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Figures of Merit Software: Description, User's Guide, Installation Notes, Versions Description, and License Agreement

H.D. Hoelzer and K.A. Fourroux
Teledyne Brown Engineering, Inc., Huntsville, Alabama

D.L. Rickman
Marshall Space Flight Center, Marshall Space Flight Center, Alabama

C.M. Schrader
BAE Systems, Huntsville, Alabama

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National Aeronautics and
Space Administration

Marshall Space Flight Center • MSFC, Alabama 35812

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LIST OF ACRONYMS AND SYMBOLS

3-D	three-dimensional
Ca	calcium
$CaAl_2Si_2O_8$	anorthite
CFD	cumulative frequency distribution
CVI	C for Virtual Instrumentation
DC	discrete category
DLL	dynamic link library
Fe	iron
FoM	figure of merit
ITAR	International Traffic in Arms Regulations
MCR	MATLAB Compiler Runtime
MSFC	Marshall Space Flight Center
$NaAlSi_3O_8$	albite
RFD	relative frequency distribution
RTE	run-time environment
TBE	Teledyne Brown Engineering
TM	Technical Memorandum
U.S.	United States

TECHNICAL MEMORANDUM

FIGURES OF MERIT SOFTWARE: DESCRIPTION, USER'S GUIDE, INSTALLATION NOTES, VERSIONS DESCRIPTION, AND LICENSE AGREEMENT

1. INTRODUCTION

The surfaces of rocky planets, moons, and some other astronomical bodies have significant amounts of broken geologic materials. In the absence of more specific, applicable terminology, such materials are generically termed regolith. Even on relatively simple bodies like the Moon, the nature of regolith is fairly complex. For space mission development, a regolith needs to be simulated, and many regolith simulants have been created for the Moon and Mars.

Therefore, the choice of simulant and its performance are significant considerations. An engineer specifying, procuring, or using a simulant needs to know how accurately the simulant replicates the actual regolith. Geologists do not have a relevant standard method for such comparisons. Those who have listened to lunar geology experts publically argue whether a simulant is good know that expert opinion, lacking quantifiable criteria, can be a very poor basis for making engineering decisions, but making such a comparison is nontrivial. Regoliths are complex and highly variable mixtures of many constituents; there are wide variations in most properties at almost all sampling scales.

Figures of Merit (FoMs) and FoM software provide a method for evaluating the quality of a regolith simulant by comparing the simulant to a reference material. FoMs are concepts new to simulant development that may be used for comparing a simulant to an actual regolith material, for a specification by stating the value a simulant's FoMs must attain to be suitable for a given application, and for comparing simulants from different vendors or production runs. FoMs may even be used to compare different simulants to each other.

A single FoM is conceptually a defined procedure for comparison of functionally identical measures made on two different materials. As implemented in an algorithm, a single number is computed to quantify the similarity or difference of that single characteristic of a simulant material and a reference material. Therefore, it provides a clear, unambiguous, standardized measure of how well a simulant and reference material match or compare. As a practical aid in their use, FoMs have been constructed to lie between zero and 1, with zero indicating a poor or no match and 1 indicating a perfect match.

Four top-level characteristics and several lower level characteristics for comparing materials have been defined for which FoMs may be computed. These characteristics are as follows:

- Modal composition:
  - Minerals.
  - General.

- Particle size distribution.

- Particle shape distribution:
  - Aspect ratio.
  - Angularity.

- Density.

An FoM may be constructed from multiple, more detailed FoMs. For example, one can have an FoM for modal composition and an FoM for each mineral considered under modal composition.

For additional explanation of the underlying concepts and motivations, the reader is directed to references 1, 2, and 3. The concepts implemented in the FoM software are also the basis of an ISO standard for lunar simulants.[4]

The FoM software is a computer software implementation of the FoM algorithms and may be used to compute the FoMs. The software was created for two reasons. There was a need to prove that concepts embodied in the FoMs were fully consistent and realizable. As any inventor knows, it is one thing to have an idea; it is another to make it into a reality. It was through this prudent exercise that several problems were identified and corrected. Second, there was a need to actually make the necessary comparisons and there is more computational and data management burden than one should do without dedicated software.

It should be noted that the FoM software only computes a set of numbers (the FoMs) that indicate how well a simulant material matches a reference material. It does not say anything about how well a simulant is suited for a particular application or purpose. The user of the software must make that determination. Further, the FoM software does not contain any data; it is only a computational engine that computes FoMs from data supplied by a user.

The existing FoM code is not a full implementation of the essential concepts. It is missing some details, such as the handling of contaminants and intricacies related to solid solutions. It also does not deal with spectroscopy, which will need to be added in the future. But, there is no serious question that the implementation contained in this release is a massive revolution in evaluation and comparisons of lunar regolith and simulants.

2. DEFINITIONS

2.1 Reference and Simulant Materials

An FoM algorithm is a method for comparing two materials. These are given the labels Reference material and Simulant material, but this labeling is arbitrary and does not factor into the computation. It is done only to provide handles for the two materials being compared. Normally, one would consider the reference material to be an actual material that one is trying to replicate or simulate. However, a reference material may be completely hypothetical.

A simulant is usually considered to be a material that replicates a reference material as much as possible or to the degree specified. However, note that both materials may be simulants, which would allow one to compare two simulants to each other, or both may be actual lunar (or other material) samples, which would allow one to compare these materials to each other.

For engineering purposes, comparisons need to be based on defined, standardized measurements. Broadly speaking, one may subdivide possible measurements into either nominal or continuous functions. Nominal comparisons include such things as male versus female and apples versus oranges. Inherently, nominal characteristics do not recognize partial states. For example, a half apple-half orange is not generally physically meaningful terminology. Nominal designations are usually considered to be discrete functions. Continuous functions are those characteristics expressed using a real domain numbering system. For example, consider weight or length. For a real world particle, it is understood that there can, in principal, exist another particle that is arbitrarily close but not identical. The mathematics of comparing nominal and continuous functions is different.

2.2 Definition of Discrete Category Functions

A discrete category (DC) function is a function whose domain (i.e., input, independent variable, or argument) is a collection of discrete objects or categories all of the same kind and whose range (i.e., output, dependent variable or value of the function) is the quantity, fraction, or other value for each of the elements in the domain. Discrete category functions may be plotted as bar graphs. An example of a DC function is the composition of a material whose domain is the various constituents of the material and whose range is the various fractions of each constituent. A plot of such a function is shown in figure 1.

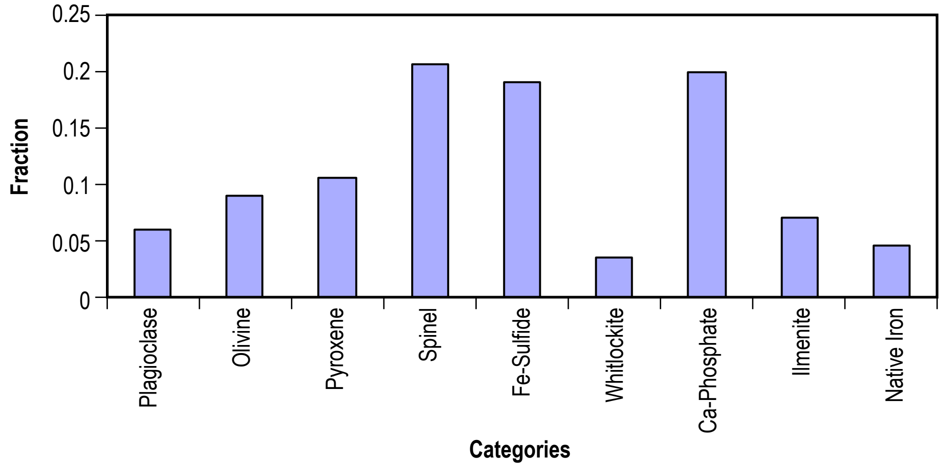


Figure 1. Example discrete category function showing composition for a hypothetical material.

