

Multilateration tutorial

This tutorial describes the method (Multilateration) that PlanePlotter uses to estimate the position of an aircraft that is transmitting Mode-S reports but not ADS-B position reports (termed "position-less" aircraft). It is important to understand how the method works in order to appreciate the limitations of the method, and the possible positional errors that can arise.

Raw data access - Kinetic SBS1- all versions using BaseStation software version 160 or later

Version 160 of BaseStation and later versions provide a raw data port that PlanePlotter will use automatically if you enable the "Mode-S..SBS1/ANRB TCP" and "Raw data for Mlat" options in Options..I/O settings. It is strongly recommended that if you are using an earlier version of BaseStation, you upgrade to the latest version available for free download from the Kinetic site.

Raw data access - Other receivers

Almost all other receivers including the PGR, the FPGA Beast, the SSRx and the variants of the AVR (microADSB etc), are able to provide precision timing data for Mlat purposes. Having set up the receiver for normal operation, it is only necessary to enable "Raw data" in Options..I/O settings. Consult your receiver documentation in case there are switch settings required in the receiver to enable the precision time tags.

Multilateration basics

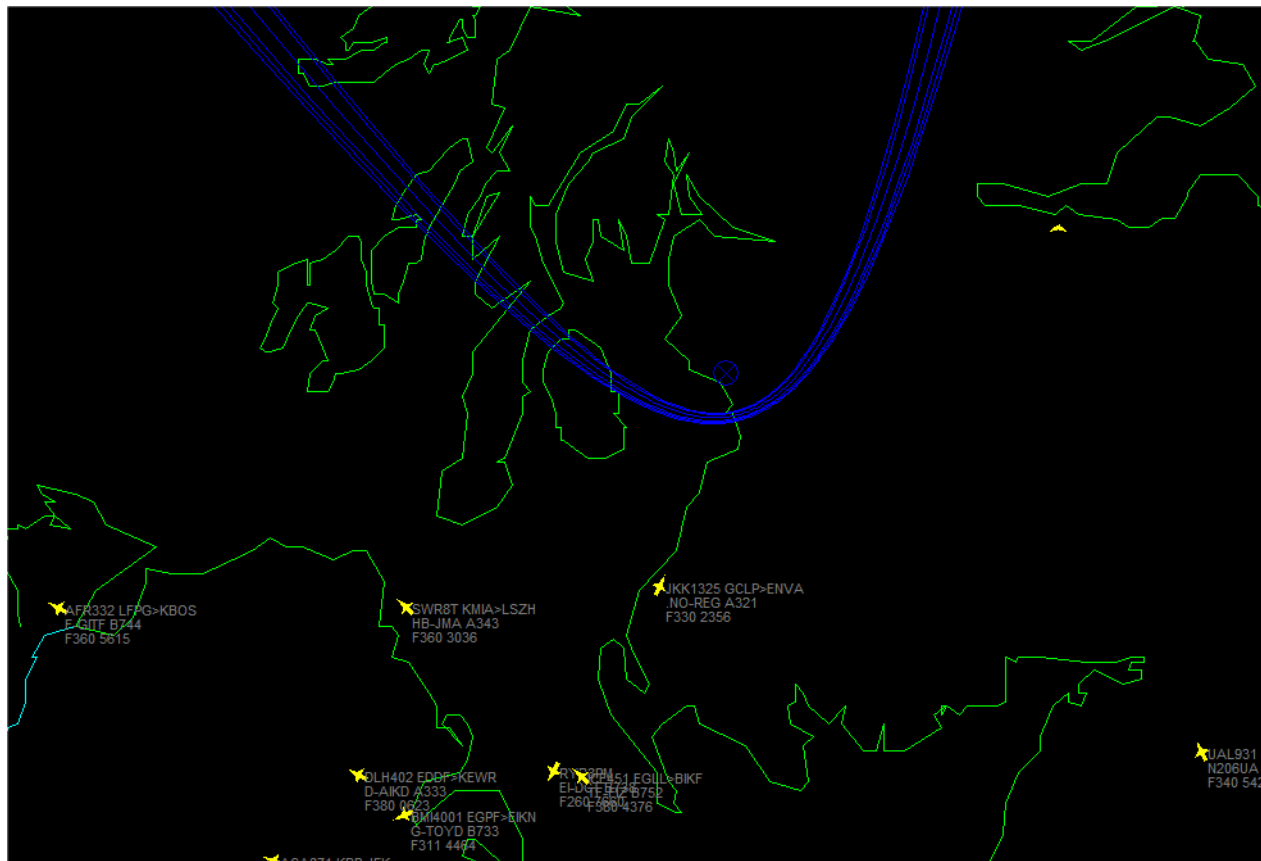
If you know the precise distance between an unknown location and three known locations, then it is simply a matter of geometry to determine the position of the unknown. In the case of multilateration using radio signals, the distance is measured in terms of the travel time of the signal at the speed of light (300 metres per microsecond).

