AnalyzeLoad User’s Manual
(Version 3.2, September 2018)

1.0 Introduction

AnalyzeLoad is a combined set of computer programs that have at their core, physics-based interior and exterior ballistics models developed by Box Elder Innovations, LLC. The intent of these programs is to provide the shooting community with low cost tools for generating computational data to aid in the development and understanding of safe loads for small arms ammunition, for failure investigations, and for computing the influence of unknown conditions on cartridge performance. In summary, AnalyzeLoad has the following capabilities:

1) Interior ballistics forward calculation module for computing muzzle velocity, pressure vs. time curves, pressure vs. bullet position in the barrel (x), velocity vs. x, and mass of propellant vs. x.
2) Sensitivity analysis module for computing sensitivity of the pressure-time curve, P(t), to the primary interior ballistics model input properties.
3) Interior ballistics inverse calculation module for computing: i) bullet/barrel friction constant given measured values for muzzle velocity, bullet weight, barrel length, and powder weight for a selected cartridge and powder type, or ii) propellant burn rate constants and ratio of specific heats given values for muzzle velocity, bullet weight, barrel length, friction coefficient, and powder weight for selected cartridge and powder.
4) Exterior ballistics model for computing bullet trajectory after the bullet leaves the muzzle of the barrel.

2.0 Summary

The initial user interface, shown in Figure 1, appears when AnalyzeLoad is started. To start the program, the “START Program” in the upper left corner must be clicked. It is noted that there are three groups of input/output windows for program control, property selection, and computational output, respectively. The left-most group, "Calculation Mode and Program Control" is for:

2) Messages
3) Property selection mode: "Use Default Properties" or "Change Properties", various buttons to run the respective calculations and
4) "End Program."

The center group, "Input Properties" is for selecting and inputting the properties and parameters needed to run the interior ballistics model. The five pages of input are each selected by clicking on the respective tabs labeled "Cartridge," "Bullet," "Powder," "Primer," and "Friction."
Figure 1. Software user interface for AnalyzeLoad.

The right-most group, "Calculation Outputs", has several pages of output for the various calculation modes. The first four pages are output for the interior ballistics "Forward Calculation" mode. The fifth page is for "Sensitivity Analysis". The sixth page, "Inverse Calculations", shows output for two inverse calculation modes, "Friction" and "Burn Rate". The seventh and eighth pages are for exterior ballistics output, "Trajectory 1 y(x)" and "Trajectory 2 v(x), E(x)"; and the ninth and tenth pages, "Compare IB Calc" and "Compare EB Calc", are for reviewing and comparing up to three interior ballistics calculations and up to three exterior ballistics calculations, respectively. All "Calculation Outputs" results are viewed by clicking on the corresponding tabs. In summary, they contain the following information:

1) "P(t)" : Pressure versus time
2) "P(x)" : Pressure versus bullet position, x, as it moves down the barrel
3) "v(x), mp(x)" : Bullet velocity and remaining propellant mass as a function of bullet position, x
4) "P(t,x)" : Pressure versus time at user-selected locations, x, along the length of the cartridge or barrel
5) "Sensitivity Analysis" : Output from sensitivity analysis as a function of time
6) "Inverse Calculations" : a) "Friction" : Fit results in a graphical format and the best fit bullet/barrel friction constant in numerical format, and b) "Burn Rate" : Fit results in graphical and numerical format for the propellant burn rate coefficient and the burn rate exponent
7) "Trajectory 1 y(x)" : Sight-in trajectory and trajectory relative to line-of-sight for shooting at angles different from horizontal as a function of distance down range
8) "Trajectory 2 v(x), E(x)" : Sight-in velocity and kinetic energy dependence on range
9) "Compare IB Calc" : Review and compare up to three interior ballistics calculations
10) “Compare EB Calc”: Review and compare up to three exterior ballistics calculations

3.0 Calculation Modes

This section discusses in more detail the four primary calculation modes available to the user: 1) interior ballistics (forward model), 2) sensitivity analysis, 3) inverse calculations (inverse models), and 4) exterior ballistics. Each of the four windows that appear when the respective calculation mode tab is clicked is shown in Figure 2.