2.2.1 Definition of Reference and Simulant Category Value Vectors

A DC function relates its domain (input), which is a set of objects called categories, to its range (output), which is a set of values with one for each element of the domain. The domain and range may be collected into two vectors, one being a vector of categories and the other being a vector of values for those categories with a one-to-one correspondence between the elements of the two vectors. The vector of categories shall be called the category vector and the vector of category values the category value vector. Note that for category value vectors whose elements represent fractions of the categories, the sum of the elements of such a category value vector must necessarily sum to unity (the sum of the fractional parts must equal the whole). An example showing a composition category vector and category value vector is given in equation 1. The category vector is a vector whose elements are the various composition constituents of a material. The category value vector is a vector whose elements are the factions of the various constituents of the material as demonstrated in equation 1.

$$\begin{array}{cc} \text{Category Vector} & \text{Category Value Vector} \\ \begin{bmatrix} plagioclase \\ olivine \\ \cdot \\ \cdot \\ \cdot \\ native\,iron \end{bmatrix} & \begin{bmatrix} 0.060 \\ 0.090 \\ \cdot \\ \cdot \\ \cdot \\ 0.045 \end{bmatrix} \end{array} \tag{1}$$

2.2.2 Figure of Merit Computation

The FoM for a characteristic of a given reference and simulant material that is quantified by a DC function is defined as 1 minus the L1 norm of the weighted difference between a reference category value vector and a simulant category value vector scaled by the sum of the L1 norms of the weighted reference category value vector and the weighted simulant category value vector. This is shown in equation 2.

$$FoM = 1 - \frac{\left\| w\left(cvv^{reference} - cvv^{simulant}\right)\right\|_1}{\left\| wcvv^{reference}\right\|_1 + \left\| wcvv^{simulant}\right\|_1} = 1 - \frac{\sum_i w_i \left|\left(cvv_i^{reference} - cvv_i^{simulant}\right)\right|}{\sum_i w_i cvv_i^{reference} + \sum_i w_i cvv_i^{simulant}} \quad , \tag{2}$$

where:

cvv is the category value vector of a material characteristic (reference material or simulant material).

w is a weighting vector (also referred to as the importance vector— consisting of a vector of weights). The weighting factor is used to specify the relative importance of particular elements of the category vector so that differences for certain categories may be made more important than others. This vector is an internal control for the FoM algorithm designers and developers and is a part of the FoM algorithm, so the user does not supply this vector.

v_i is the *i*th element of vector *v*.

$$\left\| v \right\|_1 = \sum_{i=1}^{n} \left| v_i \right| \quad , \tag{3}$$

is the L1 norm of vector *v* (also known as the taxi cab or Manhattan norm).

2.3 Relative Frequency Distribution Functions

2.3.1 Definition of Relative Frequency Distribution Functions

The cumulative frequency distribution (CFD) (from which the relative frequency distribution (RFD) is derived) is defined and will be used in the FoMs that use an RFD for description of a material characteristic.

The CFD function $CFD_x(z)$ is defined as,

$$CFD_x(z) = Fraction\{x \leq z\} \quad , \tag{4}$$

which reads, $CFD_x(z)$ is the fraction of material characteristic *x* less than or equal to *z*. This is analogous to the probability cumulative distribution function $F_x(z)$ that yields the probability that *x* is less than or equal to *z*. As an example, $CFD_{size}(a)$ is the fraction of particles of size less than or equal to *a*.

Interest will be in the derivative of the cumulative size frequency distribution function, which is defined as

$$RFD_x(z) = \frac{d}{dz} CFD_x(z) \ . \tag{5}$$

This derivative is known as the RFD and yields the fraction of particles per particle material characteristic of material characteristic x. As an example, $RFD_{size}(a)$ is the fraction of particles per particle size of size a. In concept, an RFD function is a function whose domain (i.e., input, independent variable, or argument) is a property of a material that varies discretely over some set of values (also known as bins) and whose range (i.e., output, dependent variable, or value of the function) is the quantity, fraction, or other value for bins in the domain. An RFD function may be plotted as a bar chart that shows the distribution by fraction of a given property of a material. As a bar chart, it consists of bars (which may be of varying widths) that are the bins for the quantity whose distribution is being described. The height of each bar represents the fraction of a given quantity over that bin.

Examples of a size CFD function and its size RFD function are shown in figure 2.

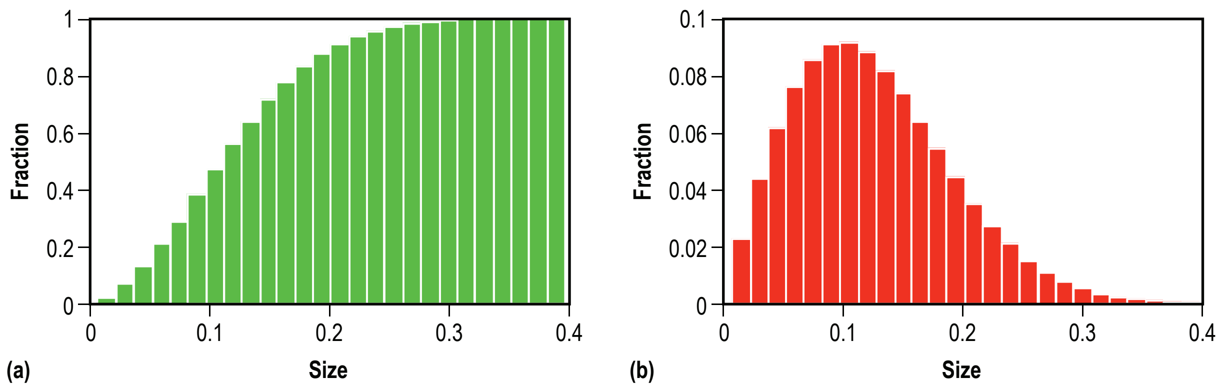


Figure 2. Example cumulative (a) and relative (b) frequency distributions for particle size of a hypothetical material.

2.3.2 Figure of Merit for Relative Frequency Distribution Functions

2.3.2.1 Definition of Discrete Data Relative Frequency Distribution. A relative frequency function may be defined as a continuous function (continuous domain or input) or a discrete function (discrete domain or input). However, for computational purposes, discrete data will be worked with, and the RFD is that histogram whose bars represent the fraction of particles within a given span of values for a given material characteristic such as size. The discrete RFD's domain shall be defined by n+1 values that define n contiguous bins with the value of each bin (height of the histogram bar) representing the fraction of particles between the lower and upper bin values, thus constituting the range of the RFD. There is no requirement for the bin sizes to be of the same size across the RFD, and variable bin sizes are allowed. Summation of the RFD range values between lower domain value z_i and upper domain value z_j yields the fraction of particles between z_i and z_j. Note that the summation of the entire RFD range (from minimum to the maximum domain value) must necessarily equal unity (the sum of the factional parts must equal the whole).