In our case, the problem is rather more complicated for three reasons. Firstly, we know the relative arrival times, but not the absolute transmission time, of each message. Secondly, in the case of the Kinetic receiver, the measurement of time is reported in units of 50ns modulo 24 bits, which yields an ambiguity every 0.8 seconds. Thirdly, related to the second, the absolute arrival times are unknown because the 20MHz clock in each receiver is not synchronised to any absolute reference.

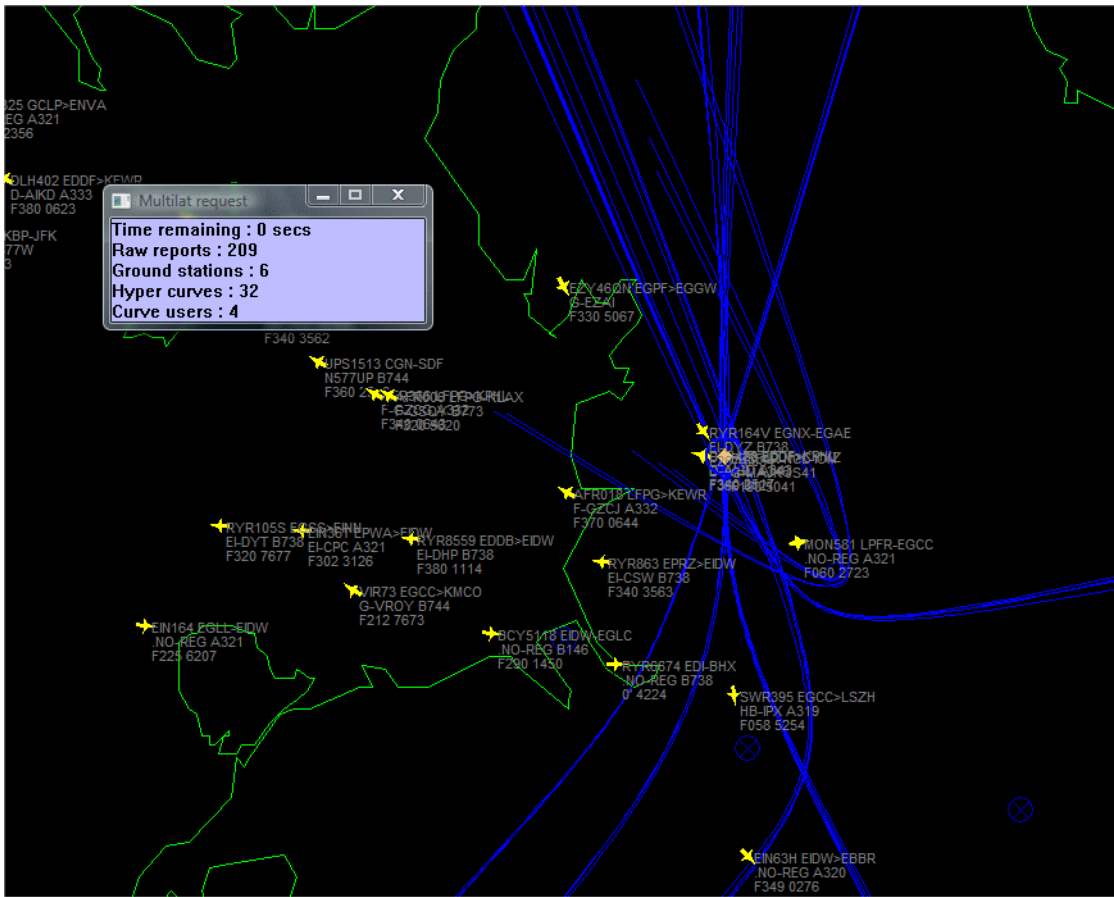
The way PlanePlotter resolves these problems is by analysing ADS-B messages that include position, from other reference aircraft together with data bursts from the wanted, position-less, aircraft. By examining the arrival time of these various messages at two separate receivers, PlanePlotter is able to calculate the coefficients of a curve (hyperboloid) on which the unknown aircraft must lie.

