Short Introduction To

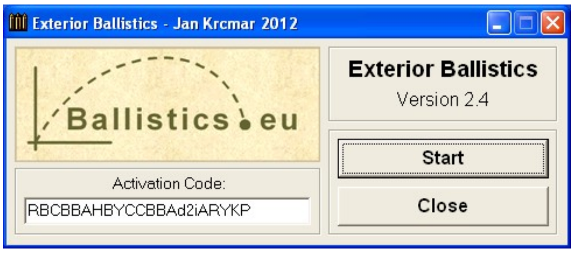
Exterior Ballistics 2.6

Software by Jan Krčmář

From a user's perspective written by Jochem Peelen*

1 Program Start and Registration

When starting the program after installation (see page 32) a window similar to the following will appear (screenshot from version 2.4):



The character string visible below *Activation Code* indicates that this is an unregistered copy of the program. It runs with the muzzle velocity fixed at 555 m/s. This allows you to get an impression of the functionality, but prevents making meaningful trajectory calculations.

The activation code is different from computer to computer. Therefore you must ensure to transmit it exactly as shown on your hardware to Dr. Jan Krčmář via his email-address: `krcmar@ballistics.eu`

Registered users will receive a file named `keys`. Copy it to the directory that also contains the exectutable `ballistics.exe`. On the next program start, the field *Activation Code* will be replaced by *Full Version*.

A mouse click on the **Start** button will bring up the main window.

CAUTION: this introduction shows the panels as they appear on a German language Windows. You will see commas where other language versions may show decimal points.

*This was written for my own use when learning how this software works. Dr. Krčmář kindly gave me some corretions and additions. Maybe it is useful for others. I was not involved in the development of this program. J.P.

American users may be in for a shock: this program, like the engineering world outside the U.S., is metric.

1.1 New in 2.6

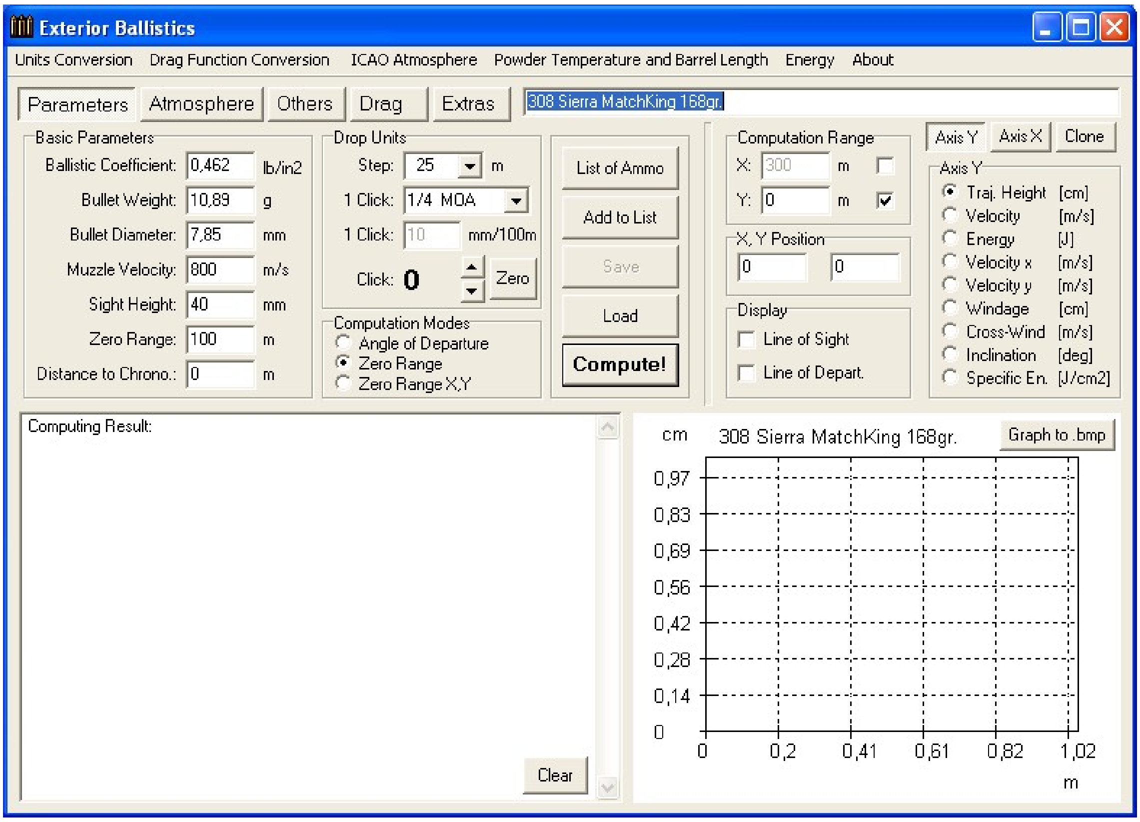
The program is compatible with Windows 10 and has the ICAO Atmosphere extended to 20 km altitude.

In the graph section of the Main window, the effective drag coefficient C_D along the trajectory can be plotted. This is particularly interesting in the transonic region, where large changes happen. See page 20.

The other extensions address the needs of users who want to study the computed trajectory more closely:

- It is now possible to save the bullet coordinates x, y, z and respective velocities v_x, v_y, v_z at every integration step of the calculation. See page 21 and the output example on page 31.
- The change of air drag when the bullet rises on its trajectory to less dense parts of the atmosphere can be switched off. This enables the user to see the impact of altitude effects on the trajectory. See page 9.

2 Main Window



Initially the data for the popular .308 Sierra Matchking (168 gr) is shown. On later program starts, the input data of your last computation will be shown.[1]

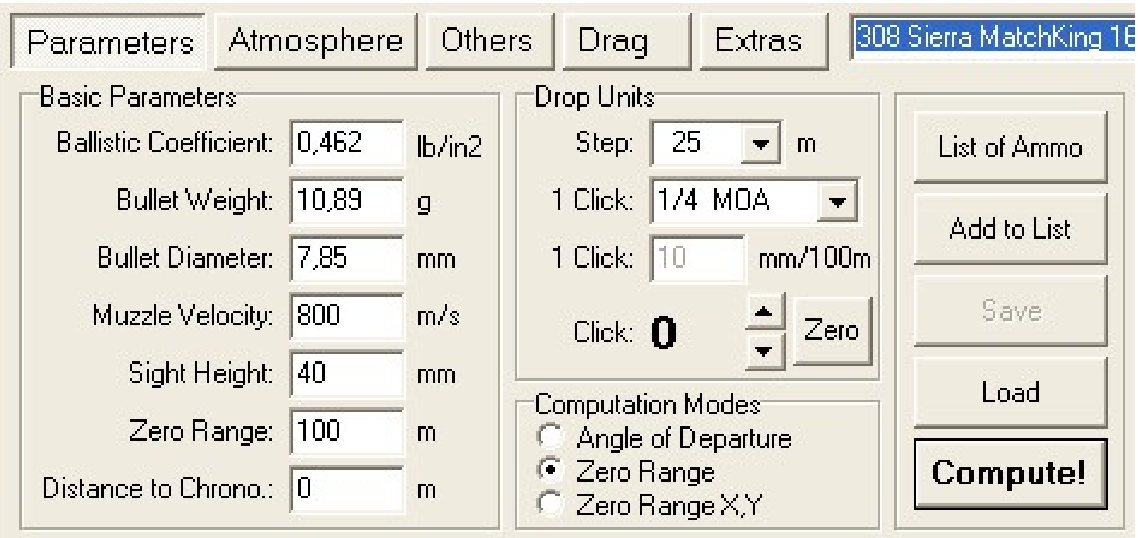
The lower half of the main window will be used for display of computing results: a table on the left and graphics on the right.

The menu line at the top of the window:

makes accessible several auxiliary computations which we will explain later (page 22).

For input, the top left quadrant of the main window is used. Initially a collection of fields called **Parameters** is active. Alternatively field collections **Atmosphere, Others, Drag** and **Extras** can be activated by buttons.

2.1 Parameters Button



On the left, the input fields for basic data are shown:

Ballistic Coefficient

This is a factor that expresses how well the bullet can overcome air drag. CAUTION: this number only makes sense in connection with the correct drag model as selected in the **Drag** field (see page 15). Initially this is **G1**.

Bullet Weight

self explaining

[1]If you want to get rid of previous data, delete file `init` as described in subsection 8.1 on page 33.

Bullet Diameter

CAUTION: for most cartridges the actual bullet diameter is larger than the calibre. For example 7.62 mm (0.300 inch) calibre typically has diameter 7.82 mm (0.308 inch).

Muzzle Velocity

Enter the muzzle velocity **or**, if using your own chonograph, the measured velocity.

Sight Height

Height of the line of sight above the center of the muzzle.

Zero Range

Range at which the line of sight crosses the trajectory (bullet path is zero).

Distance to Chrono

If a chronograph is used, its distance from the muzzle must be entered here. Maximum is 30 m. The program then corrects the value measured by the chronograph to the velocity at the muzzle. It uses the flat fire theory for this.

2.1.1 Parameters: Drop Units

Step

This is a selection list for the range intervals at which output data is written. Stepsize can be chosen from: 1, 5, 10, 25, 50, 100, 200 or 1000 m. The program may limit the number of computed ranges. For example, even if stepsize 1 m is chosen, a trajectory to 1000 m is shown in 5 m steps. In case a smaller stepsize is needed, the **Computation Step** time (page 10) has to be changed to a small value and **Automatic** deactivated.

1 Click

The program can show the height of the bullet path as well as windage in terms of centimeters or clicks. Here it is defined how much one click moves the line of sight on your weapon. Selectable units of movement per click are MOA (*minutes of angle*) or millimeters per 100 m distance. Industry standard values can be selected from a list; others may be entered in the field below the list.

