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# MagComp<sup>TM</sup>

Magnetometer Compensation Software  
0024910-01 Rev.C

*User's Guide*

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## 1 Introduction

Congratulations on your purchase of Geometrics MagComp™ airborne, multi-sensor motion compensation software. This feature rich program with easy to use graphical user interface is designed to provide you with powerful and well-proven compensation algorithms that improve the quality of high sensitivity magnetometer data. This is accomplished by removing much of the “noise” associated with motion-induced signatures generated by the vehicle transporting the sensor. Improvement ratios of 30:1 or more are not uncommon.

MagComp™ is the result of the combined efforts of Geometrics and Pearson, DeRidder and Johnson (PRJ) who teamed in the redevelopment and testing of a compensation system designed by Geometrics in the 1980’s. New capabilities and features have been added (such as immediate plotting of compensation results and power spectrum plotting to improve filter selection) to assist the user in fine tuning the compensation for his or her specific survey. And the system is fast, allowing compensation of an entire day’s survey in a matter of minutes.

Compensation coefficient computation using calibration flight data is included. This provides the user with the ability to quickly generate, iterate and evaluate the quality of the compensation solution. In addition, filters may be applied to any recorded data (fluxgate magnetometer inputs, multi-sensor magnetometer arrays, gyro compass, etc.) to minimize other noise sources. This results in compensation improvement ratios unmatched by any other hardware or software products commercially available today.

The compensation solution need no longer be implemented via a heavy and space wasting on-board dedicated computer system. Now the compensation can be applied, adjustments made and reapplied in the comfort of the data processing lab. And multiple sensors and multiple aircraft or other vehicular platforms may be sequentially compensated on one workstation using one copy of the software.

We invite your comments or questions as you employ MagComp™ software to your aircraft or other vehicle compensation needs. Please contact us at [support@mail.geometrics.com](mailto:support@mail.geometrics.com) for support.

## 2 Theory and Process Overview

### 2.1 General Background

When magnetic measurements are made using an instrument mounted on or near the platform (such as an aircraft), the magnetometer senses not only the magnetic field of the earth, but also distortions caused by the survey platform. Generally speaking, the platform magnetic field is of no interest and represents a significant noise source. Because the platform magnetic field depends primarily on the attitude of the vehicle

relative to the earth's magnetic field, the effects of the platform are often called "heading errors", although specialists sometimes reserve this term for effects intrinsic to the sensor itself.

Heading errors are extremely important in geophysical surveys because they are long-wavelength, and thus overlap strongly with the geological signal. As we have already remarked and will explain later in some detail, heading errors depend almost entirely upon the attitude of the aircraft (or other platform) in the earth's field and therefore are constant to a first approximation along a survey line. In the past, this led to the use of mechanical leveling schemes to reduce heading error. Unfortunately such schemes cannot accurately account for variations in the aircraft attitude along-line. Thus, a more deterministic method for correcting heading errors is required.

The need for corrections is even greater for gradiometers (multi-sensor arrays) than for total field instruments (single magnetometer installations). Because the sensor separation achievable in reasonable light-plane installations is quite small, the difference signal is also correspondingly small and the raw gradient measurements are often dominated by heading and motion generated errors. Unless a really accurate correction algorithm is used, such measurements are virtually worthless.

The process of reducing heading errors is known as "compensation"; over the years beginning in World War II a number of compensation processes have been developed. We will survey them very briefly, mainly to set the historical perspective for the development of the MagComp<sup>TM</sup> software.

A technique used widely in geophysical surveys because of its low cost is "passive compensation". In this method, permanent magnets or current-carrying coils and strips of high-permeability material such as mu metal are used to cancel the aircraft magnetic field. This method is limited in accuracy because of the difficulty in measuring the effects and their cancellation, and in practice is also limited to a few components of the aircraft field. We shall not consider it further.

A related approach, used only in military applications, is to apply dynamically changing electromagnetic fields to the sensor to achieve the compensation. Because this method is not available to the civilian sector, we shall also not consider it further.

The use of a mathematically computed correction for compensation has gained wide acceptance in the geophysical community over the past fifteen years. This technique, made possible by the availability of high-speed data processing, predicts the numerical correction to be made to the magnetic field reading from measurements made using a three-axis fluxgate magnetometer system strapped down to the aircraft. The method then applies a digital correction to the raw total field magnetometer data. Popular systems for computing the correction in real time are in widespread use.

MagComp<sup>TM</sup> combines the accuracy of the digital technique with the convenience, low cost and power reduction of off-line processing. The data from the three-axis fluxgate

system is simply recorded in the data acquisition software so that the compensation correction can be calculated as part of the data processing. Not only does this represent a considerable savings in cost and on-board computing requirements, it allows the correction to be adjusted if necessary after the fact. The perceived limitation is the lack of real-time compensated data, which is not normally required for geophysical survey work.

## **2.2 Components of the Aircraft Magnetic Field**

To understand the compensation process, it is necessary to have an understanding of the major components of the aircraft's magnetic field. The model discussed here was developed during World War II and has been in use ever since; experience has shown that, with some modifications, it is applicable to most installations.

### **2.2.1 Permanent Fields**

So-called "permanent fields" actually arise from two sources: the permanently magnetized material in the aircraft, and the effects of current-carrying conductors, usually the major electrical feeds in the aircraft. As far as a magnetometer is concerned, these are indistinguishable. The permanent fields can be quite large, often several tens of nT and sometimes much higher. At first, it would seem that such fields should be harmless, since they are fixed in the aircraft's reference frame; *but total field magnetometers measure the component of the disturbance along the earth's field direction, and this changes with aircraft heading*. There are three components of the permanent field, corresponding to the three principal aircraft axes.

### **2.2.2 Induced Fields**

The induced fields arise because of the interaction between the earth's magnetic field and the magnetically permeable material in the aircraft. Because aircraft are mostly tubular in shape, only a few components of the induced fields are generally important for any given sensor location; but these can be quite large, up to several tens of nT. The induced fields are proportional to the earth's field intensity, and for each component of the earth's field in the aircraft reference frame there are three components of the response. Thus, the induced fields form a second-rank tensor. Less obviously, this tensor is symmetric and trace-free so there are only five independent components.

### 2.2.3 Eddy Current Fields

Metallic surfaces of the aircraft act as conductive loops. When the aircraft orientation in the earth's magnetic field changes, so does the magnetic flux contained by these loops, and a secondary magnetic field is generated according to Lenz's Law. Unless the magnetometer is very close to a large conductive surface, these eddy current effects are generally at most a few tenths of a nT under normal survey conditions, but there can be large effects in some installations. The eddy current fields are proportional to the earth's field strength, and for each component of the rate of change of the earth's field there is a component of the response. Hence, the eddy current fields form a second-rank tensor like the induced fields. Also like the induced fields, this tensor is trace-free, but unlike the induced fields the tensor is not generally symmetric, so there are eight independent components.

Counting the total for all three types of aircraft fields, we see that there are 16 components in all. In practice, we also fit an overall constant term and a term for the vertical gradient of the earth's field to the data, forming an 18-parameter mathematical model.

## 2.3 *The Compensation Flight*

In order to evaluate the components of the aircraft magnetic field as just described, it is necessary to acquire data in which these effects are enhanced and the interference of other sources, such as geology, is minimized. For this purpose, a compensation flight is performed.

The compensation flight is carried out at as high an altitude as is feasible, normally 10,000 feet (roughly 3,000 meters). This altitude is high enough to gain sufficient separation from at least near-surface magnetic sources, but low enough that oxygen is not required. First, a reconnaissance should be performed using the magnetometer to find a location in which the horizontal gradients of the field are small. This will normally be near a maximum, minimum or saddle point in the broader field. Visual inspection of the data trace is normally good enough to locate such a spot, but it is important to check that it has a low spatial gradient along two perpendicular directions.

Next, a survey pattern is laid out in the aircraft navigation system centered on this location. Two patterns are in common use: the traditional "cloverleaf", in which the aircraft crosses the chosen point along each of the four cardinal directions, turning sharply 90 degrees between each pass; and the box, in which the aircraft simply executes the four sides of a square surrounding the compensation point, turning sharply at the end of each leg. Either pattern will produce satisfactory results, and in either case each leg of the pattern will need to be a couple of miles (roughly 3 km) in length.

Along each leg of the pattern, it is desirable to acquire roughly 30 seconds of data while performing each of: yaws of at least 5 degree amplitude, pitches of at least 5 degree amplitude, and rolls of at least 10 degree amplitude. In some aircraft, uncoordinated yaws

are difficult to perform; this is not a critical problem long as the maneuvers have sufficient amplitude. In addition, the data from the turns at the ends of the legs should be recorded. In fact, it is generally desirable to treat the entire compensation flight, which is actually quite short, as a single survey line.