2.3.2.2 Figure of Merit Computation. For material characteristics quantified by an RFD, the FoM for how closely a simulant matches a reference is determined by comparing their RFD functions. The FoM for a characteristic of a given reference and simulant that is quantified by an RFD is defined as 1 minus the L1 norm of the weighted difference between a reference RFD and a simulant RFD scaled by the sum of the L1 norms of the weighted reference RFD and the weighted simulant RFD. This is shown in equation 6,

$$
\begin{aligned}
FoM_{before\ constrants} &= 1 - \frac{\left\| w\left(RFD^{reference} - RFD^{simulant}\right)\right\|_1}{\left\| wRFD^{reference}\right\|_1 + \left\| wRFD^{simulant}\right\|_1} \\
&= 1 - \frac{\int w\left|RFD^{reference} - RFD^{simulant}\right|}{\int w\left|RFD^{reference}\right| + \int w\left|RFD^{simulant}\right|} \\
&= 1 - \frac{\sum_i w_i\left|\left(RFD_i^{reference} - RFD_i^{simulant}\right)width_i\right|}{\sum_i w_i RFD_i^{reference} width_i + \sum_i w_i RFD_i^{simulant} width_i} \quad ,
\end{aligned} \tag{6}
$$

where,

RFD	= the RFD function of a material characteristic (reference material or simulant material)
w	= a weighting function (also referred to as the importance function) that is used to specify the relative importance of various regions of the RFD function domain (input of RFD function) to each other, so that RFD differences for certain regions may be made more important than others. This function is an internal control for the FoM algorithm designers and developers and is part of the FoM algorithm, so the user does not supply this function.
v_i	= the value of a function over the *i*th bin when a function is discretized over a number of bins (the domain of the RFD function is discretized into discrete bins).
$\|v(x)\|_1 = \int \|v(x)\| dx$	= the L1 norm of a function $v(x)$. (7)

$width_i$ = the width of the ith bin, which when multiplied by v_i, the value of the function v over the ith bin, yields the integral of the of the function over the ith bin.

The FoM just described is further subject to certain maximum error constraints as identified in equation 8,

$$FoM = \begin{cases} FoM_{before\ constraints} & if \ \left|RFD_{reference} - RFD_{simulant}\right| \le \max RFD_{difference} \\ 0 & otherwise \end{cases} . \quad (8)$$

The quantity *max* $RFD_{difference}$ is an internal control for the FoM algorithm designers and developers and is a part of the FoM algorithm; therefore, the user does not supply this quantity.

3. FIGURE OF MERIT DESCRIPTIONS

3.1 Modal Composition

Modal composition defines the geologic constituents of a simulant without reference to textural features such as particle shape and particle size. The FoM algorithm for modal composition treats composition as a vector of the fractions of the various constituents of the material, which may be viewed as a DC function and plotted as a bar graph of the various constituents. Modal composition is further subdivided into mineral composition and a broader FoM termed general composition that includes minerals and the top level categories Lithic Fragments, Glasses, Agglutinates, and Other (nonlunar materials and contaminants). In both cases, the FoM is defined as the scaled L1 Norm of the difference of two composition vectors subtracted from unity. The L1 Norm (also known as the taxi cab or Manhattan norm) is defined as the sum of the absolute values of the components of a vector (see equation 9).

$$\|v\|_1 := \sum_{i=1}^{n} \left|v_i\right| \quad . \tag{9}$$

The FoM for modal composition may be interpreted as the fraction of material that is the same in both materials and is computed as described in section 2.2.1.

3.2 Particle Size Distribution

Size distribution refers to the distribution of particle sizes within a material. Size distribution is naturally represented by an RFD that may be plotted as a histogram of the fraction of particles within a given size range. The FoM is defined as the scaled L1 Norm of the difference of two RFDs subtracted from unity. The FoM for size distribution may be interpreted as the fraction of particles sizes that both materials have in common and is computed as described in section 2.3.2.

3.3 Particle Shape Distribution

Shape Distribution refers to the distribution of particle shapes within a material. Two shape characteristics have been defined. These are the aspect ratio of the grains of the material and the angularity of the grains of the material. In general, the particles in a material will exhibit a range of aspect ratios and a range of angularities. Thus, the FoMs for aspect ratio and angularity are based on the RFD of aspect ratio and angularity respectively. However, realizing that distributional data on aspect ratio and angularity may be difficult to obtain, a provision has been made for computing an alternate FoM based on the mean aspect ratio and the mean angularity over the ensemble of particles.

When distributional data are available, the FoMs for aspect ratio and angularity are defined as the scaled L1 Norm of the difference of two RFDs subtracted from unity. The FoMs for aspect ratio and angularity are computed as described in section 2.3.2. The FoMs for shape may be interpreted as the fraction of particle shapes that both materials have in common.

When only mean data is available, the FoMs for aspect ratio and angularity are computed as described in section 2.2.1. The FoMs for shape in this case may be interpreted abstractly as the amount of shape that the two materials have in common.

When only mean data is available, the FoMs for aspect ratio and angularity are defined as the scaled absolute value of the difference of the two means subtracted from unity. In this case, computations are performed as described in section 2.2.1. The FoMs for shape in this case may be interpreted abstractly as the amount of aspect ratio or angularity that the two materials have in common.

3.4 Density

Density refers to weight per unit volume of a material; however, for divided solids consisting of a collection of particles, the volume of a material will necessarily consist of particle volume, interparticle void volume, and internal pore volume. Therefore, density is defined to refer to bulk density and require any density measurements to be made over a sample sufficiently large enough so that the sample follows the particle size distribution of the material. Because bulk density is not an intrinsic property of a material but depends in part on how a material is handled, the FoM for density is defined to include a minimum bulk density, a maximum bulk density, and the specific gravity of the material, where specific gravity is the ratio of particle density to the density of water.

Bulk densities and the specific gravity may be treated as elements of a density vector, which may be viewed as a DC function and plotted as a bar graph of the various kinds of density. The FoM for density is defined as the scaled L1 Norm of the difference of two density vectors subtracted from unity. The FoM for density is computed as described in section 2.2.1 and may be interpreted abstractly as the amount of density the two materials have in common.

4. SOFTWARE DESCRIPTION

The FoM software implements six FoM algorithms to evaluate how well a lunar regolith simulant compares to a reference material.

The software consists of the following three components:

(1) An input editor. Microsoft Excel® software is used for this purpose.

(2) A back end that computes the FoMs. Code developed with the MathWorks MATLAB® software is used for this purpose.

(3) A front end with which the user interacts that opens and reads the Excel input files, performs checks on the inputs, and calls the MATLAB routines for computation of the FoMs. This is custom code created with the LabWindows/C for Virtual Instrumentation (CVI) software from National Instruments.