Click Display and Sight Adjustment

This enables you to simulate the effect of moving your sight by a given number of clicks. The base position is **0** clicks. By means of the up and down buttons the sight can be changed by one or more clicks.

If this is done, the program automatically switches to **Angle of Departure** mode (see paragraph following next heading). The *new* angle of departure due to the clicks is immediately shown. Clicking on **Compute!** will calculate the resulting new bullet path.

Clicking on the **Zero** button resets the sight to base position.

2.1.2 Parameters: Computation Modes

Angle of Departure

If selected, the *Zero Range* entry field changes to **Angle of Departure** and expects a value in decimal degree format. This is then taken as the origin of the trajectory.

In case a trajectory calculation already exists, its angle of departure will automatically be filled in.

This mode is also a way of *freezing the launch conditions* for evaluating outside effects like atmosphere, coriolis and others on the point of impact.

Zero Range

Range at which the line of sight crosses the trajectory. In other words: where the bullet path is zero. The desired range is entered in the field to the left of this selection. Taking all known data into account, (atmosphere, gravity, etc.) the program will adjust the trajectory so that line of sight and trajectory cross at the zero range.

Because the muzzle is usually below the line of sight, the bullet crosses it two times. The first crosspoint is on its way upwards to the maximum ordinate, usually serveral ten meters from the muzzle. The second crosspoint is the desired zero range. In order to avoid confusing the program, unrealistically short zero ranges (20 m for .308 Winchester, for example) should not be used.

Zero Range X,Y

If, for example, a six o'clock hold is desired, it can be done by selecting this mode. The **Zero Range** field will change into two fields for range and desired height of bullet path.

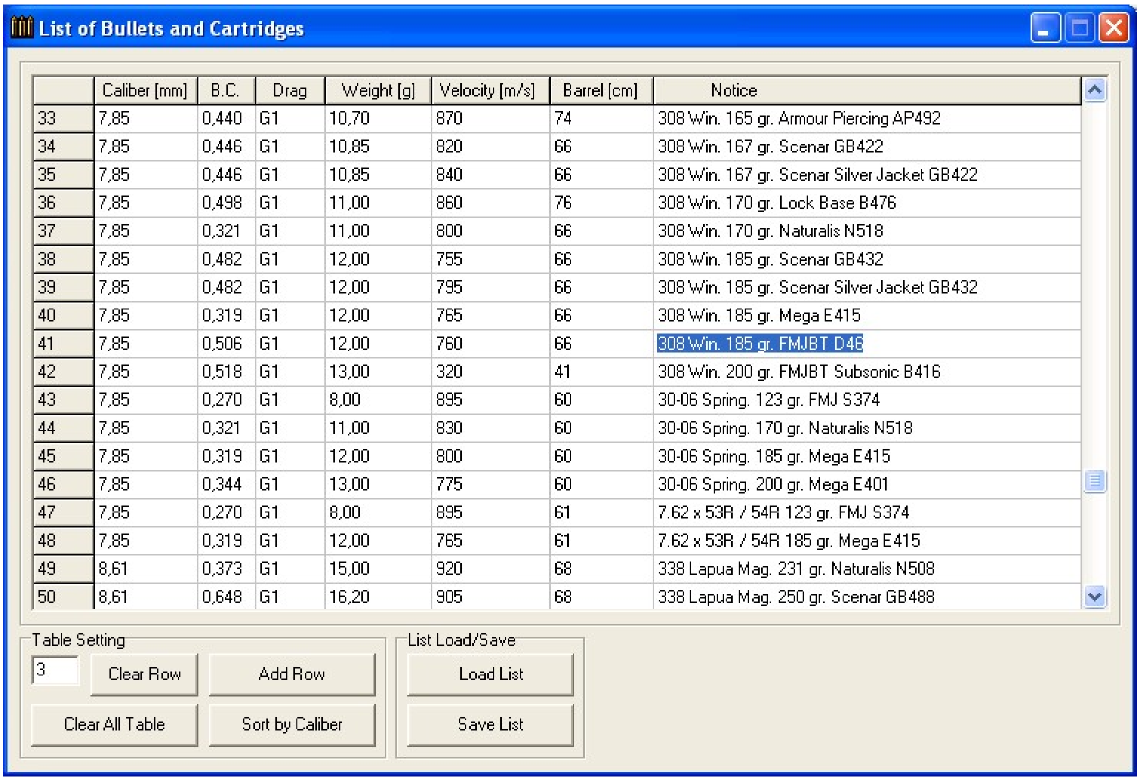
This mode can also be used to evaluate the effect of vertical errors in zeroing on the trajectory at longer ranges.

2.1.3 Parameters: Other Buttons

List of Ammo

The software as downloaded includes files with data for hundreds of cartridges and bullets. The *cartridge* files contain muzzle velocities as given by the manufacturers, whereas the *bullet* files have the same format, but with placeholder velocities and no barrel length.

Clicking the button opens a file selection dialogue that allows to select the desired directory and file. The contents of a file looks as follows:



	Caliber [mm]	B.C.	Drag	Weight [g]	Velocity [m/s]	Barrel [cm]	Notice
33	7,85	0,440	G1	10,70	870	74	308 Win. 165 gr. Armour Piercing AP492
34	7,85	0,446	G1	10,85	820	66	308 Win. 167 gr. Scenar GB422
35	7,85	0,446	G1	10,85	840	66	308 Win. 167 gr. Scenar Silver Jacket GB422
36	7,85	0,498	G1	11,00	860	76	308 Win. 170 gr. Lock Base B476
37	7,85	0,321	G1	11,00	800	66	308 Win. 170 gr. Naturalis N518
38	7,85	0,482	G1	12,00	755	66	308 Win. 185 gr. Scenar GB432
39	7,85	0,482	G1	12,00	795	66	308 Win. 185 gr. Scenar Silver Jacket GB432
40	7,85	0,319	G1	12,00	765	66	308 Win. 185 gr. Mega E415
41	7,85	0,506	G1	12,00	760	66	308 Win. 185 gr. FMJBT D46
42	7,85	0,518	G1	13,00	320	41	308 Win. 200 gr. FMJBT Subsonic B416
43	7,85	0,270	G1	8,00	895	60	30-06 Spring. 123 gr. FMJ S374
44	7,85	0,321	G1	11,00	830	60	30-06 Spring. 170 gr. Naturalis N518
45	7,85	0,319	G1	12,00	800	60	30-06 Spring. 185 gr. Mega E415
46	7,85	0,344	G1	13,00	775	60	30-06 Spring. 200 gr. Mega E401
47	7,85	0,270	G1	8,00	895	61	7.62 x 53R / 54R 123 gr. FMJ S374
48	7,85	0,319	G1	12,00	765	61	7.62 x 53R / 54R 185 gr. Mega E415
49	8,61	0,373	G1	15,00	920	68	338 Lapua Mag. 231 gr. Naturalis N508
50	8,61	0,648	G1	16,20	905	68	338 Lapua Mag. 250 gr. Scenar GB488

To select an entry, just click on its line in the window. For Sierra bullets, which have multiple lines due to multiple BCs, click on the first line. You can also enter its *line numer* into the entry field and click on the **Load List** button.

Button **Add Row** allows you to add your own data to the file and save it by clicking on **Save List**.

CAUTION: a separate file should be created for often used or own data. The files are flat files without special formatting. Using the Windows editor or Notepad, they can be easily created. This prevents loss of data in case the included files are replaced by more up to date versions later.

Add to List

Writes the bullet data of the current calculation to file.

Save

At program start, this button is greyed out and inactive. After the first computation it is activated and will write the current results to a file. See page 20.

Load

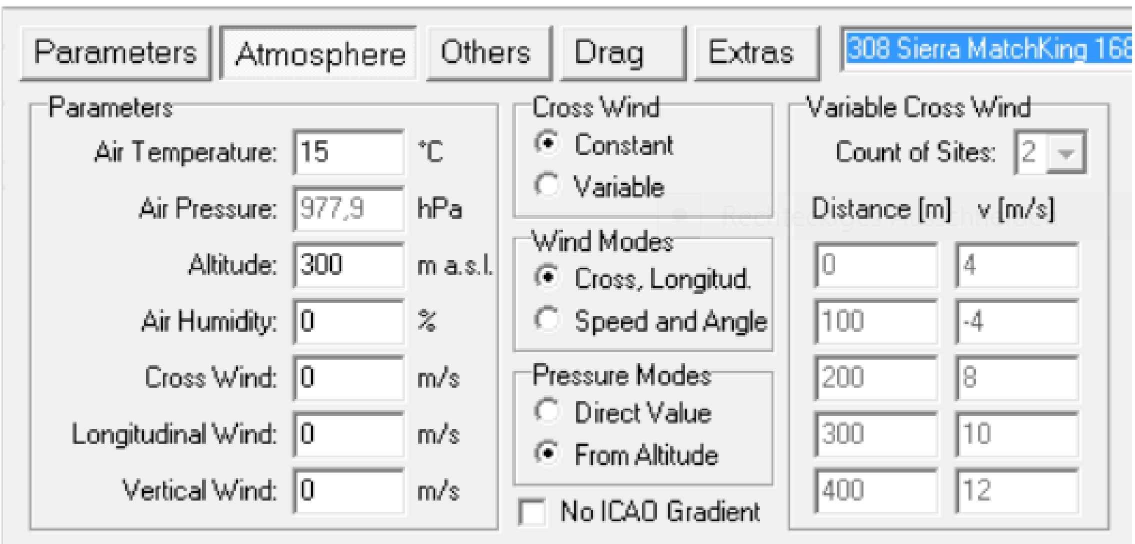
Any results file written via the **Save** button can be reloaded to continue working on its data. Values from the file will be loaded into the input fields.

