Aircraft Scatter for the Microwave Enthusiast

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I. Basics. For our purposes, we will define “aircraft scatter” as the enhancement of radio signals by airplanes. It is a specific example of enhancement of radio signals by objects in the sky. Other types of enhancement which are used by radio amateurs to increase communications range include Meteor Scatter, EME, Aurora, Sporadic E, and rain-scatter.

You have probably heard aircraft scatter while operating on the VHF or microwave bands. It sounds like a flutter superimposed on the desired signal which starts off with a fairly rapid beat frequency that slows down to zero,and then reverses course with a gradually increasing beat frequency before disappearing as the aircraft goes out of range.

If you have an SDR with a waterfall, you have probably seen aircraft scatter a great number of times. Aircraft reflection causes a Doppler-shifted signal to appear above or below the direct signal, depending on whether the airplane is moving towards or away from the receiver. The distance of the aircraft-scattered signal trace from the main signal line depends upon the Doppler-shift of the reflected signal, and thus on the speed and direction of the aircraft's travel.

Below is an example of scatter from the W3CCX 5 GHz beacon in FM29jw received by W3SZ in FN20ag. The arrow placed over the Linrad waterfall display points to the Doppler-shifted aircraft scatter signal coming from an aircraft that was heading south across the path between W3SZ and the beacon. When first detected, the aircraft was heading towards the receiver, and so the signal was shifted to a frequency above the direct signal. As the aircraft continued to travel, for a brief time it had no component of velocity along the line between it and W3SZ, and so the Doppler-shift was zero and the signal was superimposed on the direct signal. As the aircraft continued to move south, now moving away from the receiver, it produced a negatively Doppler-shifted signal before disappearing. Notice that the aircraft-scattered trace is much weaker than the direct signal.

Above the Linrad[1] waterfall display of the signal you can see a screen from the commercial software program PlanePlotter[2], which shows real-time aircraft data, and on that screen you can see the aircraft that likely produced the reflection marked with a blue ring around it.

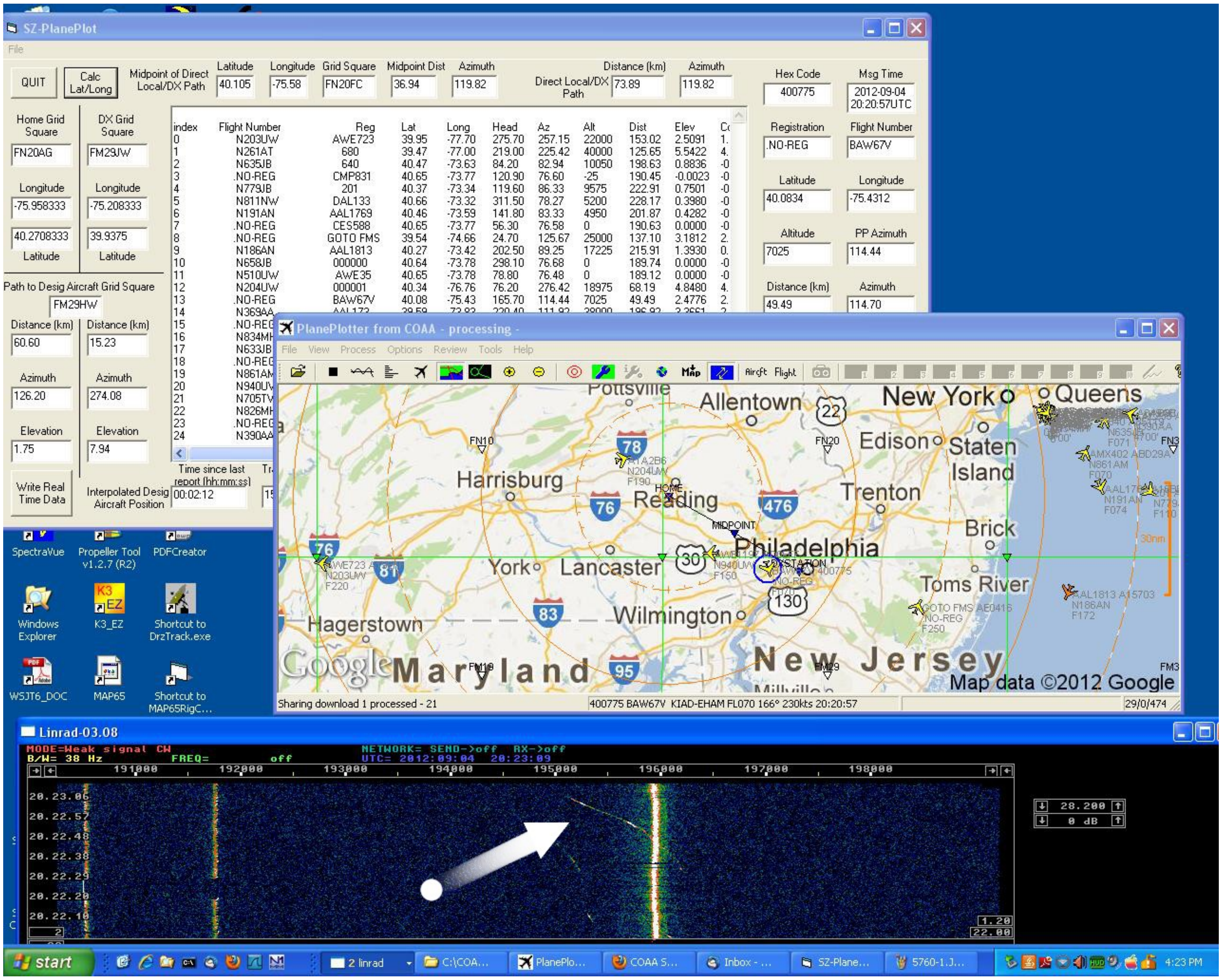


Figure 1. The arrow points to the aircraft reflection of a 5 GHz signal from the W3CCX beacon in FM29jw as received at W3SZ in FN20ag.

II. History. The history of aircraft scatter is really the history of radar. The first radio-based detection of aircraft was accomplished by L. A. Hyland of the U.S. Naval Research Laboratory in June, 1930 using a 33 MHz CW signal. The detection was accidental, as Hyland was working on ground-based direction finding equipment at a military airport and astutely noted that the received direction-finding signal increased when aircraft passed through the direction-finding beam.

The history of amateur use of aircraft scatter goes back at least to 1967. In August, 1967 Henry Root, W1QNG, wrote a two-page article for the Technical Correspondence section of QST discussing the theory of aircraft scatter, with the title “Using Aircraft Reflections in V.H.F. Communications”.[3] He showed graphs of the relationship between distance to the horizon and aircraft altitude and estimated aircraft-scatter signal to noise ratios for various distances at 50 MHz. He estimated a maximum communications distance of approximately 65 miles using a transmit power of 100 watts, a 10 dBi gain antenna, and a receiver with a noise figure of 10 dB.

The ARRL UHF/Microwave Experimenter's Manual, published in 1990, devoted two pages to a discussion of the theory of aircraft scatter by Emil Pocock, W3EP[4].

European amateurs have been very active using and promoting aircraft scatter, and for many of them it is a very productive mode both during and between contests. A number of European amateur radio operators have excellent web pages discussing aircraft scatter, that can be easily found by searching the term "aircraft scatter" with Google or a similar search engine. You can listen to an aircraft scatter CW QSO between gm4cxm and OZ1FF at http://youtu.be/QizZVkd6IiI An example where you can hear both the direct signal and the Doppler-shifted aircraft-reflected signal from ON0EME as received by ON7UN is at http://www.youtube.com/watch?v=RkZ1VSo2SrE

Recently there has been some fascinating aircraft scatter work done by Rex Moncur VK7MO and David Smith VK3HZ[5]. They have used aircraft scatter to make contacts as long as 842 km on 10 GHz, and 427 km on 24 GHz. They have published several papers on this, including an excellent discussion of their work that was part of the Proceedings of Microwave Update 2012, held in Santa Clara, California[6]. Their work will be discussed in more detail below.

III. Physics. What's behind all of this? Scattering of a signal by an aircraft so that the signal which is transmitted by one station can be received by another station is an example of bistatic radar, where the radio transmitter and receiver are at different locations. Monostatic radar is where the transmitter and receiver are co-located.

The path loss for bistatic radar is described by the bistatic radar equation. This takes into account free path loss as well as the loss due to the qualities of the scattering object, which are condensed into the value "S", the radar cross section of the aircraft. S is a function of the size of the aircraft, its geometry as presented to the transmitting and receiving stations, its material, and also the radio signal's frequency (although the effect on S of the frequency is often ignored). The radar equation expressed in terms of path loss is:

L = 10 log ((lambda**2) * S / (((Rt)**2) * (Rr)**2))) - 153 where
L = total loss (in dB)
Rt = distance from transmitter to reflector in km
Rr = distance from receiver to reflector in km
lambda = wavelength in meters
S = radar cross section of the aircraft

The radar cross section "S" of an aircraft is not the same as its physical cross section. In the ARRL Experimenter's Manual article noted above, Emil Pocock

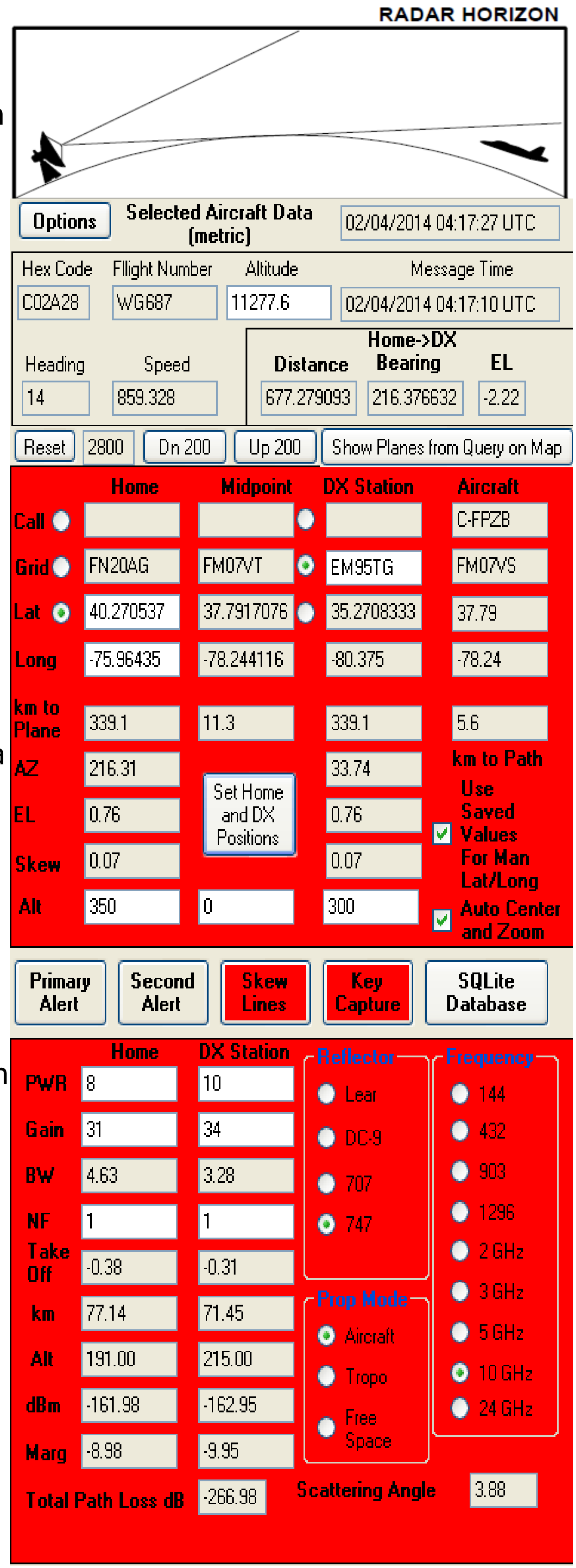
W3EP gave some estimated cross sections for several aircraft. Emil gave estimated values for S of 2 sq meters for a Lear Jet, 8 for a Douglas DC-9, 16 for a Boeing 707, and 63 for a Boeing 747. There is very little additional information to be found in the publicly available literature regarding the values of S for other aircraft, although values of 0.5 for a conventional winged missile, 2 for a small jet fighter, 6 for a large jet fighter, 20 for a medium bomber or medium jet airliner, 40 for a large bomber or a "large jet liner", and 100 for a "jumbo jet" are given in <u>Introduction to Radar Systems</u>, Third Edition, by Merrill I. Skolnik[7]. Note that there is some discrepancy between these two sets of numbers: the Experimenter's Manual gives an S value of 63 for a 747, but Skolnik reports a value of 100 for "jumbo jets". These differences likely relate to methodology used to determine S, as well as whether the maximum value of S for a target or the average value based on all presentation angles is reported. S varies depending upon the aspect of the aircraft that is presented to the RF wave. As will be discussed below, the above references use in their calculations radar cross sections derived from monostatic measurements. If these cross sections were the entire story, aircraft scatter would not be all that useful for amateur communication, although it is the source of the typical aircraft flutter that is heard over distance of a few tens of miles. It will be shown below that for long distance amateur communication, one must take advantage of a special case that occurs when the aircraft is on or nearly on the direct path between two stations. In that case, as will be shown, it is possible to have substantial enhancement of signal strength.

