warm air at this point will be 157 square metres. The shape of this cross section can only be guessed at. However, given the geometry of the aircraft, the cross section will be rather wider than it is high.

Radio refractive index (RRI)

Jessop provides a detailed explanation of the refraction of radio waves in the atmosphere. The RRI is defined in terms of "N" units. It is stated that where a layer is encountered in the atmosphere in which the RRI falls at a rate greater than 157 N units per kilometre of increasing height then radio signals from Earth will be refracted sufficiently to return to Earth.

Jessop shows that the maximum water vapour pressure at -35 degrees Celsius is 0.3 mb (dew point). Now at -25 degrees Celsius (the temperature of the air heated by the aircraft as assumed for convenience in the above example) the saturation vapour pressure would be 0.8 mb, but this cannot apply in practice, since in our case we are not dealing with a closed system. Thus the water vapour pressure in the aircraft efflux is constrained by that of the general environment, ie 0.3 mb. This interesting anomaly is a consequence of Dalton's Law.

We have already seen that the air pressure at 35,000 feet is about 3.45 PSI. This corresponds to 117 mb.

From Jessop, the RRI of air is given by:

RRI = 77.6 x p/T + 373,300 x e x 1/Tsquared N units

where p = atmospheric pressure in mb
e = water vapour pressure in mb
T = air temperature in degrees Kelvin.

At 35,000 feet and - 35 degrees Celsius, (ie ambient conditions).

RRI = 77.6 x 1117/238 + 373,300 x 0.3 x 1/238 x 1/238
= 40.13 N units.

The RRI of air in this region which has been heated 10 degrees Celsius above ambient by the passage of our B747 will be

RRI = 77.6 x 117/248 + 373,300 x 0.3 x 1/248 x 1/248 = 38.43 N units.

The RRI of the heated air is therefore 1.70 N units lower than that of the unheated air immediately below it. Provided the vertical thickness of the heated layer is less than about 11 metres, (as seems very probable, since the warm air mass must significantly be wider than it is high) the RRI gradient will exceed the -157 N unit per kilometre which Jessop says is necessary to return a radio wave to Earth.

All this shows that radio refraction sufficient for our purposes can at least occur from an air mass which exists somewhere between the 10 degrees Celsius point and the aircraft. It will also work for lesser temperature rises than 10 degrees Celsius, but I have not attempted to work out what the critical temperature might be, if indeed there is one.

The distance behind the aircraft at which the efflux has cooled to just 10 degrees Celsius above ambient is not known. However, it has been reported that work done by the RAAF some years ago showed that the thermal footprint of an aircraft is easily detectable 20 kilometres behind the aircraft.

The above demonstrates that there is adequate heat generated by the passage of a sizable aircraft to be potentially useful for radio propagation purposes. However, having a suitable sharp rate of change of RRI is only part of the story - the RRI gradient must have the right topology.

Aircraft wake geometry

In his AR article, Roger Harrison drew attention to an item in the Aviation Safety Digest issue 121 (ASD) about the wake turbulence of aircraft. From this it appears that an aircraft in transit leaves behind it contra rotating vortices generated by the action of the wings; these are quite intense, and retain their form and physical dimensions for a considerable distance behind the aircraft. The vortices trap the heated efflux from the aircraft, and inhibit, rather than encourage, its dispersal.

Meanwhile, the wings of the aircraft act as a single blade of a very large fan which thrusts air downwards as the aircraft passes. It is by this means that the aircraft derives its lift. It appears from the above issue of the ASD that the wash from an aircraft typically sinks some 900 feet before stabilising, and that it reaches this level about 1.5 minutes after the aircraft passes. By the time the efflux has reached this sink level, therefore, the aircraft has moved forward by over 20 kilometres. Thus the efflux of hot air from the aircraft is V shaped, the front half of the V (closest to the aircraft) being the sink resulting from wing action, and the rise thereafter being due to convection. Figure 1 shows this in diagrammatic form.

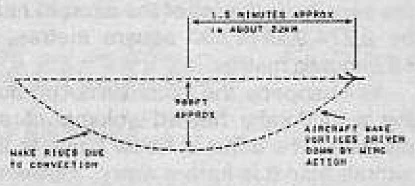

Figure 1.

What the aircraft is doing is dragging a kind of shallow, open, inverted two dimensional prism behind it, with the prism having a lower refractive index that the surrounding air. It therefore behaves in a reverse manner to that of the glass prism of our physics text books. It is instructive to do some wave tracing on some diagrams to illustrate the situation. Figure 2 shows how a ray of light behaves when passing through a prism having a refractive index higher than that of its surroundings. This is an inverted version of the diagram found in high school physics texts. As can be seen, the light ray is refracted upwards toward the base of the prism. Useless for our purposes. Figure 3 shows the situation when the refractive index of the prism is lower than that of its surroundings. In this case the wave front is refracted downwards. This is the situation created by the efflux of an aircraft. The efflux has an RRI less than that of its surroundings, and at its apex it has the form of an inverted prism.

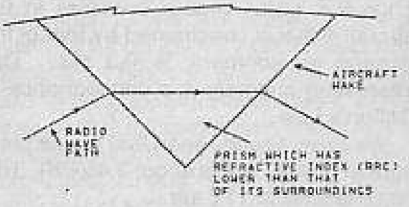

Figure 2.

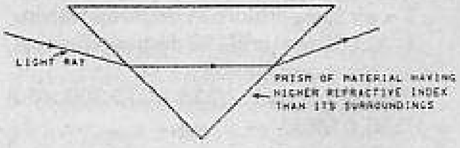

Figure 3.

The diagrams in Jessop's text show the distribution of -RRI gradients for a number of good, naturally occurring openings around Europe. Naturally occurring temperature inversions which are of use to amateurs seem to have the shape of large, broad, inverted cones, and appear to behave in a similar manner to that of the aircraft generated prism. The similarity of their cross-sectional topology is striking. Since they are roughly conical in form, naturally occurring inversions can be used over a relatively wide range of azimuth angles, whereas the aircraft generated prism, because it has two dimensional form only, proves to be quite directional in conferring its benefits.

Thus stations wishing to use this mode of propagation must be sited so that the line between them is closely parallel to, and underneath, the aircraft track.

CONCLUSION

It is shown above that a large aircraft is a heat generator of sufficient magnitude to create a temperature inversion at high altitudes and, as a result, is capable of causing significant refraction of radio waves.

The form of this inversion is such as to return the signals to Earth at a significantly distant point from the transmitter. From my investigations as explained in this article, metallic reflection from the aircraft skin is not the only mode of aircraft assisted propagation as VK2ZAB maintains. It also shows that there will be no need to put away our VHF equipment when non-metallic aircraft take to the skies.

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