Compute!

After all necessary inputs are made –we are not yet at that point– the calculation is started by clicking on this button.

The results are displayed as a graph in the bottom right area and as a table in the bottom left. This table is abridged and its numbers are more rounded compared to its saved or printed version. The graph can be saved as BMP file via a button in its top right corner.

2.2 Atmosphere Button



On the left there is a collection of entry fields describing the atmospheric conditions. The resulting density of the air may have, at long ranges, a marked impact on the trajectory.

Air Temperature

Temperature at the time of shooting. 15 degrees Celsius is an internationally used standard value.

Air Pressure

In standard mode **From Altitude** (see page 9) this field is inactive. To enter a barometric pressure, **Direct Value** has to be switched on.

Altitude

Height of the muzzle in meters above sea level.

Air Humidity

Relative humidity of the air. Contrary to widespread opinion, moist air is actually *thinner* than dry air. The difference is relatively small. Its typically comparable to a raise of temperature by one or two degrees Celsius.

Crosswind

Portion of the total wind that blows perpendicular to the line of shot. Wind going from left to right is described by a positive velocity.

Longitudinal Wind

Portion of the total wind that blows along the line of shot. A positive value describes tailwind, a negative headwind.

Vertical Wind

Positive numbers mean upwind, negative mean downwind.

CAUTION: the following applies to longitudinal and vertical wind (but *not* to crosswind). If **Zero Range** is calculated, the program takes into account these winds and nevertheless creates a bullet path height of zero. To see how much these winds influence the vertical bullet path vertically, do the following:

1. Calculate a **Zero Range** trajectory with winds set to zero.
2. Change to **Angle of Departure** mode, thereby freezing the launch conditions.
3. Now enter the desired longitudinal and/or vertical winds and re-compute. The result then shows the trajectory as affected by the wind.

The effect of crosswind is always given in a separate column, independent of zero range.

2.2.1 Atmosphere: Cross Wind Variations

Constant defines a wind of the same strength along the entire range. Selection of **Variable** activates the multiple entry fields to the right, marked *Variable Cross Wind*. There you can define 2 to 5 range zones, each with different crosswind speeds.

2.2.2 Atmosphere: Wind Modes

Cross. Longitd.

Entry of wind is done as cross and longitudinal components as mentioned above.

Speed and Angle

If this is selected, the labelling of the wind entry fields changes accordingly.

The angle the wind blows is counted clockwise from the direction of shot (e.g. 0 degrees is tailwind), wind from left to right is 90 degrees, headwind 180 degrees and wind from right to left is 270 degrees.

2.2.3 Atmosphere: Pressure Modes

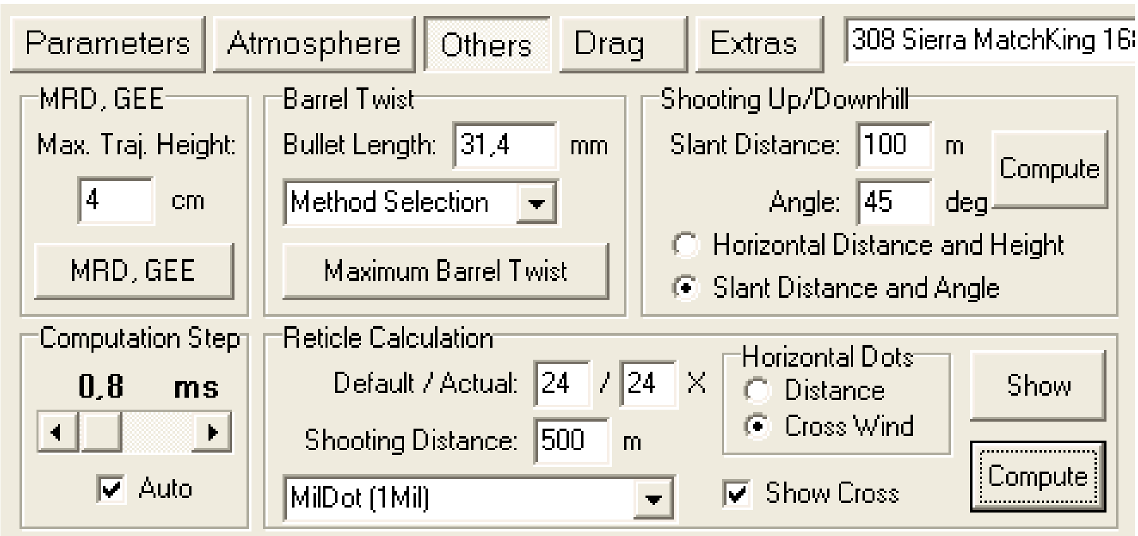
The atmospheric pressure at the location is either estimated from the height above sea level (**From Altitude**) or can be entered as a measurement (**Direct Value**).

CAUTION: make sure your instrument displays the real pressure at the location, not the pressure recomputed to sea level.

2.2.4 NEW – Atmosphere: No ICAO Gradient

This switch is normally not used. When the user activates it, the program stops to consider the reduced density of air at higher altitudes. The trajectory is computed as if the atmosphere at every point of the trajectory were the same as at the muzzle.

2.3 Others Button



2.3.1 Others: MRD, GEE

The *Most Recommended Distance (MRD)*, called *günstigste Einschießentfernung (GEE)* in German, is the zero range that corresponds to a maximum bullet path of (usually) 4 cm above the line of sight. On most shooting ranges it is not practical to zero a rifle at an odd distance like 182 m. This function tells you the equivalent bullet path at 100 m instead.

Clicking the button displays a table showing the trajectory up to the range where the bullet path reaches the point 4 cm below the line of sight.

CAUTION: the **Sight Height** defined among the Parameters collection of entry fields (see page 4) has a marked impact on the result.

2.3.2 Others: Computation Step

The numerical integration is done in small time steps at the millisecond level of flight time. The stepsize is automatically adjusted depending on the range. In case you are really into the math, by running the same calculating with different stepsizes, its influence on the result can be shown.

2.3.3 Others: Barrel Twist

This is not directly related to trajectory calculation. It is an auxiliary tool to estimate from the bullet length the required twist for satisfactorily stabilizing it. Three methods are available: **Greenhill, Sierra** and **Dell**.

2.3.4 Others: Shooting Up/Downhill

If you first calculate a horizontal trajectory, this function will show you how much the point of impact is moved by up- or downhill shooting.

Horizontal Distance and Height describes a situation similar to a target on a tree top. The *horizontal* distance, measured along the ground to the base of the tree, must be entered as well as the *height* of the tree.

Slant Distance and Angle expects the range to the target measured along the line of sight and the elevation (or depression) angle needed to point the line of sight at the target.

2.3.5 Others: Reticle Calculation

(Skip to page 15 if you want to look at reticle calculation later.) This subpanel gives you the following functionality:

- several reticles (Leupold, Meopta and others),
- showing the mean point of impact due to range and crosswind,
- labeling the horizontal dots or ticks[2] with range figures.

[2]For simplicity the term *dots* is used in the following text also for ticks.

Generally, the vertical dots are labeled with the corresponding range figures.

Clicking on button **Compute** starts the computation and displays the resulting reticle view. An already computed reticle can be displayed again by clicking on **Show**.

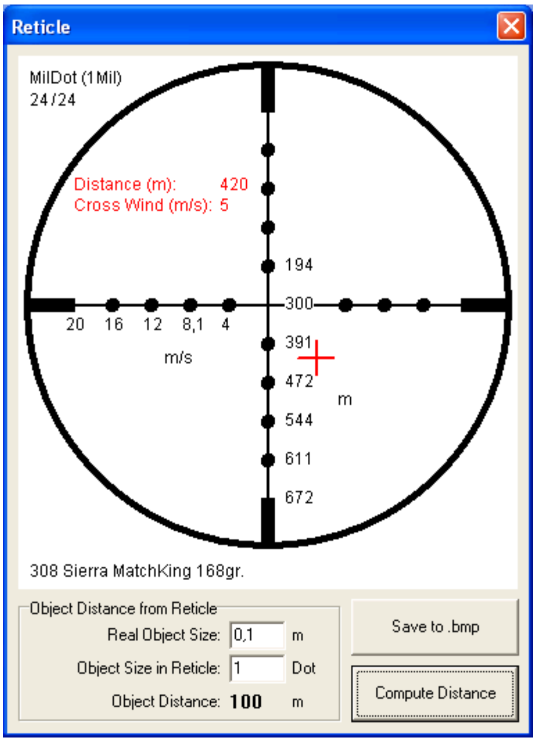
It is important to consider that two basic designs of rifle scopes exist, differing by the position of the reticle in the optical path:

First optical plane: always shows the reticle in the same relative size to the target picture. When magnification is changed, the resulting effect on reticle and target view is identical.
If two reticle dots are 4 inches apart on the target picture, this remains the same, independent of any change to magnification.

Second optical plane: keeps the size of the reticle constant to the eye of the shooter. Only the size of the target picture is affected by magnification changes.
As a result, our sample distance of 4 inches between reticle dots is *only true at one single magnification*. For all other magnifications, the distance is larger or smaller.

Mil-Dot as an Example of 1st Optical Plane

For a *1st optical plane* rifle scope it is important to enter identical values in the **Default/Actual** entry fields of **Reticle Calculation**.



Mil-Dot is a regular pattern of dots which have a distance from center to center identical to an angle of 1 mil.

The preceding image shows a value of 300 at the center of the reticle. This is the value entered in the **Zero Range** field of the **Parameters** subpanel.

As said above, the numbers near the *vertical* dots show the associated range. The first dot above the reticle center is the point of impact at 194 m. Its opposite number below the center shows the point of impact at 391 m.