If we use the equation given above to evaluate the path loss for a Boeing 707-sized aircraft (using the monostatic cross section, S=16) at 10 GHz with the aircraft at the midpoint between two stations 500 km apart, we get a path loss of 267 dB. By comparison, the EME path loss for 10 GHz at perigee is 287 dB. Typical troposcatter path loss over a 500 km path is 260 dB. Path loss over 500 km in free space would be 167 dB. So aircraft scatter over a 500 km path loses an extra 100 dB relative to free space loss, loses an extra 7 cB relative to troposcatter, and over that 500 km path aircraft scatter is only 20 dB better than a moon bounce signal which has traveled approximately 750,000 km! If you were using a 30 inch dish with a gain of 37 dBi and 10 watt transmitter, and if the receive station had a noise figure of 1 dB and was using a 100 Hz filter, then over a 500 km <u>free space</u> path you would be 101 dB above the noise, with troposcatter you would be 8 dB above the noise, and with aircraft scatter you would be 1 dB above the noise. However, as we will see below, there is more to the story.

Aircraft scatter is potentially useful because the "reflections" from aircraft flying at adequate altitudes [20-30km] will greatly increase the "line of sight" and thus allow communications between stations with no direct path. The higher the altitude of the aircraft, the greater the possible communications distance it permits.

We can quantitate how much aircraft scatter might increase the communications distance for line-of-sight horizon-limited contacts by examining the geometry of the communications path with and without an aircraft reflector.

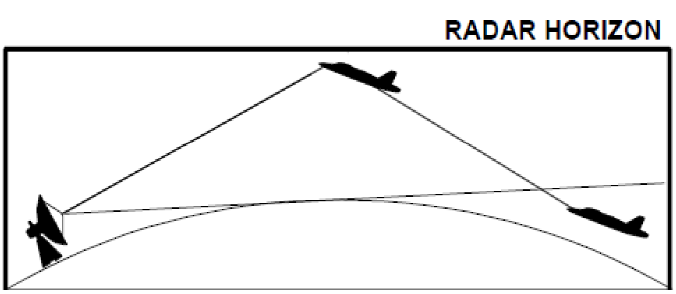
The apparent distance to the horizon for a radio signal is increased by elevation of the antenna at either end of the path. The effective elevations of the antennas at each end of the communications path are decreased by the curvature of the earth. But the phenomenon of refraction will cause the radio signal to bend a bit, which extends the horizon.



As a rough approximation, distance in km to the horizon is approximately 3.57 * Sqrt(h) where h is antenna height in meters. As an example, if a station has 30 meter antenna height, then its horizon distance is 19.6 km.

This does not take into account the effect of refraction, which introduces a factor of 4/3 and gives the equation distance is approximately 4.12 * Sqrt(h), again with distance given in km and height in m. So a 30 meter antenna height results in a horizon distance of 22.6 km.

Aircraft scatter extends the horizon by placing a "reflector" at a point where it is above the horizon for both stations, even though each station is below the horizon of the other station. An aircraft flying at an altitude of 10,000 m will extend the horizon distance to 400 km, and could thus potentially extend the communications distance between two stations to 800 km.



I have written a simple program to help those wanting to do aircraft scatter, and a portion of that program automatically calculates the elevation of a given airplane as seen by two stations, thus indicating whether or not a contact is "geometrically" possible.   The program also calculates the expected received signal strength at each station given the distance between them, the frequency in use, the type, location, and altitude of the aircraft, and the station parameters Transmit Power, Antenna Gain, and Receiver Noise Figure. These parameters as well as the type of aircraft and frequency band are user-adjustable, and one can select aircraft-scatter, troposcatter, or free space path loss calculations. The program "Calculator" window is shown above.

The results of these calculations, as noted above, are disappointing. The aircraft-scattered signal is generally approximately 100 dB weaker than would be a direct path signal. The relative strength of the aircraft-scattered signal compared to a troposcatter signal is more complex, because the strength of the troposcatter signal depends on frequency, distance between the stations, and the scattering angle of the troposcatter signal[8]. Typical values for aircraft scatter signal strength relative to troposcatter signal strength are:

Distance	144 MHz	1296 MHz	10 GHz
300 km	AS -30 dB	AS -21 dB	AS -12 dB
600 km	AS -13 dB	AS -3 dB	AS +6 dB
800 km	AS -2 dB	AS +8 dB	AS +17 dB
950 km	AS +7 dB	AS +17 dB	AS +26 dB

Fortunately, as alluded to above, there IS some potential MAGIC that appears under certain conditions, which is NOT taken into account in the calculations given above: up to 20-30 dB (at 144 MHz) of signal enhancement may occur when the aircraft is located on or very near to the direct path line between the two stations. This enhancement is called "forward scattering enhancement" and falls off extremely rapidly if the aircraft is positioned even slightly off of this line. Rex Moncur VK7MO has an excellent paper discussing this in depth[9] and VK2KU Guy Fletcher has also discussed it[10].

This "magic" occurs because of the fact that the S factor used in the bistatic radar equation given above (as well as the monostatic radar equation) is experimentally derived from monostatic radar data. But real world experience and theory both show that for bistatic radar the effective radar cross-section when the scattering angle is 180 degrees (i.e., when the aircraft lies on the direct path connecting the two stations) can be much greater than the S value obtained by monostatic-derived measurements. This is due to constructive interference of the RF wavelets that have traversed the aircraft body as they coalesce after leaving the region occupied by the aircraft as they proceed from the transmitter towards the receiver. Skolnik[11] gave the equation for the forward-scatter cross-section as 4*PI*(A**2)/(lambda**2), where A=projected area of the reflector and lambda =wavelength. For back-scatter, the cross-section is simply A, so that the expected forward enhancement is 4*PI*A/(lambda**2). Using these equations to estimate the forward enhancement one might get with spheres of various diameters, one gets the following data (expanding on a table from reference 8):

Radius in meters	Area in meters	Frequency Lambda (meters)	144 MHz 2	432 MHz 0.7	1296 0.23	2304 0.13	3G 0.1	5G 0.06	10G 0.03
1	3	dB Enhancement:	10	19	29	34	36	40	46
5	79	dB Enhancement:	24	33	43	48	50	54	60
10	314	dB Enhancement:	30	39	49	54	56	60	66

This looks great! The higher we go in frequency, the greater the enhancement! Unfortunately, the width of the forward-scattered lobe is inversely proportional to both the frequency and the size of the reflecting object, so as the frequency goes higher and the object gets larger these effects make the width of the forward-scattered lobe smaller. This is not surprising; total signal has to be conserved, so if the signal in the reflected beam is getting stronger, the volume of distribution of that signal must be getting smaller. And the narrow beamwidth applies also in the vertical direction, limiting the altitudes at which this phenomenon may be useful. The chart below shows the relationship between 3 dB beamwidth of the scattered signal, the size of the reflecting object, and frequency:

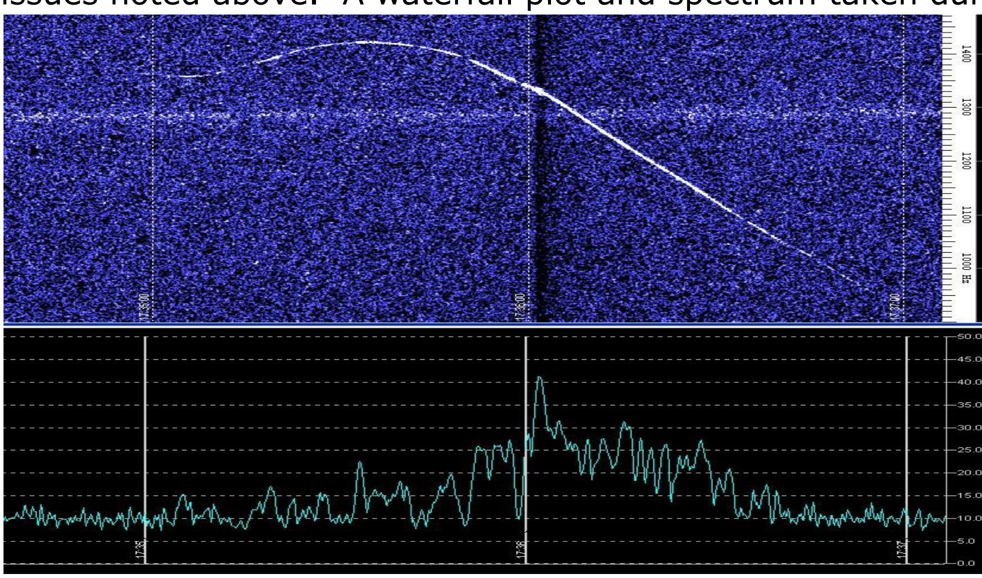
Radius (m)	**Frequency MHz**	**144**	**432**	**1296**	**2304**	**3G**	**5G**	**10G**
1	**3 dB beamwidth deg**	**28.647**	**10.02**	**3.294**	**1.862**	**1.432**	**0.859**	**0.429**
5	**3 dB beamwidth deg**	**5.7296**	**2.005**	**0.658**	**0.372**	**0.286**	**0.171**	**0.085**
10	**3 dB beamwidth deg**	**2.8648**	**1.002**	**0.329**	**0.186**	**0.143**	**0.085**	**0.043**

The following chart shows the maximum size of the scattering object that will provide a 3 dB beamwidth of at least 3 degrees:

Freq (MHz)	**144**	**432**	**1296**	**2304**	**3G**	**5G**	**10G**
Radius (m)	**9.54**	**3.34**	**1.10**	**0.620**	**0.477**	**0.286**	**0.143**

You can see from these tables that at the higher frequencies, useful scattering is likely coming not from large structures, but rather from smaller ones such as the edges of the wings, corners, nose tips, and points of discontinuity. Rex VK7MO has done a very detailed analysis of these issues and his paper, noted above as reference 8, is a “must read” for those interested in the theory of this phenomenon. He notes that for a 747 front on, the S value derived from monostatic measurements is 100 sq m, but the actual effective forward-scatter area at 144 MHz is approximately 30,000 sq m. At 432 MHz the forward-scatter area can reach 240,000 sq m. These values represent increases of "S" by 300 and 2400 times, respectively. If we plug these numbers into the bistatic radar equation, we see that they give increases in the received signal by 25 and 34 dB, respectively, consistent with the values given in the table above. These values also correlate well with observations made in 1985 by Doug McArthur, VK3UM, who reported 25-30 dB or more of enhancement of 144 MHz signals received via aircraft scatter, with the enhancement lasting on the order of 2-7 minutes[12].

The upshot of this is that we may see 20-30 dB of forward scatter enhancement from 737/747 class aircraft at 144 MHz, 30-40 dB at 432 MHz, and 40-50 dB at 1296 MHz. In reference 8 VK7MO did not evaluate higher frequencies. The table of calculated enhancement vs frequency shown above suggests even greater enhancement on frequencies above 1296 MHz, but the constraint of decreasing beamwidth with higher frequencies potentially reduces the usability of this technique at these higher frequencies. OZ1RH reports data from the VHF-UHF Dxer[13] indicating that at 144 MHz aircraft scatter provides 15 dB less signal than troposcatter at 300 km, is equivalent to troposcatter at 600 km, and at 800 and 950 km respectively is 15 dB and 20 dB better than troposcatter. These numbers are more favorable than those given in the table above. Note that Rex and David were able to use forward scatter enhancement on 10 and 24 GHz in spite of the issues noted above. A waterfall plot and spectrum taken during one of their 561 km 10 GHz contacts is shown on the left.



