



MCrunch User's Guide for Version 1.00

M. Buhl, Jr.

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for MCrunch v1.00.00

Technical Report
NREL/TP-500-43139
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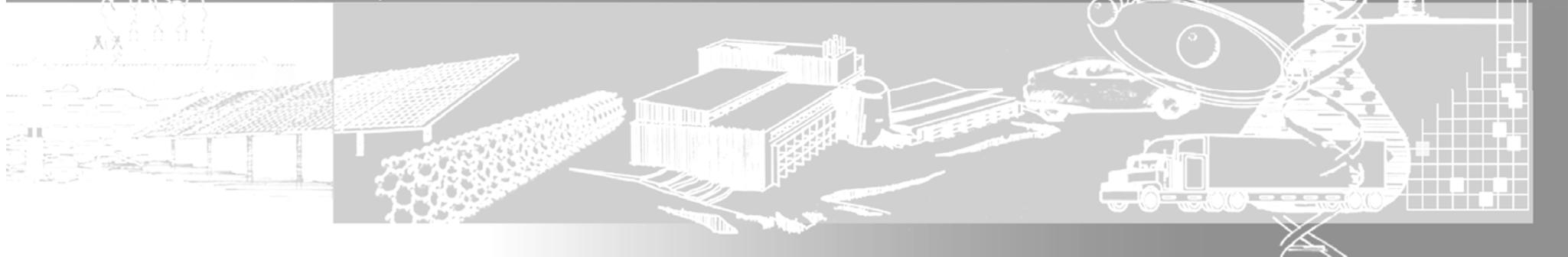
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Background

During the past 20 years, the National Wind Technology Center (NWTC) has written several programs to process wind turbine test and simulation data. These include Crunch (Buhl 2003), GPP (Buhl and Weaver 1999), and GenStats (Buhl 2002). In 2007, the NWTC queried the user community about future development of postprocessors. The consensus was that we should write postprocessors in MatLab (The MathWorks 2008) script and abandon planned enhancements to Crunch and the other Fortran-based codes. The reasoning was that schools no longer teach Fortran, but have students use MatLab instead. We decided to take the features in our old postprocessors and convert them to MatLab scripts; thus, MCrunch was born.

Introduction

MCrunch (pronounced *em-crunch*) is a set of MatLab scripts that perform many types of analyses for one or more files. Although MCrunch can operate interactively, using a supplied script to read a Crunch-style input file and run it in batch mode is more efficient. Although we developed MCrunch to process wind turbine test and simulation data, it may also be useful for other types of data.

As shown by the length of the Possible Future Enhancements section of this guide, the current version of MCrunch is just a beginning. We need to add many more features, but our resources are limited. We will establish priorities based on personal need and feedback from the user community.

MCrunch stores the input data and most of the results in various MatLab global structures that you can access outside MCrunch. This allows you to make other calculations or present the data in ways MCrunch cannot.

NREL distributes the source scripts, sample files, and a compiled version of MCrunch. If you do not own a MatLab license, you will have to use the compiled version. This requires you to download the free MatLab libraries (MCRInstaller.exe) from <http://wind.nrel.gov/designcodes/postprocessors/mcrunch/>. If you own MatLab and use the source scripts, you will need the Statistics and Signal Processing Toolboxes.

Retrieving Files From the Archive

You can download the MCrunch archive from our web server at <http://wind.nrel.gov/designcodes/postprocessors/>. The file has a name similar to *MCrunch_v1.00.00.exe*, but may have a different version number. Create an MCrunch folder somewhere on your file system and put this file there. When you double click on it from Windows Explorer, it will create some files and folders. To use the scripts, you need to add MCrunch's *Source* folder to the MatLab search path. Make MatLab's current directory the folder that contains the input file(s) you want to process.

Distributed Files

The files included in the MCrunch archive are:

<i>ChangeLog.txt</i>	The list of changes to MCrunch.
<i>MCrunch.pdf</i>	This user's guide in PDF format.
<i>CertTest*.out</i>	Time-series data used for the automated tests.
<i>CertTest*.m</i>	Scripts for the certification tests.
<i>CertTest*.mcru</i>	The MCrunch input files used by the certification script.
<i>CertTest\TestFiles*.*</i>	The results from the developer's certification test.
<i>Compiled\Mcrunch.exe</i>	The compiled MCrunch executable for those who do not own MatLab.
<i>Compiled\Mcrunch.ctf</i>	An archive of files needed for the compiled version of MCrunch.
<i>Source*.m</i>	MCrunch source files.

Certification Script

Before using MCrunch, you should run the certification script. It is a MatLab script called *CertTest.m*; make sure that the MCrunch *Source* folder is in the MatLab search path and the *CertTest* folder is the current directory, and then enter *CertTest*.

MCrunch will run multiple times. The test procedure will compare the results to those stored in the *CertTest\TestFiles* folder. The procedure will write the differences between the output files to a file called *CertTest.comp*. The test procedure will automatically open this file with the MatLab editor at the end of the tests. Scan through the file; the only differences should be the date and time stamps in the headers. If you run MCrunch with a version other than the one used in development, there may be slight differences in the last digits of some of the numbers.

Running MCrunch

The syntax for the MCrunch script is *MCrunch('SettingsFile')*, where *SettingsFile* is a Crunch-like input file that tells MCrunch what to do and how to process the data files. MCrunch will call *ReadSettings* to read the *SettingsFile*. After processing the settings input, MCrunch will call the appropriate scripts to do the requested analyses.

You do not need to call MCrunch to perform its analyses. You can create your own scripts that set the parameters and read the data files into the structures the MCrunch analysis scripts use. You can call the analysis scripts from your script or interactively in the MatLab *Command Window*. The results from the scripts that read the input files and analyze the data are available as global structures. You can access them using MatLab functions or scripts or with the MatLab *Array Editor* if you declare them to be global in the MatLab *Command Window* or within your scripts. Table 1 contains a list of the most important data structures, which are mostly self-explanatory and change slightly depending on several factors. Using the MatLab Array Editor to explore them should help you find information you need.