3.1 Interior Ballistics

This mode is selected from the “Calculation Mode and Program Control” group by clicking on the tab in the left most window labeled "Interior Ballistics". The page shown in Figure 2(a) is displayed for this mode. As can be seen, there are three controls on this page: "Press to Save Current Settings", "Press to Restore Saved Settings", and “Run Interior Ballistics Calculation”. The primary inputs and controls for the "Interior Ballistics" mode are found on the pages of the center group, "Input Properties." These inputs are used by the interior ballistics (forward) model and are also used in the other two calculation modes. Figure 3 shows all five input pages. The settings on these pages can be saved and restored by using the "Press to Save Current Settings" and "Press to Restore Saved Settings". The pink-highlighted inputs are primary inputs on each page and are input by the user. The black-highlighted and red-highlighted inputs are filled-in by the software when the "Use Default Properties" option is selected. The red-highlighted properties can be manually changed when the "Use Default Properties" (see Figure 1) button is clicked and changed to "Change Properties."

On the “Select Cartridge” tab of the "Cartridge" page, the cartridge, barrel length, and barrel twist must be selected or input. On the “Add/Delete Cartridge” tab of the “Cartridge” page, new cartridges can be added, and/or existing cartridges can be deleted. Instructions on the page must be carefully followed to make sure the cartridge data is input correctly. On the “Bullet” page, all properties are automatically filled in when the “Bullet wt. (gr)” and “Bullet Shape” are input/selected. On the “Select Powder” tab of the "Powder" page, all properties are automatically filled in when the “Powder” and “Powder wt. (gr)” are selected/input. The “Add/Delete Powder” tab on the “Powder” page, new powders can be added, and/or existing powders can be deleted. Instructions on the page must be carefully followed to make sure the powder data is input correctly. The "Primer" properties are all input automatically when the cartridge is selected. The parameters on the "Friction" page are needed to estimate the bullet/barrel friction as a function of bullet position as it moves down the barrel. The friction model is based on experimental work and the default input parameters work for many bullets and can be used as is. The inverse calculation for friction can be used if the shooter believes that friction is an issue that needs to be studied.

After all properties and parameters are set, the forward model is run by clicking the “Run Interior Ballistics Calculation” button. The calculation outputs are then displayed in “Calculation Outputs”, the right-most group of windows. For the interior ballistics calculation, the output results are shown in the first four pages of the right group. These pages are shown in Figure 4 with calculations using the input data shown in Figure 3. On the fourth page, "P(t,x)", the calculated pressure curve is for the barrel location selected on that page. In Figure 4(d), the "Mid-Case", or middle of the case, option was selected. This option, or any other desired option for the barrel location, does not take effect when changed until the "Run Interior Ballistics Calculation" button is clicked again. Input x-values less than zero correspond to positions within the cartridge.
3.2 Sensitivity Analysis

Sensitivity analysis is a method for determining the sensitivity of output calculations of the interior ballistics model to the input properties. This may be of importance to those developing or modifying individual components of the cartridge. For example, the developer may want to know how much affect changing the mass, volume, or energetic material properties of cartridge components by incremental amounts will have on the maximum pressure or muzzle velocity, or on the shape of the P(t) curve. This type of analysis leads to an understanding of input properties that dominate cartridge performance. Sensitivity analysis also helps in developing an intuition for changes that have potential to cause unsafe or extreme conditions, or changes that may lead to the desired performance, or even changes that are of little consequence. This calculation mode also has value in failure investigations.
Figure 3. "Select Properties" pages for "Interior Ballistics" mode, also used in other calculation modes.
Figure 4. "Calculation Output" pages for "Interior Ballistics" calculation mode selection.
The sensitivity analysis mode is selected by clicking on the tab labeled "Sensitivity Analysis" under the label "Calculation Mode and Program Control". The page shown in Figure 2(b) will then appear. On this page, the property that is to be varied is selected by clicking the button below the property name. Only one selection is allowed for each calculation. Definitions of the property names can be pulled up by clicking on the "Get Definitions" button (See Figure 2(b)). To run the desired sensitivity analysis, select the cartridge, bullet, and powder properties on the respective windows under "Input Properties", then click the "Run Sensitivity Calculation" button.