IV. ISCAT-A and JT65C on 10 and 24 GHz. Rex and David's first 10 and 24 GHz long distance contacts used JT65C, but on 10 GHz they subsequently preferred a new mode Joe Taylor, K1JT developed and optimized for this work called ISCAT-A. ISCAT has two sub-modes. ISCAT-B, the original ISCAT mode, has total bandwidth 1809 Hz. ISCAT-A runs at half the rate, uses half the bandwidth, and (for average decodes on steady signals) is about 1 dB more sensitive than ISCAT-B. You may listen to ISCAT-A at http://www.nitehawk.com/w3sz/ISCATA.wav WSJT9 includes both ISCAT modes.

JT65C is more sensitive than ISCAT-A, but ISCAT-A does better than JT65C when signals are present in short bursts, as is the case with long range aircraft scatter. ISCAT-A can be run in 15 second transmit cycles, whereas JT65C requires 60 seconds (there is now a mode JT65C2 that has 30 second transmit cycles). Doppler-shift is an issue on these bands. For aircraft moving along the direct path between two stations, the Doppler-shift is near zero, because the aircraft is moving away from one station at the same velocity with which it is approaching the other station. However, for aircraft crossing the direct path, Doppler-shift is an issue, with Doppler-shift increasing as the aircraft crosses the direct path at progressively greater angles. Rex and David published a nice discussion of Doppler-shift issues associated with aircraft scatter at 10 GHz[14], and they noted that at 10 GHz the maximal shift was on the order of 1 kHz per minute. Because ISCAT-A is less affected by Doppler-shift, they prefer it to JT65C on 10 GHz unless the aircraft crossing angle with the direct path is less than 15 degrees. At 24 GHz Doppler-shift limits the use of JT65C to crossing angles of less than approximately 5 degrees. They have not attempted to use ISCAT-A on 24 GHz because of their impression that it does not provide enough sensitivity. The table below, from K1JT's WSJT 9.0 Supplement to the User's Guide[15] shows where ISCAT-A and JT65C fit in relative to the other WSJT modes that you may be more familiar with. The ISCAT modes are 5-6 dB less sensitive than JT65C (Deep Search will give JT65C an additional 4 dB advantage).

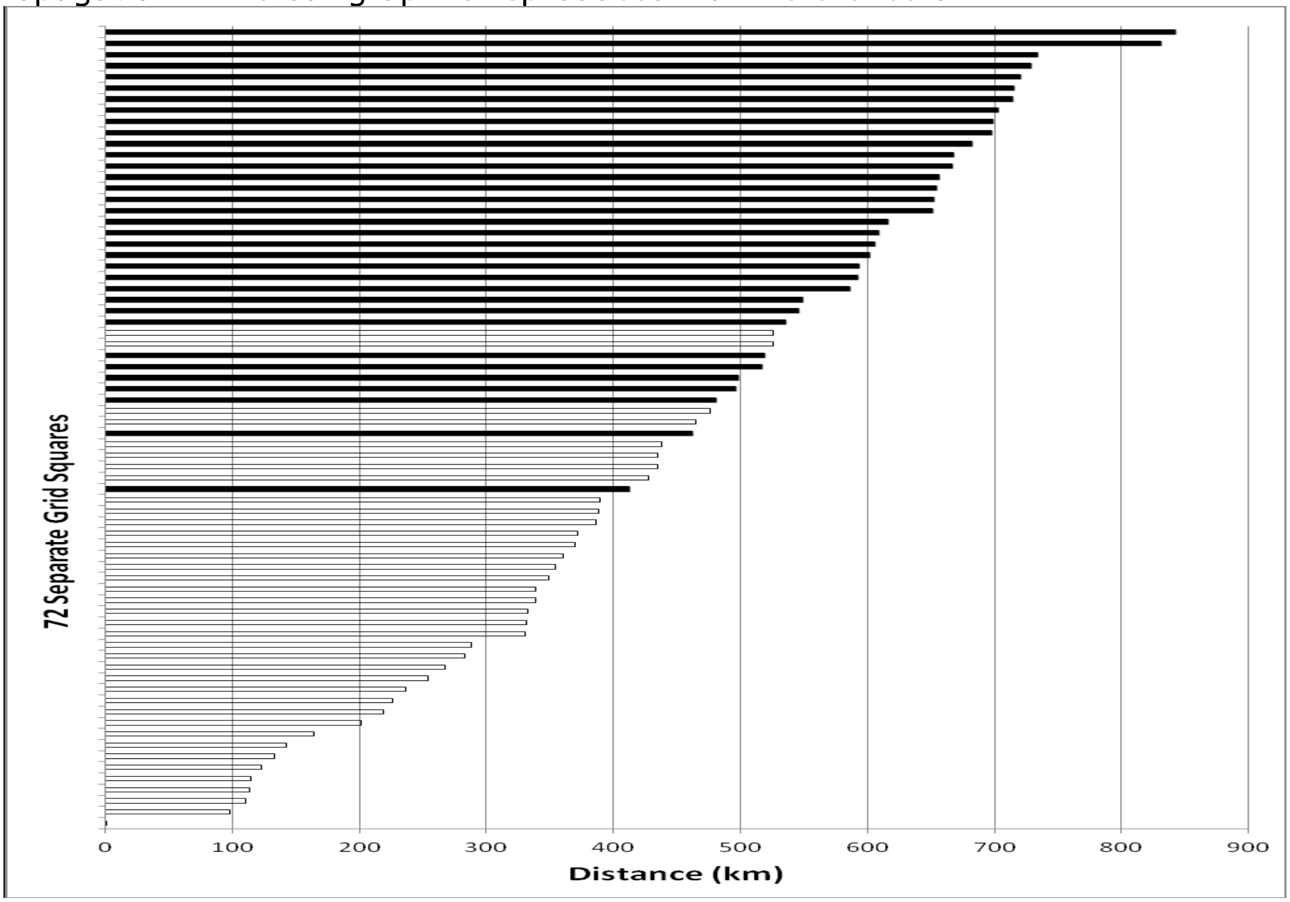
Parameters of WSJT Modes

Mode	T/R (s)	Mod	FEC	Nsps	Baud	Δf (Hz)	BW (Hz)	cps s^{-1}	S/N (dB)
FSK441	15, 30	4-FSK	-	25	441	441	1764	147	-1
JTMS	15, 30	MSK	parity	8	1378	689	2067	197	-1
ISCAT	15, 30	42-FSK	-	256	43.1	43.1	1809	32.3	-17
								TxT (s)	
JT65A	60	65-FSK	RS(63,12)	4096	2.69	2.69	178	46.8	-25
JT65B	60	65-FSK	RS(63,12)	4096	2.69	5.38	355	46.8	-24
JT65C	60	65-FSK	RS(63,12)	4096	2.69	10.77	711	46.8	-23
JT4A	60	4-FSK	K=32,r=1/2	2520	4.375	4.375	17.5	47.1	-23
JT4B	60	4-FSK	K=32,r=1/2	2520	4.375	8.75	35	47.1	-22
JT4C	60	4-FSK	K=32,r=1/2	2520	4.375	17.5	70	47.1	-21
JT4D	60	4-FSK	K=32,r=1/2	2520	4.375	39.375	157.5	47.1	-20
JT4E	60	4-FSK	K=32,r=1/2	2520	4.375	78.75	315	47.1	-19
JT4F	60	4-FSK	K=32,r=1/2	2520	4.375	157.5	630	47.1	-18
JT4G	60	4-FSK	K=32,r=1/2	2520	4.375	315	1260	47.1	-17
Diana	30	42-FSK	-	2048	5.38	5.38	226	23.4	-22

A brief mention of the equipment VK3HZ and VK7MO used is in order. On 10 GHz VK3HZ used a 60 cm prime focus dish, a Qualcomm “Lambchop” converted to 10 GHz, a Kuhne preamplifier for receive, and a DEMI 8 watt amplifier for transmit. His IF rig was an 817, modified for GPS locking. VK7 MO used a 640 cm offset dish with a Kuhne 10G3 transverter, a Kuhne preamplifier for receive, and a Kuhne 10 watt amplifier for transmit. VK7MO's IF radio was an IC910H, modified for GPS locking. VK3HZ used a Meade computerized telescope mount and tripod for positioning, and VK7MO used a surveying tripod with homebrew Az/El mount. On 24 GHz VK3HZ used a 38 cm prime-focus dish and a Thales module giving 1.5 watts for transmit with the other components the same. On 24 GHz VK7MO used a 47 cm offset dish, a DB6NT transverter, preamplifier, and 3 watt PA, and a Celestron 8 inch telescope mount with a builders tripod, with the other components the same as for 10 GHz.

You can see an interview with Rex VK7MO while he was out at a remote site setting up for this long distance work at http://www.youtube.com/watch?v=tHU85RHURGs

Rex and David created a bar graph shown below that demonstrates just how much aircraft scatter adds to their communications range. The black bars are aircraft scatter, and the white bars are troposcatter or line-of-sight. You can see that every contact longer than 600 km used aircraft-scatter as the method of propagation. This bar graph is reproduced from reference 6.



V. Getting Started. What does it take to get started with microwave band aircraft scatter? I suggest the following list:

1. Willing partner to be the other end of the contact
2. Good station with accurate antenna pointing
3. SDR with waterfall
4. GPS locking of transverter frequency for higher bands
5. Knowledge of when aircraft will be in suitable position (requires historical data)
6. Real-time knowledge of where aircraft are at a given moment while attempting a contact

Items 1-4 are self-evident and I will not discuss them further. Although when you are planning to do aircraft scatter you will likely review historical data as described in #5 before using the real-time data from #6, it will make for a clearer discussion if I discuss #6 first.

VI. Getting Real-Time Aircraft Position Information. There are two ways of determining where aircraft are at any moment. The first is to receive that information yourself over the air, and the second way is to get that information from internet servers. Both of these methods rely on the fact that virtually all aircraft now regularly transmit information regarding their identity and position. The two technologies in common use are Mode S and ADS-B. Aircraft carrying mode S transponders will reply to an interrogation from a ground station by sending back a packet of information. Mode S aircraft can also send out unsolicited packets called squitters. The ADS-B or Automatic Dependent Surveillance-**B**roadcast system sends out unsolicited packets. With both of these systems, aircraft send out their data signals on 1090 MHz. Whether you receive your information over the air or via the internet, it originated with one of these systems. You can obtain more information on these systems from these references[16] [17] [18] [19], all of which can be found on the internet.

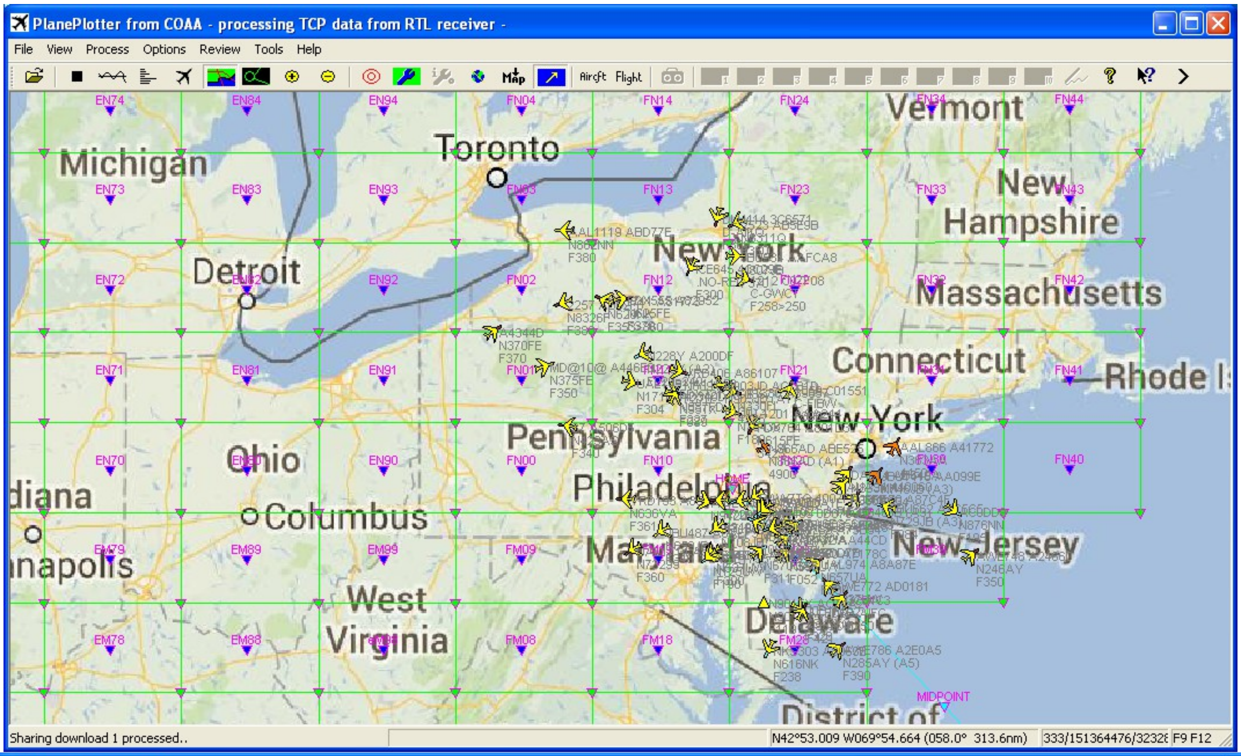
There are a number of receivers available to enable you to receive these signals directly over the air. These include the Kinetic-Avionic SBS3, the AirNav Systems Radar Box, the microADSB receiver, the Aurora Virtual Radar Mode S Receiver, and the Mode-S Beast[20], which was designed by DL4MEA and is considered to be the best 1090 MHz receiver available. Each of these has a web site easily found and full of information. Or, you can save some money and use as your receiver a cheap RTL2382 Dongle obtainable for $20 or less. That is what I did, getting a "NooElec TV28T v2 USB DVB-T & RTL-SDR Receiver" from Amazon for $19.95 with free shipping. I then went to the website http://rtl1090.web99.de/ where I downloaded the RTL1090 software and drivers (do NOT install the drivers that come with this device if you want to use it for this purpose!). This site also has an excellent instruction manual on getting up and running with an RTL2382 dongle. You want to run the RTL1090 software in "Mode S" mode.