Table 1. Primary Global Structures in MCrunch

<i>FileInfo</i>	Contains information about the structure of the input files, the time-series data, and basic statistics.
<i>Binning</i>	Contains settings and results for binning.
<i>Fatigue</i>	Contains settings and results for the fatigue analysis.
<i>PDF</i>	Contains settings and results for the probability-density analysis.
<i>PSD</i>	Contains settings and results for the power-spectral-density analysis.

Running MCrunch without MatLab

If you do not own a license to MatLab, you can run the compiled version of MCrunch, but it will work only with Microsoft Windows. We have done only the minimum required to make it work, but initial tests have shown that it is inferior to running within MatLab. For example, you will see none of the informational messages that would normally go to the MatLab *Command Window*. The program *appears* to do nothing at first and the command prompt returns immediately after you start it, which can give you the impression that it has completed. Eventually, plots will pop up (if requested) and output files will show up in the current folder. The damage-equivalent-load tables that MCrunch normally displays with the MatLab HTML viewer generate error messages. There may be ways to eliminate these problems, but we consider these issues to be very low priority.

To use the compiled version of MCrunch, you first have to install the MatLab Component Runtime (MCR). You need do this only once per version of MatLab. It must be compatible with the MatLab version used to compile MCrunch. You can find a compatible copy of the MCR Installer on the MCrunch Web page (see the Introduction). The file is very large, so be prepared to take some time downloading it. Once you have downloaded it, execute the file (*MCRInstaller.exe*) to install it, following the prompts.

Next, you have to modify the Windows search path to include the MCR *win32* folder (for example, *C:\Program Files\MATLAB\MATLAB Component Runtime\v77\bin\win32*). To do this in Windows XP, right click on *My Computer* and choose *Properties*. In the *System Properties* window, click on the *Environment Variables* button on the *Advanced* tab. In the *System Variables* list, select *Path* and click on *Edit*. Hit the *Home* key on your keyboard and enter the appropriate path followed by a semicolon. Click on *OK* several times to save your changes.

Using MCR requires that you copy *MCrunch.exe* and *MCrunch.ctf* to any folder that contains MCrunch input files you want to process. The first time you run it within any given folder, it will extract files from the *MCrunch.ctf* archive and create an *MCrunch_mcr* folder with encrypted versions of the MCrunch scripts along with a lot of support files. To process an MCrunch input file, open a *Command Prompt* window (*Start, Programs, Accessories, Command Prompt*) and change the current directory to one containing your input file(s). In the window, enter *MCrunch <input file>*. For example, in MCrunch's *CertTest* folder, enter *MCrunch test_01.mcr*.

Types of Output

For most analyses, you have the option of writing results to plain text files, Excel workbooks, plots, or a combination of these. MCrunch also tabulates DELs in HTML files for viewing with a browser.

MCrunch can generate many types and almost any combination of analyses during a single run. Most analyses process individual files and an aggregate of all the files. The aggregate is essentially a concatenation; that is, a series or chain of all the files into a single data set. It is appropriate for most of the analyses. For rainflow cycle counting, a usually negligible error occurs because of the discontinuities. Instead of taking the PSD of the aggregate of the files, MCrunch averages the PSDs of the individual files. Otherwise, a significant amount of white noise can be added to the result because of the potential discontinuities at the interfaces.

Plain text output files generated for individual files use the original data file's root name and append an appropriate extension. Output files generated for aggregate analyses use a user-specified root name instead. The extensions are:

<i>dels</i>	Damage-equivalent loads
<i>extr</i>	Extreme events
<i>pdfs</i>	Probability-density functions (histograms)
<i>psds</i>	Power spectral densities
<i>rflo</i>	Rainflow cycles (raw or binned)
<i>stat</i>	Statistics
<i>sums</i>	Summary statistics

For output to Excel workbooks, MCrunch does not create a separate output file for each input file plus one for the aggregate. Instead, it creates a single workbook and uses separate sheets instead of separate files.

File Headers

All output files have similar headers. The headers contain the following information:

- Program name, version, compile date, and run date.
- Number of records used in the analysis and, for aggregates, the number of files comprising the aggregate. This is not currently true for all analyses.

The Settings File

Settings File Format

Use one of the sample *.mcr* files found in the *CertTest* folder as a template. Except for a few block tables that follow lines that include comments such as "NumCChan rows of data follow" and the list of data files at the end, you should not add or remove any lines from the sample settings file. For data files, list the file names one per line and enclose them in double quotes. A line beginning with *==EOF==*

must come after the last data file. MCrunch's *ReadSettings* function ignores anything after the `==EOF==` line.

As long as the parameter(s) being read is (are) the first "word(s)" on the line and it is (they are) separated from the comment portion of the line with white space, MCrunch will not be affected. The amount of spacing is not important—use whatever looks good to you. You must separate any lists of numbers with white space—not commas. Block tables have their own special formats.

Title Line

The second line of the file is for a job title. The line can be of any length and contain anything you might find useful. Although MCrunch does not currently use this line for anything, it may someday include it in output files.

Job Options

There are currently five inputs in the Job Options section of the settings file. The first, *EchoInp*, allows you to request MCrunch to echo your settings file input parameters to another file so you can debug your settings file. The echo file has the same root name as your settings file and *echo* for an extension.

One common complaint about our old Crunch postprocessor is that if you add new channels to your data files, you have to change the channel numbers used in the settings file. We find that quite tedious and prone to error when we have more than 100 channels in our data files. We decided to allow users to specify channels by their names instead of numbers. If you want to take advantage of this feature, set *StrNames* to true and use the channel names following a \$ anywhere channel numbers would normally go. Here's an example:

```
$RootFxc1 $RootFyc1 $RootFzc1 SFChans
```

If you enable *StrNames*, you don't have to use them exclusively; numbers will still work as *ReadSettings* simply replaces all the *\$ChanName* strings found in the settings file with the channel numbers before processing the file.

