RSFit3000 User Guide

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RSFit3000 consists of two files: RSFit3000.m, and RSFit300.fig. To run the program, both files must be on the MATLAB path. Then the program can be run like any other m-file, by entering the name in the MATLAB command window. Note, opening the fig-file will open a window with a static image of the GUI, but the program will not be operating. In this guide, we use the singe state variable synthetic data that is discussed in the main text.

1 Loading Data

1. To begin, load data into the MATLAB workspace and click the **Update Listbox** button on the GUI (Figure 1a). This will load the names of the variables in the workspace into the GUI; the variable names will appear in the **List Box**. Anytime variables are created or deleted in the workspace, clicking the **Update Listbox** button is required to pass the current variable names to the GUI.

2. The following data are required to perform fits: friction coefficient, load point displacement, normal stress, and time. Each of these data sets must be loaded into the MATLAB workspace as vectors with identical sizes. To proceed, type the proper variable names into the corresponding fields in the **Experimental Data** panel.

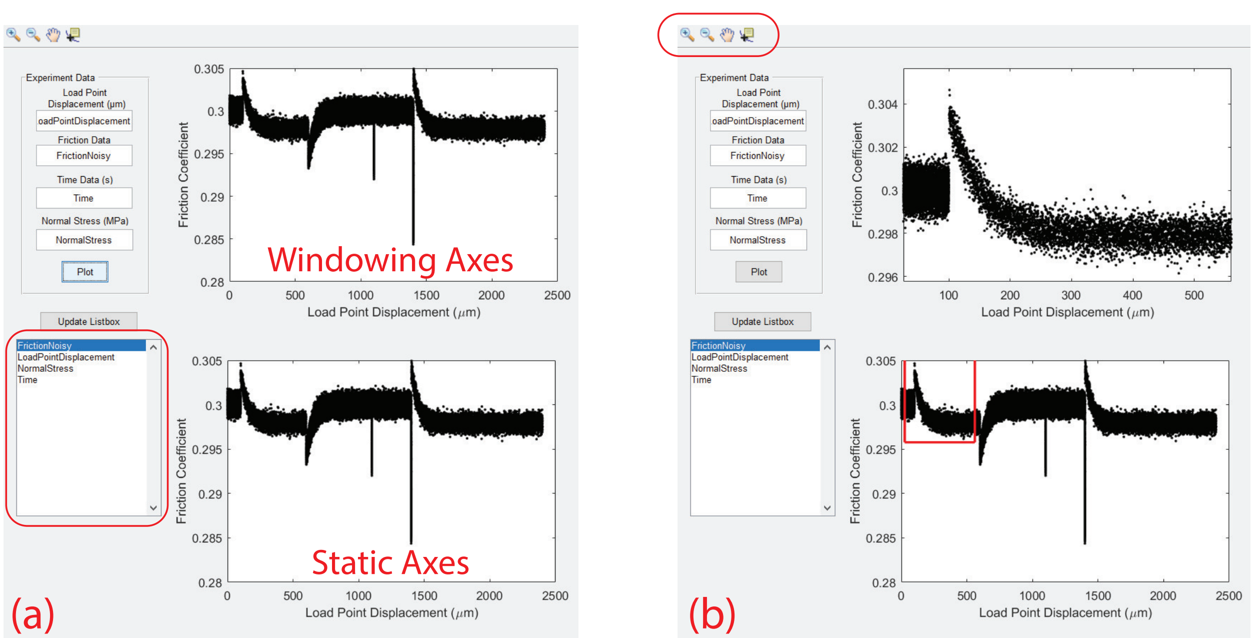


Figure 1: **Loading Data**. **(a)** The **Listbox** (red outline) displays the names of the variables that were in the MATLAB workspace the last time the **Update Listbox** button was pressed. **(b)** Use the zoom and scroll tools (red outline) to isolate a single friction event in the **Windowing Axes**. A red box will show the current zoomed location on the **Static Axes**.

3. When all fields have valid entries, click the **Plot** button. When the **Plot** button is clicked, initially identical plots of friction coefficient against load point displacement appear in the **Static** and **Windowing Axes** (Figure 1a).

4. To continue, use the selection tools (zoom, scroll) to isolate an event of interest in the **Windowing Axes**, such as a single velocity step or SHS event (Figure 1b). A red box will appear on the **Static Axes** showing the location of the windowed data within the entire data set.