Outputs from the sensitivity analysis calculations are found on the "Sensitivity" page of the "Calculation Outputs" group. Figure 5(b) shows example output calculations using the inputs properties in Figure 3 and the selection shown in Figure 5(a). Note that there are two additional controls on the "Sensitivity" calculation output page: 1) "Percent Change" and 2) "Select P(t) Location". The "Percent Change" input is set by the user to the desired property percent change. This number can be any reasonable positive or negative real number. The "Select P(t) Location" control is a drop-down menu where the x-location in the barrel for the P(t) calculation can be selected. These controls do not take effect until the "Run Calculation" button is clicked.

The first graph on the "Sensitivity" page shows the pressure-time curves for two conditions, one with the selected property unchanged, and the other curve with the selected property changed by the amount determined in the "Percent Change" box. In the second graph the normalized derivative, of P(t) with respect to the selected property, is plotted. In this graph, it can be seen where in time the parameter change has the greatest effect on the P(t) curve. Also shown are the maximum pressure and muzzle velocity before and after the property change.
3.3 Inverse Calculation

3.3.1 Friction

This calculation mode is offered to help the shooter determine the effects of bullet/barrel friction and other unknown effects which can be lumped into the bullet/barrel friction such as energy losses from heat transfer into the barrel. The underlying mathematical process is a polynomial fit to the interior ballistics model by least-squares minimization. In this inverse calculation mode, the input data for cartridge, barrel length, bullet weight, and fixed powder type, are powder weight, and muzzle velocity. The least-squares fit adjusts the value for the bullet/barrel friction constant, $f_0$, to give the best fit to measured muzzle velocities. The value for $f_0$ is the average for all the input conditions (guns, bullets, etc.). If the bullet/barrel friction constant is wanted for just one gun/bullet combination, then all inputs must be for that gun/bullet combination. Up to ten sets of measurements can be input for this calculation mode. When in the inverse calculation mode, the powder type and bullet shape must be selected on the "Inverse Calculations" page under the "Calculation Mode and Program Control" label.

To select this mode, the "Inverse Calculation" tab under the "Calculation Mode and Program Control" label must be clicked and then the friction tab on that page is also clicked. Input conditions are entered on this page and output is found on the “Friction” tab of the “Inverse Calculations” page under the "Calculation Outputs" label. Example output is shown in Figure 6. The plot on the "Friction" output page, Figure 6(b) shows the measured velocity plotted against the best fit calculated velocity for several bullet/barrel combinations using the input shown in Figure 6(a). Figure 6(c) and 6(d) show input and results for a single bullet/barrel combination. For a good fit, data points should lie on, or close to, the 45° line shown in the plot. The best fit value for the bullet/barrel friction constant is given numerically. If the user desires to keep and reuse the fit value for $f_0$, the button "Press to Save" must be clicked. This will cause the fit value to become the default. If $f_0$ is someway changed, this default value can be restored by pressing the “Press to Restore” button on the “Friction” page under “Input Properties” (See Figure 3(g)). The limits on the graphs can be adjusted by changing the values for "v-lower limit" and "v-upper limit". This calculation mode will take a few minutes to execute.