These base components were chosen because they are sold world wide (minimizing potential International Traffic in Arms Regulations (ITAR) and other legal complications), are relatively inexpensive, their use greatly reduces costs to the simulant development program, and they simplify licensing problems

4.1 Software Inputs

Input to the software consists of six spreadsheet tables that tabulate the composition, size distribution, shape, and density of a simulant material and the reference material to which it is being compared. Portions of the input for computation of the Modal Composition—Minerals FoM, Modal Composition—General FoM, Size Distribution FoM, Shape—Aspect Ratio FoM, Shape—Angularity FoM, and Density FoM are presented in section 5.

5. DATA ENTRY FOR THE FIGURE OF MERIT SOFTWARE

5.1 Introduction

Reference and simulant data are stored in a specific format in Excel data files. The data files must be formatted per the FoM Template.xlt file. This read-only file is automatically placed in the \FoMData folder under the root directory (nominally c:) on the Windows volume of the computer during installation of the FoM software. Reference material and simulant material data files are identical.

5.2 Structure of the Data Files

The FoM template workbook contains seven worksheets as described in the following paragraphs. The workbook is protected to prevent moving, adding, or deleting worksheets. Each worksheet is protected to prevent modification of any field except data entry fields. The worksheets are color coded to designate data entry fields, computation fields, and help fields.

Data entry fields are highlighted with a yellow background color and a red border. These fields are the only fields in which the user can enter data. Figure 3 shows an example of a blank data field.

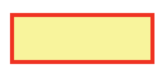


Figure 3. Example data entry field.

Data validation is provided as much as possible to help the user enter data completely and correctly. For example, on the Size Distribution sheet, checks are performed on size ranges to verify that the sizes are in ascending order.

Fields with light-green shading indicate cells that are computed; that is, they compute a value based on data that the user has entered. These cells are included for error checking and to aid the user in data entry. As an example, the elements of a composition vector must necessarily sum to unity (the sum of the fractional parts must equal the whole). To help the user in entering data, summation fields are provided that sum up the elements of a composition vector and contain an error message if a set of data entry fields does not sum to unity as required. An example from the Modal Composition—General worksheet (showing columns for Size Range 1 and Size Range 2) is shown in figure 4.

Figure 4. Example computation field.

Fields with help are labeled with blue, underlined text. Moving the mouse over blue, underlined text will cause an input tip to appear. Each data input worksheet also has a blue outlined box with short instructions unique to that page. Figure 5 shows an example.

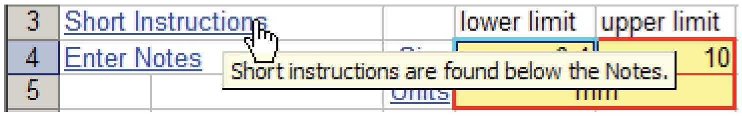


Figure 5. Example help.

Certain fields obtain their values from other fields on the same or other worksheets via links. These fields are shown in gray. An example of a linked field is on the Modal Composition—General worksheet that contains data from the Modal Composition—Minerals worksheet under the category Mineral Grains. Figure 6 shows an example of a linked field in gray.

Albite	0.0140
Anorthite	0.0260

Figure 6. Example linked data field.

5.3 Worksheet Definitions

5.3.1 Description Worksheet

This worksheet contains version control information for the template file and has a notes field in which the user may enter notes for this workbook. This sheet is for documentation purposes only and is not used by the FoM software. It is shown in figure 7.

5.3.1.1 Specific Instructions. Step 1: Notes for the workbook may be entered in the block titled Notes.

5.3.2 Modal Composition—Minerals Worksheet

This worksheet is used to enter modal composition data for minerals. Modal composition is specified by the fraction of each constituent in a material for a given particle size range. If a component is not present in a sample, the fraction field should be filled with zero or may be left blank.

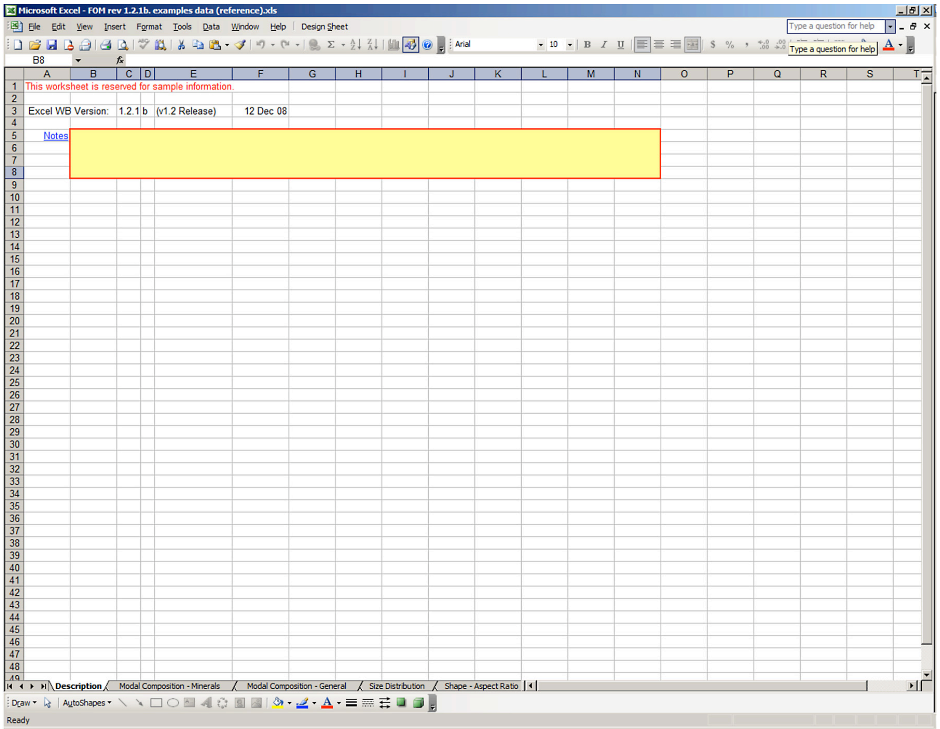


Figure 7. Description worksheet.

Certain minerals are actually solid solutions of various compounds. These are best handled by providing the mean fraction of the solution components as subcategories. For example, consider that a plagioclase consisting of a mixture of 60% albite ($NaAlSi_3O_8$) and 40% anorthite ($CaAl_2Si_2O_8$) may be classified as andesine, and a plagioclase consisting of a mixture of 50% albite and 50% anorthite may be classified as labradorite. If these were so labeled, the FoM algorithm would consider these to be separate unrelated minerals even though they are fairly similar, as the algorithm does not understand mineral composition. By specifying the underlying compounds in the solution, this problem is avoided and an accurate comparison may be made.

For the solid solutions, a second level of constituents is specified, namely the fractions of the compounds that make up the solution.

Level 1 contains a list of nine minerals (plagioclase, olivine, pyroxene, spinel, iron (Fe) sulfide, whitlockite, apatite, ilmenite, and native Fe). As of now, whitlockite and apatite cannot be separately distinguished because both are similar calcium (Ca) phosphates; however, it is hoped that a differentiation can be made in the future. Therefore, a placeholder for whitlockite is provided but is currently not used. All Ca phosphates should be entered under apatite. Of the level 1 components, four are solid solutions (plagioclase, olivine, pyroxene, and spinel), whose constituents may be further specified at level 2. Figure 8 shows this hierarchical arrangement on the Modal Composition—Minerals worksheet.