2 Detrending

1. To detrend the data, select two points (δ_1, μ_1) and (δ_2, μ_2) on the windowed data (Figure 2a). First click the **Set Point 1** button, this will activate the data cursor mode on the GUI. Select a data point in the **Windowing Axes**, the load point displacement and friction values for the selected point will appear in the fields below the **Set Point 1** button. Do the same for the **Set Point 2** button. Be sure to select points so that the displacement for Point 1 is less than that for Point 2.

2. Click the **Fit Trend** button. This will fit a line to the data points that are between **Point 1** and **Point 2**. The line will be plotted in red on the **Windowing Axes**, and the slope of the fitted line will appear in the field below the **Fit Trend** button.

3. Select a Reference Point by clicking the **Set Reference Point** button. We recommend choosing a point just before the start of an event. Now the data can be detrended by clicking the **Detrend Button**

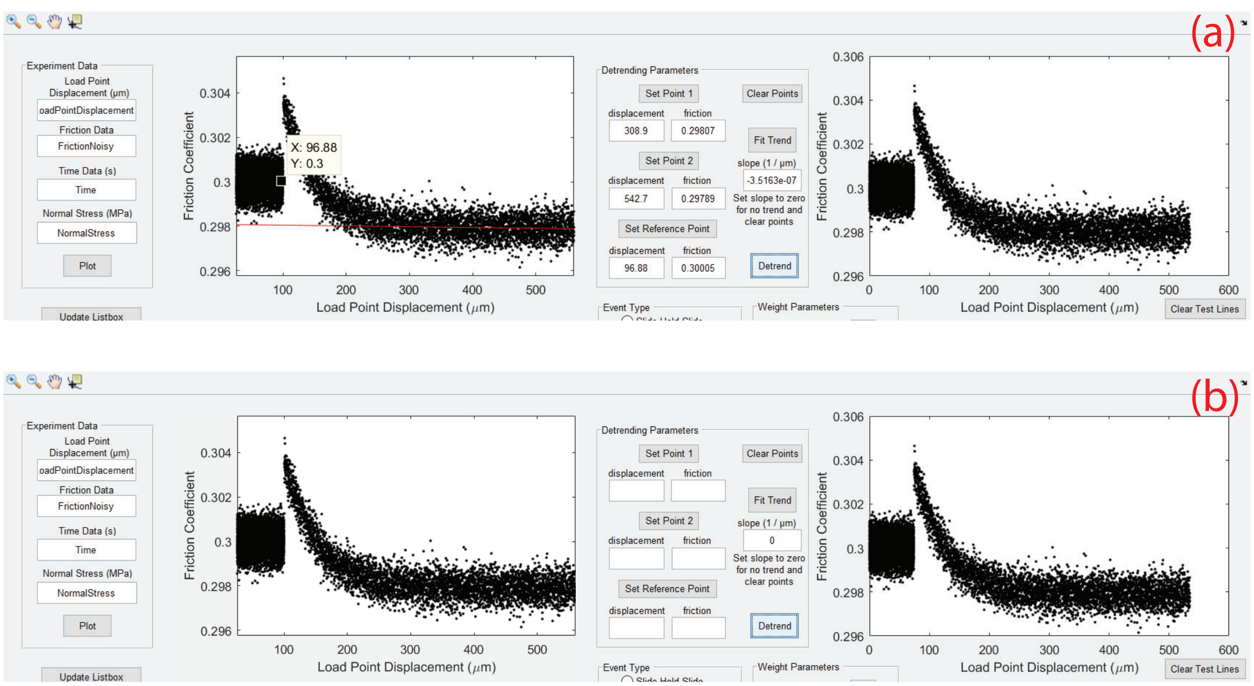


Figure 2: **Detrending (a)** Select Points 1 and 2, and the Reference Point on the **Windowing Axes**. **(b)** If no detrending is desired, click the **Clear Points** button, then set the slope value to "0" and click the **Detrend** button.