3.3.2 Inverse Calculation - Burn Rate

This mode of calculation is offered in the advent that some propellant properties may not be known, or are believed to be inaccurate for the shooting conditions and propellant lot or batch being used. The underlying mathematical process is a Levenberg–Marquardt least-squares fit to the interior ballistics model. In this inverse calculation mode, the input data are cartridge type, barrel length, bullet weight, powder weight, and muzzle velocity for a selected powder type. The least-squares fit adjusts values for parameters in Vieille’s Law ( $u = u_T p^\alpha$ ) for 1) propellant burn rate coefficient ($u_T$) and 2) propellant burn rate exponent ($\alpha$) until the "best fit" to the input velocity measurements is achieved. When in the inverse calculation mode, the powder type must be selected on the "Inverse Calculation" page.
Figure 6. Input selection (a) and output calculations (b) for inverse calculation - friction mode for different gun/bullet combinations. Input selection (c) and output calculations (d) for one gun/bullet combination.
To select the burn rate inverse calculation mode, the "Inverse Calculation" tab under the "Calculation Mode and Program Control" label must be clicked. The "Burn Rate" tab on this page is also clicked and the powder type bullet shape selected. Additional input properties for up to ten cartridge loads are entered on this page. The output calculations are found under the "Calculation Outputs" label on the “Inverse Calculations” page and the tab labeled "Burn Rate". An example output is shown in Figure 7. The plot on the "Burn Rate" output page shows measured velocities plotted against best fit calculated velocities. For a good fit, data points should lie on, or close to, the 45° line shown in the plot. The best fit values for burn rate coefficient and burn rate exponent are given numerically. If the user desires to temporarily use these values, the button, “Press to Use” must be clicked. To keep and reuse these fit values, the button "Press to Save" must be clicked. In both cases, the fit values will replace the corresponding values under the "Select Powder" tab of the "Powder" page under the "Calculation Mode and Program Control" label. For the latter case, the propellant properties are permanently saved and will come up the next time the program is run, and the corresponding propellant selected. The limits on the graphs can be adjusted by changing the values for "v-lower limit" and "v-upper limit". Other controls on this page should be left with their default values unless the user has sufficient technical background in least-squares fitting of arbitrary functions to make appropriate changes. This mode of calculation will take up to a several minutes to execute.

The Burn Rate inverse calculation mode can also be used to find measurements that are out-of-family. The example calculation shown in Figure 8 uses the same input data as in Figure 7 except the muzzle velocity for the second cartridge (243 Win) is changed from 2806 ft/sec to 3425 ft/sec. It is easily seen in Figure 8 (b) that the new value is out-of-family, and can be assumed to be in error.

It should be noted that the results from both inverse calculation modes are only as good as the input measurement data. If there are significant errors in muzzle velocity measurements, or the wrong barrel length is input, or other errors exist in the data, the calculated barrel friction or propellant burn rate properties will be in error. One clue that there may be error in the input measurements is if the output value for “Residue” is negative or "NaN" (not a number) is displayed in place of the numerical output. This can happen if one or more measured muzzle velocities are unrealistically high or low for the amount of powder. The best practice is to repeat the calculation for three or more sets of data and then average results for calculated burn rate properties. Also, better results are obtained when providing data in all ten measurement inputs and, of course, using high precision, high accuracy measurements.

On the “Inverse Calculations” page under the “Calculation Mode and Program Control” label, with the "Burn Rate" tab selected, there is a button labeled “RSH” for Ratio of Specific Heats. If this button is green, as shown in Figures 7(a) and 8(a), the inverse calculation will calculate not only the burn rate constants, but also the ratio of specific heats. If it is red, only the burn rate constants will be calculated.

If the user is interested in having AnalyzeLoad customized to fit other parameters such as those listed on the "Sensitivity Analysis" page, the Box Elder Innovations software developers can be contacted through the website at www.boxelderinnovations.com with a request.
Figure 7. Input selection (a) and output calculations (b) for inverse calculation mode.

Figure 8. Least-Squares fit showing out-of-family 243 Win measurement (circled value in graph)
3.4 Exterior Ballistics

Input for the exterior ballistics module is found by clicking the “Exterior Ballistics” tab under the “Calculation Mode and Program Control” heading of the main user interface. The page shown in Figure 9 will then appear. Generally, this module will be used after the interior ballistics module is run first. The muzzle velocity, bullet weight and bullet diameter can then be imported by clicking the “Get Properties from Interior Ballistics Calc” button. Other properties and shooting conditions are manually input on the same page. Note that the “Scope Offset (in)” and the “Shooting Angle (deg)” are defined in the diagram on the lower right-hand side of the main user interface. It is not necessary to run the interior ballistics model first, before running the exterior ballistics model, but the user must remember to input all parameters needed for the exterior ballistics model. If this is not done, the program may crash, or most certainly give erroneous results.

There are additional input parameters on the “Calculation Output” page, “Trajectory 1 y(x)”. These include two numerical inputs, “Select Distance (yd)” and “Select Height (in)”, needed for computing the “Sight-In” trajectory. These must be correctly input into their respective fields before the exterior ballistics model is run. When all input data has been properly entered, the exterior ballistics module is run by clicking the button, “Run Exterior Ballistics Calculation” on the “Exterior Ballistics” page under the “Calculation Mode and Program Control” heading show in Figure 9.