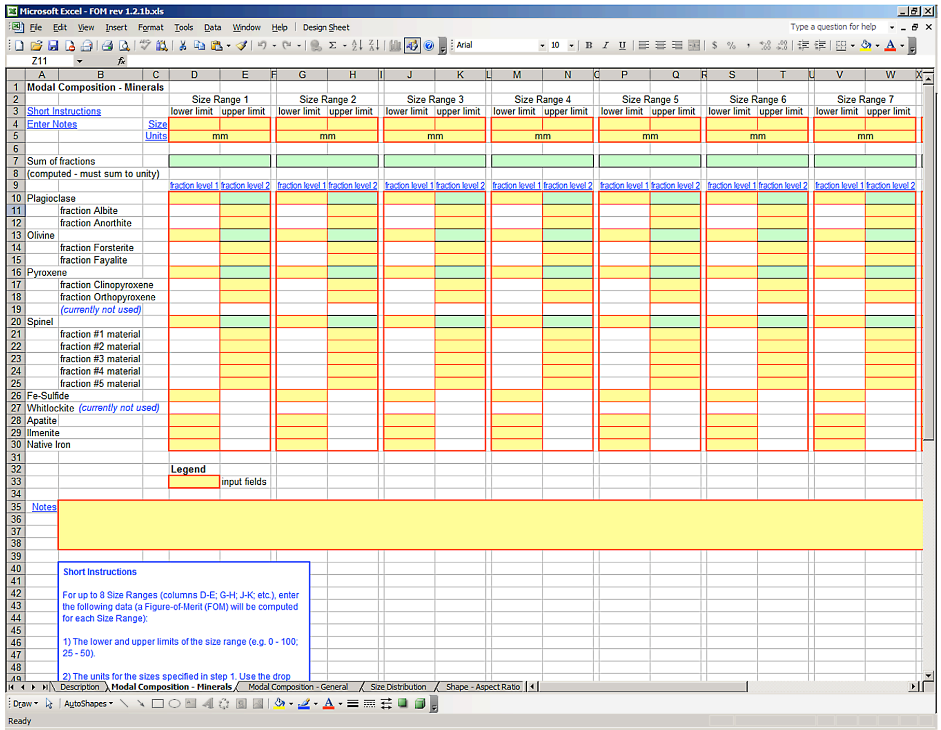


Figure 8. Modal Composition—Minerals worksheet.

The level of detail need not be uniform across the various levels, nor must it match the other material being compared. Note that the fractions at level 1 must necessarily sum to unity (the sum of the fractional parts must equal the whole), and the children of a level 1 item must also sum to unity. Thus, the fractions at level 2 represent the fractions of the parent.

If no information is available at a sublevel when entering data, then a rolled up value may be supplied one level higher up. Since currently there are only two levels, this means that data may be supplied just at level 1 if no data is available at level 2. More detail is presented in section 5.3.2.1.

Modal composition data may be entered as a function of particle size for up to eight size ranges. The FoM software computes a separate Modal Composition—Minerals FoM for each size range in which both the reference and simulant data files contain data. The data in corresponding size ranges is used to compute the FoM. As composition may be a function of size, care should be taken to compare data containing closely matching size ranges to ensure an accurate comparison. Since an FoM is computed for each size range, size ranges are not required to be contiguous and may even overlap.

5.3.2.1 Specific Instructions. The following steps are specific instructions for entering data.

Step 1: Enter the particle size range lower and upper limits into the cells in the row labeled Size, under the heading Size Range *i* for the *i*th size range set of data.

Note: If compositional data is not a function of size or if the particles span all sizes, then the size fields may be left blank. This data is currently not used for any computations and is for informational purposes only. However, it may be used in the future.

Step 2: Enter the units for the sizes in the fields below the size fields in the row labeled Units.

Note: Both the sizes (lower size limit and upper size limit) must be in the same units.

Note: This field features a drop-down menu from which the µm, mm, and cm units may be selected. This data is currently not used for any computations and is for informational purposes only. However, it may be used in the future.

Step 3: For the size ranges defined in steps 1 and 2, enter the mineral modal compositional fractions of the material in the column under the heading Fraction Level 1. Note that there are eight categories of modal composition at this first level (plagioclase, olivine, pyroxene, spinel, Fe sulfide, apatite, ilmenite, and native Fe).

Step 4: For the size ranges defined in steps 1 and 2 and for the level 1 items that have children (plagioclase, olivine, pyroxene, and spinel), enter the modal compositional fractions of the constituent minerals of the parent in the column under the heading Fraction Level 2 if they are known. If they are not known, then leave blank.

Note: As constituent fractions are entered, they are totaled in the light green computation fields of the worksheet for the material as a whole and for the four level 1 constituents that have children. This aids in data entry, as one of the requirements is that the fractions must sum to unity.

Step 5: Notes for the worksheet may be entered in the block titled Notes.

5.3.2.2 Example. In the example shown in figure 9 for Size Range 1, it is known that the mineral composition for plagioclase, olivine, pyroxene, spinel, Fe sulfide, apatite, ilmenite, and native Fe is 24%, 30%, 18%, 15%, 5%, 6%, 0%, and 2%, respectively. Further, the composition of the solid solution plagioclase is 35% albite and 65% anorthite. The composition of the solid solution pyroxene is 72% clinopyroxene and 28% orthopyroxene. No further information is available on the composition of the olivine or spinel.

5.3.3 Modal Composition—General Worksheet

This worksheet is used to enter modal compositional data for minerals and other constituents. Modal composition is specified by the fraction of each constituent in a material for a given particle size range. If a component is not present in a sample, the fraction field should be filled with zero or may be left blank.

Data may be specified at various levels of detail. Presently, there are three levels of categories. The first level consists of four categories of materials (Lithic Fragments, Mineral Grains, Glasses, and Agglutinates) and, for simulant materials only, Other (lunar regolith by definition

	A	B	C	D	E
1	**Modal Composition - Minerals**				
2				Size Range 1	
3	Short Instructions			lower limit	upper limit
4	Enter Notes		Size	0.1	10
5			Units	mm	
6					
7	Sum of fractions			*1.0000*	
8	(computed - must sum to unity)				
9				fraction level 1	fraction level 2
10	Plagioclase			0.2400	*1.0000*
11		fraction Albite			0.3500
12		fraction Anorthite			0.6500
13	Olivine			0.3000	
14		fraction Forsterite			
15		fraction Fayalite			
16	Pyroxene			0.1800	*1.0000*
17		fraction Clinopyroxene			0.7200
18		fraction Orthopyroxene			0.2800
19		*(currently not used)*			
20	Spinel			0.1500	
21		fraction #1 material			
22		fraction #2 material			
23		fraction #3 material			
24		fraction #4 material			
25		fraction #5 material			
26	Fe-Sulfide			0.0500	
27	Whitlockite *(currently not used)*				
28	Apatite			0.0600	
29	Ilmenite				
30	Native Iron			0.0200	

Figure 9. Modal Composition—Minerals example.

does not contain nonlunar materials or contaminants). The second and third levels are further decompositions of levels 1 and 2, respectively, into components as shown in the Modal Composition—General Worksheet, figure 10. The level of detail need not be uniform across the various categories and subcategories, nor must it match the other material being compared.