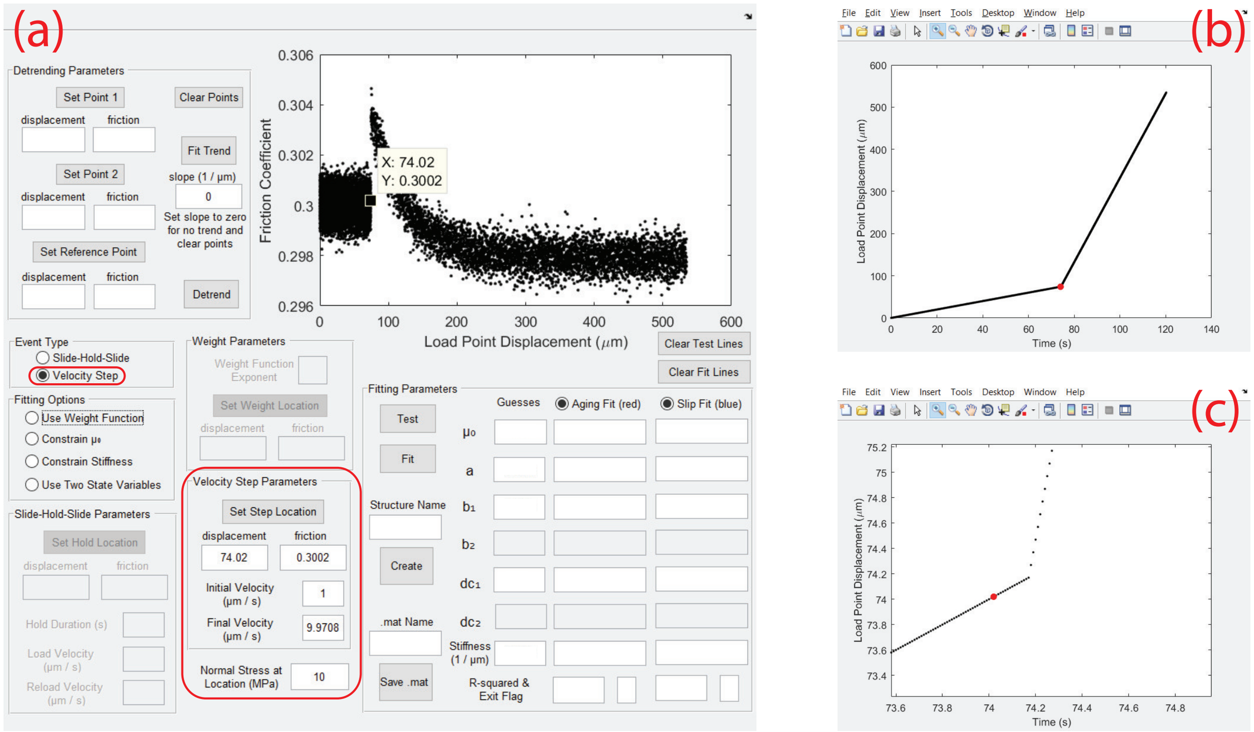


Figure 3: **Velocity Step Parameters (a)** Select the **Velocity Step** option on the **Event Type** panel. On the **Velocity Step Parameters** panel, click the **Set Step Location** button. **(b)** A plot of the load point displacement vs. time will appear when the velocity step location is selected. The red dot indicates the selected location. **(c)** To examine how well the location was selected, zoom in on the red dot in panel **(b)**. This location should be re-selected to be closer to the change in velocity.

4. Upon clicking the **Detrend Button**, the detrended and windowed data will appear in the **Fitting Axes**. The load point displacement data in the **Fitting Axes** will be referenced to zero at the beginning of the windowed event.

To continue without detrending the data, click the **Clear Points** button if any previous points have been set (Figure 1b). Then manually enter "0" into the **slope** field, and click the **Detrend** button.

3 Fitting

Select the proper event type (velocity step, or SHS) in the **Event Type** panel. Next set the event type parameters.

3.1 Velocity Step Parameters

1. Click the **Set Step Location** button, this will enable data cursor mode (Figure 3a). In the **Fitting Axes**, select a data point as close as possible at the displacement where the velocity step begins. If desired, use the zoom tool to zoom in on the start of the velocity step, then click the **Set Step Location** button. This will make selecting a good location much easier.