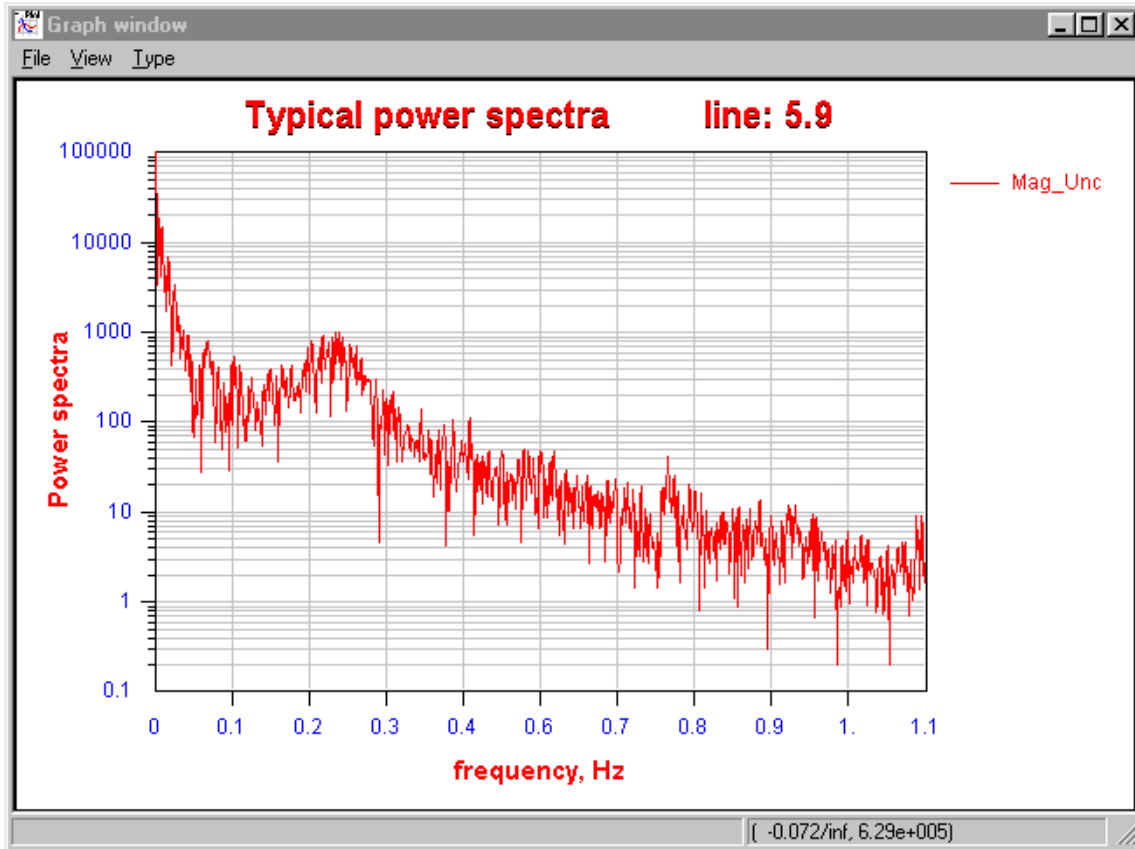
All data to be included in the compensation, including the total field sensors, the data from the three-axis fluxgate system, the altitude (barometric or GPS), and any available auxiliary information such as heading, pitch and roll, should be recorded just as they would be along any production line. The data are then used to compute the compensation coefficients as described in the Section "Calculating Coefficients Using a Compensation Flight".

#### ***2.4 Interference from Geologic Sources and Setting the Filter***

The most serious difficulty in obtaining good compensation results is usually maintaining isolation of the aircraft effects from those due to geologic signal. As most light aircraft maneuvers have a natural period of 3-5 seconds, if the compensation flight were flown at low altitude the geologic signal would overlap the maneuver signal completely. Thus, it is important that the compensation flight be performed at as high an altitude as practical, as described previously. However, because the geologic signal is broadband and rises roughly exponentially at low frequencies, there will always be a low frequency below which the geologic signal dominates. Thus, it is necessary to high-pass filter the compensation flight data to obtain useful results.

The high-pass filter can generally be selected with some degree of confidence from the total-field spectrum of the compensation flight. Because of the very low frequencies under consideration, it is usually necessary to select only the low-frequency part of the spectrum (below 1 Hz, say) for display.





Typical power spectra for recorded magnetic field.

Performing a power spectral analysis of the compensation flight data shows a broad peak centered on approximately 0.25 Hz, corresponding to the maneuver signal, a slight notch below this at approximately 0.1 Hz, and a linearly rising feature (on a logarithmic scale, corresponding to an exponential in linear scale) below that down to DC. The strategy in choosing the filter is to begin the filter roll at the notch and to allow for a transition band of about half the distance to DC in order to avoid ripple artifacts in the filtered data. This gives a filter that in this case begins to roll off at 10 seconds and is zero at 20. It turns out, because most light aircraft have similar maneuver frequency characteristics, that the optimal filter is usually fairly similar to this. However, it is important to go through the design process for every compensation flight because the high-pass filter is the most crucial ingredient in obtaining a good compensation.

## 3 Data Requirements

### 3.1 Data Formats

MagComp<sup>TM</sup> software uses the following input file formats:

1. A column-oriented space separated ASCII file with a header. This format closely resembles the Golden Software SURFER<sup>TM</sup> \*.dat file format. Each column in the file corresponds to one data variable such as total magnetic field, fluxgate reading, altimeter reading, etc. There are no limitations to the number of columns and the file can include fields not used in MagComp<sup>TM</sup> processing. These unused fields are copied to the output file without alteration. The input file should have a simple ASCII header with column names separated by space(s) or tabs. One of the file columns should correspond to the line number (flight line or track number). This column has “Line” (case is irrelevant) as the header that enables MagComp<sup>TM</sup> software to automatically recognize it. Any character strings can be used as line numbers, with the total length of the string not to exceed 8 characters.
2. GeoSoft<sup>TM</sup> XYZ export format. This format is very similar to the Golden Software SURFER<sup>TM</sup> with the following differences:
  - The header string starts with the symbol “/”. This is needed for GeoSoft and preserved by MagComp<sup>TM</sup>. Please note that only one such string is allowed in the file (some GeoSoft<sup>TM</sup> versions can output an arbitrary number of header strings; see the GeoSoft<sup>TM</sup> manual for details.)
  - Line numbers occupy separate strings and start with the keyword “Line” followed by a space and the line number. The keyword “Line” is used by MagComp<sup>TM</sup> to recognize records with line numbers. Other string names should not be used in place of “Line” as the program will not recognize the line numbers. Each line number is a string of up to 8 characters in length.

After the data processing is completed, the program creates an output file with the same structure as the input file (SURFER<sup>TM</sup> or GeoSoft<sup>TM</sup>). Calculated variables are added to the output file and the header is modified to reflect these new columns.

### 3.2 Data Content

The following variables are required in the input file:

1. One or more total field magnetometers. The magnetometer(s) can be mounted at different locations, and up to 8 magnetometers can be processed simultaneously.

2. Three-component fluxgate magnetometer data. Only one three-component fluxgate magnetometer is allowed per compensation run. All three components should be recorded in the same units; however the units can be arbitrary (nT, gauss, mV, etc).
3. Barometric or GPS altimeter readings. These values can be presented in meters or feet. MagComp™ can scale them to the appropriate values.

The following input file variables are optional:

4. Heading, pitch and roll sensor data. These sensors are optional and can improve compensation results, however their presence is not required for a successful MagComp™ compensation solution.

Values in every line of the data file should be measured at or interpolated to the same time. If the hardware and acquisition software used during the survey do not allow simultaneous measurement of values, then all data should be interpolated to magnetometer reading time. This would normally include fluxgate and altimeter readings. Interpolation of the data sets can be accomplished post survey using the Geometrics MagMap2000 GPS Interpolation Wizard, free from Geometrics and available on our website (please see the MagMap2000 manual available in the program as a PDF file.)

Please note that MagComp™ does not require time information to be present in the file, only that the data to be interpolated to the magnetometer reading time. The program uses sample number (fiducial) instead of sample time. These fiducial numbers are assigned internally and are not saved in the output file.

For best results, a constant sample rate (i.e., 10 Hz) should be maintained throughout the file.

### ***3.3 Output File: All Lines At Once vs. Line-by-Line Processing.***

As was already mentioned, the output file contains all the information available in the input file plus the result of the compensation computation. The output file has the same format as the input file. However, the record number in the output file can differ from the record number in the input file. This record number difference may occur because there are two data loading options available: load data all-at-once or load data line-by-line.

For small to medium size surveys (with the total number of magnetometer readings around 100,000) there is no significant difference between these two load modes.

#### **3.3.1 Processing All Data at Once.**

In this mode all the records in the file are loaded regardless of which lines the user has selected for processing. The output file holds the same number of records as the input file. For non-selected lines, zeroes will replace the newly computed fields. This mode has

a speed advantage because the data are loaded only once. However, the amount of data that can be processed is limited by the amount of available computer memory. With new fast computers and low memory prices, this will not be a serious limitation for most surveys.

The user selected line data is saved upon completion of the compensation calculation.

### 3.3.2 Processing Data Line-by-Line.

Because many production airborne and marine surveys contain huge amounts of data, it may be impossible to load all the data at once into computer memory. Therefore MagComp™ provides the ability to work with one line of data at a time. In this mode the input and output files may have a different number of records, because the user may choose not to process all available lines. The data is saved as soon as the selected line processing is complete, and lines appear in the output file in the order in which they were selected, not in the order they exist in the input file.