I then got the WIMO GP-1090 antenna (part number 17500) from http://www.wimo.com/cgi-bin/verteiler.pl?url=sbs-3-virtual-radar_e.html and I obtained a Kuhne 1090 MHz preamplifier from http://www.kuhne-electronic.de/en/products/low-noise-amplifiers/ku-lna-1090-a-tm.html
With this system I have superb performance, generally seeing 20-60 aircraft at one time, with the exact number depending on the time and day of the week, as air traffic varies greatly as a function of these variables.

Below is a screen shot of the RTL1090 software running on my laptop.

This software sends the data over a wireless link from my Hilltop shack to my home, where a computer running the program PlanePlotter (see reference 2) displays the data in user-friendly fashion, as demonstrated in the screen shot below.

The aircraft scatter program I wrote, called Aircraft Scatter Sharp, will also display the data obtained from these aircraft via RTL1090. A screen shot of Aircraft Scatter Sharp displaying these “local” aircraft is below the PlanePlotter screen shot. The screen shots were not taken at the same time, and so different numbers of aircraft are shown on the two screen shots.



PlanePlotter from COAA - processing TCP data from RTL receiver -
File View Process Options Review Tools Help
Michigan
Toronto
Vermont
New Hampshire
Detroit
New York
Massachusetts
Connecticut
Pennsylvania
Ohio
Columbus
Philadelphia
New Jersey
Maryland
West Virginia
Delaware
MIDPOINT
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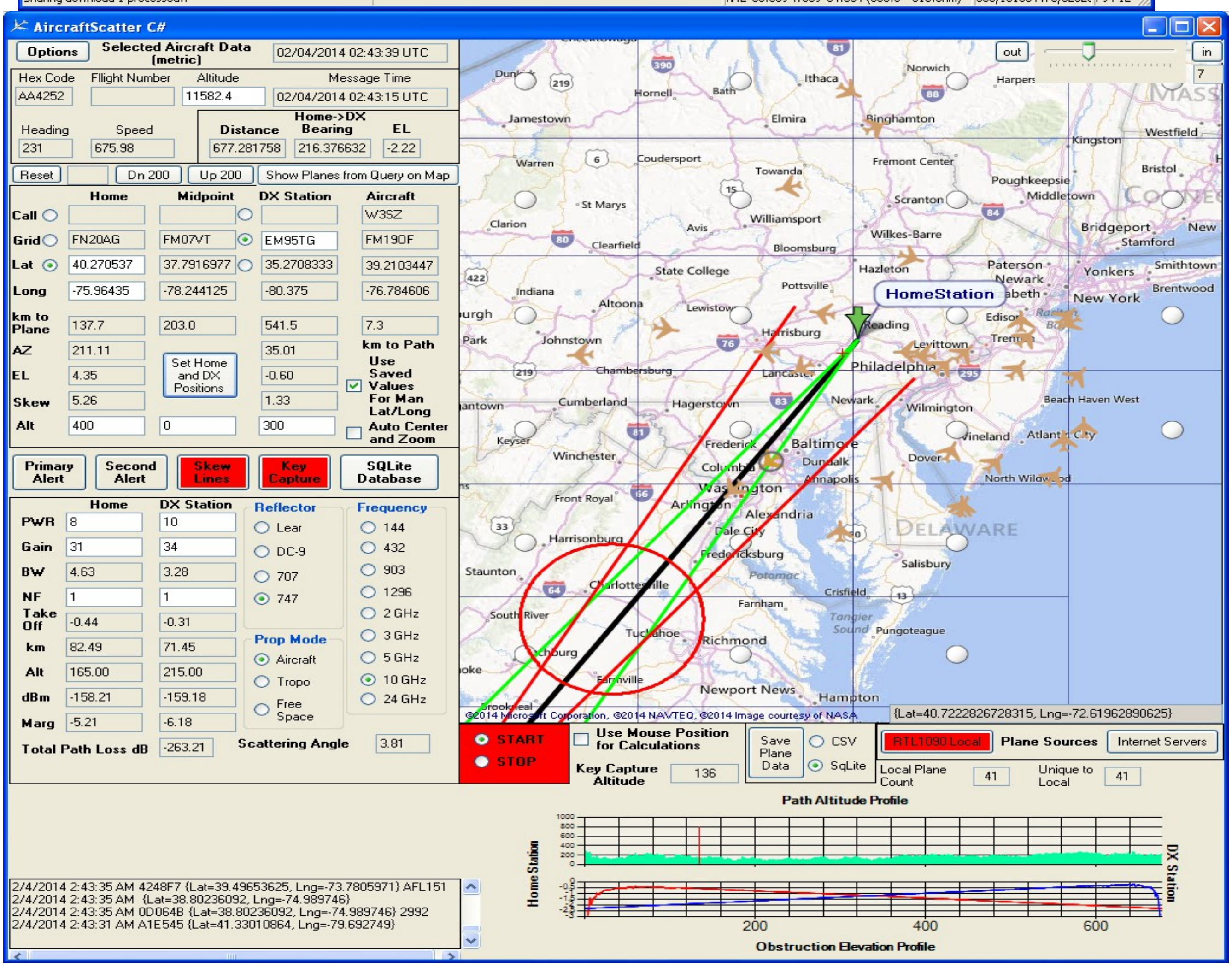

AircraftScatter C#
Options
Selected Aircraft Data (metric)
02/04/2014 02:43:39 UTC
Hex Code
Fllight Number
Altitude
Message Time
AA4252
11582.4
02/04/2014 02:43:15 UTC
Heading
Speed
Distance
Home->DX Bearing
EL
231
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216.376632
-2.22
Reset
Dn 200
Up 200
Show Planes from Query on Map
Home
Midpoint
DX Station
Aircraft
Call
W3SZ
Grid
FN20AG
FM07VT
EM95TG
FM19OF
Lat
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37.7916977
35.2708333
39.2103447
Long
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-78.244125
-80.375
-76.784606
km to Plane
137.7
203.0
541.5
7.3
AZ
211.11
35.01
km to Path
EL
4.35
-0.60
Skew
5.26
1.33
Alt
400
0
300
Set Home and DX Positions
Use Saved Values For Man Lat/Long
Auto Center and Zoom
Primary Alert
Second Alert
Skew Lines
Key Capture
SQLite Database
Home
DX Station
Reflector
Frequency
PWR
8
10
Gain
31
34
BW
4.63
3.28
NF
1
1
Take Off
-0.44
-0.31
km
82.49
71.45
Alt
165.00
215.00
dBm
-158.21
-159.18
Marg
-5.21
-6.18
Lear
DC-9
707
747
144
432
903
1296
2 GHz
3 GHz
5 GHz
10 GHz
24 GHz
Prop Mode
Aircraft
Tropo
Free Space
Total Path Loss dB
-263.21
Scattering Angle
3.81
HomeStation
{Lat=40.7222826728315, Lng=-72.61962890625}
START
STOP
Use Mouse Position for Calculations
Key Capture Altitude
136
Save Plane Data
CSV
SqLite
RTL1090 Local
Plane Sources
Internet Servers
Local Plane Count
41
Unique to Local
41
Path Altitude Profile
Home Station
DX Station
200
400
600
Obstruction Elevation Profile
2/4/2014 2:43:35 AM 4248F7 {Lat=39.49653625, Lng=-73.7805971} AFL151
2/4/2014 2:43:35 AM {Lat=38.80236092, Lng=-74.989746}
2/4/2014 2:43:35 AM 0D064B {Lat=38.80236092, Lng=-74.989746} 2992
2/4/2014 2:43:31 AM A1E545 {Lat=41.33010864, Lng=-79.692749}

The disadvantage of the over-the-air method of getting aircraft data is that it is dependent on your receive location. My antenna is high on a hill, and performance is generally superb, but the terrain is forested, and the antenna is not above the trees. This somewhat blocks reception from the south for me, and so although sitting in FN20 I see aircraft as far north as Lake Ontario, I cannot see much further south than Maryland or Delaware.

That is why I use aircraft information obtained in real-time from internet servers. I have checked the aircraft position data coming from these servers against the on-air data I have received directly, and the data from these servers is accurate.

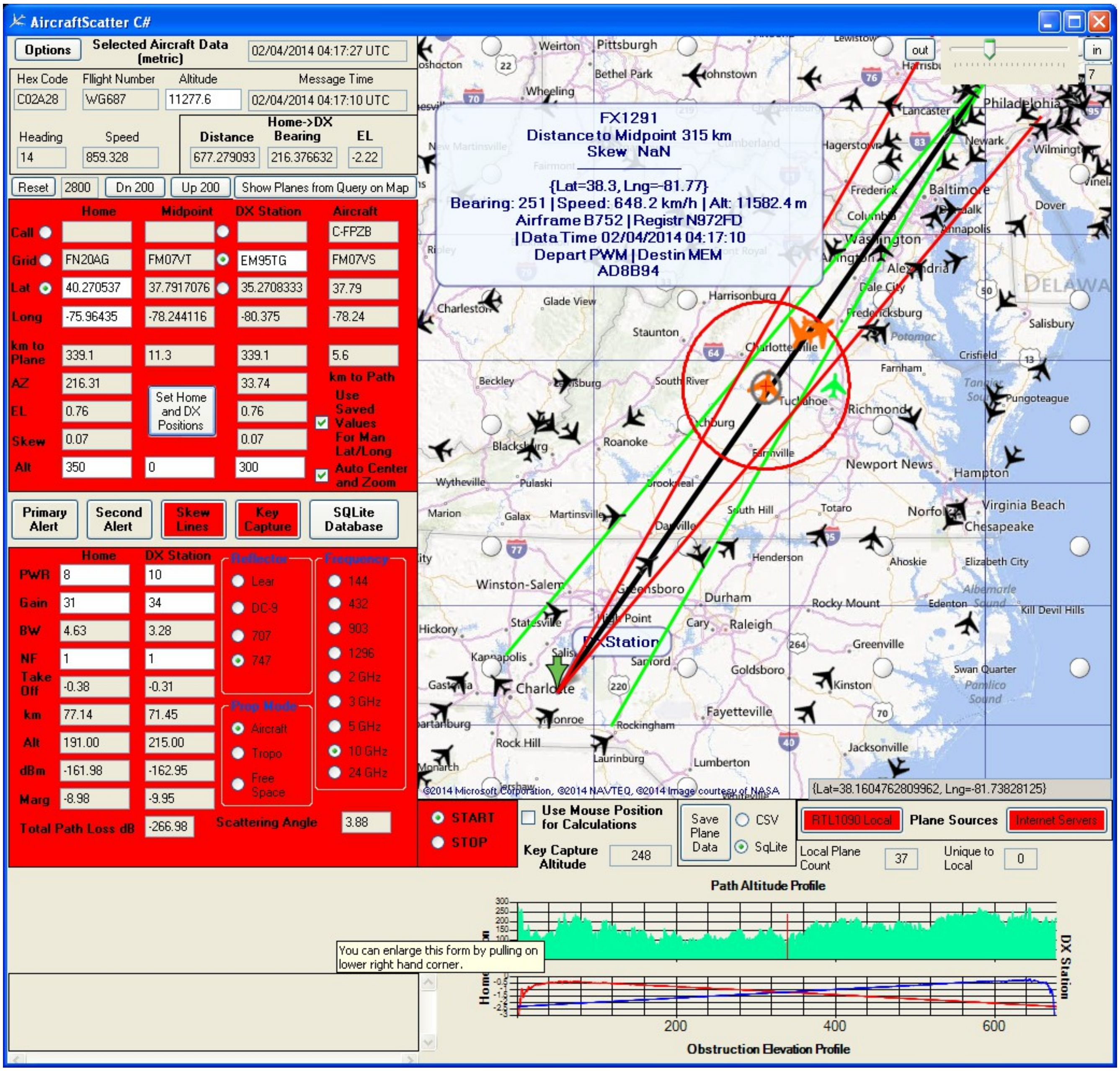
There are several servers that you can use. I initially used PlanePlotter, because the first generation aircraft scatter software I wrote worked through PlanePlotter to get its data. There is a description of this on one of my webpages, at http://www.nitehawk.com/w3sz/AircraftScatterOld.htm Don't spend any time there learning the messy details of how to set up my program with PlanePlotter, however, because I have written a new program that connects directly to the servers on the web and does not require PlanePlotter or any other program to display internet-server-derived aircraft data.