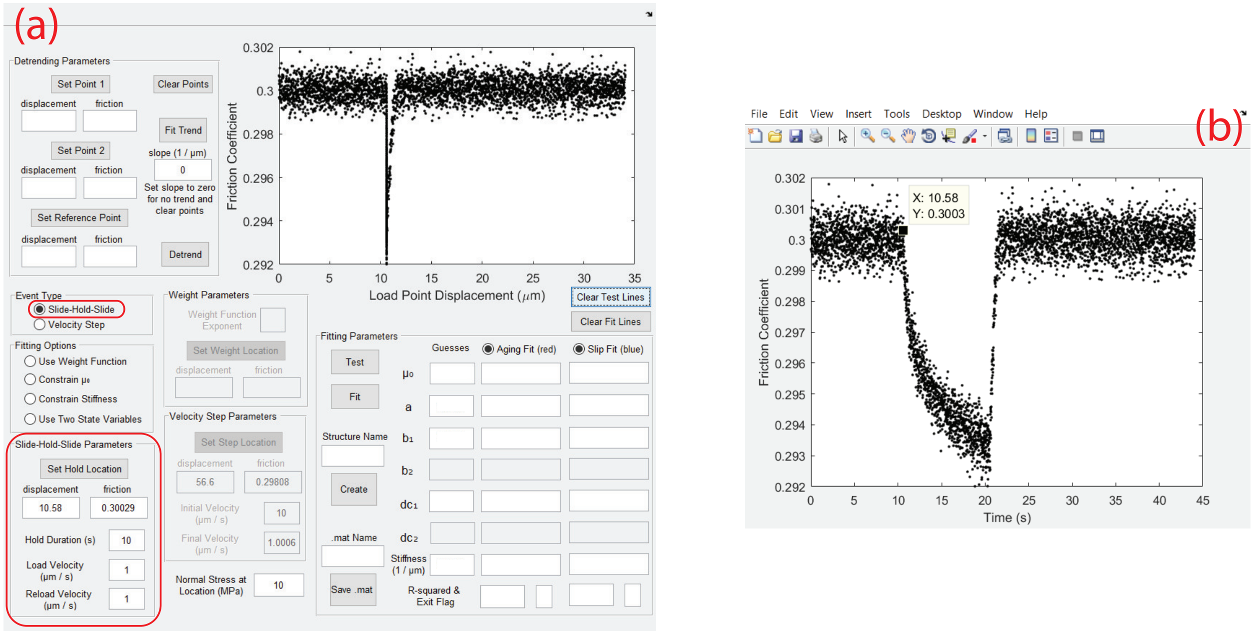


Figure 4: **Slide-Hold-Slide Parameters (a)** Select the **Slide-Hold-Slide** option on the **Event Type** panel. On the **Slide-Hold-Slide Parameters** panel, click the **Set Hold Location** button. **(b)** A plot of the load point displacement vs. time will appear, select the hold location on this new plot.

2. Upon making a step location selection, several things will happen. A figure will appear showing a plot of the zero-referenced load point displacement against time for the windowed data (Figure 3b). A red dot on this plot will show the selected location. This plot serves as a way to verify that the selected location is at the change in velocity (Figure 3c). If it is not, click the **Set Step Location** button again and make a new selection. The load point velocities before and after the selected location will appear in the **Initial Velocity** and **Final Velocity** fields, and the normal stress at the selected location will appear in the **Normal Stress at Location** field.

3.2 Slide-Hold-Slide Parameters

1. Click the **Set Hold Location** button (Figure 4a). This will enable data cursor mode and generate a new figure showing a plot of the windowed, detrended friction data against time (Figure 4b). On this figure, select a data point as close as possible at the time where the hold begins.

2. Upon making the selection, the normal stress at the selected location will appear in the **Normal Stress at Location** field.

3. The load point velocities before and after the hold must be manually entered in the **Load Velocity** and **Reload Velocity** fields. The length of time that the hold lasted must be manually entered in the **Hold Duration** field.