The red-coloured cross shows the actual point of impact resulting from the following inputs:

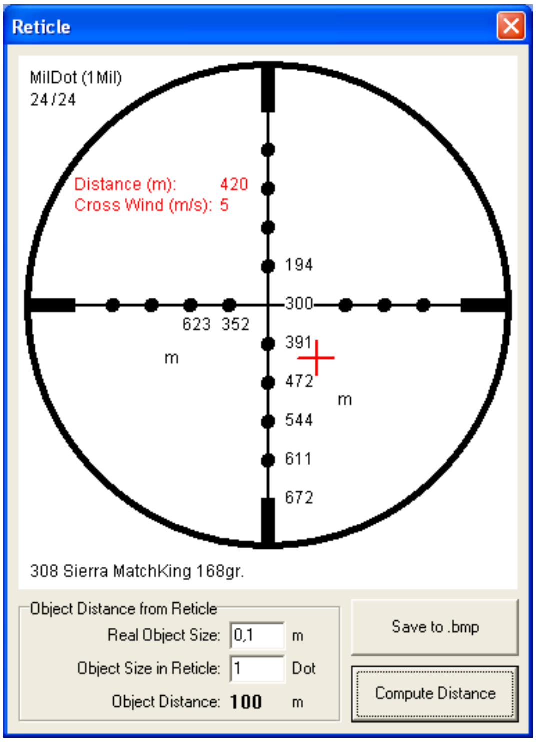
In the **Reticle Calculation** subpanel, a **Shooting Distance** of 420 m was entered. In the **Atmosphere** subpanel a crosswind of 5 m/s (positive number: crosswind from left to right) was entered.

As a result, the red-coloured cross (impact point) is below the reticle center (420 m is larger than 300 m zero range) and to its right (due to the wind from left).

The image you see on this page results when in field **Horizontal Data** the button **Cross Wind** is active. In this case the horizontal dots are labeled with the *crosswind speeds*. A crosswind of that speed will create a deviation matching the dot. In our example, the innermost dot matches the deviation due to 4 m/s crosswind, the next that for 8.1 m/s, and so on.

To avoid cluttering up the image, only the left-hand dots (for wind from the right) are labeled. The deviations on the opposite side are the same.

If, on the other hand, button **Distance** was activated in the **Horizontal Data** field, the following image is created. The only difference is the horizontal axis. Labels show the *range* at which deviation due to crosswind matches the dots. The first dot in this example is identical to the deviation at 352 m range, caused by the 5 m/s crosswind.



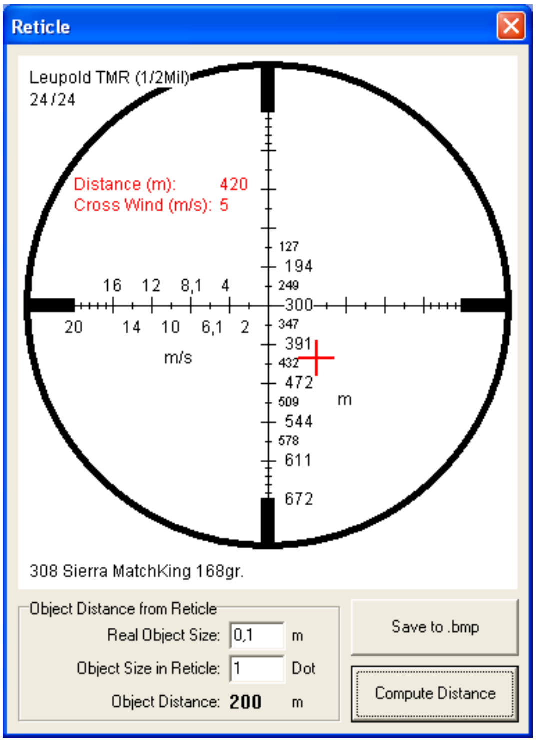
Distance Computation

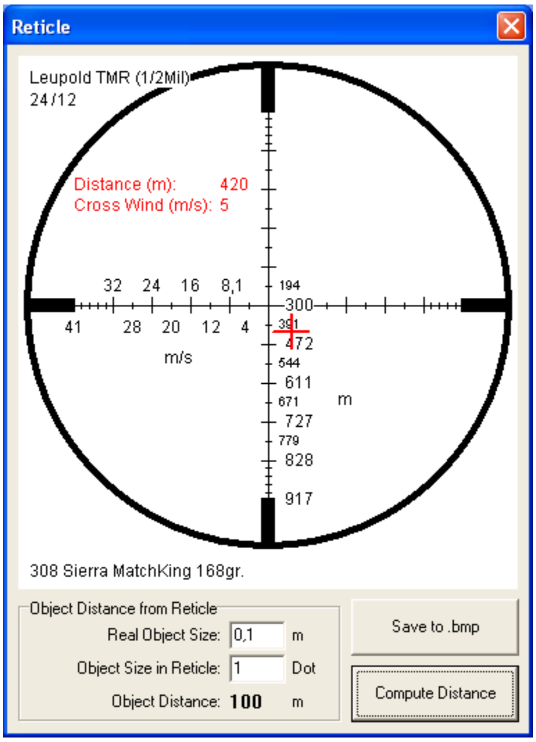
The field named **Object Distance from Reticle** aids in using the reticle for estimating range. The example shows that an object known to be 0.1 m wide, if its apparent size covers the distance of 1 dot, will be 100 m away.

The **Compute Distance** button has to be clicked after every change of the input fields shown here, or of the magnification. It is independent of the reticle computation itself.

Leupold TMR (1/2 Mil) as an Example of 2nd Optical Plane

> For a *2nd optical plane* rifle scope it is important to enter into the **Default** field the magnification for which the manufacturer gives the reticle dimensions.
> Into field **Actual** the user has to enter the magnification used for the shooting problem at hand.



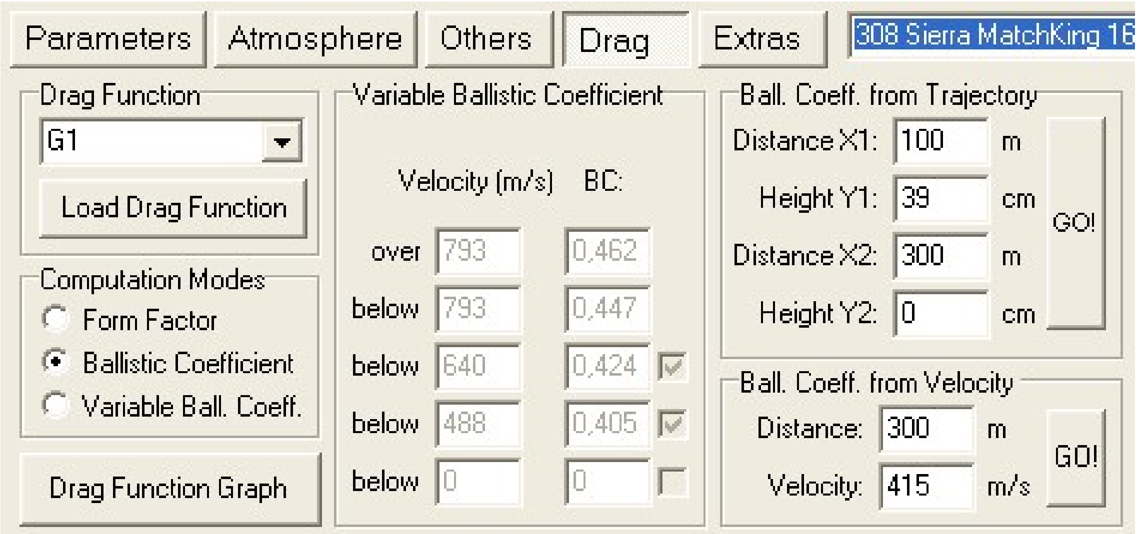


The left image results when shooting is done using a magnification of 24 (entry fields **Actual = Default = 24**).

The right image results when, for example, a magnification of 12 is used for shooting with the same scope. The field of view doubles and the distances covered by the reticle also double.

Apart from this, the shooting problem shown is the same as on the previous pages (range 420 m with a 5 m/s crosswind).

2.4 Drag Button



2.4.1 Drag: Drag Function

A large number of drag models are available to the user. Some are *builtin* into the program code, especially the U.S. models G1, G2, and G5 through G8 as well as the Soviet model of 1943. In addition, the author makes available as separate DRG-files:

- 135 models that Ruprecht Nennstiel had originally included with his DOS-based ballistics program EB Version 4.21. (courtesy Ruprecht Nennstiel).
- 56 models published by Finnish bullet maker Lapua, based on radar measurements.

Also, the user can add own drag models as DRG-files.

The *builtin* models may be directly selected from the list. To use a DRG-file, click on the **Load Drag Function** button and select the desired file from a dialogue box.

2.4.2 Drag: Computation Modes

Initially, the use of the **Ballistic Coefficient** (BC) as a base for trajectory calculation is active. A short explanation can be found on page 26. In this case, bullet diameter and mass are not considered in the trajectory calculation

When using one of the modern drag models, which are given as DRG-files (Nennstiel, Lapua or own), the computaion mode automatically switches to **Form Factor** and its value is set to 1.0.

In my personal view, the BC is a concept adapted to mathematical methods that do not sperarate clearly between bullet sectional density (diameter, mass) and it aerodynamic shape (form factor). I think with modern drag models the form factor is the appropriate way to adjust the model to the drag of a given bullet. See also page 28.