The new program is called AircraftScatter Sharp and it has several important capabilities:

1. Real-time aircraft position information capture and display of aircraft data derived from internet servers, from a local RTL1090 server, or both
2. Display of the direct path line between two stations, along with skew lines to allow a quick assessment of the angular deviation of an aircraft position from the direct path line for both stations, and a midpoint circle to show when an aircraft is within a specified distance from the midpoint of the path. Path altitude and elevation/obstruction profiles are also shown.
3. Highlighting of aircraft near the ideal position for reflection, based both on distance from the midpoint of the path as well as angular deviation from the path
4. Real-time calculation of path loss/received signal at both locations based on aircraft location and user-adjustable station parameters, using either bistatic scatter or troposcatter or free path formulas
5. An integrated SQLite database that allows you [1] to save information on all aircraft appearing on your screen for however long you want [minutes, hours, days, weeks, months] and [2] to then analyze that data to determine when aircraft scatter opportunities will most likely occur. You can analyze the data without interrupting its collection, and powerful SQL search functions are automatically included and easily selectable using only mouse-clicks to generate the SQL query statements.

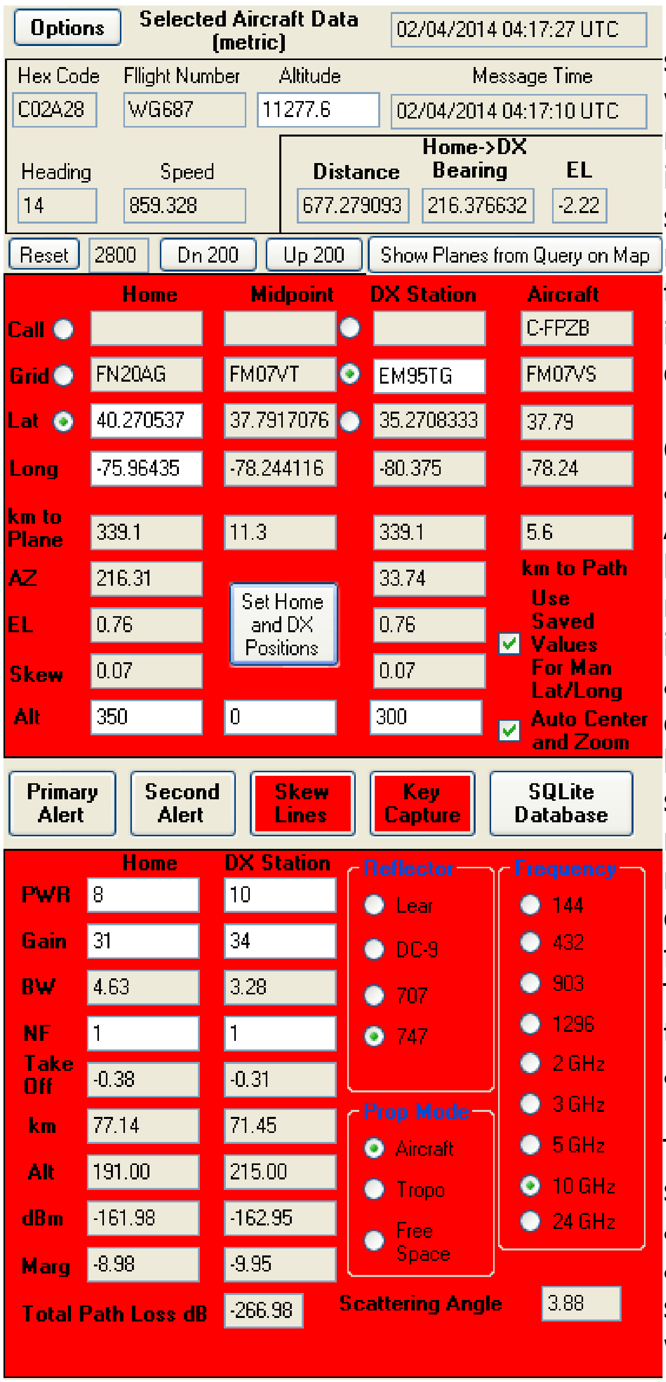
This last piece, the SQL database, provides what has been missing from previous aircraft-scatter software (except for my earlier program mentioned above, which also included this feature). For EME we have software predictors of when the moon will be “available” to us as a reflector. For rain-scatter we have RainScatter, by Andy Flowers, K0SM[21] to give us this information. But there has been nothing similar for aircraft scatter until now.

The remainder of this presentation will focus on this new program, Aircraft Scatter Sharp, a screen shot of which is shown below.



The main form consists of a map on the right side of the form which contains a real-time display of all aircraft downloaded from the server. The aircraft icons shown on the map accurately represent aircraft positions and headings. Below the map is a path altitude profile and a path elevation profile for the path between the home and DX stations. On the left is the data and calculator area.

The path between W3SZ and W4DEX shown on the map has been selected by entering the appropriate 6 digit grid square for W4DEX, and entering latitude and longitude directly for W3SZ into the text boxes on the left. This causes the direct path line, the skew lines, and the midpoint circle to be drawn on the map along with markers and labels for the Home and DX stations. If grid square is entered, latitude and longitude are calculated, and vice versa, as determined by user selection. The program also contains the call3.txt file and can use it to supply grid information for stations included in it. New stations can be added to it via this program. The path altitude profile will only appear if SRTM3 data files have been installed[22] [23].



Before making the screen shot above, I selected an aircraft by by left-clicking it with the mouse. This action put a black ring around the aircraft icon for easier identification. You can easily see the selected aircraft near the center of the map above. Selecting this aircraft in this manner also placed additional information about the aircraft into the data area on the left side of the form.

On the left is an enlargement of the data area on the left side of the main form. Across the top it shows the ICAO hexcode for the aircraft, its flight number, altitude, and the time at which its data was received. Just below that are its heading and speed. To the right of that is a description of the length and bearing of the path from the home station to the DX station, along with a notation of the elevation of each station relative to the horizon as seen from the other station. The next portion of the form has four buttons and a textbox. These are used to display aircraft from the stored SQLite database on the map, and will be discussed more fully below.

The portion of the form just below this section is colored red because there is an aircraft (in this case the selected aircraft) that has activated the secondary alert. This alert is activated when an aircraft is within the circle defining when an aircraft is within the user-defined "optimal range circle" that is drawn around the midpoint of the path (the radius is user-adjustable). This red color is just an easily visible indication that the secondary alert has been activated. This section of the data area has 4 columns. These respectively give positional information about the Home station, the midpoint of the path between the Home and DX stations, the DX station, and the selected aircraft. This information includes for the Home and DX stations (optional) callsign, grid square, latitude, longitude, km to aircraft, azimuth to aircraft, elevation of aircraft as seen from that station, skew angle of the aircraft position from the direct path as seen from that station, and altitude of the location. Callsign, grid square, latitude, longitude, and altitude are user-adjustable. Radiobuttons allow the user to select direct entry of callsign, grid square, or latitude and longitude. A check box allows one to recall previously stored data for latitude and longitude rather than entering those values manually. If Key Capture is turned on, one can use the latitude and longitude of a point on the map as the data for the Home station by hitting <Clt>F1, or as the data for the DX station by hitting <Clt>F2 while manual Lat/Long entry is selected.

The next portion of the display contains buttons that activate or deactivate the audio primary and secondary alarms (but do not affect the panel color changes that accompany these audio alerts), the skew lines/midpoint circle display, and key capture, and it also contains a button that brings up the SQLite database analysis page. The secondary alert sounds when any aircraft enters the midpoint circle. The primary alert sounds if at least one of those aircraft is also within both sets of skew lines. An aircraft turns from black to green when it enters the midpoint circle (i.e., if it activates the secondary alert), and it turns red if it is also positioned between the skew lines (i.e., if it activates the primary alert). Both the skew lines and the midpoint circle are adjustable from one of the options page tabs.

The next section of the display is used for entry and display of RF-related information. It is red because an aircraft was both within the midpoint circle and also within the skew lines when this screen capture was performed (i.e., the primary alert was activated). The user selects aircraft size and frequency, and enters power, antenna gain, and receiver noise figure for both the Home and DX stations. Once this has been done, the program continuously calculates and displays the received signal level, signal margin, and total path loss for both stations in real time. A check box located below the map display and labeled "Use Mouse Position for Calculations" is provided so that these calculations can be made for the case where a reflector is positioned at a user-selected point on the map, rather than using aircraft data. This allows path analysis to be performed for any given map position in the absence of any aircraft at the desired position, and is accomplished by checking this box and then double-left-clicking on the desired map position. A set of radiobuttons allows one to substitute troposcatter or free-space path loss calculations for the aircraft-scatter calculations.

This portion of the form also contains at its bottom right corner a text box that indicates the scattering angle that is used for troposcatter calculations.

Below this section of the main form is a textbox that displays a small portion of the data for the unique “local” aircraft, in order to provide a visual indication of the status of the local RTL1090 server connection. If no unique local aircraft information is available, then this textbox remains blank.

The map portion of the form has a few features that should be noted. Boundary lines for the Maidenhead grid squares are shown by default. These can be turned off using one of the tabs on the Options form, which is accessed by clicking the Options button at the top left of the main form. A grid square label pop-up for a given grid is activated by hovering the mouse over the marker placed in the center of that grid. A tab on the options form allows one to turn this function on or off, and to make the grid square center markers more or less visible.

At the top right of the map are controls for zooming the map in and out.

At the lower right edge of the map is a box that displays the latitude and longitude for the point over which the mouse is hovering.

Below the map are several additional control/display groups. Below the left bottom edge of the map are the radiobuttons used to either start or stop aircraft data download from either the internet server or the local RTL1090 server, labeled “START” and “STOP”. It is necessary to click on “START” to initiate downloading of aircraft information.

To the right of the START/STOP control group is the checkbox described above that allows one to use the mouse to select the map location that will be used as the scattering point, instead of an actual aircraft. The textbox below this, labeled “Key Capture Altitude” will display the altitude for any point on the map if one has key capture enabled and hits <Ctl>F3 while the mouse is over the selected point. This feature, like the path altitude profile feature, requires that SRTM3 height files be installed in the appropriate directory. Hitting <Ctl>F4 will display a Message Box containing the position and altitude of the point last referenced by hitting <Ctl>F3.