A future release will allow you to write out the input data after MCrunch applies scales and offsets, filters the data, and adds calculated channels.

Use the *RealFmt* parameter to specify the formatting of fixed-point numbers in the output. The standard MatLab *sprintf* syntax applies. You must enclose this string in double quotes.

AggRoot holds the root name of output files that contain analysis results based on using all input files as a single time series. You must enclose this string in double quotes.

Input-Data Layout

MCrunch can automatically determine the number of columns and rows in your data files, or you can specify these things explicitly. If you want this, set the number of input channels to zero and don't give it a list of channels.

If you want MCrunch to parse channel names and units from the input file, specify the lines that contain such information. If you specify a zero for either, MCrunch assumes there is no such line. If you tell MCrunch which line contains names, it will use that line to determine the number of channels. It assumes that channel titles are a contiguous group of letters and/or symbols that do not contain any whitespace. For example, if the channel-names line is as follows:

```
Chan1 "Chan2"Chan_3, Chan-4 " Chan 5",
```

MCrunch would find six channels whose titles would be `<Chan1>`, `<"Chan2"Chan_3,>`, `<Chan-4>`, `<">`, `<Chan>`, and `<5">` (without the angle brackets). If your input file has a title line similar to this:

```
"Chan 1" "Chan 2" "Chan 3"
```

and it has three columns of data, you cannot use the auto-detection feature for columns because MCrunch will think it has six channels (three named *"Chan"*). If something such as this is the case, you should specify the channel information in the parameter input file.

Currently, you must either specify channel names and units within the settings file, or tell MCrunch to read them from the data file(s). A future release will assign default names such as *Chan001* if there is no source of names.

If you choose autodetection of channels and give a zero for the line containing the units, MCrunch will not include any unit strings in the output. If that is the case, you must not specify the units for calculated channels.

If you want to specify channel layout, set *NumChans* to a number greater than zero. After the comment line describing the format for the channel table, enter *NumChans* lines with the channel names in double quotes, the units in double quotes, a fixed-point number for the scale, and another for the offset.

MCrunch cannot currently reorder or use a subset of channels, but it can rename channels from the original data file with this feature. It will apply scales and offsets as it reads the data. If you let MCrunch autodetect channels, it cannot apply scales and offsets.

Unlike Crunch, MCrunch does not require that all files have the same number of lines. Like Crunch, it does require that the channel layout be the same for all files; that is, all data files must have the same number of channels and the same number of header lines.

MCrunch can also create new channels using typical MatLab expressions with references to other channels. (See the Calculated-Channels section.)

Filtering

We have yet to add filtering to MCrunch, but the Filtering header line must still be in the settings file.

Calculated Channels

You can create new channels of data through the calculated-channels feature, which allows you to specify a single MatLab expression for each new channel.

MCrunch numbers calculated channels in the order created; the number of the first one is one more than the number of input channels.

NumCChan specifies the number of new channels being created. If a calculated channel will need a seed to initialize a pseudo-random sequence, use *Seed* to store that value. Even if you don't use the random-number generator, you must include *seed* in the input file. A comment line describing the format for the lines describing the calculated channels is next. After that, enter one line for each calculated channel. These lines contain three fields; each should be enclosed in double quotes and separated by white space. The first field is for the channel name. The second is for the channel units (omit this if you are not using units). The last field is the MatLab-style expression.

Figure 1 is an example of the calculated-channels section of the settings file when string names are used (*StrNames=true*):

```
----- Calculated Channels -----
2          NumCChan The number calculated channels to generate.
1234567890 Seed The integer seed for the random number generator
Col_Title Units Equation Put each field in quotes. Titles and...
"RootFMxy1" "(kN)" "sqrt( FileInfo.Time(:, $RootFxc1).^2 +
                FileInfo.Time(:, $RootFyc1).^2 )"
"RootMMxy1" "(kN·m)" "sqrt( FileInfo.Time(:, $RootMxc1).^2 +
                FileInfo.Time(:, $RootMyc1).^2 )"
```

Figure 1. Example input for calculated channels.

Generic Plot Information

Several analyses have optional plot output. Some parameters are common to all plot types. Use this section to specify them. The *LineWidth* parameter specifies the width of curves in points (1/72 in.). Use *FigLeftPos*, *FigBottomPos*, *FigWidth*, and *FigHeight* to specify the location and size in pixels of all plots generated on your screen. All plots are the same size and placed in the same location; the last ones lie on top. If you would like a figure title placed in the top-center of each figure window, enable *FigTitles* by setting it to *true*. All figure windows will have the same window names as the titles regardless of the setting of *FigTitles*. If you enabled *SaveFigs*, each MCrunch will write each figure to a *.fig* file with the figure title as the root of the file name.

Time-Series Plots

You can plot time series with MCrunch. This works with input channels and calculated channels. If you apply scales and offsets to the input data, the plots will reflect the scaling. *NumTimeFigs* specifies the number of figure windows; each can contain one or more subplots. If you are processing multiple files, each subplot will contain one channel with a line for each file. Enter one line in the settings file for each channel you want to plot. The fields of each line are the figure titles enclosed in double quotes, the number of rows of subplots, the number of columns of subplots, and the list of channels. Enter the channels row by row.

In the example in Figure 2, channels 23 and 24 will appear on the first row of the second figure window, which MCrunch will name "Tip Deflections." The resulting chart, containing the time series for two files, appears in Figure 3.

```
----- Time-Series Plots -----
2          NumTimeFigs          Number of time-series figures...
FigureName #Rows #Cols Channel list (must...
"Wave Elevation" 1 1 5
"Tip Deflections" 3 2 23 24 26 27 29 30
```

Figure 2. Example input for time-series plots.