When entering data, if no information is available at a sublevel, then a rolled-up value may be supplied one level higher. More detail is presented in section 5.3.3.1.

The fields for Mineral Grains and Size Ranges show up as gray, indicating that data cannot be entered into them. Rather, the data in these fields are linked to the data that were previously entered into the worksheet Modal Composition—Minerals, since the constituents and size ranges are the same.

On the Modal Composition—Minerals worksheet, level two items that were siblings (have the same parent) summed to unity. However, on the Modal Composition—General worksheet, all fractions are fractions of the total, not the parent; therefore, all fractions must sum to unity.

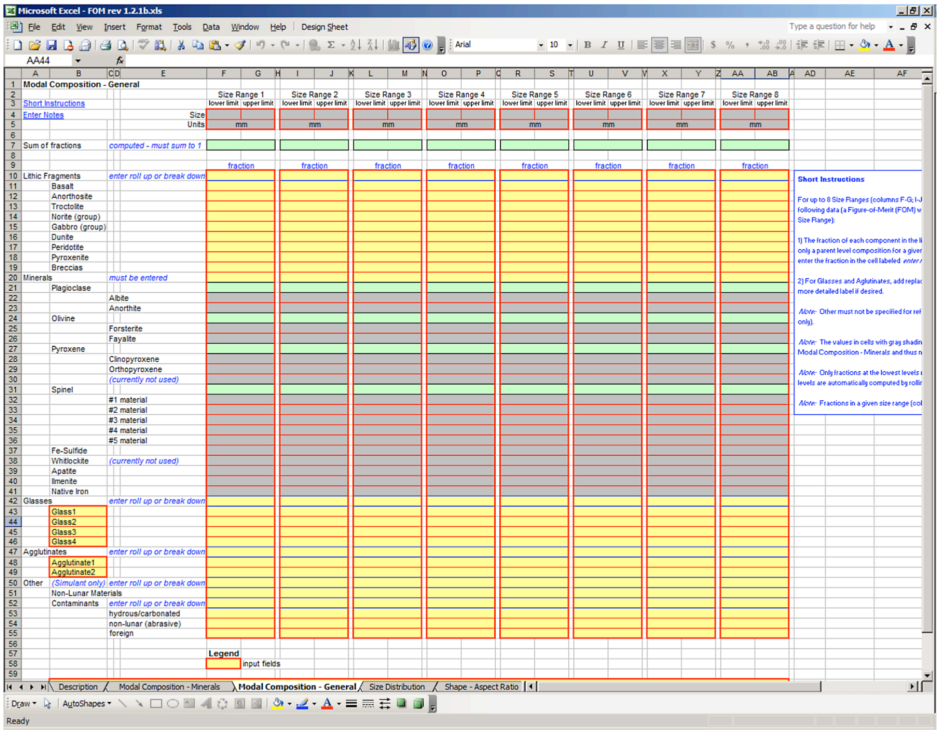


Figure 10. Modal Composition—General worksheet.

Modal composition data may be entered as a function of particle size for up to eight size ranges. The FoM software computes a separate modal composition FoM for each size range in which both the reference and simulant data files contain data. The data in corresponding size ranges is used to compute the FoM. As mentioned previously, size range data on the Modal Composition—General worksheet are linked to the size range data on the Modal Composition—Minerals worksheet; therefore, these data need not and cannot be entered on this worksheet.

5.3.3.1 Specific Instructions. The following steps are specific instructions for entering data.

Step 1: For the size ranges previously defined, enter the modal compositional fractions of the constituents in the material in the column under the heading fraction. Note that there are five subdivisions of modal composition at the first level, Lithic Fragments, Mineral Grains, Glasses, Agglutinates, and Other.

If one or more level 1 constituents cannot be further subdivided (i.e., if data is unavailable at a lower level), the fraction of material at this level is entered in the field labeled 'enter roll up or break down' (see figure 10). This is also known as entering a rolled-up value for the level below. Otherwise, if fractional data is available at a lower level, leave this field blank and enter the fractions for the appropriate constituents at the lower level.

Note: Fractions should only be entered in the field labeled 'enter roll up or break down' (see figure 10) or in the fields below this field.

Note: As constituent fractions and data for the material as a whole are entered, they are subtotaled at the next higher level in the light green computation fields of the worksheet. This aids in data entry, as one of the requirements is that the fractions must sum to unity.

Step 2: For Glasses, enter a descriptor for the kind of glass.

Note: The descriptor for kind of glass must match between the reference material and the simulant material and must be in the same row for both materials.

Step 3: For Agglutinates, enter a descriptor for the kind of agglutinate.

Note: The descriptor for kind of agglutinate must match between the reference material and the simulant material and must be in the same row for both materials.

Step 4: A category labeled Other exists for simulant material worksheets only, which may be used to enter fractions for unknown (nonlunar materials) constituents and for contaminants.

Note: Lunar regolith by definition does not contain nonlunar materials or contaminants, and so must have a zero value for Other.

Step 5: Notes for the worksheet may be entered in the block titled Notes.

5.3.3.2 Example. In this example, shown in figure 11, it is known that 58% of a material in the first size range is made up of lithic fragments; however, no further breakdown is known. Therefore, 0.58 is entered on the line labeled Lithic Fragments in the field labeled 'enter roll up or break down' (see figure 11). Mineral data were previously entered in the worksheet Modal Composition—Minerals; therefore, only the fraction of mineral grains in the material needs to be entered. This is known to be 24%. Finally, it is known that the remaining composition consists of 8% green glass, 6% brown glass, 1% agglutinates (no further breakdown available), and 1% nonlunar materials and contaminants, which consist of 0.5% hydrous/carbonated material and 1.5% nonlunar abrasive material. Figure 11 shows Size Range 1.

5.3.4 Size Distribution Worksheet

This worksheet is used to enter the size distribution data. Size distribution is specified as an RFD histogram by the fraction of the material that falls within a specified size bin. If the data are not in RFD form, then they must first be converted to this form (see section 3.2). The fractions within all specified bins must sum to unity. A value of zero is the default if no fraction is entered. Figure 12 shows the Size Distribution worksheet.

Bin sizes for the size distribution must be contiguous, and bins must be specified in order of ascending size. The user enters the upper bin size with units for a given bin size. For the lower bin size, the FoM software uses the previous bin's upper bin size; therefore, for the first bin, a lower bin size and units must also be specified.