The graphical outputs show the trajectory for the “Sight-In” conditions, and the “Trajectory Relative to the Line-of-Sight” when the gun is fired at the angle input in the “Shooting Angle (deg)” field of the “Exterior Ballistics” page under the “Calculation Mode and Program Control” heading. The user will note that the apparent trajectory when shooting at angles different from horizontal can differ considerably from horizontal shooting as given by the “Sight-In” conditions. On the “Trajectory 2 v(x), E(x)” page under the “Calculation Outputs” heading, the “Sight-In Velocity” and the “Sight-in Energy” curves are shown graphically as additional outputs. Figures 10 and 11 show typical results from the “Trajectory 1 y(x)” and “Trajectory 2 v(x), E(x)” pages, respectively. The plot labeled “Trajectory Relative to Line-of-Sight” is what the shooter will expect to see. The “max rise (in)”, “distance at max rise (yd)”, and “point blank range (yd)” are shown on this graph in Figure 10. Note that the maximum rise is greater when shooting uphill at a 30 deg angle than when shooting horizontally as shown in the “Sight-In” plot in Figure 10. The “point blank range (yd)” is defined as the range where the bullet is within +/− “max rise (in)”.

The “Sight-In Velocity” and “Sight-In Energy” are shown in Figure 11. These graphs have a cursor that marks the location where x (yds), v (ft/s), and E(ft-lbs) are indicated in the read-outs on the respective graphs. The button, “Cursors Unlocked” can be clicked and changed to “Cursors Locked” to lock the cursors in the two graphs so that the cursor in the energy graph will move, lock-step, with the cursor in the velocity graph when it is moved.

Referring to Figure 10, there are three save trajectory buttons below the top graph labeled “Save Trajectory 1”, “Save Trajectory 2”, and “Save Trajectory 3”. These buttons can be clicked to save up to three different trajectory calculations that can be reviewed on the “Compare EB Calc” tab shown in Figure 12. Also note that there are also three save pressure buttons on the “P(t)” tab (see Figure 4(a)) that can be used to save up to three different pressure-time curve calculations which can then be reviewed on the “Compare IB Calc” page as shown in Figure 13.
Figure 9. Input for Exterior Ballistics model
Calculation Outputs

Figure 10. Exterior ballistics calculation output using input parameters as defined in Figure 11 and in this chart just below the top graph.
**Figure 11.** Exterior ballistics calculation output using input parameters as defined in Figure 9.
Figure 12. Trajectory comparisons for up to three trajectory calculations.
**Calculation Outputs**

![Calculation Outputs](image)

**Figure 13.** Pressure-time comparisons for up to three interior ballistics calculations.

### 4.0 User Customization

As briefly discussed in previous sections, AnalyzeLoad has capability for the user to add cartridges and gun powders if they have the necessary physical and thermo-chemical properties.

#### 4.1 Adding or Deleting Cartridges

On the “Cartridge” page under the “Input Properties” heading, there are two tabs, one for inputting cartridge properties, “Select Cartridge”, and the other for adding or deleting cartridges, “Add/Delete”
**Cartridge** (See Figure 14). To add a cartridge, properties are inserted into the cartridge text list in the order shown in the heading at the top of the list. Each item is separated by a comma, with no spaces added. To delete a cartridge, simply delete the line corresponding to the cartridge no longer desired. When ready, press the “Save” button on that page. The cartridge list is permanently stored and can be immediately used, and it will also be read into the program the next time it is started up.

### 4.1 Adding or Deleting Powders

On the “**Powder**” page under the “**Input Properties**” heading, there are two tabs, one for inputting powder properties, “**Select Powder**”, and the other for adding or deleting powders, “**Add/Delete Powder**” (See Figure 15). To add a powder, properties are inserted into the powder text list in the order shown in the heading at the top of the list. Each item is separated by a comma, with no spaces added. To delete a powder, simply delete the line corresponding to the powder no longer desired. When ready, press the “Save” button on that page. The powder list is permanently stored and can be immediately used, and it will also be read into the program the next time it is started up.

![Screenshot of Input Properties](image)

**Figure 14.** AnalyzeLoad page for adding or deleting cartridges.
Input Properties

Figure 15. AnalyzeLoad page for adding or deleting powders.