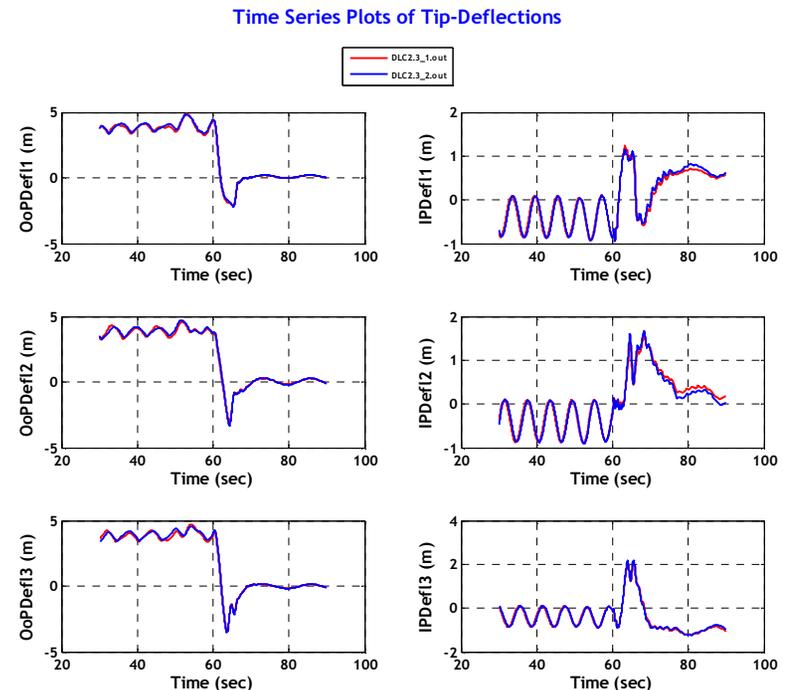


Figure 3. Example time-series plots.

Moving Averages

We have yet to add moving averages to MCrunch, but the Moving Averages header line must still be in the settings file.

Time and Wind-Speed Columns

You can tell MCrunch which of your input columns contain the time and wind speed. Although none of the analyses currently use the wind-speed channel, some will in the future and the parameter must appear in the settings file.

Load Roses

We have yet to add load roses to MCrunch, but the Load Roses header line must still be in the settings file.

Azimuth Averages

We have yet to add azimuth averages to MCrunch, but the Azimuth Averages header line must still be in the settings file. You may be able to use the Binning feature (see Binning subsection) to generate azimuth averages.

Crosstalk Removal

We have yet to add crosstalk removal to MCrunch, but the Crosstalk Removal header line must still be in the settings file.

Peak Finding

We have yet to add peak finding to MCrunch, but the Peak Finding header line must still be in the settings file.

Statistics and Extreme Events

MCrunch can generate the following statistics:

- Minimum
- Mean
- Maximum
- Standard Deviation
- Skewness
- Maximum Range (Maximum-Minimum)

If you set *WrStatsTxt* to *true*, MCrunch will write a table of statistics for each input data file with a *.stat* extension. When there is more than one data file, MCrunch will use the aggregate of all the data to generate a statistics table and use the value of *AggRoot* followed by *.stat* to name the plain text file (if requested).

If you set *WrStatsXLS* to *true*, MCrunch will create an Excel workbook with one tab for each data file and one for the aggregate if you processed more than one data file. The tabs will have names using the root names of the data files and *Aggregate* for the aggregate statistics. MCrunch will use the root name of the settings file followed by *_Stats.xls* to name the workbook.

MCrunch can also create summary files of the statistics for selected channels. Set *NumSFChans* to the number of channels you want processed this way and list the channels on the *SFChans* line that follows. MCrunch generates files of statistics for each requested channel. The file names use the channel names for the root and *.sums* for the extension. Each summary file contains one line for each data file with the statistics following on the line. The resulting files are plain text files. A future release will include an option for Excel workbooks.

MCrunch can also generate extreme-event tables. It creates one plain text file for each data file, plus another for the aggregate data if there are multiple data files. The file names use the roots of the data files followed by *.extr*. For the aggregates, it uses

the value of *AggRoot* followed by *.extr*. Within each output file, MCrunch writes one table for each extreme-event block. Each block has two lines for each tested channel—one for the minimum and one for the maximum. The tables have one column for each tested channel, plus one for each information channel. The minima and maxima are not computed for information channels. These channels are available for channels such as time and wind speed so you know what they are when the extremes for the tested channels occur.

To request extreme-event tables, set *NumEETables* to the number of tables. Add one line for each table after the following comment. The lines must have the name of the table enclosed in double quotes, the number and list of tested channels, and the number and an optional list of additional channels. The additional channels, such as time or wind speed, are those you might like to know the values of at the moment of the extreme events. We plan to add an Excel output option in the future.

Figure 4 shows an example of the input needed to generate extreme-event tables. The first table will have the name “Tip Deflections” and will have six tested channels (23, 24, 26, 27, 29, and 30). MCrunch will add the values for channels 1, 2, and 5 at each extreme event.

```
3          NumEETables      Number of tables of extreme events.
TableName  #Chans          ChanList          #InfoChans...
"Tip Deflections"  6      23 24 26 27 29 30  3      1 2 5
"Tower Clearances"  3      32 33 34          3      1 2 5
"Blade-1 Loads"    4      134 52 135 55     3      1 2 5
```

Figure 4. Example input for specifying extreme-event tables.

Binning

You can bin in one or two dimensions. For example, you can generate a power curve by binning power against wind speed. Use *NumDepChans* to tell MCrunch how many binnings you want to do. If you are binning against one independent channel (1-D), you have the option (*UseBinAv*) of reporting the bin locations as the average value of the points in the bin instead of using the bin centers. As the three-dimensional plotting routines require regularly spaced grids, and the bin tables assume that all cells in a given row or column have the same bin location, MCrunch does not allow the use of bin averages when binning against two independent channels. (See Figure 5 for an example of the plot for a two-dimensional binning.)