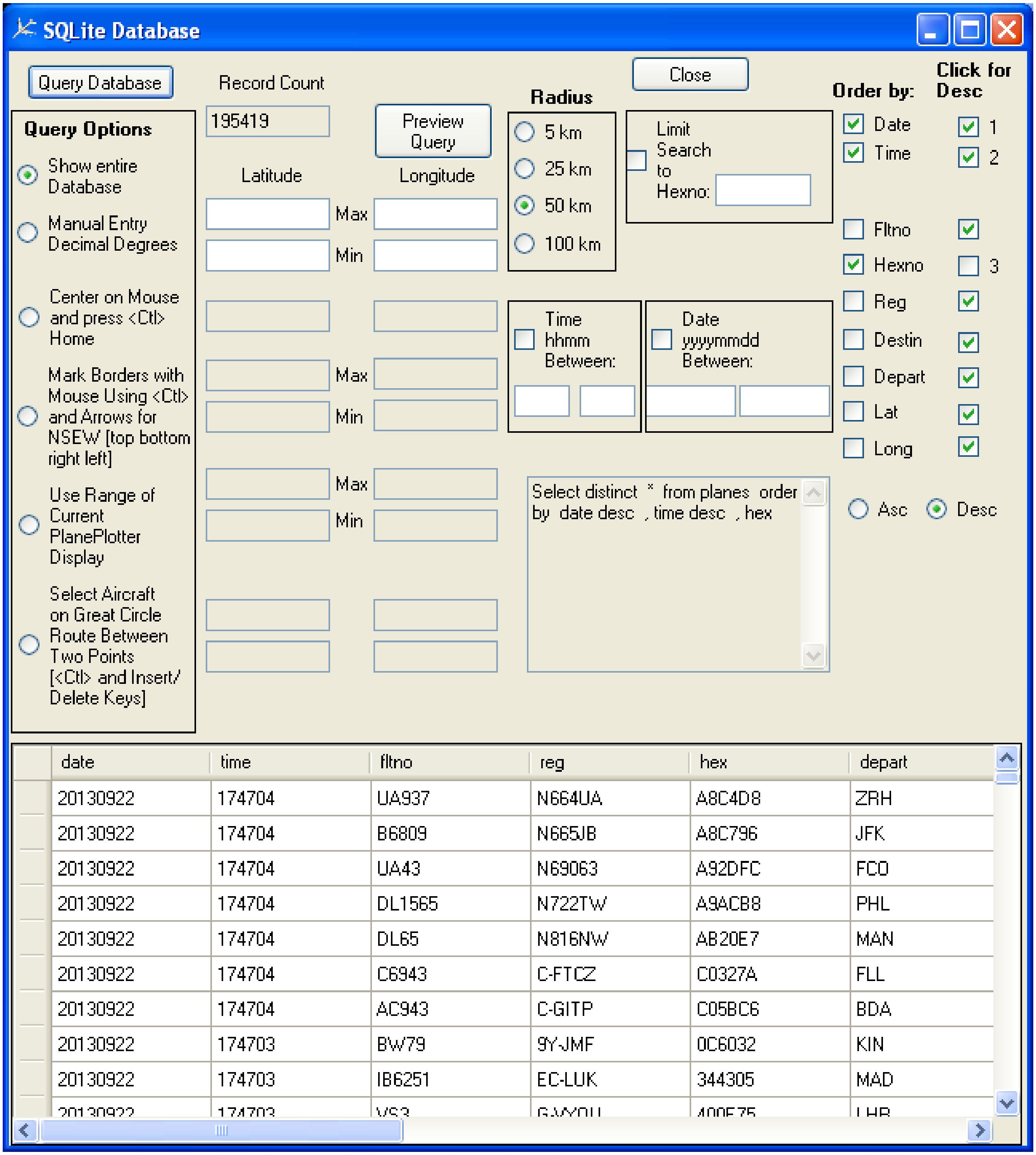
To the right of these objects is the SQL Database control group. Included in this control group are buttons used to activate the function to save all aircraft data to a file, labeled “Save Plane Data”, and to select between CSV file or SQLite database file storage (labeled “CSV” and “SqLite” respectively. The SQLite database file is the default and is strongly recommended.

To the right of this button group are two buttons, used to select for downloading, display on the map, and for analysis aircraft from the RTL1090 server, from the internet server, or both. These buttons are labeled “RTL1090 Local” and “Internet

Server", respectively. Below this are two textboxes. The textbox on the left is labeled "Local Plane Count" and it displays the total number of aircraft currently "seen" by the local RTL1090 receiver. The textbox on the right is labeled "Unique to Local" and it gives the number of these local aircraft that are "unique", and not "seen" by the internet aircraft server.

If one hovers over an aircraft, information for that aircraft will pop up whether or not that aircraft is the "selected" aircraft, as demonstrated in the MessageBox on the left. However, to conserve computer resources, certain data such as the skew angle is only calculated for the selected aircraft and for aircraft within the midpoint circle. The image on the left was obtained by hovering over an aircraft that was not within the midpoint circle. Thus skew information is not available, and is displayed as "NaN" (shorthand for "Not a Number").

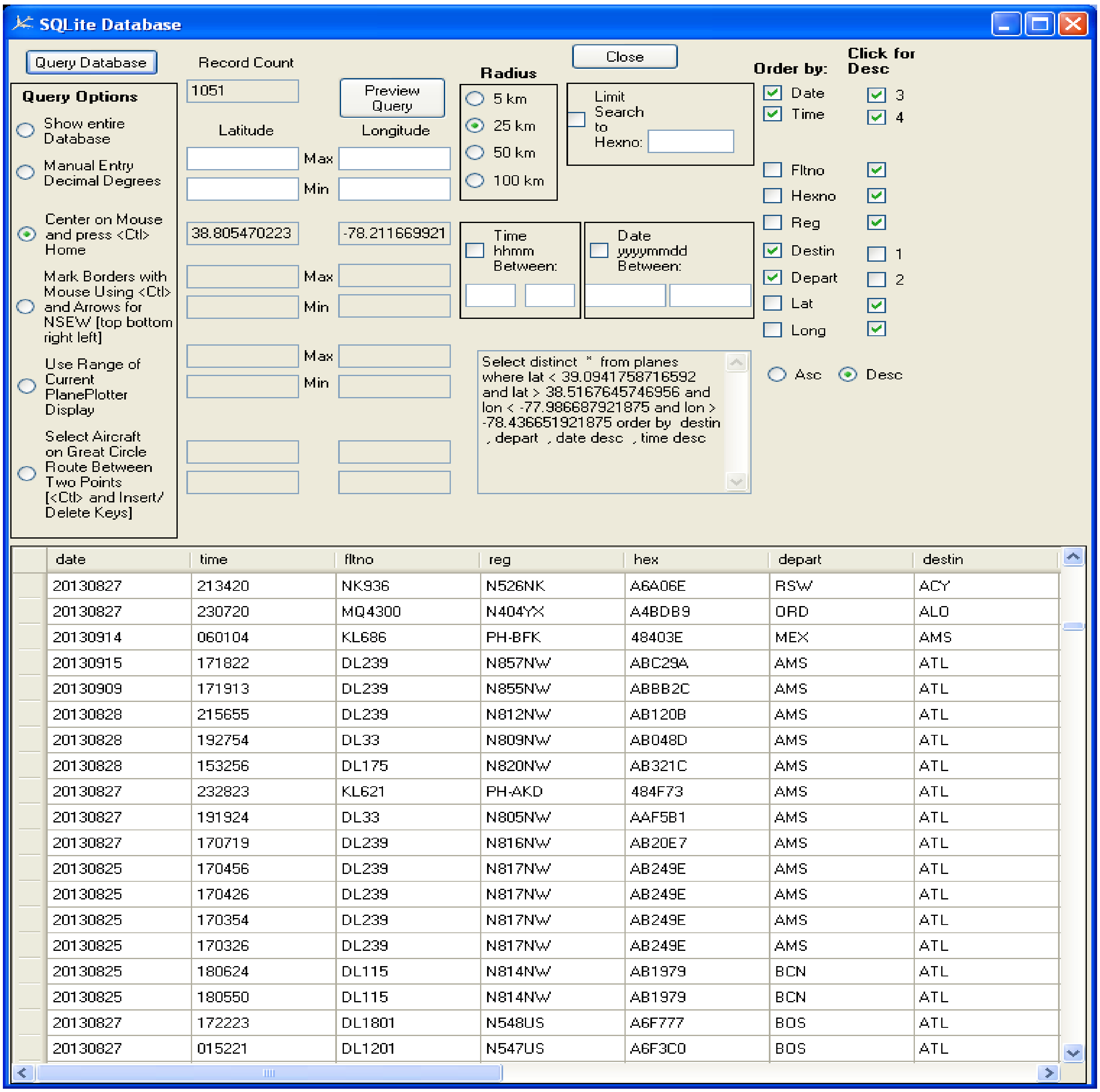
VII. Getting Historical Aircraft Position Data. Below is the SQLite database analysis form that is accessed by clicking on the "SQLite Database" button on the main form of the program. This form shows at the top left that 195,419 aircraft records have been saved in this database.



Information saved about each aircraft by the database includes date, time, flight number, registration (whether FAA or other), ICAO hexcode, departing airport, destination airport, latitude of aircraft, longitude of aircraft, altitude, bearing, speed, airframe type, squawk, and vertical speed. You can see by the checkboxes near the top right of this form that the entries are ordered by date, then time, and then by the ICAO hexcode. The "Query Options" box on the left shows that "show entire database" has been selected, so the table contains all

195,419 aircraft.

In order to plan an aircraft-scatter session, one enters the Home and DX station 6-digit grid squares into the primary form and left-clicks the “Calculate Lat/Long from Home/DX Grids” button. That places the direct path line and the midpoint circle and skew lines onto the map, to help one decide on exactly what geographical area to explore with the database. One then opens the SQLite database form by either left-clicking the “SQLite Database” button, thus bringing up the SQLite database form, or by clicking on the “Show Planes from Query on Map” button, which will bring up the SQLite database form and also display the first 200 aircraft in the selected dataset on the map, where they can be analyzed and viewed just as if they were “live” aircraft.



date	time	fltno	reg	hex	depart	destin
20130827	213420	NK936	N526NK	A6A06E	RSW	ACY
20130827	230720	MQ4300	N404YX	A4BDB9	ORD	ALO
20130914	060104	KL686	PH-BFK	48403E	MEX	AMS
20130915	171822	DL239	N857NW	ABC29A	AMS	ATL
20130909	171913	DL239	N855NW	ABBB2C	AMS	ATL
20130828	215655	DL239	N812NW	AB120B	AMS	ATL
20130828	192754	DL33	N809NW	AB048D	AMS	ATL
20130828	153256	DL175	N820NW	AB321C	AMS	ATL
20130827	232823	KL621	PH-AKD	484F73	AMS	ATL
20130827	191924	DL33	N805NW	AAF5B1	AMS	ATL
20130827	170719	DL239	N816NW	AB20E7	AMS	ATL
20130825	170456	DL239	N817NW	AB249E	AMS	ATL
20130825	170426	DL239	N817NW	AB249E	AMS	ATL
20130825	170354	DL239	N817NW	AB249E	AMS	ATL
20130825	170326	DL239	N817NW	AB249E	AMS	ATL
20130825	180624	DL115	N814NW	AB1979	BCN	ATL
20130825	180550	DL115	N814NW	AB1979	BCN	ATL
20130827	172223	DL1801	N548US	A6F777	BOS	ATL
20130827	015221	DL1201	N547US	A6F3C0	BOS	ATL

From the SQLite database form, one can then select a region from which to display aircraft records in one of several ways.

If one wants to see when aircraft are likely to be within a 5, 25, 50, or 100 km square centered on the midpoint of the direct path, one clicks the appropriate radio button on the SQLite database page to set the radius desired. With the key capture function activated, one uses the mouse to place the cursor over the midpoint of the direct path and hits <Ctl>HOME on the keyboard. This puts the coordinates for the midpoint into the appropriate text boxes on the SQLite database page, as shown in the illustration below. One then left clicks the RadioButton labeled "Center on Mouse and press Home Key" on the database page to choose this method of location selection for the database query, and finally one left clicks the "Query Database" button. This sends the appropriate query to the database, and the data returned to the data grid includes only aircraft that were within this region. One can order the display of these aircraft by date, time, etc. as described below and quickly see what aircraft are likely to be available when for use.