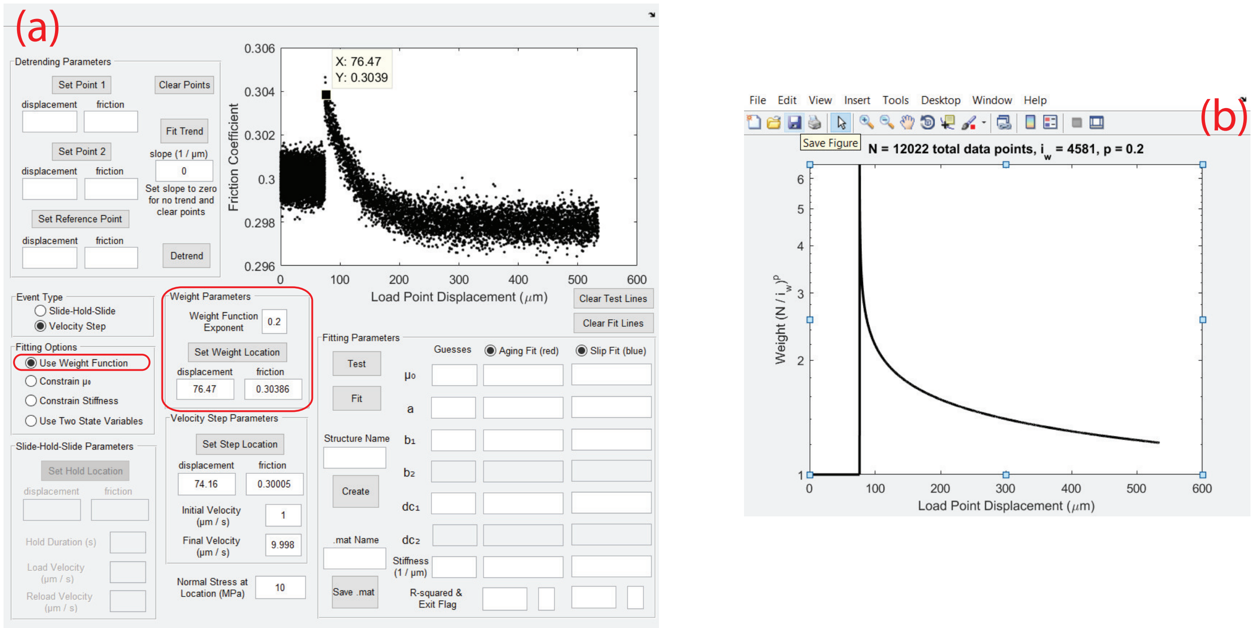


Figure 5: **Weight Function**. **(a)** Selection the **Use Weight Function** option on the **Fitting Options** panel. This will activate the **Weight Parameters** panel. Enter a value in the **Weight Function Exponent** field before clicking the **Set Weight Location** button. **(b)** A plot of the weight values vs. load point displacement will appear when the weight location is selected.

3.3 Fitting Options

There are four options available for performing a fit: 1) use of a weighting function, use of 2) μ_0 or 3) stiffness k as fitting parameters, and 4) use of two state variables. Any of these options may be combined with one another. Selecting any combination of the **Constrain** μ_0, **Constrain Stiffness**, or **Use Two State Variable** options will activate/deactivate the corresponding fields in the **Fitting Parameters** panel.

3.3.1 Weight Function

1. If the **Use Weight Function** option is selected, the **Weight Parameters** panel will become active. First enter a value in the **Weight Function Exponent** field (Figure 5a).

2. Click the **Set Weight Location** button, this will enable data cursor mode. Set the weight location by selecting a data point in the **Fitting Axes**.

3. Once selected, the corresponding values of load point displacement and friction coefficient will appear in the fields below the **Set Weight Location** button. A new figure will also appear, showing a plot of the resulting weight values against load point displacement (Figure 5b).

4. The weight values w_i are calculated according to

$$w_i = \begin{cases} 1 & i < i_w \\ \left(\frac{N}{j}\right)^p & i \geq i_w \end{cases} \tag{1}$$

where $i = 1, ..., N$, and N is the total number of windowed data points, j is an index that runs from 1 to $N - i_w$, and i_w is the index of the selected weight location (taken from the set of indices i, rather than j).

3.4 Fitting Parameters

1. The fitting procedure can now be applied to the detrended data. First, select whether to perform fits using either, or both of the state evolution laws.

2. Enter trial values for μ_0, a, b_1, d_{c1}, k (Figure 6a). If using two state variables, enter trial values for b_2 and d_{c2} as well. Values for μ_0 and k must be entered regardless of whether the options to constrain these two values are selected.

3. After entering the trial values, click the **Test** button. The program will run a spring-slider simulation using the trial values, and the event parameters in either the **Velocity Step Parameters** panel, or the **Slide-Hold-Slide Parameters** panel. The results of the simulation will be plotted as dashed lines over the data in the **Fitting Axes** (Figure 6a).