You can plot the results of binning by enabling *PltBins*. With the *PltRawData* option, you can add the raw data as a scatter plot on top of the bin curves for all bin plots that have just one independent channel. (See Figure 6 for an example.)

The *WrBinsTxt* and *WrBinsXLS* options allow you to write the bin tables to plain text files or Excel workbooks.

You must enter one data line for each dependent channel you want to bin. The lines contain the channel number, the number of independent channels, the first independent channel number followed by its bin width and (optionally) the second independent channel followed by its bins width. Figure 7 shows an example of the

Binning section of the input file where channel numbers are specified using channel-name strings.

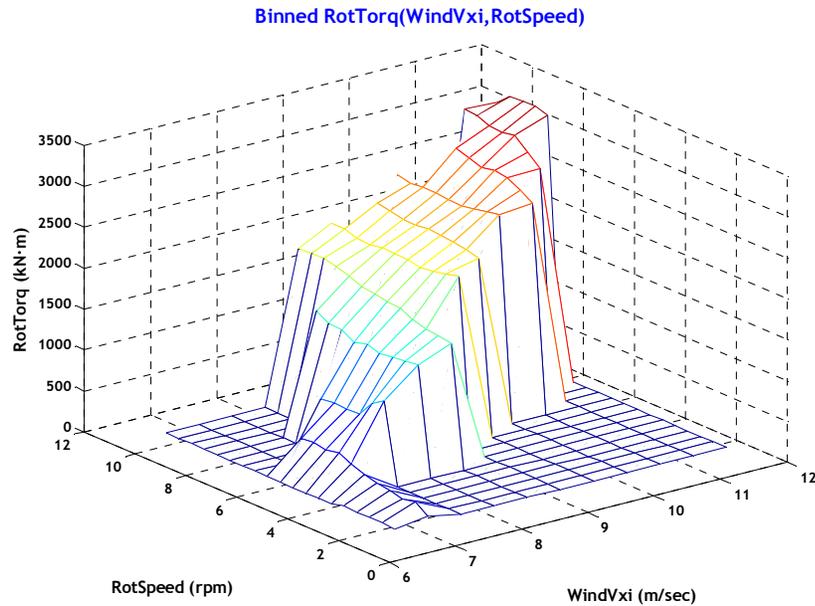


Figure 5. Example of a binning plot for two independent channels.

Peak and Valley Listing

We have yet to add peak and valley listing to MCrunch, but the Peak and Valley Listing header line must still be in the settings file.

Probability Density

MCrunch can generate probability density functions (PDFs), sometimes called histograms. A plotted PDF of a signal can give a much better feel for how the data vary than a table of simple statistics.

MCrunch requires you to specify how many channels you want to generate PDFs for (*NumPDFChans*) and what they are (*PDFChans*). To generate the PDFs, MCrunch divides the range of each analyzed channel into *NumPDFBins* bins. It then calculates the probability of occurrence from the number of records that fall within each bin.

In addition to generating tables of data with *WrPDFsTxt* and *WrPDFsXLS*, MCrunch can plot the results. Instead of using column plots for histograms, MCrunch generates line plots. For multiple files, it adds an aggregate line. If you prefer column charts, you can modify the *GenPDFPlots* function in *GenPDFs.m*. We show an example of the PDF input section in Figure 8.

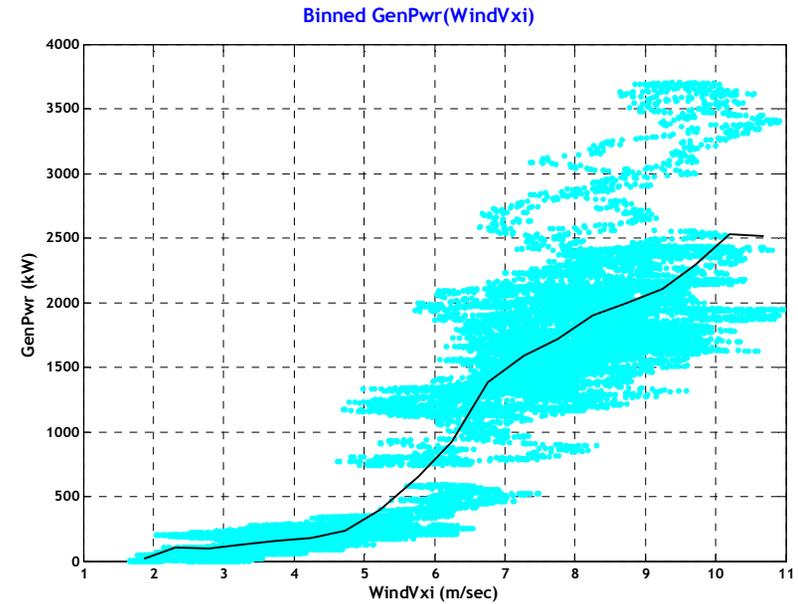


Figure 6. Example of a binning plot for one independent channel with raw points added.

```

----- Binning -----
true      DoBins           Bin selected channels?
2         NumDepChans      Number of dependent channels to...
true     UseBinAv         When reporting the location of...
true     PltBins          Plot the binned data?
true     PltRawData       Plot the raw data on top of the...
true     WrBinsTxt        Write binning results to a...
true     WrBinsXLS        Write binning results to an...
DepChan  NumDims  IndChan1  BinWid1  IndChan2  BinWid2
$GenPwr  1        $WindVxi  0.5
$RotTorq 2        $WindVxi  0.5  $RotSpeed 0.5
    
```

Figure 7. Example of the binning section of the input file.