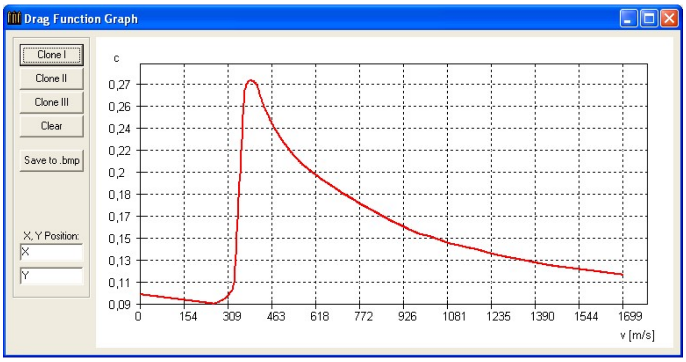
The flexibility of the program allows you to use both. Even with form factor, the program internally combines it with bullet diameter and mass to a BC specific to the current drag model.

2.4.3 Drag: Variable Ballistic Coefficient

Some bullet makers, especially Sierra publish not a single BC for a given bullet, but three or four values, valid for different velocity ranges. These BCs are for the G1 drag model. If this computation mode is selected, the collection of entry fields to the right of it is activated that allows to enter such a list.

2.4.4 Drag: Drag Function Graph

Clicking on this button displays a graph of the currently active drag model, showing its drag coefficient C_D versus the velocity.



The buttons labelled **Clone** make it possible to compare the shape of up to four drag models. When clicking a clone button, the current drag curve (always red) is saved in another colour (1=blue, 2=black, 3=green). After selecting a new drag model and opening this window again, it will show the clones in comparison to the now active model.

The graph can be saved as a bitmap file. Field **X,Y Position** displays the coordinates of the mouse cursor, if clicked within the graph.

2.4.5 Drag: Ball.Coeff. from Trajectory

Mathematically, two measured bullet path heights are sufficient to compute a BC for a bullet. The program searches the BC range 0.001 to 20 to find a value matching the drop.

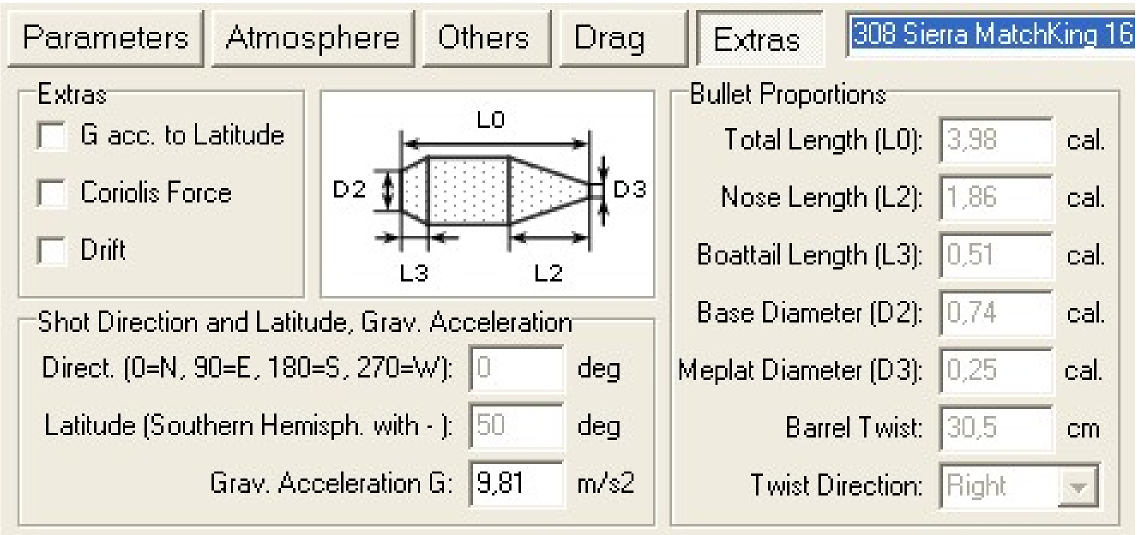
CAUTION: in practice the necessary *extremely precise measurement* of these values is very difficult to obtain. Real world bullet dispersion may hide the true position of the mean trajectory.

2.4.6 Drag: Ball.Coeff. from Velocity

Measured velocities at two different points are frequently used to determine the ballistic coefficient. Here you enter the data for the second point. The program takes the muzzle data as the first point. If a chronograph is used (see page 4) the program automatically takes its distance from the muzzle into account.

2.5 Extras Button

This collection of entry fields allows to take secondary effects on the trajectory into consideration. They have marked effects only at very long distances.



Grav. Acceleration G

Gravity is not constant. At the North Pole it is slightly stronger than at the Equator. The effect of this on a trajectory can be studied here. The program uses the international value of 9.81 m/s^2, which is a rounded version of the exact standard 9.80665 acceleration due to gravity. Some examples of local variation are:

9.832 North Pole

9.819 Oslo

9.808 Seattle

9.803 Roma

9.801 Washington (U.S. ballisticians used 9.800 until 1956)

9.793 Houston

9.780 Equator

Above examples were computed using an approximation by Physikalisch-Technische Bundesanstalt (PTB) of Germany.

As an alternative to direct entry of the gravity acceleration, the selection **G acc. Latitude** can be activated. Then the *geographical latitude* of the shooting location has to be entered and the program will use an estimation formula.

2.5.1 Coriolis Force

Because the earth is a rotating sphere, a shooter standing at the equator moves at 465 m/s eastward on a circular course. In central Europe (Cologne) it is still 293 m/s and at the North Pole this velocity is zero. These differences lead to deviations of the trajectory in the vertical and horizontal plane. The magnitude and direction is dependent on geographical latitude and azimuth of the shot. If the selection **Coriolis Force** is activated, both have to be entered.

2.5.2 Drift

Selecting **Drift** activates calculation of the horizontal deviation caused by *bullet spin*. It is done based on the McCoy code for the overturning moment. The direction of the deviation is always the same as that of the twist. To estimate the magnitude of it, the program takes into account the **Bullet Proportions** and the appropriate fields (see the small graph on the screen) have to be filled in.

Total Length – L0

Nose Length – L2

Boattail Length – L3, if present, otherwise 0

Base Diameter – D2, if boattail, otherwise 1

Meplat Diameter – D3 (the rounded or flat tip of the bullet)

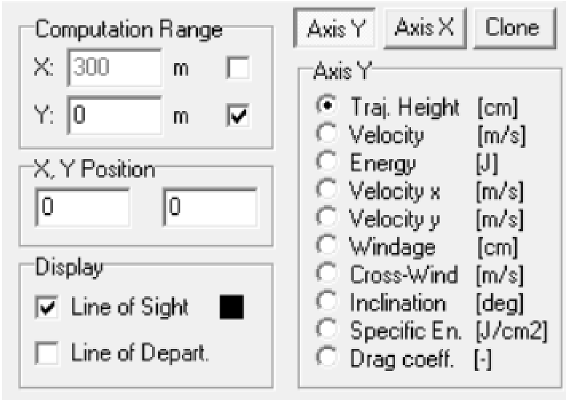
Barrel Twist – length of one turn of the rifling [cm]

Twist Direction – right or left

CAUTION: all bullet dimensions are relative to the bullet diameter. For example, if the bullet diameter is 8.20 mm, a length of 28.0 mm has to be entered as 3.41.

2.6 Output Controls

The upper right quadrant of the main window shows the elements for controlling the output format.



Output Controls: Computation Range

Here you tell the program where the trajectory should end, either when a certain range **X** or a height of bullet path **Y** is reached. If both selections are active, the one that is fulfilled first stops the program.

Output Controls: X,Y Position

This is purely a display of cursor position. When, after a calculation, a graph is displayed in the bottom right quadrant, you can move the mouse cursor to any point of interest. A click will display its current coordinates in the scales of the X and Y axis.

Output Controls: Display

Controls whether a graph of the trajectory will additionally show the **Line of Sight** as a black horizontal line and/or the **Line of Departure**. The latter is simply a straight line in dark green along the angle of departure (elevation).

Output Controls: Axis

For **Axis X** you can simply choose between range or time of flight.

Axis Y can display one of the following values:

Traj. Height – bullet path

Velocity – self explaining

Energy – self explaining

Velocity x – horizontal portion of bullet velocity

Velocity y – vertical portion of bullet velocity. Because usually shots are fired with an elevation, the bullet starts with some upward velocity. Under the influence of gravity, this slows down, drops to zero and becomes negative (downward speed).

Windage – horizontal deflection due to wind etc.

Cross Wind – self explaining

Inclination – Angle of the bullet path. It starts at some positive value (angle of departure) due to elevation, is zero at the maximum height and is negative (pointing downwards) for the remainder of the trajectory.

Specific Energy – kinetic energy divided by cross section. This is a very rough estimate of the penetration capability.

NEW – Drag Coeff. – the change of the drag coefficient acting on the bullet as it travels along the trajectory.

Output Controls: Clone

This button makes it possible to compare curves in the graph by saving the current curve (always shown in red) as a so-called *clone*. A clone is not overwritten by the next calculation.