## 4 General Operation

### 4.1 Program Modes

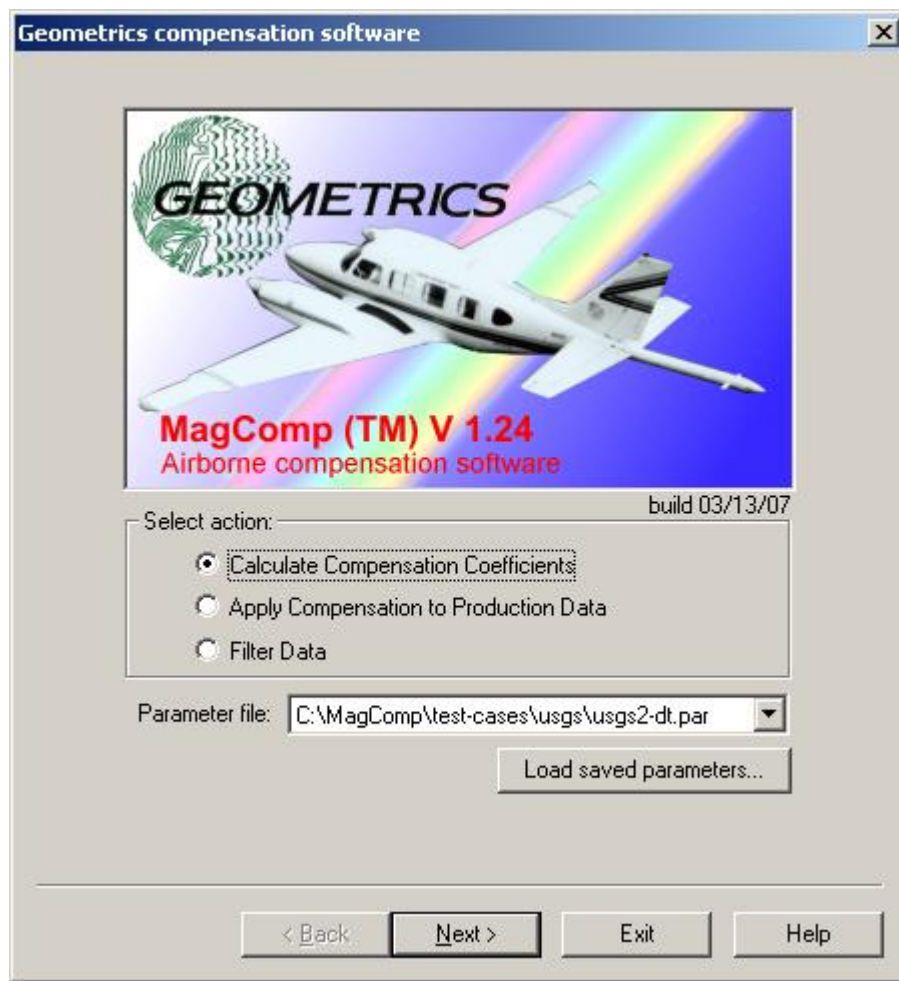
MagComp™ setup is achieved using a Wizard-style Windows application with the ability to display input or output data via graphical representation at any time. This ensures proper specification of the compensation parameters and an easy to use interface. From the welcome screen there are three separate processing branches available:

1. The Compensation Flight branch computes compensation coefficients using data collected during the compensation flight. The coefficients are saved into files used for correction of the production survey lines, and the improvement ratio (IR) is calculated during the compensation process. The user can compare compensated and uncompensated data from the compensation flight to see the effects of the platform motion removal. Compensation flight processing works only in the all-data-at-once mode because all of the data must be used for computing coefficients regardless of how many lines were included in the compensation flight.
2. The Production branch uses the compensation coefficients generated in the first step to remove platform motion noise from the production survey lines. This can be performed in the “all-at-once” or “line-by-line” mode.
3. The Filtering branch. This is an optional facility, which allows application of low-high-, or bandpass filters to any data. Because total field compensation and fluxgate time derivative calculations involve a data filtering process, it is useful to have this filter available to allow the user to compare the results of different filter regimes on the final compensation result. This optional iterative processing step is included for

those scientists who wish to evolve a more comprehensive result. Filtering can be performed in the “all-lines-at-once” or “line-by-line” mode.

All program parameters can be saved into a parameter file that can then be loaded on the next program initialization. MagComp™ maintains a history of the parameter files so the user can select from number of previously saved parameter files. A “Save” button is available on the last of the Wizard screens.

All program controls (buttons, drop lists, etc.) contain helpful “tool tips” associated with them. When the user moves the mouse over the menu item and pauses for a moment, a help text balloon window appears on the screen to explain the function of the menu item.



MagComp™ Start Screen

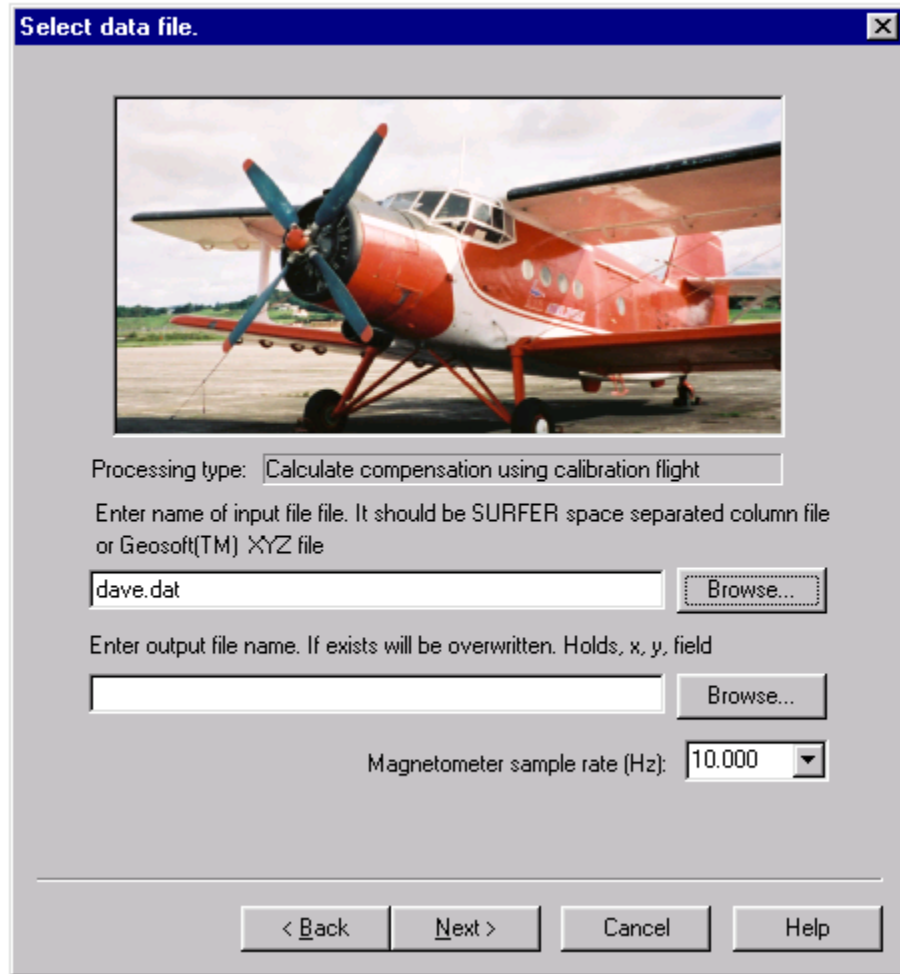
## **4.2 Loading Data Files**

After determining what type of processing to perform, the user can make his or her selection or load a previously generated Parameter File and presses “Next”. The next screen provides selection of the input file name. The input file format must be in either SURFER™ or GeoSoft™ type formats. The program can automatically distinguish between these two format types, creating an output file of the same type. The user can press the “Browse...” button to select the file interactively.

The output file name may be left blank at this time. The program will automatically create a new file name by adding suffixes such as “.new.dat” for a SURFER™ input file or “.new.xyz” for a GeoSoft™ input file. Please note that if the user runs multiple calculations (i.e., changes the compensation parameters and runs the compensation routine several times) the output file will be overwritten each time unless the output file name is changed.

A “Processing type:” menu box at the top of the window indicates which processing branch is selected.

The user should specify the sample rate at which the data was collected. This constant is used throughout the program to present spectral parameters in seconds, rather than in samples.



MagComp<sup>TM</sup> input and output file selection screen

Pressing the “Next” button causes the program to read and index the selected input file. This can take some time depending upon the size of the file and the capabilities of the hard disk and CPU. A progress indicator appears on the screen.

After loading the file, MagComp<sup>TM</sup> indexes the data so that the user may select data field columns (by header) and lines. The program also is ready to graphical plot all or selected data fields and lines upon the user’s request.

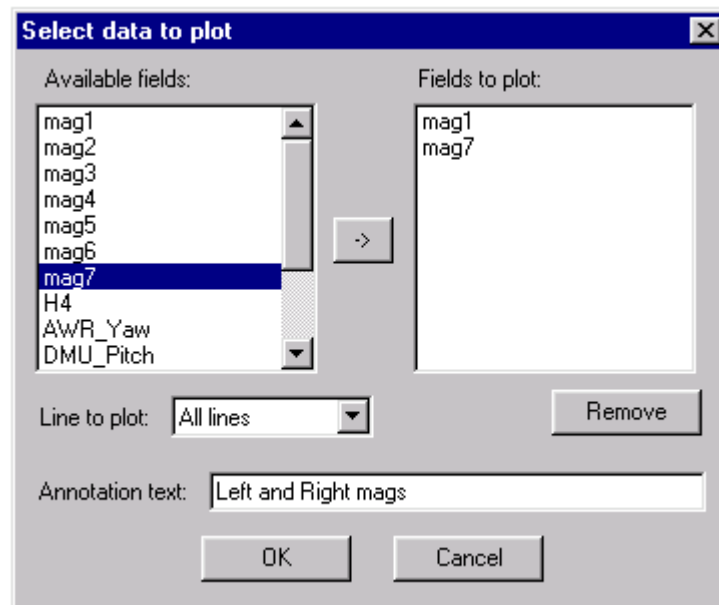
Pressing the “Back” button at this point may cause re-reading of the data file if the name or content has been changed.

### **4.3 Graphical Display Plots**

While MagComp<sup>TM</sup> was not designed as a general graphical display visualization tool, its facilities are sufficient to help the user make proper decisions about compensation parameters. Typically the user may need to see different data fields as line graphs with

time used on the horizontal axis. He or she may also find the plot of the power spectrum a useful accessory, especially when determining the type of filters that should be used to improve results. MagComp™ provides an unlimited number of graphical display windows. As soon as a visualization window is launched, it becomes independent from the main program dialog box. Each window can display a line graph or time-series spectral plot of the data line. At the same time the user can continue with the main program execution, keeping the data display windows on the screen for reference. However information in the display windows is not updated when new computations are performed. To see the effects of the computation, a new display window is required.