	A	B	C	D	E	F	G
1	**Modal Composition - General**						
2						Size Range 1	
3	Short Instructions					lower limit	upper limit
4	Enter Notes				Size	0.1	10
5					Units	mm	
6							
7	Sum of fractions		*computed - must sum to 1*			*1.0000*	
8							
9						fraction	
10	Lithic Fragments		*enter roll up or break down*			0.5800	
11		Basalt					
12		Anorthosite					
13		Troctolite					
14		Norite (group)					
15		Gabbro (group)					
16		Dunite					
17		Peridotite					
18		Pyroxenite					
19		Breccias					
20	Minerals		*must be entered*			0.2400	
21		Plagioclase				*0.0576*	
22			Albite			0.0202	
23			Anorthite			0.0374	
24		Olivine				*0.0720*	
25			Forsterite				
26			Fayalite				
27		Pyroxene				*0.0432*	
28			Clinopyroxene			0.0311	
29			Orthopyroxene			0.0121	
30			*(currently not used)*				
31		Spinel				*0.0360*	
32			#1 material				
33			#2 material				
34			#3 material				
35			#4 material				
36			#5 material				
37		Fe-Sulfide				0.0120	
38		Whitlockite	*(currently not used)*				
39		Apatite				0.0144	
40		Ilmenite					
41		Native Iron				0.0048	
42	Glasses		*enter roll up or break down*			*0.1400*	
43		green glass				0.0800	
44		brown glass				0.0600	
45		Glass3					
46		Glass4					
47	Agglutinates		*enter roll up or break down*			0.0100	
48		Agglutinate1					
49		Agglutinate2					
50	Other	*(Simulant only)*	*enter roll up or break down*			*0.0300*	
51		Non-Lunar Materials				0.0100	
52		Contaminants	*enter roll up or break down*			*0.0200*	
53			hydrous/carbonated			0.0050	
54			non-lunar (abrasive)			0.0150	
55			foreign				

Figure 11. Modal Composition—General example.

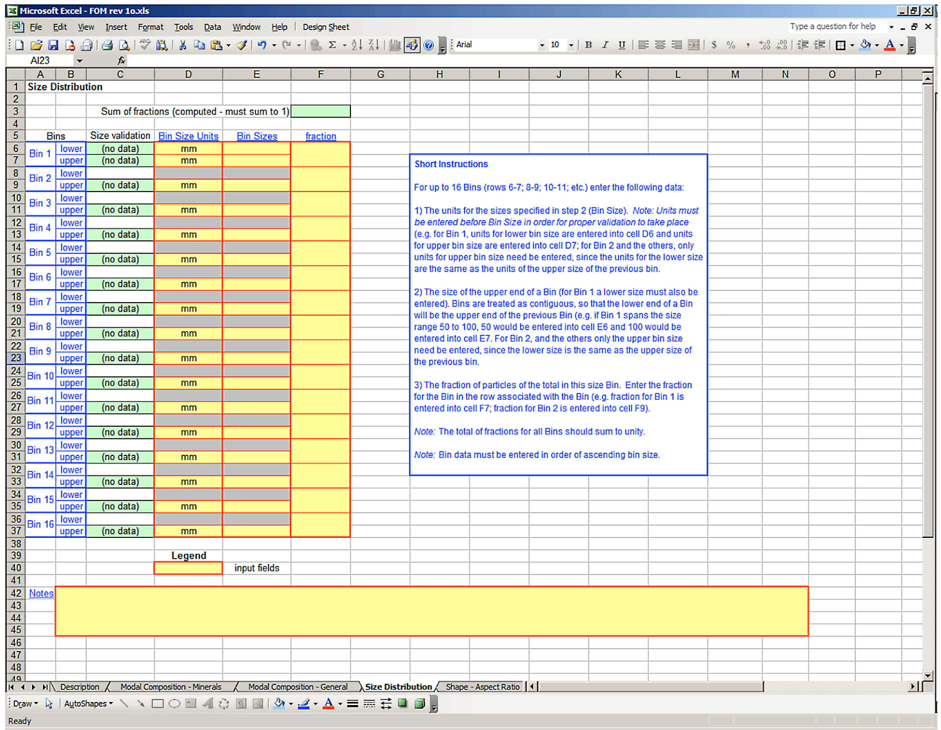


Figure 12. Size Distribution worksheet.

5.3.4.1 Specific Instructions. Size distribution is specified as an RFD histogram. If the data are not in RFD form, they must first be converted to this form.

Step 1: Enter the units for the lower and upper bin size for the first bin in the column labeled Bin Size Units. Units must be µm, mm, or cm. The units are used to scale all size data to a consistent set of units since size data may be entered in different units in different bins. Continue to enter the units for the upper bin size for the second and succeeding bins until units have been entered for every bin for which data exists.

Note: The Bin Size Units cells feature a drop down menu from which the µm, mm, and cm unit may be selected.

Step 2: Enter the lower and upper bin size for the first bin in the column labeled Bin Sizes. Continue to enter upper bin sizes for the second and succeeding bins until upper bin sizes have been entered for every bin for which data exists.

Note: Lower bin sizes for bins other than the first bin are obtained from the upper bin sizes of the preceding bins.

Step 3: Enter the fraction of particles that fall within the first size bin in the column labeled Fraction. Fraction must be a number between zero and 1. Continue to enter fractions for the second and succeeding size bins until fractions have been entered for every bin for which data exists.

Note: The fractions for all bins must sum to unity.

Step 4. Notes for the worksheet may be entered in the block titled Notes.

5.3.4.2 Example. In the example shown in figure 13, size fractions for 12 size bins are known. For Bin 1, the lower and upper bin size units and bin sizes must be specified; for all other bins, only the upper bin size needs to be specified.

	A	B	C	D	E	F
1	Size Distribution					
2						
3			Sum of fractions (computed - must sum to 1)			1.0000
4						
5	Bins		Size validation	Bin Size Units	Bin Sizes	Fraction
6	Bin 1	lower	OK	cm	0.000	
7		upper	OK	cm	0.303	0.0000
8	Bin 2	lower		cm	0.303	
9		upper	OK	cm	0.617	0.0036
10	Bin 3	lower		cm	0.617	
11		upper	OK	cm	1.040	0.0295
12	Bin 4	lower		cm	1.040	
13		upper	OK	cm	1.343	0.0875
⋮				⋮		
28	Bin 12	lower		cm	3.697	
29		upper	OK	cm	3.960	0.0124
30	Bin 13	lower				
31		upper	(no data)	mm		
32	Bin 14	lower				
33		upper	(no data)	mm		
34	Bin 15	lower				
35		upper	(no data)	mm		
36	Bin 16	lower				
37		upper	(no data)	mm		

Figure 13. Size Distribution example.

5.3.5 Shape—Aspect Ratio Worksheet

This worksheet is one of two for entering particle shape data. In particular, this worksheet allows entry of particle aspect ratio data. Particle aspect ratio is nominally specified as an RFD histogram by the fraction of material whose aspect ratios fall within a specified aspect ratio shape bin. The fractions within all specified bins must sum to unity. A value of zero is the default if no fraction is entered.

If RFD data for aspect ratio is provided, then the mean aspect ratio is computed. However, if the aspect ratio distribution is unknown, it may be replaced by the scalar mean aspect ratio over all the particles in the material. In this case, the user enters the mean aspect ratio into the field that would contain the computed mean aspect ratio had the data for the RFD been available. Figure 14 shows this worksheet.