4. If the test lines do not closely overlie the data, any of the trial values can be changed to run another test. This process should be repeated until the test lines overlie the data as much as

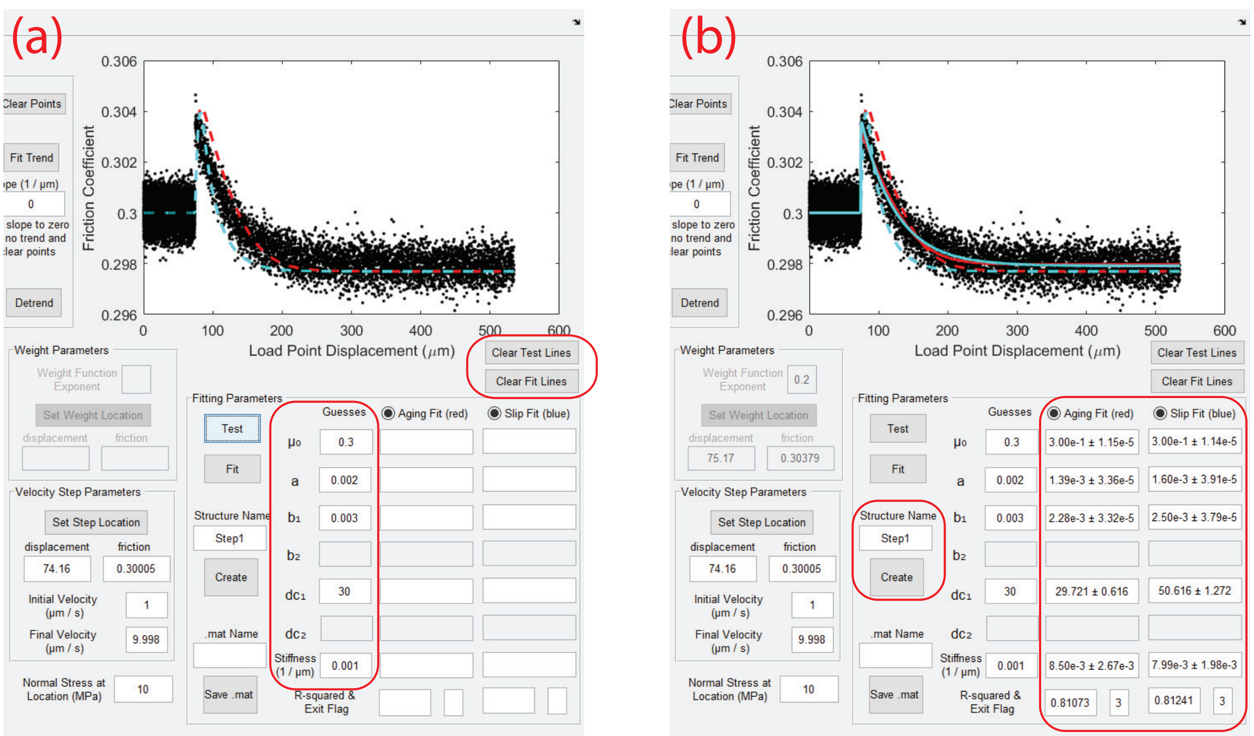


Figure 6: **Fitting Parameters (a)** Enter guess values for all of the active fields. In this example the b_2 and d_{c2} fields are deactivated because the **Use Two State Variables** option is not selected. After clicking the **Test** button, dashed lines showing the results of spring-slider simulations using the guess values will appear on the **Fitting Axes**. At any time, the test or fit lines can be cleared from the **Fitting Axes** by clicking the **Clear Test Lines** or **Clear Fit Lines** buttons. **(b)** The fitting routine will run when the **Fit** button is clicked. The results will appear in the **Fitting Parameters** panel, and on the **Fitting Axes** as solid lines.

possible. Obtaining trial values in this manner is critical to obtaining good fitted parameter values.

5. After generating satisfactory parameter guesses, click the **Fit Button**, and the program will carry out the nonlinear least squares fitting routine. Information regarding the number of solution attempts, and the parameter values for each attempt will be displayed in the MATLAB Command Window as the fitting routine is running.

6. When the routine has completed, the fitted parameter values, along with the $2s$ error intervals, will be displayed in the corresponding fields in the **Fitting Parameters Panel**. The results of a spring-slider simulation using the fitted values will be plotted over the data as solid lines in the **Fitting Axes** (Figure 6b). The R^2 value, and an exit flag indicating why the solver stopped will also appear at the bottom of the **Fitting Parameters Panel**.

7. Save the fit parameters and data using the **Create Structure** button (Figure 6b, see below).

8. Window another velocity step or SHS event in the **Windowing Axes** and repeat the procedures described above to obtain more fits, as desired.