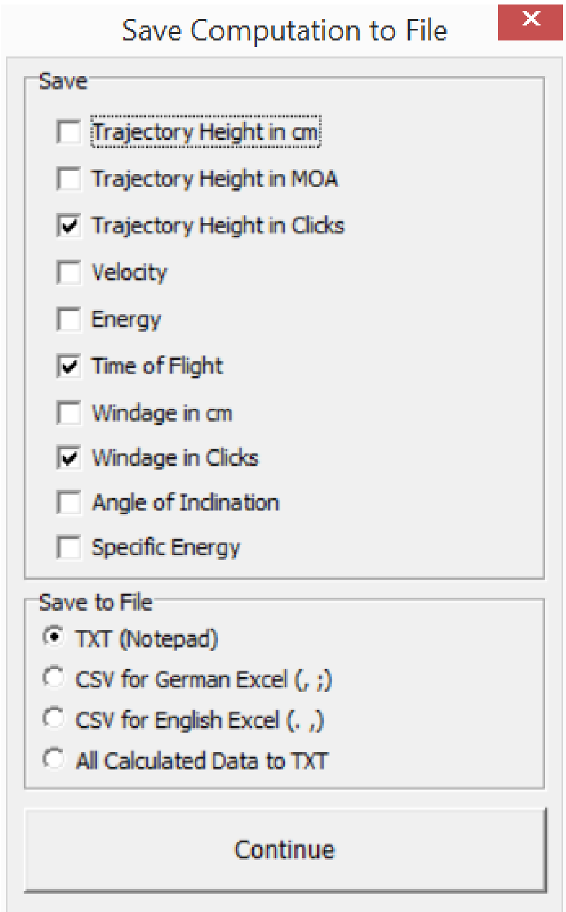
Clone I – saves as blue curve

Clone II – saves as black curve

After saving the current curve, you can modify one or more parameters (zero range, for example) and click on **Compute!**. The new result will be shown in red, the previously cloned in blue and black. So it it possible to display three curves at the same time: two clones and the last result.

2.7 Saving Results to File

Calculation results are shown on the screen in an abbreviated tabular form. By clicking the **Save** button the *complete* result can be written to a file. First a selection window for the output fields is shown:



TXT saves the results as an ordinary file that can be opened by any simple editor.

CSV is the *comma separated value* format, where the fields are separated by control characters. Many statistics and spreadsheet programs can read this format. You are offered two choices: **CSV for German** uses a semicolon as field separator and a comma as decimal point. This may be the best choice not only in Germany but also other countries where Windows uses the comma for this purpose. **CSV for English** creates a CSV file with decimal points and the comma as field separator.

NEW – All Calculated Data to TXT saves one data line for each integration step of the calculation, showing the current bullet coordinates x, y, z and velocities v_x, v_y, v_z. See page 31 for an example of the data saved by this selection. It is independent of the selected output fields above.

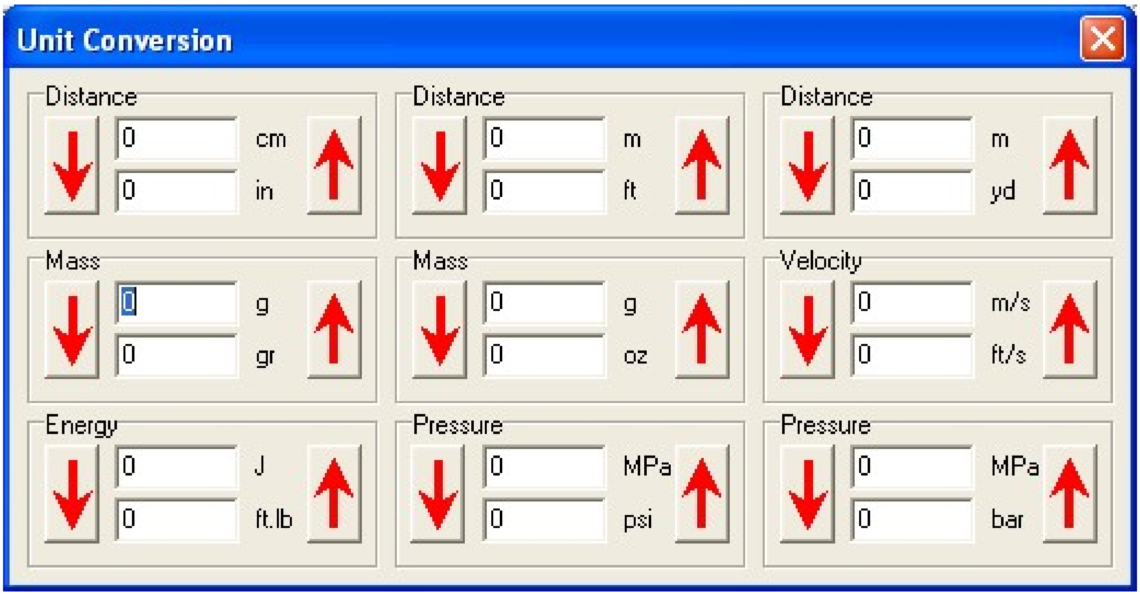
Clicking the **Continue** button opens a file dialogue to select a directory and choose a name for the output file.

CAUTION: to avoid writing data files to the program directory, it is recommended to select a different directory.

3 Auxiliary Computations

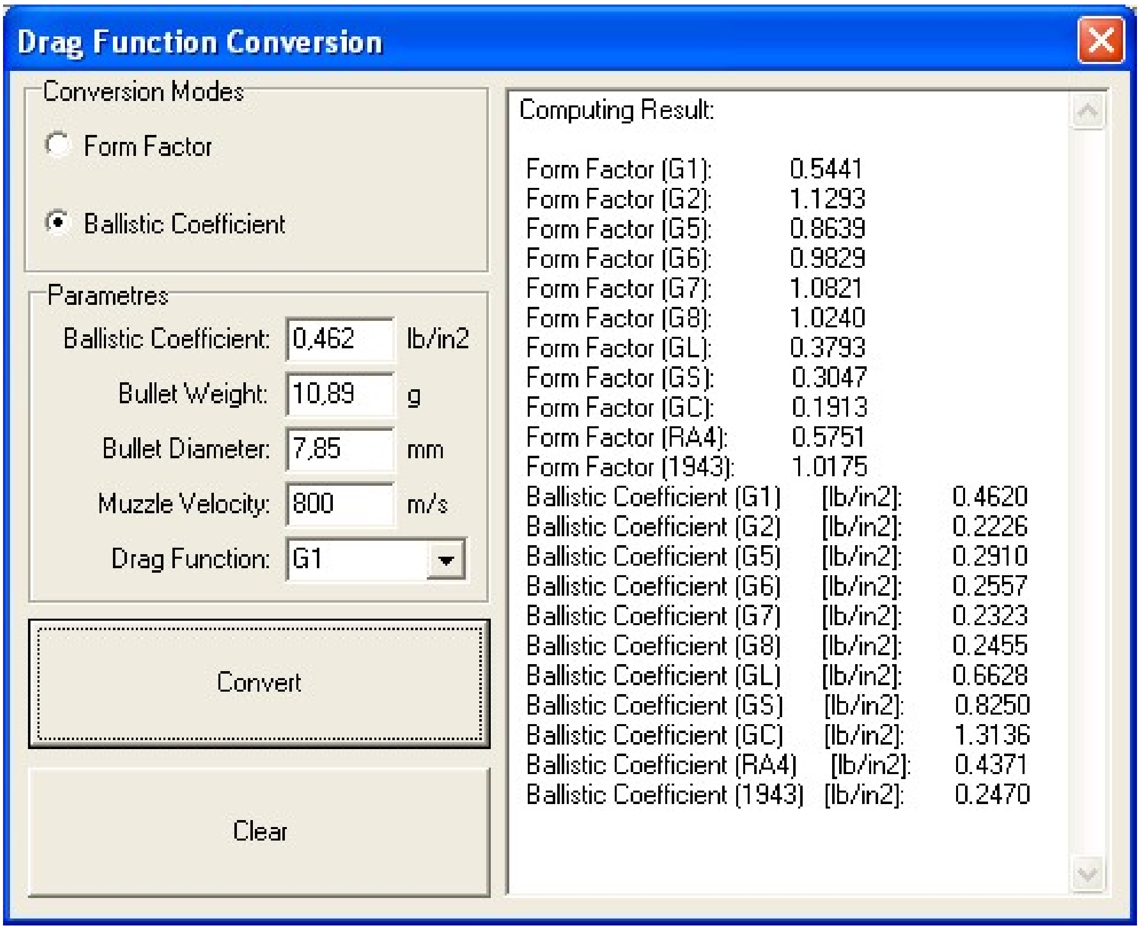
This menu gives you access to a number of windows for auxiliary calculations, which are totally independent of the main program.

3.1 Unit Conversion



This window is self explaining.

3.2 Drag Function Conversion



This conversion is only available for the *builtin* drag models. If for a given bullet the BC is known for one drag model, for example G1, the corresponding BCs for the other models will be shown. The same can be done with the form factor. Apart from G1 and its sisters, the following *builtin* models are available:

GL – developed by Ed Lowry at Winchester-Western for hunting type bullets with a round nose

GS – cone 3:1 length to diameter

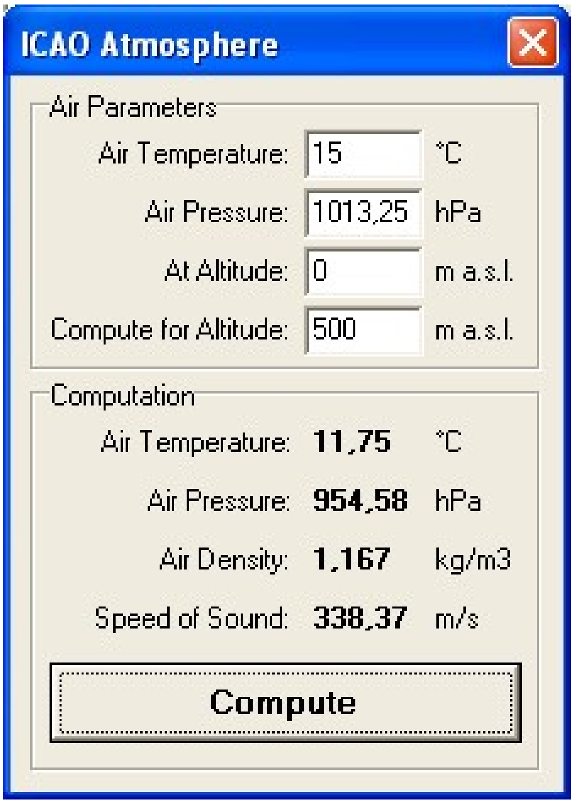
GC – steel sphere

RA4 – lead round nose smallbore bullet (.22 long rifle)