The plot in Figure 9 is an example of how MCrunch can display the probability that a signal will be at a given level. The black line (labeled “Aggregate”) results from processing the two data files as if they were one long one.

```

----- Probability Density -----
true          DoPDFs          Generate PDFs of all channels.
7            NumPDFChans      Number of PDF channels.
5 23 24 26 27 29 30 PDFChans  List of PDF channels.
100         NumPDFBins      Number of bins for the PDFs.
false       WrPDFsTxt        Write PDFs to a plain text file?
true       WrPDFsXLS        Write PDFs to an Excel workbook?
2          NumPDFFigs       Number of figures for the PDFs...
FigureName #rows #columns  Channel list (must number...
"Wave Elevation" 1      1      5
"Tip Deflection" 3      2      23 24 26 27 29 30

```

Figure 8. Example of the PDF section of the input file.

Power Spectral Densities

MatLab's Signal Processing Toolbox can compute PSDs, and numerous options are available. MCrunch takes advantage of a subset of these options. If you need to use unimplemented options, you can modify MCrunch's *GenPSD.m* file or replace it with your own script. You cannot use this feature unless you have the Signal Processing Toolbox or unless you are using the compiled version of MCrunch with the MatLab libraries.

You specify the number and the list of channels with the *NumPSDChans* and *PSDChans* variables. You should consider "prewhitening" the signals by removing the means (*RmvMean*), detrending the time series (*Detrend*), and applying a cosine taper (*CosTaper*) to the ends of the time series. This should increase the sharpness of the peaks and reduce distortion (Kane and Trivendi 1986).

MCrunch gives you the option of using one of two window types (*WindowType*). Bartlett (or triangular) windows give good results for deterministic signals such as sine waves. Hamming-style cosine windows are the best choice for random signals.

Once MCrunch generates the PSDs, you can process them in several ways before plotting or recording them in files. Enable *IntPSDs* to integrate them. The integral gives you an approximation of the signal's variance (square of the standard deviation). You can smooth the PSDs by enabling the two-pass filter (*FiltPSDs*) or by binning them (*BinPSDs*). Binning will enable you to compare multiple PSDs when the numbers of points or time steps of the original time series differ.

As with most of the other tools, you can plot the results or store them in plain text files or Excel workbooks. Figure 10 is an example of the PSD input section of the MCrunch parameter file.

Figure 11 is an example of a PSD plot. This plot was for two time series; the black curve represents the average of the PSDs for the individual files. Unlike many other analyses, we decided to average the PSDs instead of taking the PSD of the aggregate of the files. We may change this later.

Probability Density Plots of Wave Elevation

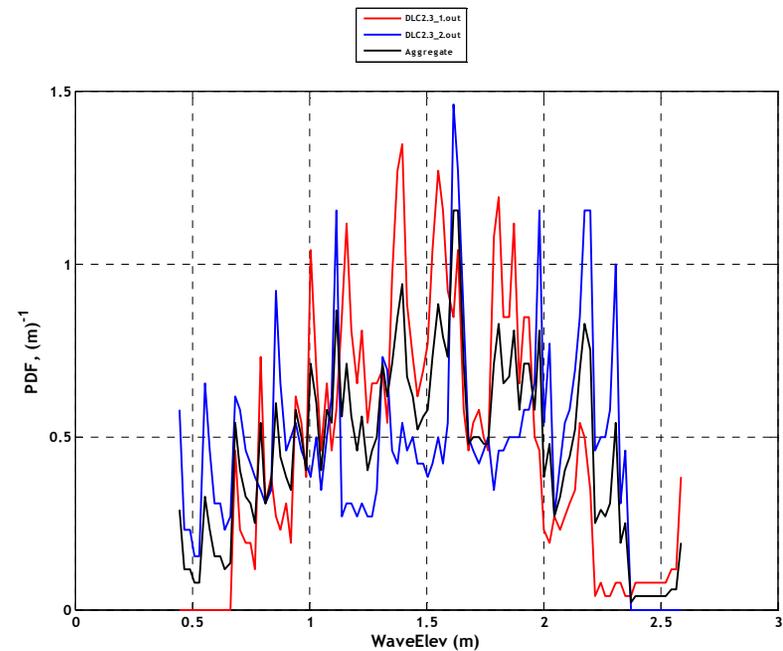


Figure 9. Example of a PDF plot.

```

----- Power Spectral Density -----
true          DoPSDs          Generate power spectra...
3            NumPSDChans      Number of PSD channels.
$RotTorq $0oPDef11 $IPDef11  PSDChans      List of PSD channels.
false       RmvMean          Remove the mean of the signal(s)?
true       Detrend           Remove linear trend of the...
true       CosTaper          Add a cosine taper to the ends...
"hamming"  WindowType       Type of data window.
false     IntPSDs            Integrate the PSDs before...
true     FiltPSDs            Filter (two pass) the PSDs...
false     BinPSDs            Bin the PSDs before plotting or...
0.1       BinWidth           Width of the PSD bins.
true     WrXLS                Write the PSDs to an Excel file?
true     WrTxt                Write the PSDs to a text file?
2        NumPSDFigs          Number of figures for the PSDs...
FigureName #rows #columns  Channel list (must number...
"Rotor Torque" 1      1      $RotTorq
"Tip Deflection" 2      1      $0oPDef11 $IPDef11

```

Figure 10. Example of the PSD section of the input file.