Many MagComp™ screens have a button labeled “Plot data” which when selected launches the display visualization window. After this button is pressed, the following dialog appears on the screen:



MagComp™ data plot selection dialog

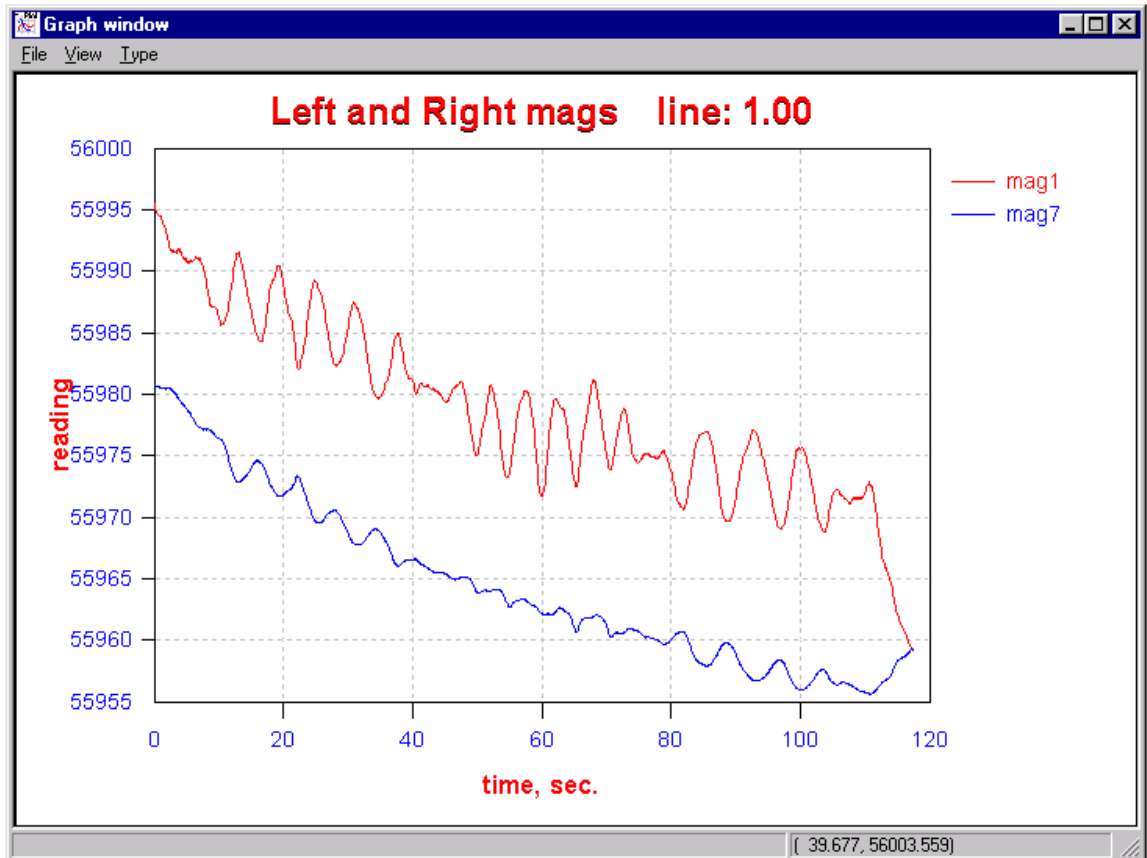
All the data fields available in the input data file are listed on the left side of the dialog box. The right side is initially blank and the user fills it in by selecting the data field of interest on the left side and clicking on the “->” button (or double clicking on the field name). Selecting fields in the right list and pressing the “Remove” button removes the fields from the plot list.

If “Line to plot” is set to “All lines”, then fiducial numbers (sample numbers) are assigned regardless of line number, and the entire contents of the file are plotted as one line. The X axis is annotated with time which is obtained by multiplying the fiducial numbers times the sample rate. An alternative would be to select a particular line of interest from the list and plot that line. In this case the X axis is labeled in seconds from the start of the line.

The “Annotation text” field is optional and allows adding text to the graph title box.



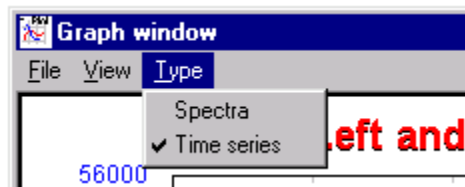
After the selections are completed and the “Ok” button is pressed the program copies selected data to memory and launches a visualization window as a separate processing thread.



Visualization window - Two data variables are plotted for one line

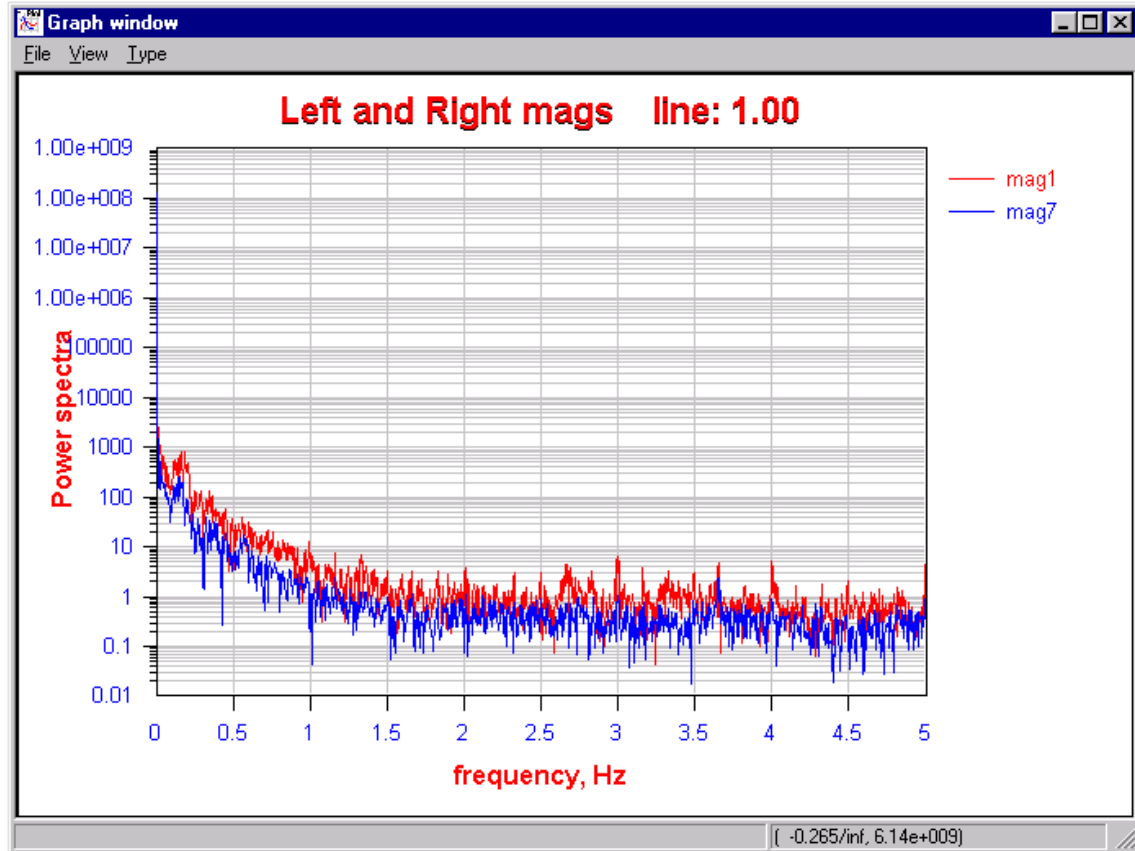
The numbers in the status bar (lower right) show the coordinates of the current mouse location in seconds and data units.

To view a spectral plot of the displayed data, the user selects “Type/Spectra” as shown in picture below:



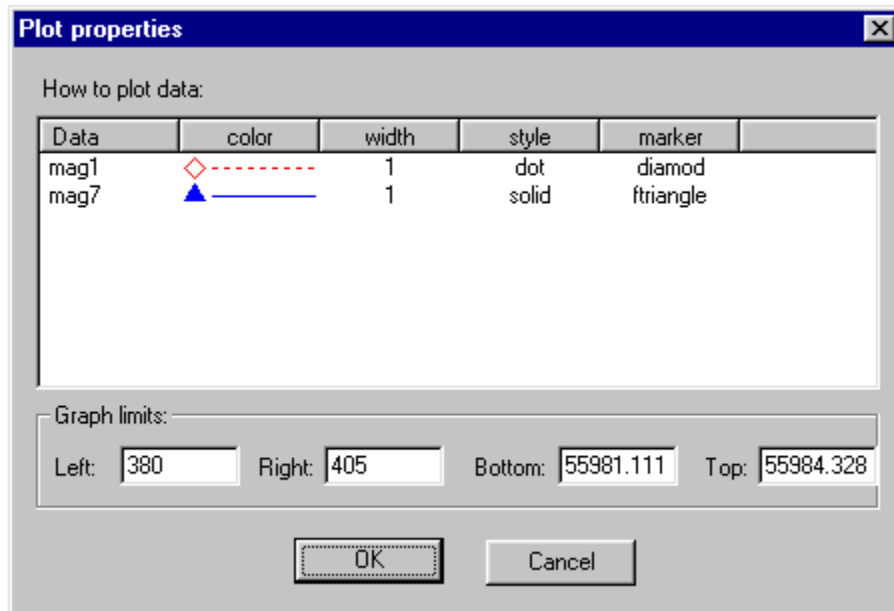
This changes the graphical presentation to the spectral mode. The mouse location information now becomes frequency in HZ (marked as “f”) and samples (marked as “samples”).

The user can zoom in on either the time series or spectral plot by depressing the left mouse button and dragging the cursor to generate a rectangle. When button is released, program plots data in the selected region. To restore the original limits, select menu and “View / Restore Limits”.



Spectral mode.