PlanePlotter users who are able to provide raw data are termed "Ground Stations" (GS) for the purposes of this discussion. As you will see from what follows, there are some configuration steps to follow in order to achieve Ground Station status.

PlanePlotter users who are able to make position request are termed "Master Users" (MU). For the Master User features to work, you will need to be specifically enabled for this function. As a general rule, users who have successfully configured their systems to be Ground Stations will, on request, be enabled as Master Users. Again, for the Master User functionality to work, some configuration steps may be necessary. These are described later in this document.



For each matching pair of messages received from the target by two Ground Stations, PlanePlotter is able to draw a curve on the chart of the Master User (diagram above). If there are more than two Ground Stations involved, there will be two or more families of curves and the unknown aircraft will lie at the intersection (or intersections) of the curves (diagram below). If the Ground Stations are well distributed and plentiful, the intersection will be unique. If there are fewer Ground Stations receiving the two aircraft and in particular if their distribution tends to linear, then there may be multiple intersections and the position of the wanted aircraft determined by the Master User, is ambiguous.



The overall requirement for successful multilateration is for data bursts from the wanted aircraft, together with data bursts from suitable reference aircraft (ones that report position), to be received by at least three well-distributed Ground Stations. This, together with some critical timing constraints, explain why positive results are by no means guaranteed.

Data flow

The calculation of the position of a selected position-less aircraft is done by PlanePlotter at the instigation of a Master User. The Master User initiates a request that is immediately passed to the sharing server. The request for raw data from the chosen target yields a list of Ground Stations within the presumed area of the target. The MU then sends a request for raw data to every Ground Station in the list requesting raw data within a specific time window (20 seconds). Each Ground Station sends the requested data directly to the requesting Master User, not to the sharing server, by UDP/IP. The requesting Master User receives data from the participating ground stations, at intervals, over a few seconds following the request being made. During this time, an information box appears on the Master User's screen showing the number of raw data messages that have been received from any Ground Stations. At the end of 10 seconds, the Master User's PlanePlotter reviews and analyses the data that it has received, to determine whether any curves can be plotted from the raw data. The curves are plotted on the Master User's chart. The information box displays the results of the analysis (number of curves; number of users) for a few seconds after the process is completed. If possible, PlanePlotter also makes an estimate of the position of the aircraft from the intersection of the curves. The position estimate, if any, is then plotted on the PlanePlotter chart display, along with the curves, using a unique white diamond-shaped symbol.