3.4.1 Exit Flags

Exit Flag	Meaning
1	Local minimum of the objective function found
3	Relative sum of squares of the objective function is changing by less than the **FunctionTolerance**
4	Norm of the step size is changing by less than the **StepTolerance**
0	Number of iterations exceeded **MaxIterations**, or number of function evaluations exceeded **MaxFunctionEvaluations**

Table 1: This is a list of the exit flags and their meanings.

Exit flags 3 and 4 are the most common result. The values of **StepTolerance**, **FunctionTolerance**, **MaxIterations**, and **MaxFunctionEvaluations** can be changed using the built-in MATLAB function **optimoptions**. These options can be set on Line 820 in RSFit3000.m.

3.5 Solver Failures

Sometimes the ODE solver will not be able to complete a simulation. For example, this can happen if the combination of parameters leads to stick-slip events. ODE solver failures can generally be avoided by starting with a good set of trail values. If the solver does fail, an error message will appear in the MATLAB command window showing the parameter values that led to the failure. This can be helpful in understanding why the solver failed. Changing the fitting options can sometimes lead to a successful fit. Additionally, a number of other warnings and error messages associated with the solver failure will also be displayed.

4 Data Structure

When a satisfactory fit has been completed, enter a name in the **Structure Name** field, and click the **Create Structure** button. A structure with the entered name will appear in the MATLAB workspace. This structure contains all of the relevant information necessary to produce the fit. The contents of the structure vary slightly, depending on whether the fitted event was a velocity step or a SHS. The fields contained in the structure are as follows:

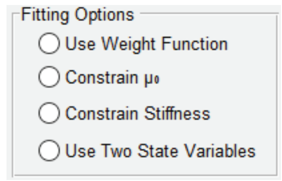
- **Load Point Displacement Data** – a vector of windowed load point displacement values.
- **Friction Data** – a vector of windowed friction coefficient values.
- **Friction Data Detrended** – a vector of detrended friction coefficient values.
- **Time Data** – a vector of windowed time values.
- **Normal Stress Data** – a vector of windowed normal stress values.
- **Detrend Parameters** – a sub-structure containing the coordinates of **Point 1**, **Point 2**, **Reference Point**, and the slope of the fitted detrending line.
- **Fitting Options** – a sub-structure indicating the friction event type, as well as what options were used to generate the fit.
- **Velocity Step / Slide-Hold-Slide Parameters** – For a velocity step: a sub-structure containing the friction and zero-referenced load point displacement when the step occurred, as well as the initial and final velocities, the time at which the step occurred, and the normal stress when the step occurred. For a SHS: a sub-structure containing the friction and zero-referenced load point displacement when the hold initiated, as well as the load and reload velocities, the time at which the hold initiated (Time Of Hold), the duration of the hold (Hold Duration), and the normal stress when the hold initiated.
- **Guess Parameters** – a sub-structure containing trial values of μ_0, a, b_1, d_{c1}, k, and optionally b_2 and d_{c2} as well. If one state variable was used, the trial values for both b_2 and d_{c2} will be listed as zero.
- **Aging Law Parameters and Slip Law Parameters** – sub-structures containing the fitted parameter values and error intervals for aging and slip law fits, respectively. The field for each fitted parameter is stored as a 1×2 array. The first column contains the parameter value, and the second column contains the $2s$ error interval. If one state variable was used, the fields for b_2 and d_{c2} will contain zeros. If either μ_0 or the stiffness were constrained, these parameters will have "0" as the error interval. The exit flag, R^2 value, and covariance matrix will also be stored in separate fields. See below for information on the contents of the covariance matrix.
- **Aging Law Fit and Slip Law Fit** – Arrays with two, or three columns. First column: load point displacement data used for the fit. Second column: predicted detrended friction coefficient values. If the data has not been detrended there will only be two columns. If the data has been detrended, there will be a third column containing: predicted friction coefficient values with the trend added back in.
- **Weight Info** – A sub-structure containing a vector of weight values, the number N of windowed data points, the index i_w of the selected weight location, the value p of the weight function exponent, and the friction and zero-referenced load point displacement at the weight location.

4.1 Covariance Matrix

The contents of the covariance matrix depend on what fitting options are selected. Depending on these options, the rows and columns of the matrix correspond to different parameters, as listed below. The covariance matrix is an $M \times M$ matrix, where M is the number of fitted parameters.