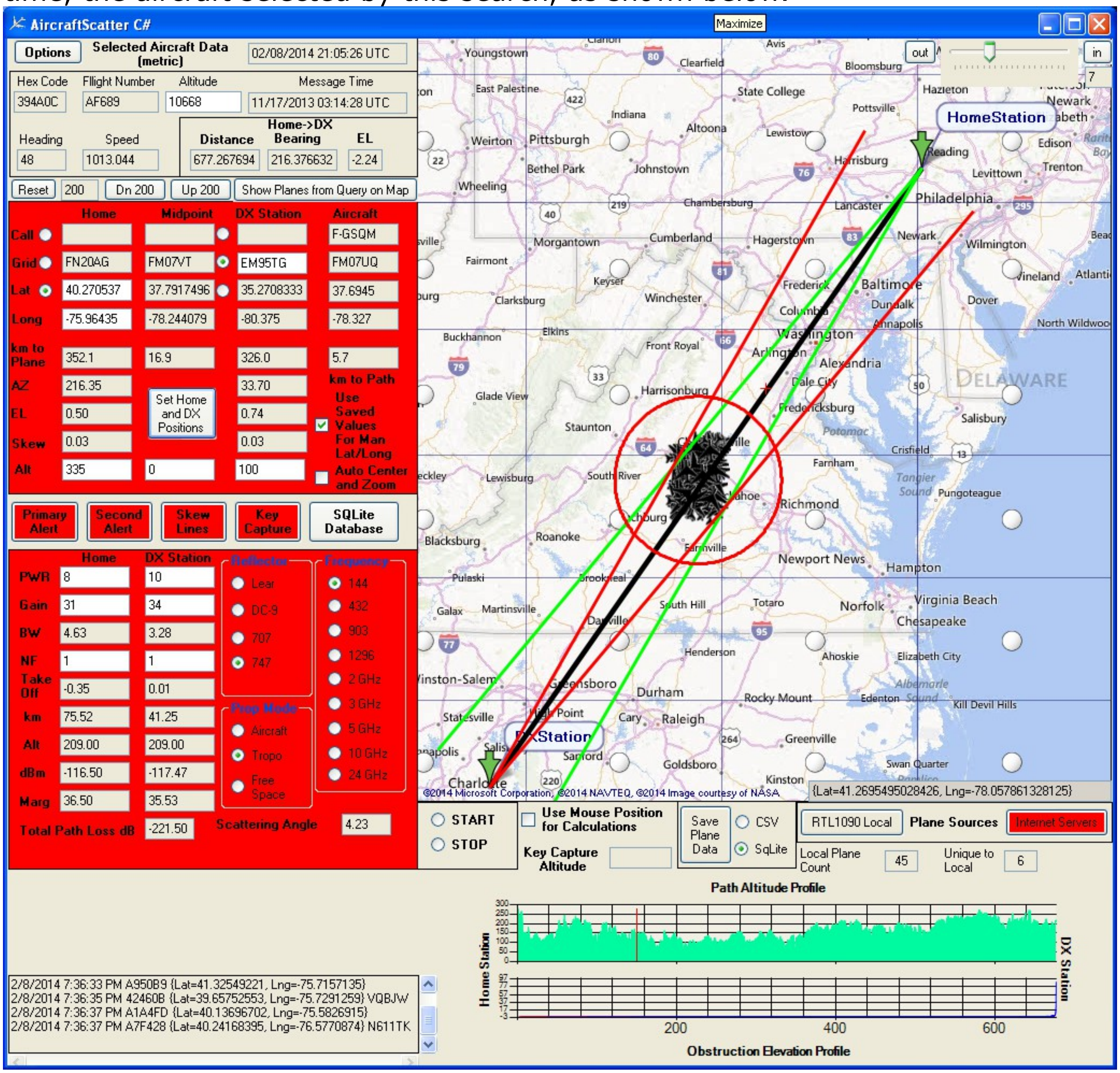
There are 4 other, alternative methods of limiting the geographic region from which aircraft are returned in the query. These are also shown in the "Query Options" panel, located both above and below the RadioButton for the option just described. These include (1) manual entry of the maximum and minimum latitude and longitude for a rectangle from within which all aircraft will be selected, (2) setting the borders of a rectangle using the map and the mouse, (3) using the display area of the map itself to set the boundaries, or (4) selecting a great circle route between any two points (such as the Home and DX stations) and using the "Radius" radiobuttons to specify a distance from that path from within which aircraft will be selected.

One can also, and simultaneously, limit the search query by date and/or time, and by the ICAO hexno, which is a unique identifier assigned to every aircraft that is put into service worldwide, and which stays with the aircraft for its entire life. The searches can also have the data returned by the query ordered by up to 9 additional parameters. For the first example above, with 195419 aircraft, you can see that the search displayed was first ordered by date, then by time, and finally by hexno. Date and time were ordered in descending fashion, and hexno was ordered in ascending fashion.

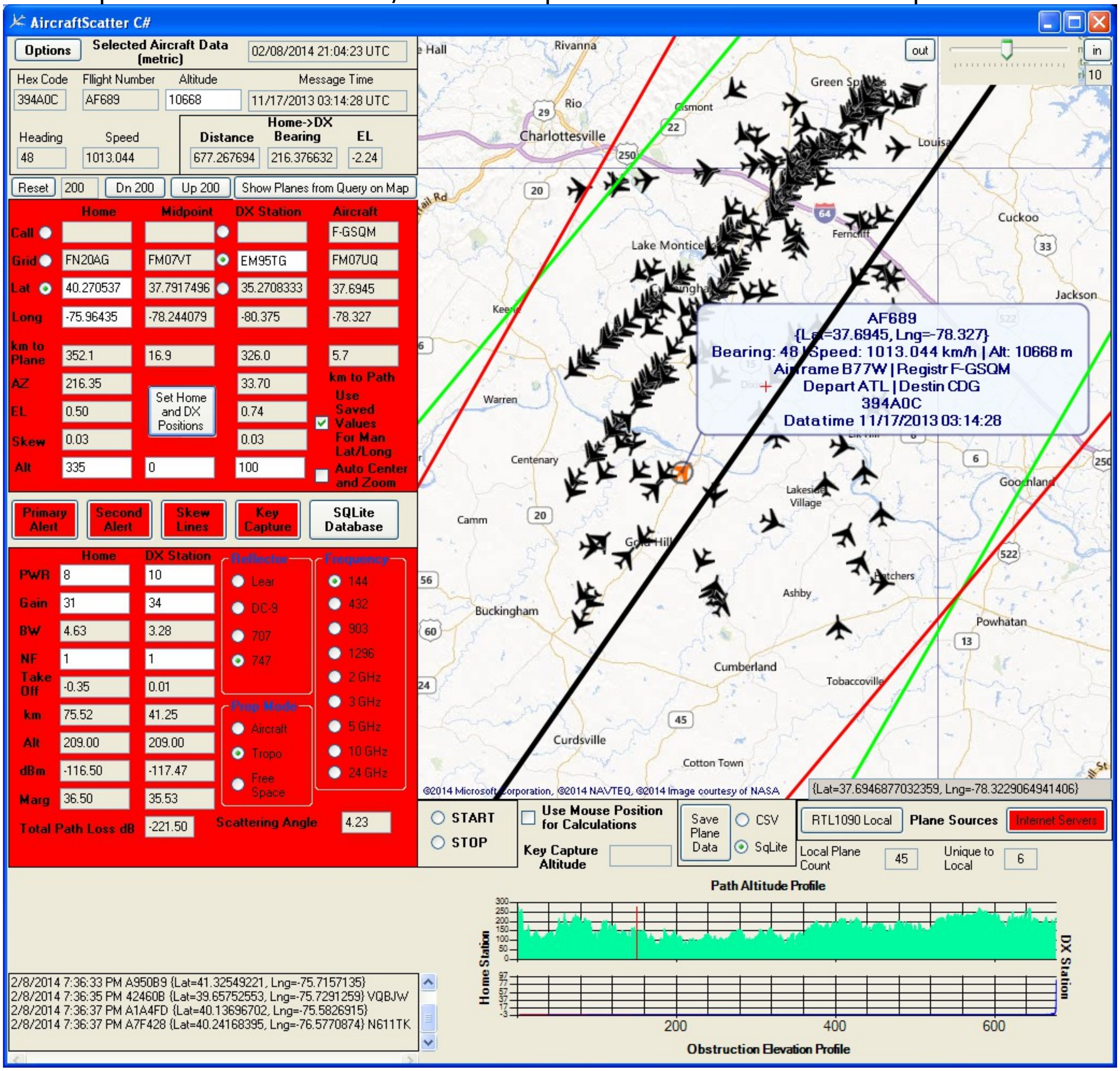
In the second example above we have limited the search to a circle with radius 25 km centered on the midpoint of the path between W3SZ and W4DEX. This query returns 1051 flight records, and in this case I ordered the query by alphabetically ascending destination, then alphabetically ascending departure airport, and then by descending date and descending time. Reviewing the data, you can quickly see that flights crossing this point in this time span were flights from RSW to ACY, ORD to ALO, MEX to AMS, AMS to ATL, BCN to ATL, etc. A careful inspection of the form will show the choices I made to direct the query, and the text box below the time and date check boxes shows the query that the program automatically formed based on the selections I made with just a few clicks of the mouse.

The order of the aircraft record display can also be changed by clicking on the heading for any column.

Clicking on the "Show Planes from Query on Map" will display, 200 aircraft at at time, the aircraft selected by this search, as shown below.

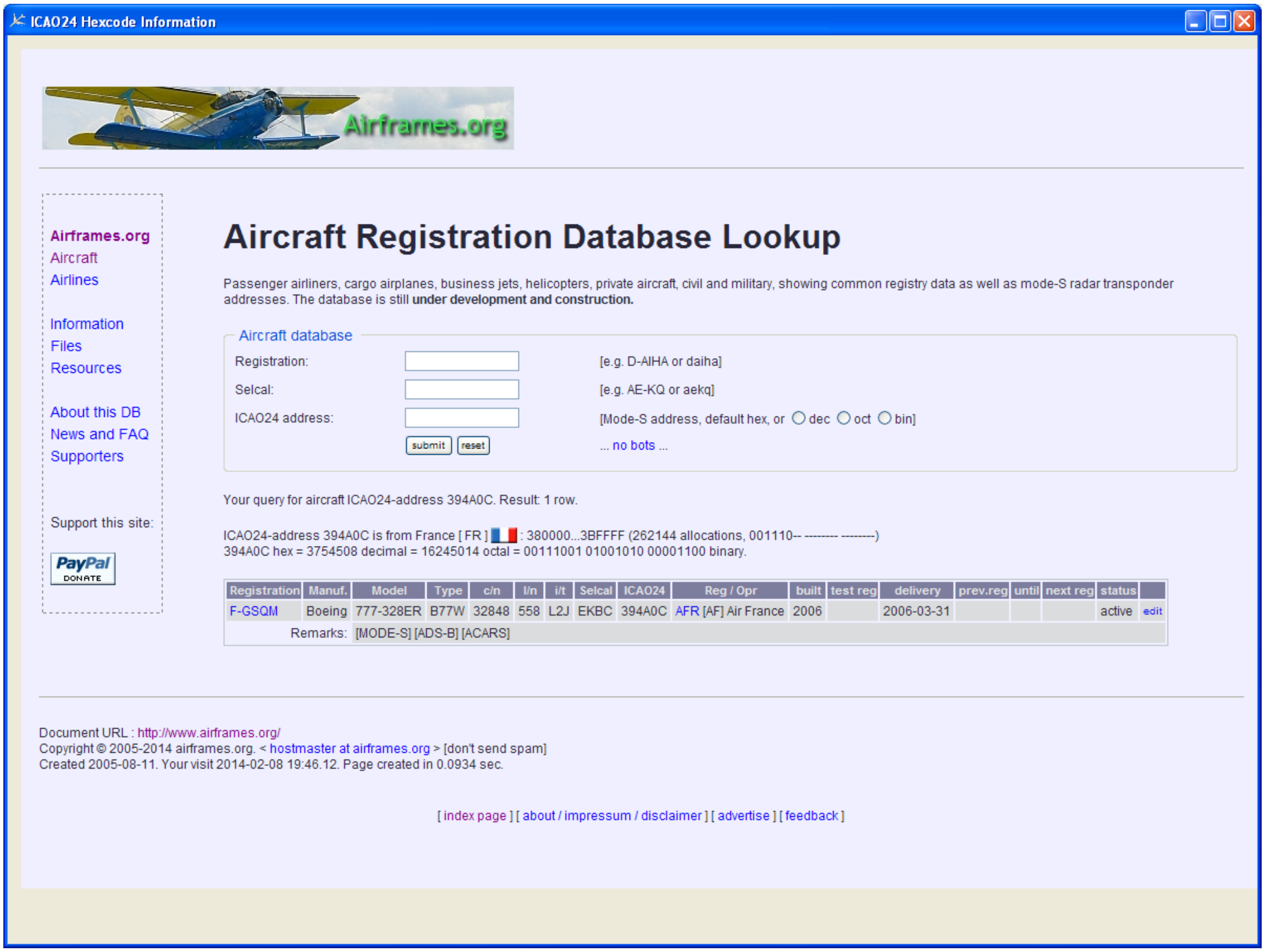


The aircraft are clearly too densely packed to provide any useful information, so we need to zoom in. With zooming in, we can easily see individual aircraft, and click on them (or hover over them with the mouse) to get more information on them. As you can see below, zooming in separates the aircraft nicely. I have both left-clicked and hovered over an aircraft near the bottom center of the display. As a result, you can see its information both in the tooltip displayed on the map and also in the data/calculator panels to the left of the map.