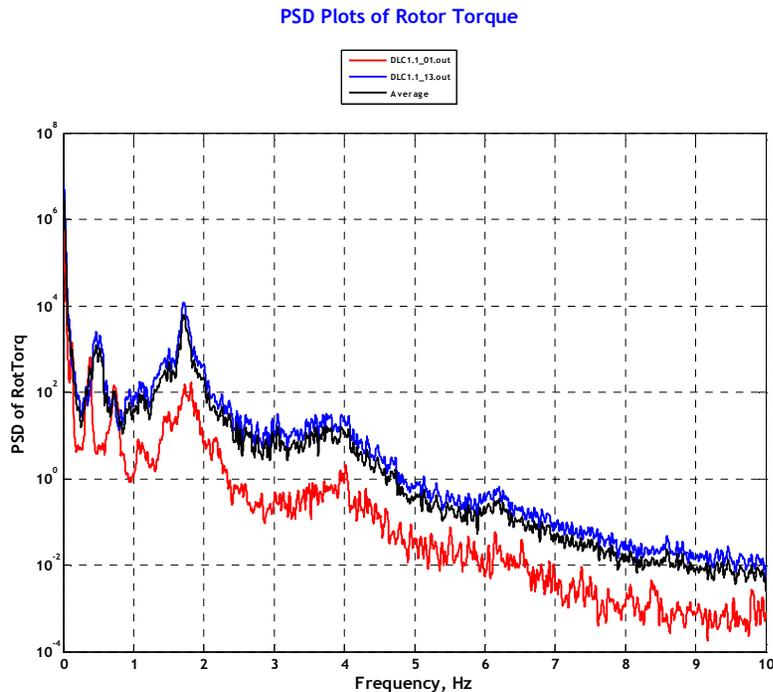


Figure 11. Example of a PSD plot.

Fatigue Analysis

MCrunch can generate range or range/mean rainflow cycles and DELs. It uses the one-pass method (Downing and Socie 1982) to generate the cycles. The DELs are only for individual or aggregate time series. We plan to add weighting for a probability distribution such as a Rayleigh distribution of wind speeds when time permits. As with most of MCrunch's tools, you can present the fatigue results in a myriad of ways.

MCrunch allows you to use a racetrack filter to eliminate small cycles (Veers et al. 1989) before you generate the rainflow cycles. The variable *FiltRatio* specifies what fraction of the maximum range of each channel will be the cutoff.

You tell MCrunch how many (*NumFatChans*) channels you want to process. If you are binning cycles (*BinCycles*), tell MCrunch to report binned cycles as cycles per the number of seconds specified by *RF_Per*. For example, to report binned cycled in cycles per hour, set *RF_Per* to 3600. Enable *BinMeans* if you want to generate binned range/mean cycles. If you request only range binning, MCrunch will also compute cumulative cycles.

You specify the widths of the range and mean bins in the third column of the channel-information table that follows the output-options section of the parameter file (see

the blue portion of Figure 12). For range bins, the first bin always starts at zero. For mean bins, the first bin always starts at the channel minimum of all the time series. If you do not request mean bins, it will be easy to add the range bins from multiple MCrunch runs because you can make the bins the same width in all runs and they always start at zero. This will not be possible if you request binning of cycle means.

You can tell MCrunch to discard unclosed cycles by setting *UCMult* to zero. Setting it to unity will cause MCrunch to count unclosed cycles as full cycles, which is conservative. You can also set it to an intermediary value such as 0.5.

If you enable *DoDELs*, MCrunch uses Miner's rule to calculate DELs, which depend on material properties specified by the slope of the S-N curve. (See Equation 26 in Sutherland 1999 for the formulation.) You can specify only one S-N slope per channel at present, but we plan to enable MCrunch to calculate DELs for multiple S-N slopes. You specify the slopes in the second column of the channel-information table.

If you are requesting plots of results, use *NumFatFigs* to specify the number of figures you want to generate. Each figure can contain plots of one or more channels. The figure-specification table (green portion of Figure 12) has columns for the figure title, number of rows and columns, and the list of channels to plot.

MCrunch can plot fatigue results in many ways. Figure 13 shows an example of two plots of the probability of exceedance for blade root loads for rainflow cycles. This type of plot tells you the probability of cycles exceeding a given range. Alternatively, the data may be presented with cumulative rainflow cycles. This is a plot of the total number of cycles that are below a given range value. MCrunch creates the stair stepping by plotting two ordinate values for each point on the abscissa.

Statistical Extrapolation

We have yet to add the ability to extrapolate extreme values to MCrunch, but the Statistical Extrapolation header line must still be in the settings file.

Limitations

MCrunch has the following limitations:

- All files must have the same channel layout.
- Computers must have sufficient virtual memory to contain all the data for a run. All time-series data are stored as four-byte, single-precision fixed-point numbers to save space.
- For aggregate rainflow cycle counting to work, all files must have the same time step.
- Channel names and units strings are limited to 10 characters each and may not contain any white space.

```

----- Fatigue -----
true          DoFatigue          Do fatigue analysis.
4            NumFatChans        The number of rainflow channels...
0.0          FiltRatio          The fraction of the maximum...
1            RF_Per            Number of seconds in the ...
false       BinCycles          Bin the rainflow cycles?
false       BinMeans          Bin by cycle means in addition...
0.5         UCMult            Multiplier for binning unclosed...
false       DoDELS            Compute damage-equivalent loads?
true        WrRFTxt           Write rainflow data to plain-...
false       WrRFXLS           Write rainflow data to an Excel...
false       WrDELSTxt         Write DELs to plain text files?
false       WrDELSXLS         Write DELs to an Excel workbook?
false       WrRainflow        Generate files containing...
false       PltBinCyc         Plot binned rainflow cycles?
true        PltProbExc        Plot probability of exceedance?
false       PltCumCyc         Plot cumulative rainflow cycles?
false       PltRngMean        Plot 3-D range and mean binned...
false       TabDELS           Generate an HTML table of...
Channel#     SNSlope  BinWidth  BinWidth not used when BinCycles...
  134         10       5.0
   52         10      10.0
  135         10     150.0
   55         10       3.0
2            NumFatFigs        Number of figures for the...
FigureName   #rows  #columns  Channel list (must...
"Blade 1 Root Forces"  1      2      134 52
"Blade 1 Root Moments"  1      2      135 55

```

Figure 12. Example of the fatigue section of the input file.

Known Bugs

- None.