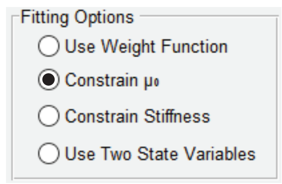
1. No options selected

$$\begin{array}{cc} & \begin{array}{ccccc} \mu_0 & a & b_1 & d_{c1} & k \end{array} \\ \begin{array}{c} \mu_0 \\ a \\ b_1 \\ d_{c1} \\ k \end{array} & \begin{pmatrix} & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \end{pmatrix} \end{array}$$



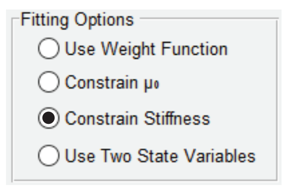
2. **Constrain** μ_0 selected

$$\begin{array}{cc} & \begin{array}{cccc} a & b_1 & d_{c1} & k \end{array} \\ \begin{array}{c} a \\ b_1 \\ d_{c1} \\ k \end{array} & \begin{pmatrix} & & & \\ & & & \\ & & & \\ & & & \end{pmatrix} \end{array}$$



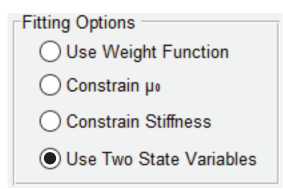
3. **Constrain Stiffness** selected

$$\begin{array}{cc} & \begin{array}{cccc} \mu_0 & a & b_1 & d_{c1} \end{array} \\ \begin{array}{c} \mu_0 \\ a \\ b_1 \\ d_{c1} \end{array} & \begin{pmatrix} & & & \\ & & & \\ & & & \\ & & & \end{pmatrix} \end{array}$$



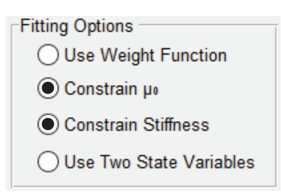
4. **Use Two State Variables** selected

$$\begin{array}{cc} & \begin{array}{ccccccc} \mu_0 & a & b_1 & d_{c1} & k & b_2 & d_{c2} \end{array} \\ \begin{array}{c} \mu_0 \\ a \\ b_1 \\ d_{c1} \\ k \\ b_2 \\ d_{c2} \end{array} & \begin{pmatrix} & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \end{pmatrix} \end{array}$$



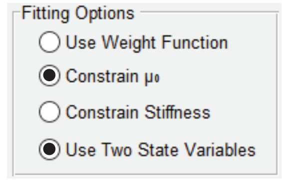
5. **Constrain** μ_0, **Constrain Stiffness** selected

$$\begin{array}{cc} & \begin{array}{ccc} a & b_1 & d_{c1} \end{array} \\ \begin{array}{c} a \\ b_1 \\ d_{c1} \end{array} & \begin{pmatrix} & & \\ & & \\ & & \end{pmatrix} \end{array}$$



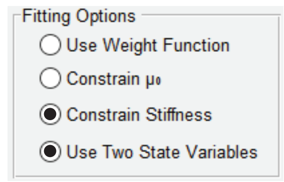
6. **Constrain μ_0, Use Two State Variables** selected

$$\begin{array}{cc} & \begin{matrix} a & b_1 & d_{c1} & k & b_2 & d_{c2} \end{matrix} \\ \begin{matrix} a \\ b_1 \\ d_{c1} \\ k \\ b_2 \\ d_{c2} \end{matrix} & \left(\begin{matrix} \quad \\ \quad \\ \quad \\ \quad \\ \quad \\ \quad \end{matrix} \right) \end{array}$$



7. **Constrain Stiffness, Use Two State Variables** selected

$$\begin{array}{cc} & \begin{matrix} \mu_0 & a & b_1 & d_{c1} & b_2 & d_{c2} \end{matrix} \\ \begin{matrix} \mu_0 \\ a \\ b_1 \\ d_{c1} \\ b_2 \\ d_{c2} \end{matrix} & \left(\begin{matrix} \quad \\ \quad \\ \quad \\ \quad \\ \quad \\ \quad \end{matrix} \right) \end{array}$$



8. All options selected

$$\begin{array}{cc} & \begin{matrix} a & b_1 & d_{c1} & b_2 & d_{c2} \end{matrix} \\ \begin{matrix} a \\ b_1 \\ d_{c1} \\ b_2 \\ d_{c2} \end{matrix} & \left(\begin{matrix} \quad \\ \quad \\ \quad \\ \quad \\ \quad \end{matrix} \right) \end{array}$$