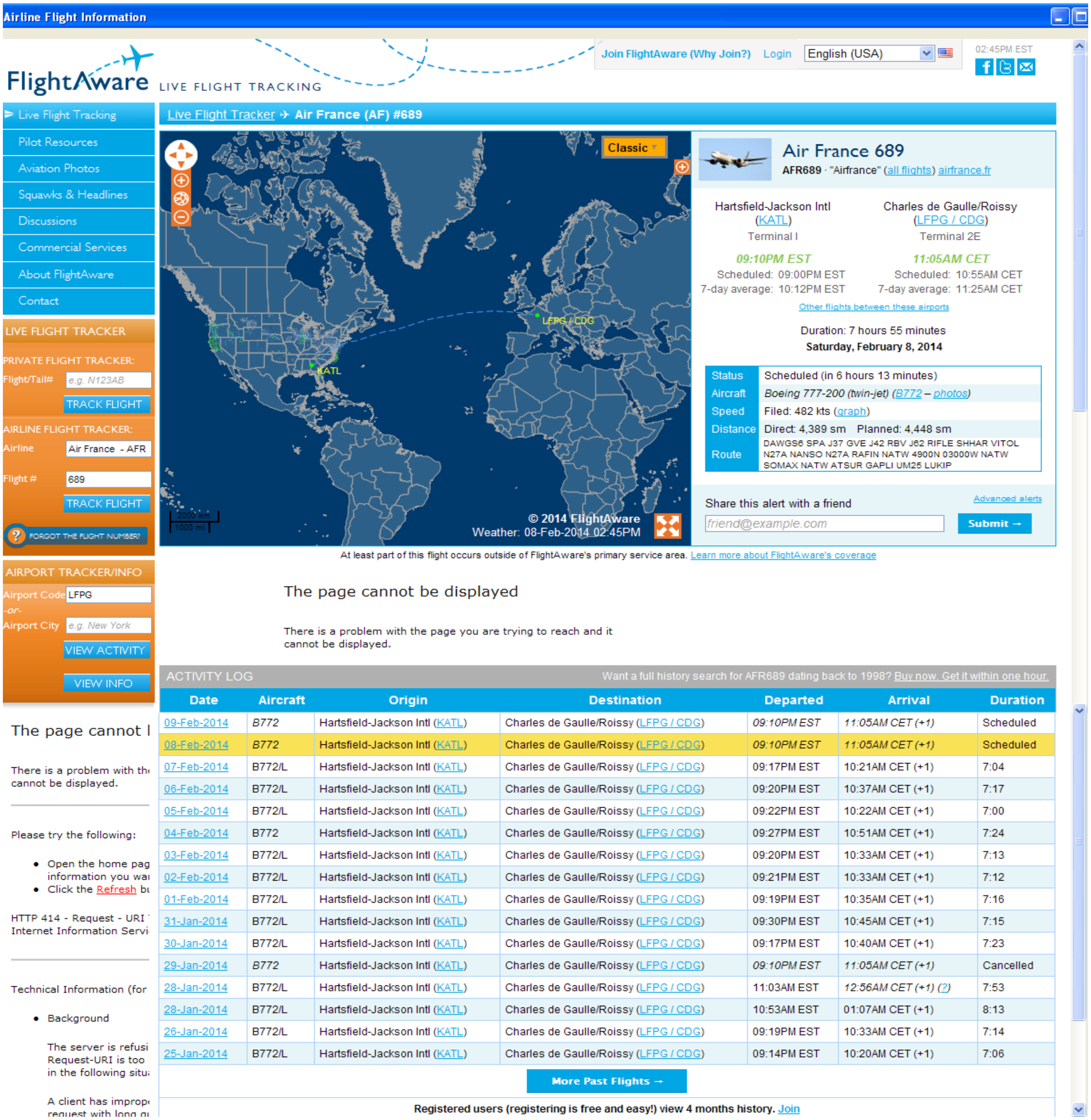


You can see that is has flight number AF689 and ICAO hexno 394AOC. You can also see that it was recorded at 03:14:28 UTC on 11/17/2013 and see all of its position and RF calculation parameters, just as if it was a “live” aircraft.

You can get more information about it by clicking <Ctl>F7, which will bring up information for its hexno at airframes.org. This is shown below.



By clicking <Ctl>F8 you can bring up flight information from FlightAware.com, as is shown below. This gives you a history of several weeks of arrival and departure times, that you can use to get an idea of how much variability there is in flight times, to supplement the data you acquired with Aircraft Scatter Sharp.



Because aircraft schedules are NOT like clockwork, using published schedules and estimating when an aircraft will be in a given area is very unproductive. But using Aircraft Scatter Sharp in the manner described above to gather large amounts of data over a period of weeks or months allows one to make statistically based decisions on when aircraft are most likely to be in the region of interest, by examining the historical data obtained using this program. Using the various functions on the database form, one can select which data is to be displayed is obtained and by analyzing that data, one can then devise operating schedules that will be most likely to be productive. Further suggestions on using Aircraft Scatter Sharp are contained in the appendix, which precedes the list of references.

VIII. Conclusion. Aircraft scatter using forward-scatter enhancement for airplanes along the direct path between two stations offers the opportunity to significantly extend communications distances for microwave operators. The use of the digital modes JT65C and ISCAT-A along with the other software resources discussed here should give the interested amateur radio operator the best chance for success with this endeavor.

If you have any questions, please contact me by email at mycall at comcast dot net. You may download a copy of the program from the web page listed below.

There is also a copy of this talk plus additional information at
http://www.nitehawk.com/w3sz/AircraftScatter.htm

Roger Rehr W3SZ
9-25-2013

Appendix. Suggestions for getting started.

1. The program has been tested and works with Windows XP 32 bit and both the 32 and 64 bit versions of Windows 7. It has not been tested with other operating systems.
2. Download Aircraft Scatter Sharp from:
http://www.nitehawk.com/w3sz/AircraftScatterSharp.zip
3. Unzip it.
4. Double-left-click "Setup.exe"
5. When installation completes, the program will start immediately.
6. When it starts it will tell you that it is writing to disk the initial dBplanes.sqlite database file and the call3.txt file. It will also remind you that you need to go to options to set up the URL, Directory, and File to use for the Internet aircraft servers, using the "URLs/IPs" tab on the "Options" form.
7. While on the Options form, you should also go to the "Home Location" tab and set the home latitude, longitude, and altitude. After you have entered the appropriate data, click the "Set Home Station" button for each and then click "OK" to close the Options form.
8. There are numerous ToolTips which appear when you hover over the various controls, textboxes, etc. to guide you as you learn the program.
9. After you have entered the URL and Directory and File for the internet aircraft server, you can start downloading aircraft data from the internet by left-clicking the "START" button near the bottom of the data/calculation form.
10. Buttons turn RED when activated, and return to their baseline color when deactivated.
11. Using the internet aircraft server is selected by default. You can deselect it by clicking on the "Internet Servers" button. When you exit the program, your choice will be remembered.
12. You can additionally select to display local aircraft data, sent using the port 30003 server of RTL1090 by clicking on the "RTL1090 Local" button.
13. To save aircraft data to the SQLite database, click the "Save Plane Data" button.
14. Hover over an aircraft with the mouse to see its ToolTip data. You need to hover near the "3 o'clock" to "6 o'clock" quadrant below the aircraft to activate the ToolTip.
15. Left-click an aircraft to make it the "selected" aircraft and put all of its data into the data/calculation portion of the main form. You need to click near the "3 o'clock" to "6 o'clock" quadrant below the aircraft to select it.
16. In order to use the Hotkeys, you need to turn on key capture, using the "KeyCapture" button near the middle of the data/calculation portion of the main form. The hotkeys are F1-F9 combined with the <Ctl> key.

    <Ctl>F1 Put the Lat/Long of the point under the mouse pointer into Home Station Lat/Long [need to have Lat/Long for the Home station selected by the radio button]

    <Ctl>F2 Put the Lat/Long of the point under the mouse pointer into DX Station Lat/Long [need to have Lat/Long for the DX station selected by the

radio button]
<Ctl>F3 Put the altitude of the point under the mouse pointer into the small textbox at the lower right corner of the data/calculation portion of the man form
<Ctl>F4 Pops up a message box with the Lat/Long/Altitude of the point last obtained with the <Ctl>F3 combination
<Ctl>F5 Turn on all helpful tooltips [does not affect aircraft tooltips]
<Ctl>F6 Turn off all helpful tooltips [does not affect aircraft tooltips]
<Ctl>F7 Gets aircraft data for the selected aircraft from airframes.org, using ICAO hexno
<Ctl>F8 Gets flight data for the selected aircraft from FlightAware.com using flight number
<Ctl>F9 Shows the list of Hotkeys

17. Zoom the map in and out using the "in" and "out" buttons at the top right of the map.
18. You may drag the map to a new center by rightclicking while you are dragging the map with the mouse pointer.
19. If you have "Auto Center and Zoom" clicked [the default] then each time you click "Calculate Lat/Long from Home/DX Grids", the map will center itself on the midpoint of the path you have created.
20. You can enter Home and DX station position data one of 3 ways:
    - Click on the "Call" radio button and type in a call. If that call is contained in the call3.txt database, its grid and Lat/Long information will be entered.
    - Click on the "Grid" radio button and type a 4 or preferably 6 digit grid
    - Click on the "Lat" radio button and enter the latitude and longitude values
21. Once you have entered the position data for Home and DX stations as described above, left-click the "Calculate Lat/Long from Home/DX Grids" button to calculate the path between the home and DX stations.
22. The Path Altitude Profile will only be displayed if you have downloaded all of the necessary SRTM3 data files from http://dds.cr.usgs.gov/srtm/version2_1/SRTM3/North_America/ and put it into the %localAppData%/W3SZ/ElevationData/SRTM3 directory. This is most likely of the form x:/Documents and Settings/Username/Local Settings/Application Data/W3SZ/ElevationData/SRTM3/.
23. Read the tooltips and the Options pages for more useful information.

1 Linrad for Newcomers, by Leif Asbrink, SM5BSZ: http://www.sm5bsz.com/linuxdsp/usage/newco/newcomer.htm
2 PlanePlotter from CoAA: http://www.coaa.co.uk/planeplotter.htm
3 Root, HG. Using Aircraft Reflections in V.H.F. Communications. QST August 1967, pp53 and 146.
4 Pocock, E. UHF and Microwave Propagation. ARRL Microwave Experimenter's Handbook, 1990, pp 3-28 and 3-29.
5 Moncur, Rex VK7MO and Smith, D VK3HZ. Aircraft Scatter Propagation on 10 GHz using JT65C. http://www.vk3hz.net/aep/AEP_on_10GHz.pdf
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7 Skolnik, MI. Introduction to Radar Systems, Third Edition. McGraw-Hill, 1981, pp. 44, Table 2.2.
8 Atkins, R. Radio Propagation by Tropospheric Scattering. Communications Quarterly Winter 1991, pp 119-127.
9 Moncur, R VK7MO. Aircraft Enhancement – Some Insights from Bistatic Radar Theory. http://www.vk3hz.net/aep/vk7mo_2000.pdf
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11 Skolnik, MI. Introduction to Radar Systems, Third Edition. McGraw-Hill, 1981, pp 557.
12 McArthur D VK3UM. Aircraft Enhancement of VHF/UHF Signals. Amateur Radio, July 1985, pp 4-6.
13 Preben-Hansen, P OZ1RH. Everyday VHF, UHF, and SHF Propagation 700 km DX Anytime using Troposcatter. http://www.qsl.net/oz1rh/troposcatter99/troposcatter99.htm
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