1943 – Soviet model of 1943

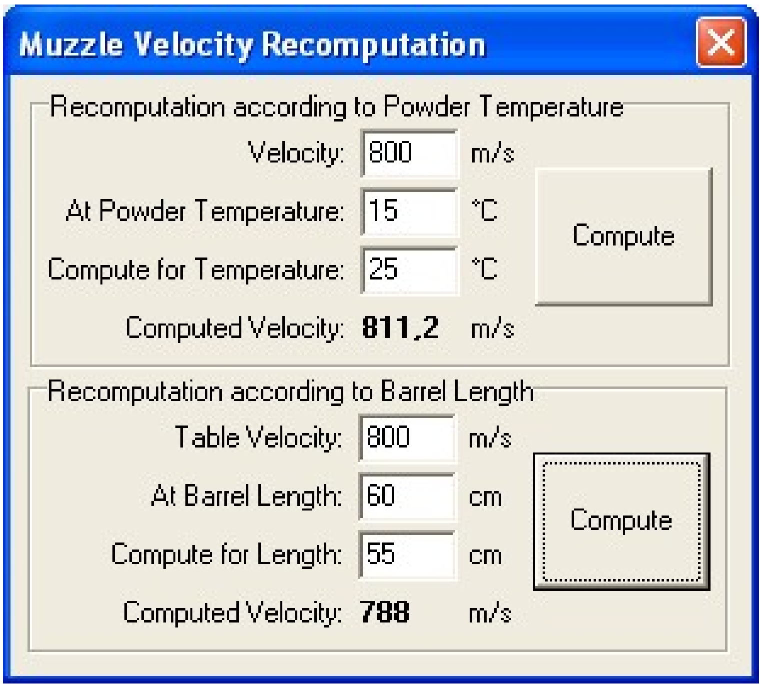
CAUTION: the curves that represent the drag models have different, often extremely deviating shapes. The BC conversions therefore apply only in the vicinity of the velocity given.

3.3 ICAO Atmosphere



In this window **Air Density** and **Speed of Sound** can be calculated using the ICAO formula. In the example shown, the standard values of the ICAO atmosphere at sea level are converted to an altitude of 500 m.

3.4 Powder Temperature ...



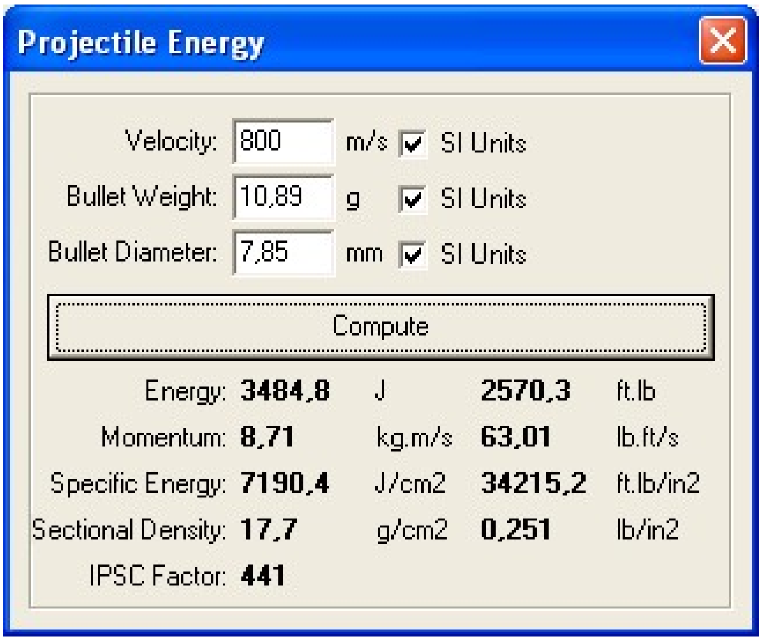
Here it is possible to *estimate* the influence of propellant temperature and barrel length on muzzle velocity.

In the field **At Powder Temperature** the temperature at the original measurements is entered. For factory ammunition, this will usually be 20 degrees Celsius as prescribed by CIP and SAAMI standards. Next you enter the propellant temperature at your actual shooting conditions on the range in the **Compute for Temperature** field. The result shows the influence of cold or hot conditions on the muzzle velocity.

The lower part of the window allows a similar calculation for different barrel lengths. Into field **At Barrel Length** the barrel length used during velocity measurements is entered. Then the barrel length of the weapon you actually use on the range is entered into **Compute for Length**. Again the muzzle velocity resulting from this difference is shown.

CAUTION: Keep in mind that the results can only be estimates. If at all possible, use a chronograph to measure the real velocity under your conditions.

3.5 Energy



From bullet velocity, mass and diameter the following can be calculated:

Energy – kinetic energy

Momentum – rough estimate of recoil

Specific Energy – kinetic energy divided by cross section. This is a very rough estimate of the penetration capability.

Sectional Density – bullet mass divided by cross section

IPSC Factor – class for tournaments according to IPSC rules

If the **SI Units** selections are deactivated, the bullet data can be entered in imperial units.

4 What is the Ballistic Coefficient?

To this day the ballistic coefficient (BC) dominates ballistics as used by American hunters and shooters. Due to the important role of American bullet manufacturers on the commercial market, this extends to a big part of the world. The BC goes back to a brilliant idea that Italian ballistician Francesco Siacci had in 1880. He computed velocity change, time of flight and other trajectory data for a **standard projectile** over a very large range of values. From these he prepared an extensive table, which today we call a Siacci table.

He found that simply by using a **scaling factor**, it was possible to compute the trajectory of practically any projectile from the standard projectile in the table. This scaling factor we know as BC.

The big advantage of the Siacci method was that it replaced the very laborious and time consuming process of numerically computing each trajectory anew. Instead, only simple interpolation in a table had to be done.

American ballistician James Monroe Ingalls transferred this method from the metric system and he selected the American standard projectile as having a mass of 1 pound (453.6 g) and a diameter of 1 inch (25.4 mm). Being the standard, its BC is 1.

During World War One, when firing was no longer limited to flat trajectories and new projectiles shapes came into use, the limitations of the Siacci method became obvious. Military ballisticians changed to numerical intergration, which required much more effort. But in the field of commercial small arms, Siacci's BC is still in use today.

This program by Dr. Krčmář of course uses numerical integration. But it is able to use a BC even with modern drag models.

4.1 Example of Finding a BC

Let us assume a bullet with a muzzle velocity of 856.5 m/s and a velocity at 100 m of 789.4 m/s.

To find its BC, we have to look up these velocity values in a G1 Siacci table and determine the distance between them. As a result we find that the standard projectile travels 221.5 m while decelerating from 856.5 m/s to 789.4 m/s.

Our bullet suffers over 100 m the same velocity loss that the standard projectile experiences over 221.5 m. Consequently our BC is: 100/221.5 = **0.451**

As you might have noticed, we need neither bullet mass nor diameter for determining BC. These values as well as the aerodynamic shape are hidden in the BC. The higher the BC, the higher is the remaining velocity of the bullet at a given range.

4.2 BC is not BC

BC values published by manufacturers are nearly always BCs for the G1 drag model, which originated from French trials performed around 1890. These must *never* be used with other drag models, as the following example will show.

We repeat the above determination of a BC with a Siacci table for the G7 drag model, which is based on British measurements made around 1940.

We find that the G7 standard projectile, due to its much better aerodynamic shape, travels 441.6 m for the same velocity loss. This is nearly double the distance found for the G1 projectile.

Our G7 based BC consequently is: 100/441.6 = **0.226**

The BC for G7 is very different from the BC for G1. It also shows that a Siacci table can only be valid for a *single* drag model. Any new model requires setting up an entirely new table.

5 Form Factor versus BC

If *cross section* and *mass* are mathematically stripped from the ballistic coefficient, the **form factor** remains. It stands for the *aerodynamic properties* in comparison to the drag model.

A bullet with form factor 1.0 behaves exactly as the selected drag model. A form factor of 0.9 means that the bullet is *better*, because it has only 90 percent of the model drag. Consequently a form factor of 1.1 describes a bullet with 10 percent larger drag. Obviously, the form factor of a given model is different for each drag model, depending on how well bullet drag and model match.

While the BC is a conglomerate of cross section, mass and aerodynamic shape, it was appropriate for the limited mathematical resources at the time of its invention. The **form factor** gives the user a much clearer picture how good a bullet is due to its shape alone. In my view today we should use the form factor instead of BC.

6 Trajectory Example

The following example shows the use of a Lapua drag model for comparing measured and calculated trajectory data at 600 m.

CAUTION: If you use a continental Windows, keep in mind that it may be necessary to use the comma: type 9,4 instead of 9.4.

Cartridge Data

Muzzle velocity 853.3 m/s; bullet mass 9.4 g; bullet diameter 7.8 mm; zero range 100 m. In addition, we use the following *assumption*: bullet drag corresponds to form factor **0.9613** with Lapua B476 drag model[3].

Change to Standard Values

After starting the program, click on the **Atmosphere** button and in the **Altitude** field enter 0 to obtain the ICAO standard pressure. The shooting was done near sea level.

Also enter 1 in the **Cross Wind** field to add wind sensitivity data to the result.

Now click on the **Drag** button and activate the selection **Load Drag Function**. The file selection dialogue is displayed. Choose directory **Drag Functions** and then subdirectory **Lapua**. Here you will find the DRG-file for the B476 Lapua calibre .308 projectile. Select it.

This brings you back to the **Drag** entry collection. By selecting a modern DRG file, the computation mode has automatically changed from BC to **Form Factor**.