Appearance of the graph can be changed by selecting “View / Properties” menu:



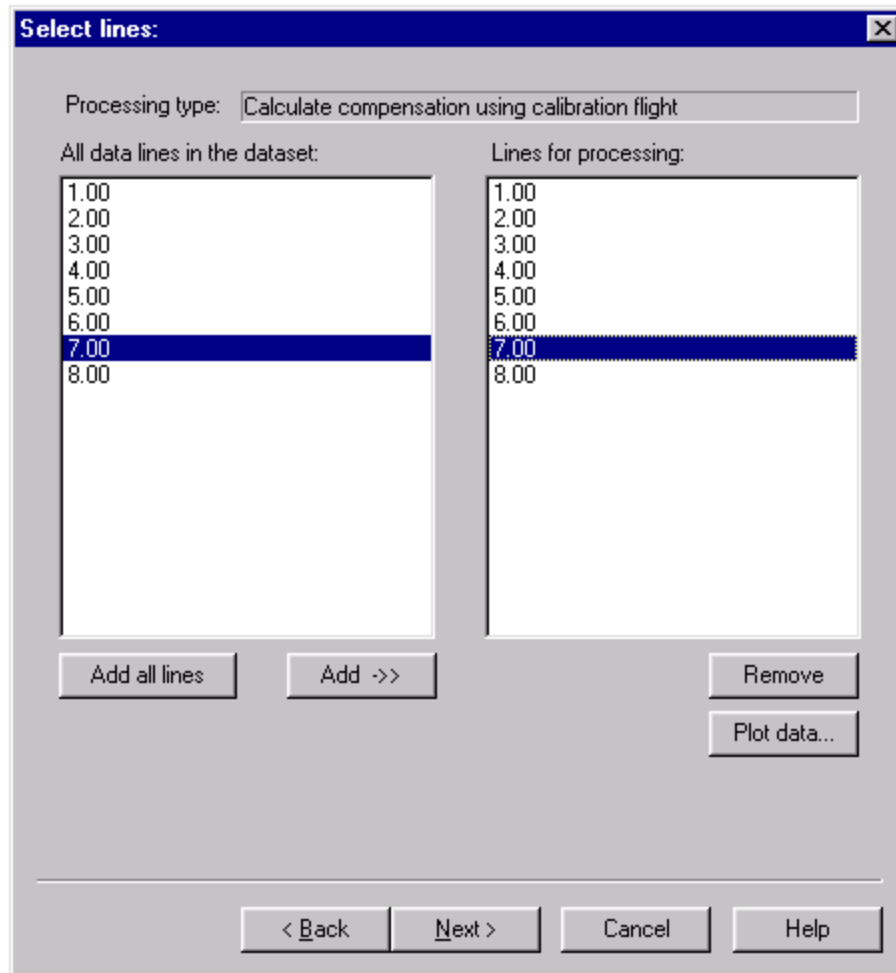
MagComp™ allows the user to change the graph appearance such as line color, marker styles, line widths and line styles in the Plot Properties dialog box. The data plot can be printed by going to File, Print Preview, Print.

## 5 Calculating Coefficients Using a Compensation Flight

After the user selects “Compensation Calculation Mode” and loads the calibration flight data, the following process is used to generate the compensation coefficients.

### 5.1 Selecting Lines for Compensation

The following Wizard Screen shows how the user may select lines to be used to compute the compensation coefficients:



Select lines.

Pressing “Add all lines” will select all available lines for use. Unless there are special concerns about the validity or quality of the data, the user should select all lines in the compensation flight. He or she can also select or deselect individual lines by using the “Add->>” and “Remove” buttons.

## 5.2 Calculating Fluxgate Time Derivatives

Pressing the “Next” button brings up the following screen:

Compute fluxgates derivatives dialog

To calculate Eddy Current effects, the program requires fluxgate time derivatives (rate of change of the platform orientation.) These derivatives are computed under the assumption that the data rate is constant for the entire data set.

The following fields must be present for the program to operate correctly:

X fluxgate - This is the fluxgate sensor parallel to TRANSVERSE axis of the aircraft.

Y fluxgate - This is fluxgate sensor parallel to LONGITUDINAL axis of the aircraft.

Z fluxgate - This is fluxgate sensor parallel to VERTICAL axis of the aircraft.

Correctly assigning these three fields informs the program where to find the fluxgate information in the data file.

“Keep results in the file” box. If this box is checked, the fluxgate derivatives are saved in the output file and thus are available for further analysis. If box is not checked, the

calculated fluxgate derivatives are considered to be temporary and are not saved in the output file. They are also not available for plotting.

Output prefix. Computed derivatives can be saved under user created names using selected prefix and fluxgate value names. For example, if the prefix is set to “d” and fluxgate name is “flux\_X”, then the derivative is saved under name “dflux\_X” Displays “d underscore” (prefix) in previous window but not here.

Low-pass filter. The derivative calculations tend to increase high-frequency noise in the data (differentiation can be considered a type of high-pass filtering). Therefore it is a good idea to apply a low-pass filter to decrease this high frequency noise. The program uses a simple low-pass filter defined by the cut off frequency (the point where the filter value starts decreasing) and zero frequency where filter value is equal to zero.

Low-pass zero wavelength – point where the filter value is equal to zero, in Hz.

Low-pass cut wavelength – point where the filter value starts to decrease, in Hz.

**Please be sure you understand the uses of these filter settings as incorrect usage can cause undesirable results in the final process – the filter values are defined in seconds.**

The user can use the spectral window to help make decisions about the proper filter parameters.

Set defaults button sets default values for low-pass zero and low-pass cut values. From the experience known that those are 1 and 2 seconds.

Cosine taper. To calculate derivatives and filter the data, the program uses a FFT (Fast Fourier Transform) that operates with  $2^n$  points. In order for the transform to operate correctly and not exhibit “edge effects” some amount of data must be added to each end of the line (termed cosine taper). The user can specify the amount of data (in % of the total line length) for extending the line to the  $2^n$  values. A 20% extension works well in most cases.

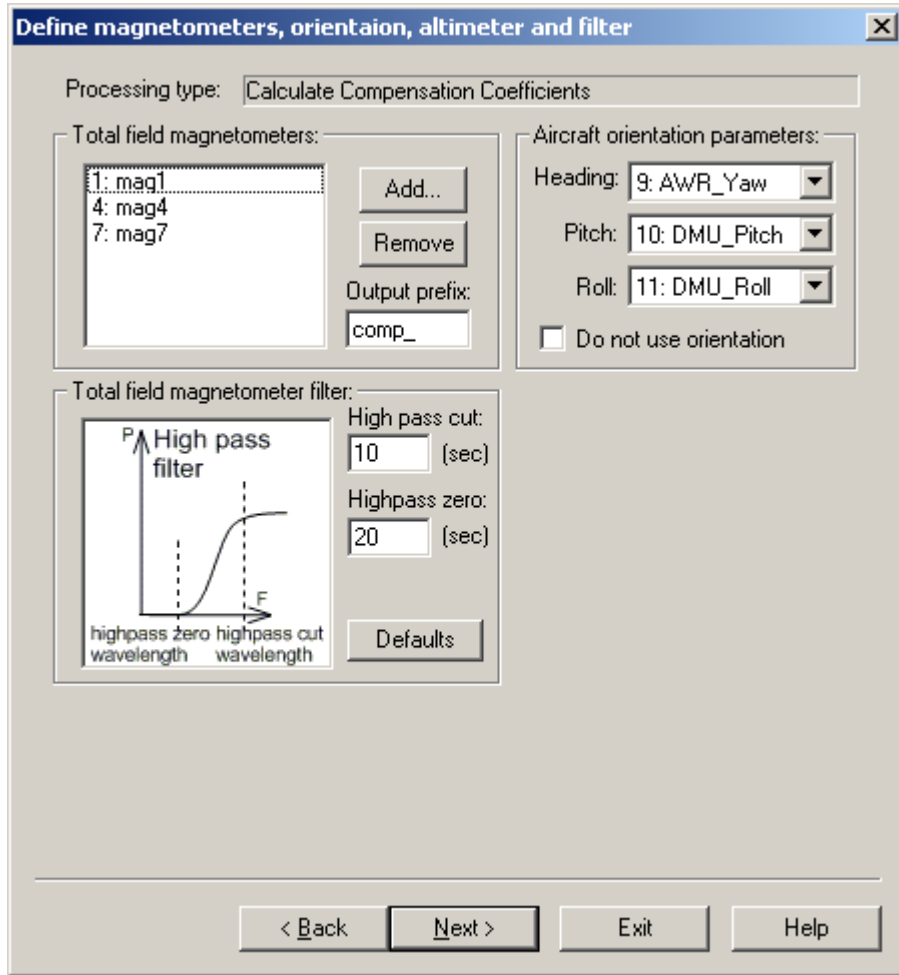
Compute derivatives now. During normal program operation the derivatives are computed only when required. However it is possible to inspect the derivatives before doing a full processing cycle. Press this button to calculate derivatives upon demand, and then press the “Plot data” button to display the computed data.

Plot data This will display the data. See [Graphical Display Plots](#)

### ***5.3 Selecting Data and Entering Compensation Parameters***

The following Wizard Screen allows the user to select data fields from the input file to be compensated and to enter other compensation parameters. These values are essential for

proper compensation and a poor choice can result in a small improvement ratio or no improvement at all.



Compensation Parameters

Total field magnetometers: Add and Remove buttons. First the user must decide which data fields to compensate. The program makes no assumption about which data fields represent total field sensor data. To select magnetometer data for compensation, press the “Add” button. A dialog box with available data fields appears on the screen. Select the fields to be compensated and close the selection dialog box. If you make a mistake, use the “Remove” button to remove data fields from the magnetometer list.

Output prefix The program will assign new names for compensated values using the prefix specified in this box. For instance, if total field magnetometer has name “mag” and prefix is set to “comp” then the result of compensation is saved as a data field column with name “compmag”.