It follows from the above that each Ground Station must enable PlanePlotter to receive UDP/IP datagrams addressed to port 9742 and to send UDP/IP datagrams to any IP address on the Internet. This facility must be enabled in the user's firewall and, if necessary, in their router. The firewall is likely to request permission the first time that PlanePlotter tries to send data and, if the user responds Allow/Always, thereafter the firewall will not impede the outgoing data. The situation may be more complicated if the Ground Station employs a router. Routers generally allow outgoing UDP/IP packets but by default refuse incoming packets. Some routers also impose a restriction on the number of successive packets or sessions that can be sent or received. It is usually possible to change this limit, where it exists, in the router setup but the procedure is specific to the make and model of router and the user must be familiar with their own router setup in order to be successful in configuring the network permissions. A key word to look for in many router setup screens is "DoS detection" in the firewall section and the parameter of interest is sometimes contains the description "incomplete TCP/UDP sessions". Such a parameter should be in the hundreds, rather than in the tens. Ground Stations should consult the manual for their router to determine the exact changes that they need to make, if any. The port forwarding facility is generally configured in the "Virtual Server" or "Port forwarding" section of the router setup.

It also follows that a Master User must also be able to receive UDP/IP datagrams from sources on the Internet. Again there will be consequences for the firewall and, if present, the router. Just as for a Ground Station to function, if the user is operating a LAN, their router must be configured to send incoming UDP datagrams addressed to port 9742 (the port that PlanePlotter uses), to the local IP address of the user's machine that is running PlanePlotter. The port forwarding facility is generally configured in the "Virtual Server" or "Port forwarding" section of the router setup. If you are lucky, the router may record the outgoing requests for raw data to each GS and when a reply comes back from each one, it forwards the raw data to the correct LAN address automatically. This luxury only applies to an MU. A GS must complete the port forwarding setup. Once the datagrams reach the target PC, the firewall must be allowed to pass such UDP/IP packets to PlanePlotter. This may require a specific setup in the "Programs" section of the firewall or it may simply be necessary to respond 'Allow/Always' to the firewall's enquiry the first time data comes in. The exact procedure depends on the type of router and the type of firewall.

Position errors

In order to achieve a reasonable probability of finding suitable data bursts from the reference aircraft and from the wanted aircraft, the time window for the transferred raw data is set at 20 seconds. The estimated position is determined by a three-dimensional, least-squares fit of the observed time differences but, without any information about the course and speed of the unknown, it is not possible to include its rate of movement in the calculation. Accordingly, the estimated position refers to a time within the 20-second window, which may not be precisely known. You should also note that the analysis of the data cannot begin until at least 10 seconds after the request is made. The method is therefore not considered to be strictly "real-time".

The calculation of position assumes that the location of each Ground Station is accurately known. If Ground Station users have entered incorrect home location coordinates (or correct coordinates in the wrong format) into the Options..Home Location dialog, then the resulting calculations will be erroneous.

The requests for raw data history specify a time window. If the Ground Station user's PC clock is telling the wrong time, the wrong data will be forwarded and no match will be found with other users' data.

As noted earlier, if the Ground Stations providing raw data are not well distributed, then the curves may cross at more than one place. This is most likely to happen if the ground stations are generally in a line. If that happens, the derived position is ambiguous and PlanePlotter may choose the wrong location for the unknown. It is the responsibility of the user to assess the curves on the chart to determine whether or not to be confident of the least-squares fix that PlanePlotter derives for the wanted aircraft.

Because Mode-S messages transmitted by a position-less (non-ADS-B) aircraft do not contain position, they are often identical to each other. This means that it is possible for PlanePlotter to confuse different messages transmitted by the same aircraft at different times but with identical content. When this happens, a spurious curve might be displayed. If there are plenty of curves on the chart, the effect of this spurious curve will be small. If there are few curves, the resulting position could be wildly incorrect.

Computer security considerations

In order for the multilateration system to work, there must be an exchange of data between Ground Stations and Master Users. The data is sent directly, peer-to-peer, in a coded format, using UDP/IP.

Users operating the Ground Stations sending the raw data, need to know that the data encoded in each datagram is limited to the following: The user's home location (latitude and longitude) as entered in Options..Home location; the PC clock time of each received message; the aircraft hex code and the raw message data obtained from the receiver. It is important to understand that your location is not available to the users themselves, only coded within the program. If you do not wish your location to be distributed to other instances of PP in this way, you may prefer not to participate in the process. Note that deliberately entering a wrong location will prevent Mlat from working correctly for other users and would be considered an abuse of the system.