[3] 0.9613 is the arithmetic mean of six range measurements for 100, 200, 300, 400, 500 and 600 m. Because I want to compare range data with computation results, I did not want to introduce additional errors by rounding this figure. It should not give you a false impression af accuracy. The largest measurement was 0.9713, the smallest 0.9538. As you can see, in real drag measurements already the second digit varies.

Trajectory Data

Click the **Parameters** button to enter the remaining data we need:

Form Factor – replace 1.0 by 0.9613

Bullet Weight – enter 9.4

Bullet Diameter – enter 7.8

Muzzle Velocity – enter 853.3

Sight Height – enter 60 because it better fits our rifle

Zero Range – leave 100 unchanged

Change the description field (top right of main window) to a text that fits the calculation at hand:
old: `.30 Lapua B476 Lock Base 11.0g ( 170gr )`
new: `.308 Winchester FMJ bullet 9.4 g FormFac 0.9613`

Go to the **Computation Range** frame below the description field. Activate field **X** and enter 600 m as the distance where the calculation should stop. Also de-activate field **Y**.

Now you can start the calculation by clicking on the **Compute!** button. After the run, the main window will show only part of the computed data. The complete result will be written to file after you click on the **Save** button.

6.1 Example: Saved Result File

To make the result fit the line length of this introduction, not all possible output rows were selected for the example below. For the same reason the line showing the path of the DRG-file has been shortened here:

```
            *** Exterior Ballistics ***
--------------------------------------------------
                   Jan Krcmar
--------------------------------------------------

 Ammo: .308 Winchester FMJ bullet 9.4 g FormFac 0.9613

 Drag Function: C:\ ... \Lapua\308-lapua b476 11,0g (150gr) lock base_radar.drg
 BC [lb/in2]:                  0.2286
 Form Factor [-]:              0.9613
 Bullet Weight [g]:            9.4000
 Bullet Diameter [mm]:         7.8000
 Muzzle Velocity [m/s]:        853.3
 Sight Height [mm]:            60.0
 Angle of Departure [deg]:     0.075183
 Zero Range [m]:               100
 1 Click:                      1/4 MOA
 Air Temperature [C]:          15.0
 Air Pressure [hPa]:          1013.2
```

```
Air Humidity [%]:              0.0
Air Density [kg/m3]:          1.2250
Cross Wind [m/s]:              1.0
Longitudinal Wind [m/s]:       0.0
Vertical Wind [m/s]:           0.0
Gravity Acceleration [m/s2]:  9.810
Computation Step [ms]:        2.00
```

X [m]	Y [cm]	V [m/s]	E [J]	T [ms]	Wind [cm]	Inclin. [Deg]
0	-6.0	853.3	3422.2	0	0.0	0.08
25	-3.1	836.2	3286.1	30	0.0	0.06
50	-1.2	819.1	3153.1	60	0.1	0.03
75	-0.1	802.0	3023.2	92	0.3	0.01
100	0.0	785.0	2896.2	124	0.5	-0.01
125	-0.9	768.0	2772.1	156	0.8	-0.03
150	-2.8	751.0	2651.1	188	1.2	-0.06
175	-5.8	734.2	2533.3	222	1.6	-0.08
200	-10.0	717.4	2418.9	256	2.1	-0.11
225	-15.3	700.8	2308.0	292	2.7	-0.14
250	-21.9	684.3	2200.6	328	3.4	-0.17
275	-29.8	667.9	2096.6	364	4.2	-0.20
300	-39.1	651.7	1995.9	402	5.0	-0.23
325	-49.8	635.6	1898.6	442	6.0	-0.26
350	-62.0	619.7	1804.7	482	7.1	-0.30
375	-75.9	603.9	1714.0	522	8.2	-0.34
400	-91.4	588.2	1626.3	564	9.5	-0.38
425	-108.7	572.7	1541.6	608	10.9	-0.42
450	-127.8	557.3	1459.8	652	12.4	-0.46
475	-149.0	542.1	1381.0	696	13.9	-0.51
500	-172.2	526.9	1305.0	744	15.7	-0.56
525	-197.6	511.9	1231.7	792	17.6	-0.61
550	-225.4	497.0	1161.1	842	19.7	-0.67
575	-255.7	482.3	1093.1	892	21.8	-0.72
600	-288.6	467.6	1027.7	946	24.2	-0.79

6.2 Comparing Example Results and Range Data

Measured velocity at 600 m was 468.3 m/s, a difference of less than 1 m/s. The measured bullet path was -269.3 cm, which differs about 20 cm from the calculation.

The difference in bullet path is probably in part due to errors of the measured bullet path at 100 m (zero range) and at 600 m. A zeroing error of 3 cm would be sufficient to account for the entire difference observed at 600 m.

6.3 NEW – All Calculated Data File Example

This example shows data for a trajectory calculated with an integration stepsize of 0.00080 seconds and a zero range of 600 m.

```
[26 header lines similar to the previous example]
Computation Step [ms]:        0.80

   T[s];     X[m];    Y[m];      Z[m];  Vx[m/s];   Vy[m/s];  Vz[m/s]
 0.00000;  0.00000; -0.04000;  0.00000;799.98210;  5.35165;  0.00000
 0.00080;  0.63982; -0.03572;  0.00000;799.57784;  5.34110;  0.00000
 0.00160;  1.27932; -0.03145;  0.00000;799.17391;  5.33056;  0.00000

   ...  [1221 data lines]

 0.97920;600.12500; -0.00117;  0.00000;472.37839; -4.41683;  0.00000
```

7 Adding an Air Drag Model

To add your own drag model, a table of Mach numbers and corresponding C_D (drag coefficient) values is needed.

As an example we will use the Soviet drag model by authors Shapiro, Mazing and Prudnikov of 1968. We take its values from the book *Äußere Ballistik* by Günter Hauck (Berlin: Militärverlag der DDR, 1972). Let us call it SHAPIRO.

File Header

The program uses the format defined by Hartmut Brömel that is also used by the Lapua radar files. It does not need any special characters and can be created by any ordinary editor like the Windows editor or Notepad.

The first line acts as a header and contains the following fields, **separated by a comma each**:

CFM, – constant string to identify the format

text, – description of the drag model (without any comma). This text will be displayed in the main window and in the output file.

number, – bullet mass in kg

number, – bullet diameter in m

number, – bullet length in m

text – optional additional text or empty

Drag models like SHAPIRO do not apply to a specific bullet. For the bullet data we therefore use the placeholder value `0.001` which in turn stands for 1 g mass, 1 mm diameter and 1 mm length. No additional text is necessary. Our example file header then looks like this:

```
CFM, Shapiro-Mazing-Prudnikov (1968) by Hauck, 0.001, 0.001, 0.001,
```

Alternatively, if a model is derived from a specific projectile, its values *can* be used. For the U.S. calibre .30 M2 ball bullet (9.72 g mass, 7.82 mm diameter and 28.5 mm length) the header could be:

```
CFM, U.S. M2 Ball according to McCoy (1999), 0.00972, 0.00782, 0.0285,
```

Table of Values

After the header, each line holds a pair of values: drag coefficient first and, separated by a blank, Mach number. (Usually the sequence is the other way, but here we have swapped columns.) Up to 298 pairs are possible. The Lapua files have a horizontal tabulator character (09h) as separator, but a blank can be used without problem.

Our example file (abbreviated) for Mach numbers 0 to 5 then looks as follows:

```
CFM, Shapiro-Mazing-Prudnikov (1968) by Hauck, 0.001, 0.001, 0.001,
0.1020 0.00
0.1010 0.10
0.1000 0.20
  ...
0.1210 4.70
0.1200 4.80
0.1190 4.90
0.1180 5.00
```

This we save as file SHAPIRO.DRG in any directory we desire. For ease of use it is recommended to create a subdirectory **extras** in the **Drag Functions** directory. The graph shown on page 16 illustrates this drag model.

8 Appendix: Installation

The following description is based on tests under the Windows XP, Windows 7 and Windows 8.1 operating systems from an account with administrator privilege.

The software can be downloaded from web page `www.ballistics.eu` and comes as a packed file named: `ballistics_2.6.zip`

The ZIP file contains the directory **Exterior Ballistics 2.6** which in turn contains the executable file `ballistics.exe` and the following subdirectory structure:

```
Exterior Ballistics 2.6
   +---Bullets
          ... [bullet data files]
   +---Cartridges
          ... [cartridge data files]
   +---Drag Functions
          +---Exterior Ballistics 4.0
          +---Lapua - old
          +---Lapua - November 2015
          +---Others
```

Directory **Exterior Ballistics 2.6** may in principle be unpacked to any location that is convenient, for example: `c:\Exterior Ballistics 2.6\`

This location is not the one used for programs according to the Windows standard. But because the software writes files into subdirectories below the directory of the executable program, is seems prudent to deviate from the standard. The software can also be run from an **USB stick**.

To start the program, open the program's directory in Windows Explorer and double click on the executable file `ballistics.exe`. To be able to run it from the desktop, create an icon the normal way by right clicking on the desktop and make it point to `ballistics.exe`.

8.1 Data Files

A file named **init** is stored on closing the program. It contains the inputs of the last computation. These will be used on the next start of the program. You can delete this file is you want to revert to the status after installation.

Subdirectories **Bullets** and **Cartridges** hold a collection of identically structured TXT-files with input data from several manufacturers.

In subdirectory **Exterior Ballistics 4.0** the DRG-files kindly supplied by Ruprecht Nennstiel are stored. These are in an encoded form and therefore only useable within the program.

The DRG-files published by Finnish manufacturer **Lapua** are stored in two subdirectories, one for the latest update made in November 2015 and the other holding the previous versions. The files are in a format taken over from *Quick Target Unlimited* software by Hartmut Brömel. This format is explained on page 31.

Subdirectory **Others** contains additional DRG-files in this format.