Aircraft orientation parameters. If roll, pitch and heading data from a gyro are available in the calibration and production flights it is possible to use this information to improve compensation results. The program will attempt to locate these fields looking for words

“pitch”, “roll” and “heading” in the input data file. If these words are not found in the file header, the program leaves these fields blank. If they are present under other names the user should select the proper fields.

Do not use orientation. If the optional heading, pitch and roll sensors are not available, this box should be checked. If this box is checked, the position of the magnetometer sensor relative to the fluxgate sensor will not be taken into account and entering magnetometer offsets (sensor to GPS antenna) is disabled in the next screen.

Total field magnetometer filter. The compensation flight should be performed in an area with constant or nearly constant magnetic field, at a high altitude, low gradient area. This reduces the influence of the underlying geological structures. However there always remains some geologic signal in the data and the measured total field will have some low-frequency geologic component not related to the motion and orientation of the aircraft. These components should be filtered using the provided high-pass filter before the compensation coefficients are generated.

**Correct filter specification setting is crucial for good compensation results. Using the graphical data display window(s) in spectral mode will assist the user in determining the proper cut off frequency. Please note that filter parameters are in seconds.**

Good starting point is the cut at 10 seconds and the zero at 20 seconds. Then user should try a "reasonable" range of values until he or she gets the best IR. In practice, the shortest known filter was 7.5 and 15 seconds and the longest something 20 and 40. Even this narrow range can make a substantial difference. The "BACK" button in MagComp (see below) is extremely useful at this point.

Default button sets filter values to their default values, which are 10 and 20 seconds.

Please see “[Interference from Geologic Sources and Setting the Filter](#)” for additional details.

Barometric altimeter. The user may select the barometric altimeter data field. The scale factor can be used to convert altimeter reading to the same units as the magnetometer offsets (see next Wizard Screen). Typically the scale factor is equal to 1 if the GPS altitude is used, or equal to 0.3048 if the barometric altimeter is calibrated in feet. Starting with version 1.24 barometric altimeter usage is disabled by default. This simplifies data acquisition and only slightly affects compensation results. To enable usage of this variable, user should edit “magcomp.ini” file (typically found in C:\Windows folder) and set USE ALTIMETER=1.

#### **5.4 Defining gradients and offsets.**



If more than one total field magnetometer sensor is installed gradients can be calculated and independently compensated with the MagComp™ software. Generally the improvement ratio for gradients is better than for total field data, and the gradient compensation procedure does not require the application of the high pass filter.

Define gradients. Using N magnetometers, the user can define up to N-1 gradients using weighted data contributions for each sensor. The simplest case is defined as two total field sensors deployed on the wingtips, e.g., MAG<sub>1</sub> and MAG<sub>2</sub>. To define the transverse gradient as a difference calculation (MAG<sub>2</sub> - MAG<sub>1</sub>), the weighting factors would be (-1, 1). If there are 3 sensors deployed, then the longitudinal gradient can be calculated from two wingtip total field sensors and a tail stinger using the weights (+0.5, +0.5, -1.0).

The user enters coefficients by clicking on the table cells and using in-place editing.

The following Wizard Screen (upper section) allows the user to specify weighting factors for gradient calculations. This section would be disabled if there is only one total field sensor is available.

Define gradients and offsets

Processing type:

Define gradients:

gradient	mag1	mag4	mag7
grad	1.00000	0.00000	-1.00000

Compensated prefix:

Enter magnetometer(s) and gradient offsets:

sensor	X offset	Y offset	Z offset
comp_mag1	4.500	0.000	0.000
comp_mag4	0.000	0.000	0.000
comp_mag7	-4.500	0.000	0.000
comp_grad	0.000	0.000	0.000

< Back   Next >   Cancel   Help

Defining Gradients and Offsets for compensation

Add Gradient. Allows entering a new gradient name with the default weights (-1, 1). User must edit the table to change weights accordingly.

Remove Gradient Removes selected gradient from the table.

Enter Magnetometer(s) and Gradient Offset. If heading, pitch and roll sensors are available, the user can specify a sensor's offset relative to the aircraft's center of gravity. Units should be the same as scaled altimeter units (see [Selecting data to compensate and compensation parameters](#)). X-offset is the distance from the midline of the aircraft, positive starboard. Y-offset is the distance from the longitudinal center of mass of the aircraft, positive forward. Z-offset is distance from the horizontal center of mass of the aircraft, positive upward. As soon as a new gradient is defined, a new string is added to the table with initial (0, 0, 0) offsets.

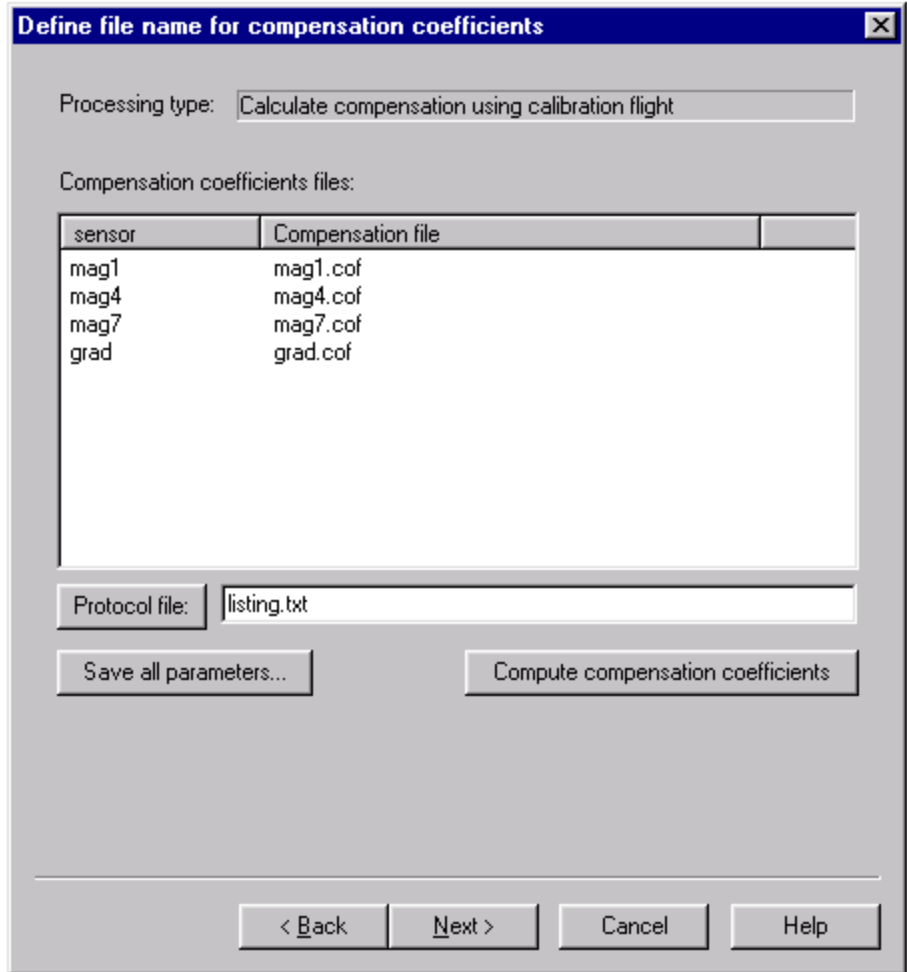
The user can enter offsets by clicking on the table's cells and using in-place editing.

If there are no orientation sensors available, all offsets are fixed at (0, 0, 0) and the user is not allowed to modify them.

Compensation prefix Newly defined gradients are saved in the output file under the names generated by the user. Their compensated counterparts are saved under the names created by using a prefix specified by the user. For example, if the user has created a raw gradient with the name "grad" and used prefix "comp" then the compensated gradient is saved under the name "compgrad".

## **5.5 Selecting Coefficient File Names and Running Compensation.**

Compensation coefficients files. MagComp<sup>TM</sup> indicates where the computed coefficients are saved. The program automatically assigns file names for the coefficients file for each variable selected for compensation (including gradients). These files will be needed for the production compensation run, and must be kept intact. The user can alter the file names by using in-place editing.



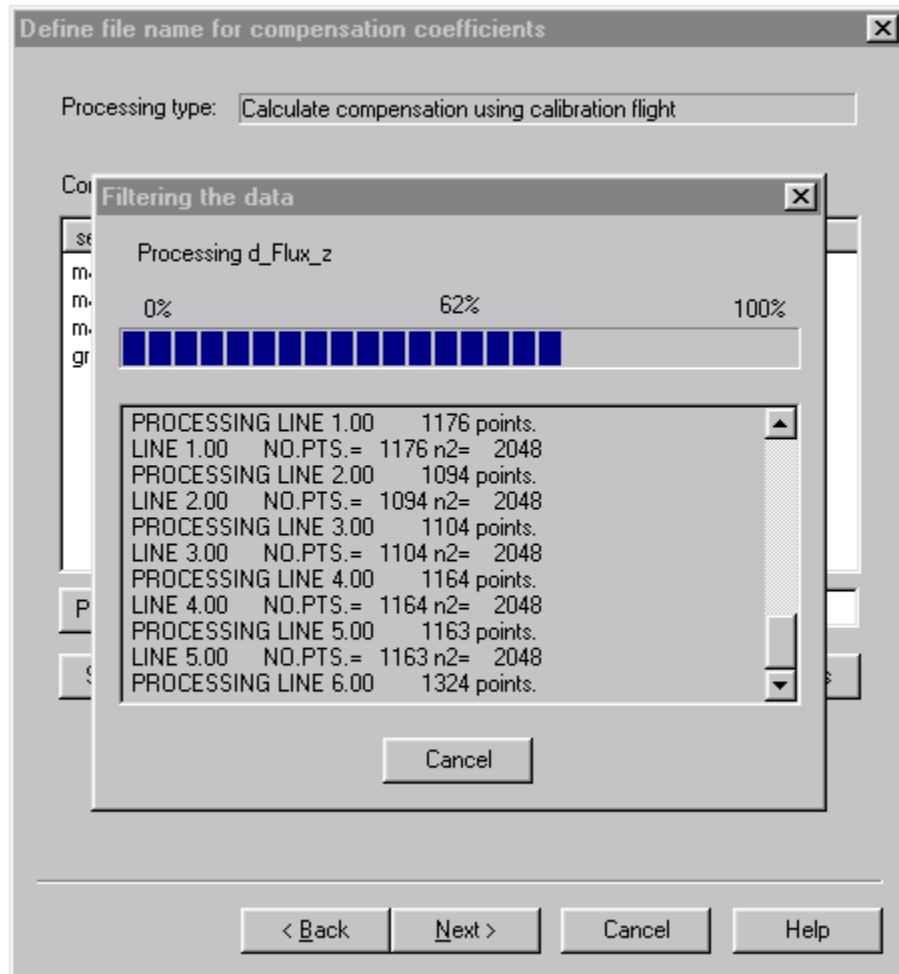
Inspecting Coefficients File Names before running compensation

Protocol file. This file contains general output from the compensation software. It can be useful in tracking potential problems. Typically this file contains a listing of all variable names, offsets, lines and number of samples used. It stores parameters of the numerical procedure as a sequence including numerical fit, standard deviation of the model terms and their approximate effect on compensation. Correlation matrices are also presented for each total field sensor or gradient being compensated. Finally, a full compensation coefficient set is recorded in this file.