For the avoidance of doubt, completely unrelated to any Mlat functionality, PP users very approximate home location data is also available via <http://www.coaa.co.uk/sharerlocations.php> The data available is deliberately degraded (rounded to the nearest 1/25 degree in both latitude and longitude), which means that at temperate latitudes, the positional uncertainty for each user is somewhere within 12 square km area. If on the other hand, you want your precise location and any other details, to be available to all users, the Yahoo user group also includes a database to which users can optionally insert their own data with more or less precision. This database, and information derived from it, shows whatever data each user chooses to place into it but this is not related to, nor derived from, the Home location in PlanePlotter. If you do not put your details into the database, nothing will be shown there about your installation.

The Master User needs to know that the incoming UDP datagrams are analysed by PlanePlotter and are then discarded. Because of the limitations on UDP packet size, it is very unlikely that a malicious user could exploit any kind of buffer overflow vulnerability to insert malware into the PC via the received datagrams. PlanePlotter checks the size of the datagrams and the validity of the contents and discards any data that does not conform. The firewall should be program specific and so incoming data on port 9742 should only be possible as a valid destination when PlanePlotter is running and after the firewall has explicitly allowed it. It is the responsibility of each Master User to decide whether the above is acceptable or not.

Setting up your system to participate in multilateration

Note that it is only possible to participate in multilateration as a Ground Station if you are using a compatible receiver that is correctly configured to provide time-tagged raw data.

1. PC clock (Ground Stations)

It is important that a Ground Station's PC clock is accurate. You can set it against a precise time source or better still, download and install this utility. It will set and keep your computer clock exact without any further intervention.

<http://www.meinberg.de/english/sw/ntp.htm>

2. Home Location (Ground Stations)

It is important that a Ground Station user sets their correct home location in the 'PlanePlotter..Options..Home location' dialog.

If you are uncertain that the data you have entered is correct, and if you are connected to the Internet, click on the "Test" button in the PlanePlotter "Options..Home location" dialog. PlanePlotter will open a window showing Google-Maps centred on the coordinates that you have entered. If the marker on the map is not pointing at your location, you have not entered your location correctly. Try again or ask for help.

If you change the Home location when you are an active Ground Station, you will receive a warning by email. Please respond to the warning by confirming that you have checked the new location and that it is correct.

3.1 (Ground Stations) - Kinetic SBS1 - BaseStation version 160 and later

BaseStation version 160 and later incorporates a raw data TCP port specifically for Multilateration.

In PlanePlotter, select Options..I/O settings and check the "Mode-S...SBS/ANRB TCP" option and the "Raw data for Mlats" option. No other changes are required.

If you do not have version 160 or later of BaseStation then download the latest version from the Kinetic web site.

3.3 (Ground Stations) - Other receivers

Open PlanePlotter and in Options..I/O settings, make sure that you have checked the correct receiver and, below the list, check the 'Raw data' option.

Now start PlanePlotter processing by clicking on the green start button. Check that it is working normally and that the fourth numeric field in the box alongside the date-time display in the PlanePlotter status bar, is counting round 0-9.

4. Firewall and Router changes (Ground Stations and Master Users)

Because firewalls and routers are all different, it is only possible to give general advice. You should be able to study the section relating to Ground Stations in the "Data flow" paragraph above, together with the user manual for your specific firewall and router (if you have one) and then be able to make any necessary changes. In many cases, especially if you have a direct Internet connection, you may not need to do anything apart from answer some questions from your firewall when the time comes to share some data.