Possible Future Enhancements

- Add Excel output for summary files and extreme event tables.
- Allow default channel names and units if none are supplied.
- Allow processing of a subset of channels from the input data files and permit reordering of channels.
- Include the number of lines/files used in the analyses for all types of analysis.
- For summary statistics, add the aggregate statistics.
- Add ability to read Controls Advanced Research Turbine and Unsteady Aerodynamics Experiment binary files.
- Add cross spectra to the spectral analysis.

Rainflow-Cycle Exceedance Probabilities of Blade 1 Root Forces

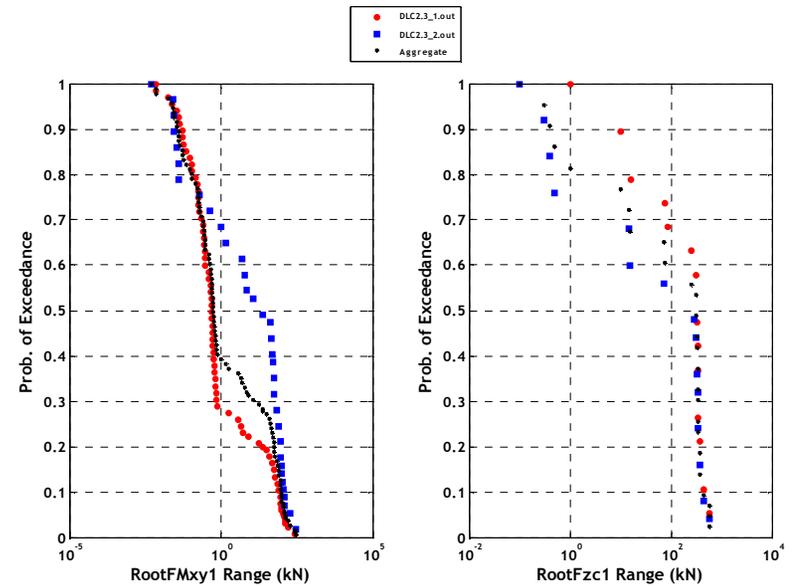


Figure 13. Example of a probability-exceedance plot.

- Add polynomial fitting of data, which would be useful for converting BModes mode shapes into FAST-style polynomials.
- Convert AeroDyn-style element files to the WT_Perf style.
- Add probability-weighted DELs.
- For DELs, allow many S/N slopes.
- Add Load Roses.
- Add peak annotation to the PSD plots.
- Add data filtering (low-pass, high-pass, band-pass, and notch filters).
- Add moving averages.
- Add azimuth averaging.
- Add crosstalk removal.
- Add peak and valley listing.
- Add statistical extrapolation.
- Add decimation and averaging.
- Allow output of modified input. This is useful if scales and offsets are used, when only selected channels are used, when channels are reordered, when data are filtered, or when calculated channels are generated.

Cumulative Rainflow Cycles of Blade 1 Root Moments

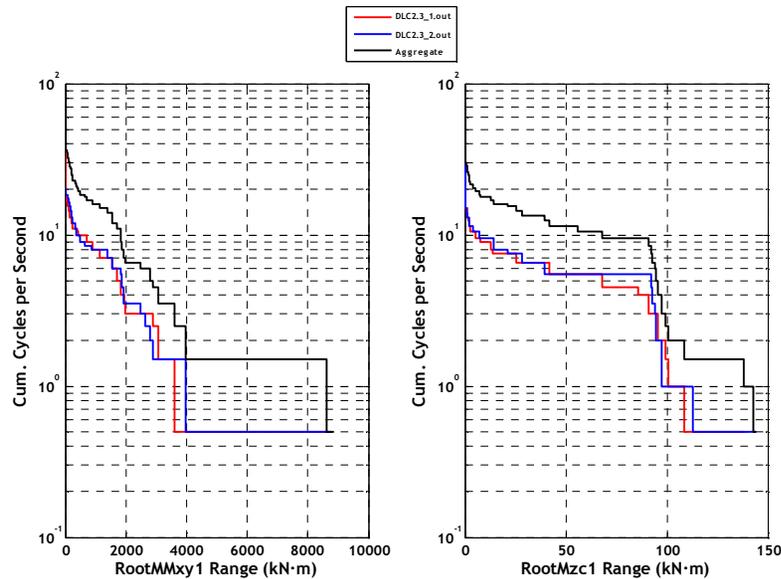


Figure 14. Example of a probability-exceedance plot.

- Add data interpolation.
- Add an option to have only one file in memory at a time.
- For the Extreme-Events feature, add the ability to generate runners up. That is, the second largest values of a time series.
- Add extreme-value extrapolation. (Moriarty et al. 2004)
- Enable MCrunch to signify that a value of zero for the time column means that no time column is available. This will mean many features will have to be disabled for that run (extreme-value extrapolation, binned rainflow cycle counting, and filtering).
- For the rainflow counting analysis, add an option to specify the number of wind speed bins and hours in each bin. Run MCrunch once to cycle count and scale, with, for example, a list of 25 files (5 ten-minute files in each of 5 wind speed bins). This would speed up the process and enable one to calculate fatigue under different International Electrotechnical Commission wind turbine classes.
- Make it impossible to cycle count the time column.
- Make it impossible to cycle count the same column twice.
- Eliminate the need for the Statistics Toolbox.

Caveats

NREL makes no promises about the usability or accuracy of MCrunch, which is essentially a beta code. NREL does not have the resources to provide full support for this program. *You may use MCrunch for evaluation purposes only.*

Acknowledgments

Marshall Buhl of the NWTC wrote MCrunch. Bonnie Jonkman of the NWTC generously helped Marshall learn how to use and program MatLab. Jason Jonkman suggested the concept of using channel names instead of numbers in the input file. Garrett Bywaters proposed the enhanced rainflow analysis. Many other colleagues in the international wind energy community provided much input, encouragement, and feedback.

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Feedback

If you have problems with MCrunch, please contact Marshall Buhl. If he has time to respond to your needs, he will do so, but please do not expect an immediate response. Please send your comments or bug reports to:

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