Save all parameters All entered parameters can be saved in a single parameter file that can be loaded on the next MagComp™ run. It is highly recommended that the user save all parameters at this stage of the processing.

Compute compensation coefficients. This is the core of the compensation procedure. Pressing this button begins computation and automatically advances to the next wizard screen upon completion. Depending on the amount of data and CPU processor power, calculations can take various amounts of time, typically ranging between 30 seconds to 10 minutes. It is possible to cancel the computation but it may take some time for the program to react.

Please note that pressing the “Next” Wizard button advances the Wizard to the next screen without computing the compensation coefficients. Use “Compute compensation coefficients” to compute compensation and advance to the next screen.



MagComp™ calculates compensation coefficients

## 5.6 Inspecting Results – Improvement Ratio (IR) Screen

The following screen is displayed when computation is complete:

RMS and improvement ratio

Sensor	line	Original RMS	Compensated RMS	IR
mag1	1.00	2.050	0.099	20.72
mag4	1.00	2.507	0.114	22.00
mag7	1.00	0.581	0.135	4.29
grad	1.00	3.373	0.101	33.31
mag1	2.00	1.203	0.056	21.45
mag4	2.00	2.076	0.066	31.66
mag7	2.00	0.426	0.055	7.78
grad	2.00	2.086	0.094	22.17
mag1	3.00	1.220	0.103	11.83
mag4	3.00	2.333	0.174	13.43
mag7	3.00	0.584	0.094	6.19
grad	3.00	2.332	0.079	29.67
mag1	4.00	1.732	0.140	12.37
mag4	4.00	2.460	0.256	9.60
mag7	4.00	0.605	0.128	4.73
grad	4.00	3.189	0.098	32.52
mag1	5.00	1.831	0.315	5.82

Save table... Save All... Plot data...

< Back Finish Cancel Help

Improvement Ratio (IR) screen

After the coefficient computation is complete, MagComp<sup>TM</sup> calculates the improvement ratio for each data line using the following procedure:

- Each raw total field sensor is filtered with a high-pass filter as defined in [Selecting Data and Entering Compensation Parameters](#). Then the RMS value of the filtered data is calculated. For gradients, the RMS value is calculated without using the filter. This calculated value is presented in the column “Original RMS”
- This procedure is repeated for compensated fields and gradients. Results are presented in the column “Compensated RMS”
- The ratio of Original RMS to Compensated RMS is calculated and presented in the column IR (improvement ratio).

To save the results in a simple ASCII file, press the “Save table...” button. To save parameters used for compensation, press the “Save All..” button.

The user can visually check the results by pressing the “Plot data” button and simultaneously plotting compensated and uncompensated values for comparison. Clicking the buttons “Finish” or “Cancel” will close the application.

## **6 Applying compensation to the production data.**

The best method for performing production compensation runs is to save all program parameters for the compensation flight in the parameter file, reload it and then adjust selected values. We recommend the following procedure:

- On the initial screen, select “Apply Compensation to Production Data”.
- Enter the Input data file name on the second screen.
- Enter Lines for Processing on the third screen

The rest of the parameters should be reviewed and adjusted as necessary. Corrections might be needed if structure of the production file differs from structure of the compensation survey file.

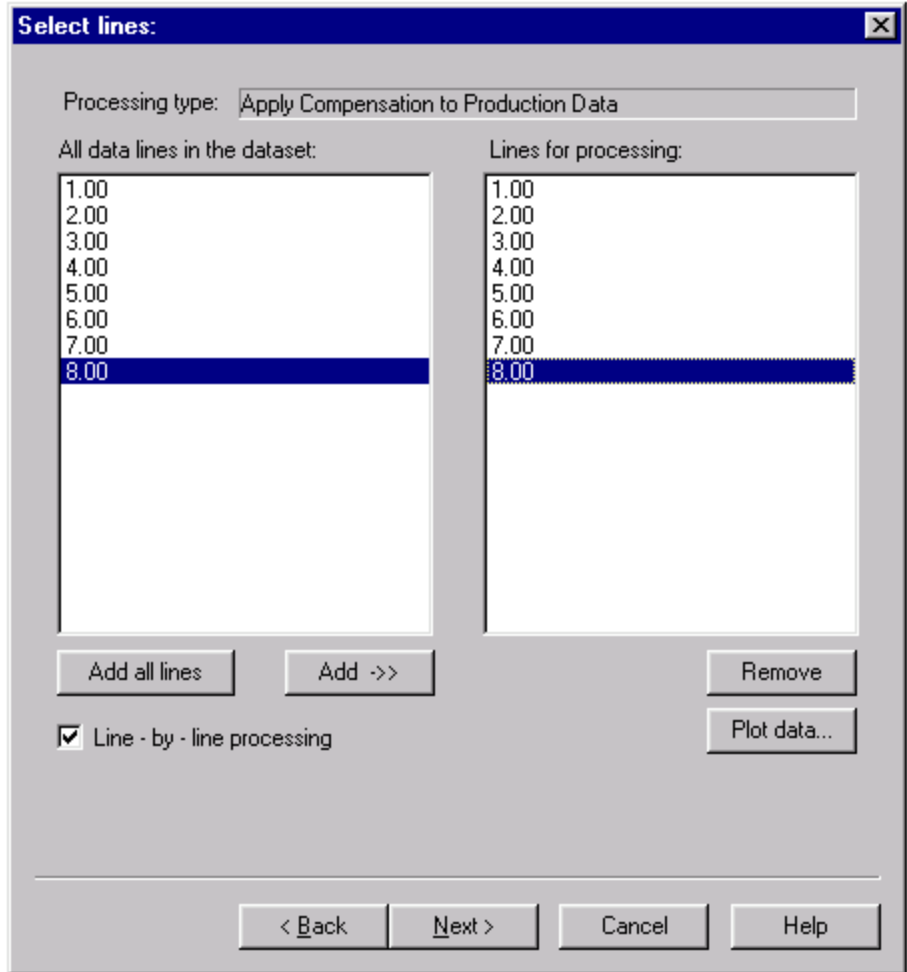
Compensation of Production data takes the user through a similar set of screens as reviewed in [Calculating compensation coefficients using compensation flight](#).

On the first screen, select the option “[Apply Compensation to Production Data](#)”. Then input and output files should be specified, and the program will load and index the input file.

If the field names used in a production survey differ from the names used during the compensation survey, special care should be taken regarding the coefficients file names. The user will need to adjust them to match those used during compensation survey flight.

### **6.1 Selecting Production Lines.**

After a data file is loaded, the user can specify the production lines to be compensated. This screen is almost identical to “[Selecting lines for compensation](#)” dialog box except that there is an optional line-by-line processing check box available. If checked, MagComp™ will load only one line at a time and only those selected lines will be saved into output file (see [Processing all data at once](#) and [Processing data line by line](#) for details).



Select production lines. Line-by-line processing is available.

## 6.2 Computing Fluxgate Derivatives for Production Lines.

The same screen as for [“Calculating Fluxgate Time Derivatives”](#) of the compensation branch is employed for computing fluxgate derivatives in the production branch. Note that the actual parameters might differ here from those used for computing compensation coefficients, based on the quality of the production data.

It is recommended that the same parameters be used for compensation flight as for the production flight unless there are special considerations regarding the production lines, such as higher noise levels etc.

### 6.3 *Selecting Data and Entering Compensation Parameters for Production Data.*

In the following dialog, the user specifies the total fields to be compensated and specific parameters to be used.

Define magnetometers, orientation and altimeter.

Processing type:

Total field magnetometers:

- 1: mag1
- 4: mag4
- 7: mag7

Add...  
Remove

Output prefix:

Aircraft orientation parameters:

Heading:

Pitch:

Roll:

Do not use orientation

Barometric altimeter:  Scale:

< Back   Next >   Cancel   Help

Defining compensation parameters for production data

In production survey processing there is no need to high pass filter the total field data and therefore the filter parameters are omitted.



## 6.4 Defining Gradients and Offsets for Production Data.

The “[Defining gradients and offsets](#)” screen is exactly the same as that used for the compensation survey. All gradients and offsets should be defined in the same manner and with the same offsets as supplied for the compensation flight

## 6.5 Defining Compensation Coefficient File Names.

The “[Selecting coefficient file names and running compensation](#)” screen is similar to the one employed for the compensation survey, with the exception being the start button that reads “Compensate survey data”. This is the last screen in the production-processing branch, and the “Finish” button exits the program.