If your computer is on a LAN and you have a router to control the network then you will need to tell the router where to send the incoming data. The objective of this step is to ensure that when a UDP packet destined for UDP port 9742 arrives at your network, the router will recognise it and will send it to the correct machine on your LAN (ie. the one running PlanePlotter). First you need to know the LAN IP address of the computer running PlanePlotter. Select Help..Test networking..Check own LAN Address. A window will open and, among other information, you will see the local (LAN) IP address of the machine that you are using. Often it will be something like "192.168.1.105". Note that it is not the address shown as "Default gateway". Make a note of your LAN IP address. Now open the control panel of your router. Your router manual will tell you how to do this - it will give you the username and password to log in. Find the section on Network Address Translation (NAT) and look for "Virtual Servers" or

"Port forwarding". In the Virtual server/Port forwarding setup, create a new entry. Formats differ but there should be a space for the LAN address (the local IP address you just noted); the protocol (set it to "UDP" - not to "TCP"); the port on the LAN (set it to 9742); the external port on the WAN (also set to 9742). Sometimes there is a provision for a range of port addresses, in which case put 9742 in all the port boxes. Do not enable trigger port operation if it is offered. There may be an enable checkbox and an "Apply" button. Follow the instructions in the user manual for your router to achieve the desired result.

If you find that you are not sending data when it was expected, you may need to look for those key words "DoS detection" and "incomplete TCP/UDP sessions" and to adjust the values that you find to a few hundred rather than a few tens.

If you find the technical level of the preceding paragraph, too daunting, you could try visiting this web site:

<http://portforward.com/>

It explains the terms and describes the processes as well as having a huge collection of details which are specific to each router manufacturer and model. It is almost certain that you will find there, the correct procedure for your make and model of router.

If you have a router that is UPnP capable, and if UPnP is enabled, the above steps may be accomplished for you automatically by executing the batch file "upnpmaster.bat" that you will find in the application directory where PlanePlotter is installed. The batch file runs the utility UPnPPW.exe available from

<http://www.upnpworks.alcidelic.com>

and tries to effect the required changes. The process takes a few seconds so be patient. Because not all routers are UPnP enabled, and because some security systems will prevent applications from manipulating the UPnP interface, this simplified procedure may not work.

. Testing your system.

You can check to see if the changes that you have made are working, by selecting Help..Test networking..Check GS/MU functions. This will open a browser page and initiate a test of your system as a potential Ground Station and Master User. The results of the test should be self explanatory. Once you have successfully accomplished the test, you can ask to be enabled as a Ground Station/Master User. A brief request posted on the PlanePlotter user group will complete the process. Remember to give your share code so that your installation can be identified. After additional verification, your Ground Station/Master User status will be confirmed.

. Mlat operation (Master Users)

Once you have verified that you have Master User status, you can initiate a multilateration request for an aircraft with unknown position.

You will generally only see position-less aircraft in the View..Aircraft display if you select "Download position-less" in Options..Sharing..Setup.

In PlanePlotter, select View..Aircraft. Depending on your display options, it may help to sort the aircraft by latitude so that the position-less aircraft are at the top of the list. If your current chart area covers a region where there are plenty of Mlat Ground Stations (eg UK), then you will see a number of aircraft highlighted in orange or green. (Note : These colours are user defined and so may be different). Choose one of these that has a relatively high altitude and, while holding down the Control key, left click on the aircraft. You should see a pop up window indicating that the process has started. If not, check the title bar, there may be a reason why the progress could not start. After a short delay, the window will show a count down of ten seconds and the chosen aircraft will now be highlighted in red. If you see a warning alert, it may be that you are not enabled to do multilateration requests. Otherwise, all being well, you will start to see a number of reports coming in from other users who are able to provide raw data for your chosen aircraft. At the end of the countdown, PlanePlotter will analyse the data that has come in and try to determine the position of the unknown. You will see a report describing the success or otherwise in the pop up window. If there was enough information to determine the position of the chosen aircraft, the display will switch to the chart/outline view with the chosen aircraft in the centre.

A second cycle of multilateration will start automatically and if successful, PlanePlotter will use the two positions to determine a course and speed for the chosen aircraft.

PlanePlotter will then automatically repeat the multilateration process every thirty seconds until you press Escape, change the designated aircraft or the multilateration process fails. In this way, you can continue to monitor the progress of the designated aircraft without further intervention.

You can interrupt the multilateration process by pressing the Escape key when PlanePlotter has the focus. It will take a few seconds to wind up the multilateration process.