Define file name for compensation coefficients

Processing type:

Compensation coefficients files:

sensor	Compensation file
mag1	mag1.cof
mag4	mag4.cof
mag7	mag7.cof
grad	grad.cof

Protocol file:

Select coefficient files for production data

To compute compensated magnetic fields and gradients press “Compensate survey data” button. The computation time depends on amount of data to be compensated.

Variables names should be the same for the compensation flight as the production flight to avoid confusion. For instance, if the data columns were named “mag1” and “mag2” during the compensation flight and these names were changed to “prod1” and “prod2” during the production flight, then the left column (“sensor”) should read “prod1” and “prod2” and the right column (“compensation file”) should read “mag1.cof” and “mag2.cof” (or whatever names were used for files during compensation run).

There is a provision on the last screen for graphical data visualization. User can use “Plot data” button to display data the same way as it is done for compensation flight.

User may also employ more advanced display and analysis software (like GeoSoft™) to plot the data.

## **7 Filtering Data**

This wizard branch is optional and not required for compensation. However it may be useful in analyzing raw data and the compensation results, and is therefore included.

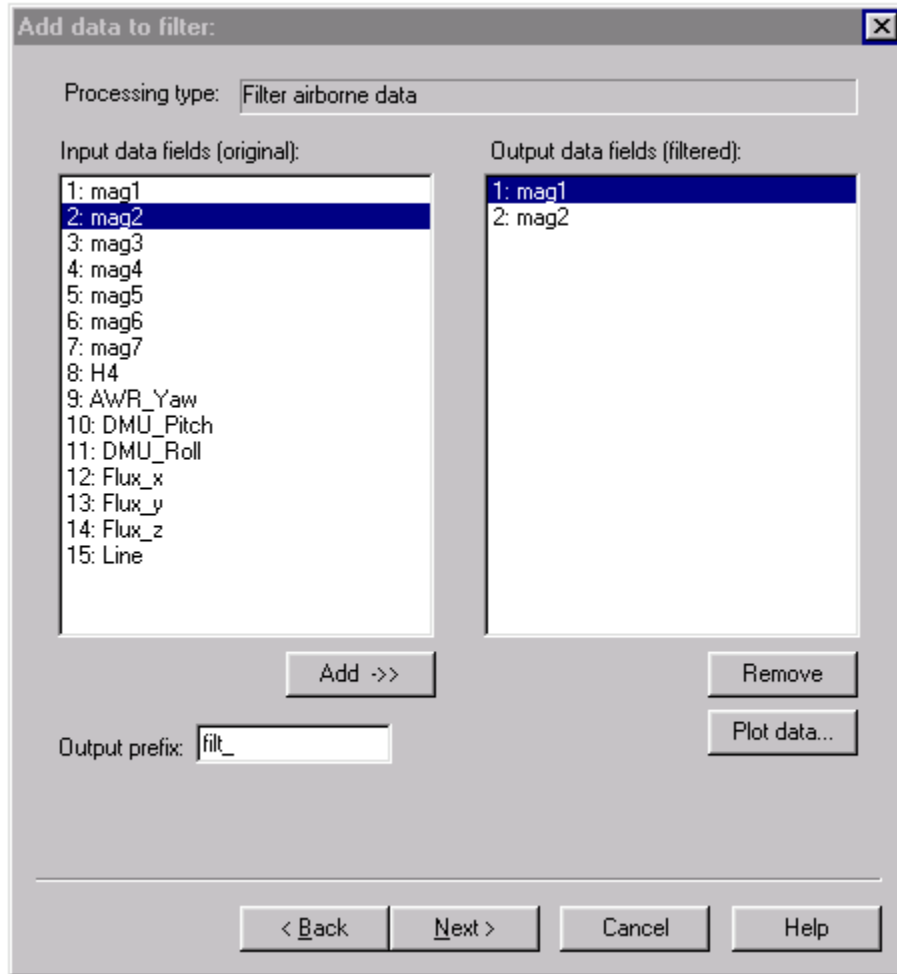
To proceed with the filtering, select “Filter data” on the initial screen of the program.

### **7.1 Select Data to Filter**

To apply filters to data, load the file of interest. It is possible to filter any type of recorded data. On the left side of the dialog box all available data fields are displayed. Select the data field you wish to filter. Double click or press the “Add->>” button to bring the selected fields into right part of the dialog box. To remove data already selected for filtering, highlight them in the right list and press the “Remove” button.

The data can be plotted using the MagComp™ plotting facility as discussed in [“Visualization in MagComp™”](#)

Output prefix is used to create new names for filtered values. For example, if the data field variables “mag1” and “mag2” are to be filtered and output prefix is set to “filt” the results are saved under the names “filtmag1” and “filtmag2”.



Selecting Data for Filtering

After pressing the “Next >” button, a line selection screen appears (see [Selecting lines for compensation](#)). It is possible to process data line-by-line by checking the “Line – by – line processing” box (see [Output file: all lines at once versus line by line processing](#)).

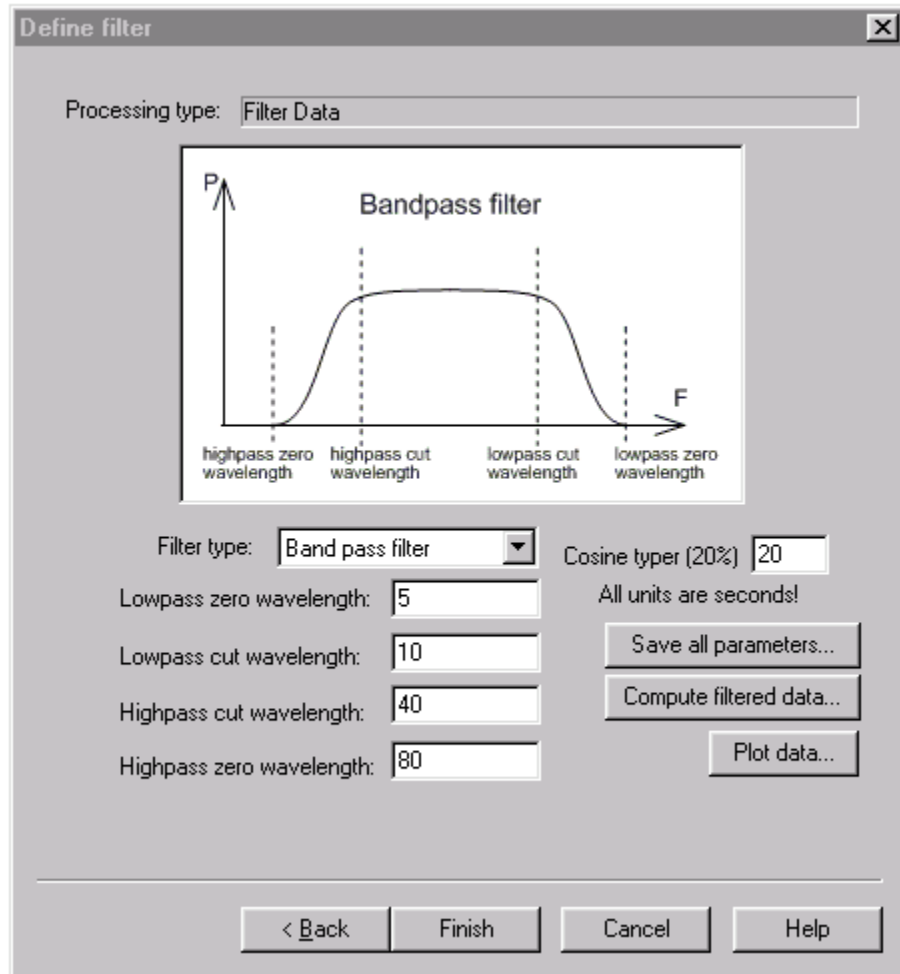
## 7.2 Defining the Filter and Filtering the Data.

After data fields and lines are selected, the user selects the type of filter and defines the filter parameters.

Filter type and parameters. The program provides the following filter types:

- Bandpass filter: limits spectra of output signal on low and high ends and is defined by low pass zero wavelength, low pass cut wavelength, high pass cut wavelength and high pass zero wavelength.

- Low pass filter: limits only the high frequency end of the input signal and is defined by its low pass zero wavelength and low pass cut wavelength.
- High pass filter: limits only low frequency part of the input spectra and is defined by its high pass cut wavelength and high pass zero wavelength.



Filtering screen

Cosine taper. MagComp<sup>TM</sup> uses a FFT (Fast Fourier Transform) to calculate derivatives and filter the data, which operates with  $2^n$  number of points. The user can specify the amount of data (in % of the total line length) that line will be extended or appended to the  $2^n$  value to reduce edge effects. 20% works well in most cases.

Save all parameters. Saves all program parameters in the single parameter file for future use.

Compute filtered data. This starts the filter calculations.

Plot data. This launches a graphical data plot display window. It is useful to inspect the data visually before and after filtering to ensure that proper parameters were used.

Finish or Cancel closes the program.

## **8 GLOSSARY**

Words commonly used in this manual and their definitions:

Total Field Magnetometer - a scalar measurement tool that senses and reports the ambient total magnetic field strength in nT or gammas ( $10^{-5}$  gauss).

Fluxgate Magnetometer – a vector magnetometer using a “ring core” saturable core reactor usually comprising three separate component magnetometers and used for measurement of the platform orientation.

Compensation – removal of the platform motion and intrinsic sensor heading errors using information received from the fluxgate magnetometer and using previously flown or towed compensation survey data coefficients.

Compensation Coefficients – a mathematical model of the magnetic field effects of orientation upon the remanent, induced and eddy current magnetic variables of a moving platform. Typically 18 terms are employed.

Compensation Coefficient Survey – a survey whose sole purpose is to move the platform through many different directions and orientations in a very low gradient area for the purpose of recording those effects upon the measured earth’s magnetic field. This process generates compensation coefficients.

Production Data – data collected under actual production survey runs for later compensation and processing.