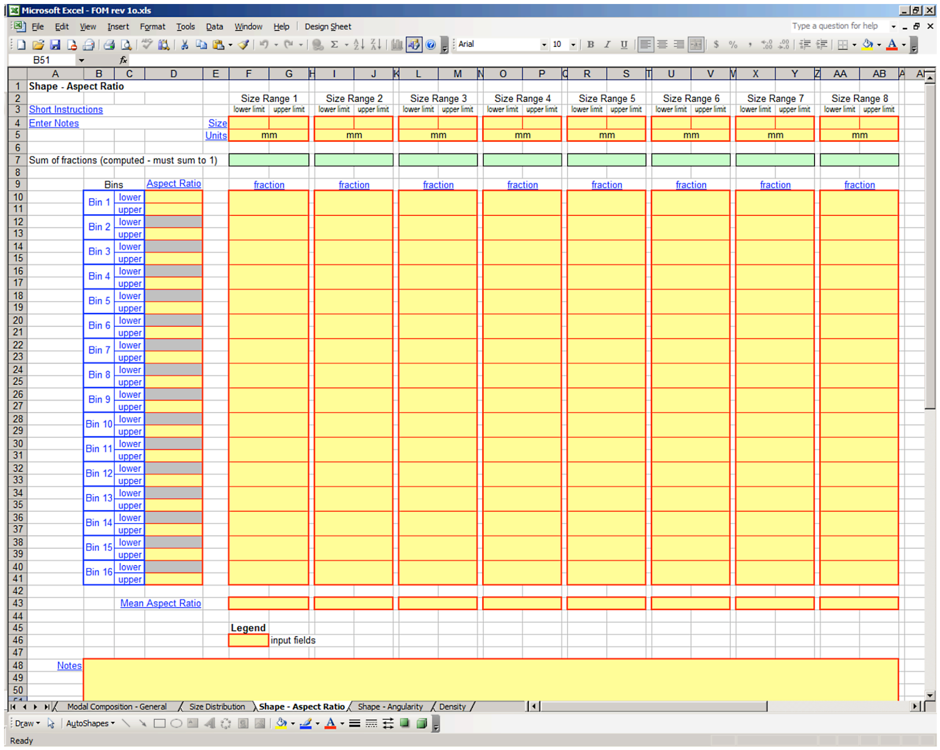


Figure 14. Shape—Aspect Ratio worksheet.

Since aspect ratio is a ratio of two values, it is a dimensionless quantity and units are not specified. Bin values for the aspect ratio distribution must be contiguous. Also, bins must be specified in order of increasing aspect ratio. The user enters the upper bin value for a given bin. This value also becomes the lower bin value for the next bin. For the first bin, a lower and upper bin value must be specified.

5.3.5.1 Specific Instructions. Aspect ratio distribution is specified as an RFD histogram. If the data are not in RFD form, then they must first be converted to this form.

Step 1: Enter the particle size range lower and upper limits into the cells in the row labeled Size, under the heading Size Range *i* for the *i*th size range set of data.

Note: If aspect ratio data is not a function of size, or if the particles span all sizes, then the size fields may be left blank. This data is currently not used for any computations and is for informational purposes only; however, it may be used in the future.

Step 2: Enter the units for the sizes in the fields below the size fields in the row labeled Units.

Note: Both the sizes (lower size limit and upper size limit) must be in the same units.

Note: This field features a drop-down menu from which the µm, mm, and cm units may be selected. This data is currently not used for any computations and is for informational purposes only; however, it may be used in the future.

Step 3: For the size ranges defined in steps 1 and 2, enter the lower and upper bin aspect ratio values for the first bin in the column labeled Aspect Ratio. Continue to enter upper bin aspect ratio values for the second and succeeding bins until upper bin aspect ratio values have been entered for every bin for which data exists.

Note: Lower bin aspect ratio values for bins other than the first bin are obtained from the upper bin aspect ratio values of the preceding bins.

Step 4: Enter the fraction of particles whose aspect ratios fall within the first aspect ratio bin in the column labeled Fraction. Fraction must be a number between zero and 1. Continue to enter fractions for the second and succeeding aspect ratio bins until fractions have been entered for every bin for which data exists.

Note: The fractions for all bins must sum to unity.

Step 5. If the aspect ratio distribution is unknown, the user may enter just the mean aspect ratio into the field labeled Mean Aspect Ratio. If aspect ratio distribution data is known, it is used to compute the Mean Aspect Ratio.

Note: Do not enter both RFD aspect ratio data and mean aspect ratio data.

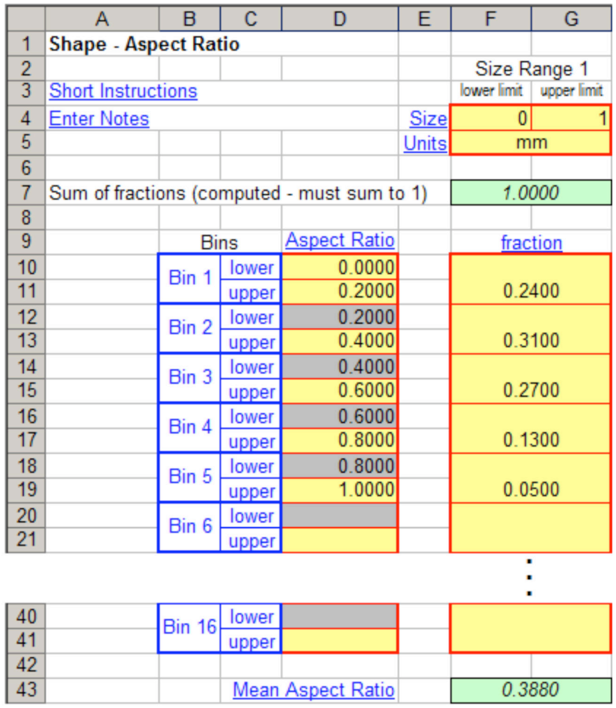
Step 6: Notes for the worksheet may be entered in the block titled Notes.

5.3.5.2 Example. In this example, shown in figure 15, aspect ratio fractions for five aspect ratio bins are known. For Bin 1, the lower and upper bin aspect ratios must be specified; for all other bins, only the upper bin aspect ratio needs to be specified.

5.3.6 Shape—Angularity Worksheet

This worksheet is the second of two for entering particle shape data. In particular, this worksheet allows entry of particle angularity data. Particle angularity is nominally specified as an RFD histogram by the fraction of material whose angularities fall within a specified angularity shape bin. The fractions within all specified bins must sum to unity. A value of zero is the default if no fraction is entered.

If RFD data for angularity is provided, the mean angularity is computed. However, if the angularity distribution is unknown, it may be replaced by the scalar mean angularity over all the particles in the material. In this case, the user enters the mean angularity into the field that would contain the computed mean angularity had the data for the RFD been available. Figure 16 shows the Shape—Angularity worksheet.



	A	B	C	D	E	F	G
1	Shape - Aspect Ratio						
2						Size Range 1	
3	Short Instructions					lower limit	upper limit
4	Enter Notes				Size	0	1
5					Units	mm	
6							
7	Sum of fractions (computed - must sum to 1)					1.0000	
8							
9		Bins		Aspect Ratio		fraction	
10		Bin 1	lower	0.0000			
11			upper	0.2000		0.2400	
12		Bin 2	lower	0.2000			
13			upper	0.4000		0.3100	
14		Bin 3	lower	0.4000			
15			upper	0.6000		0.2700	
16		Bin 4	lower	0.6000			
17			upper	0.8000		0.1300	
18		Bin 5	lower	0.8000			
19			upper	1.0000		0.0500	
20		Bin 6	lower				
21			upper				
⋮							
40		Bin 16	lower				
41			upper				
42							
43			Mean Aspect Ratio			0.3880	

Figure 15. Shape—Aspect Ratio example.

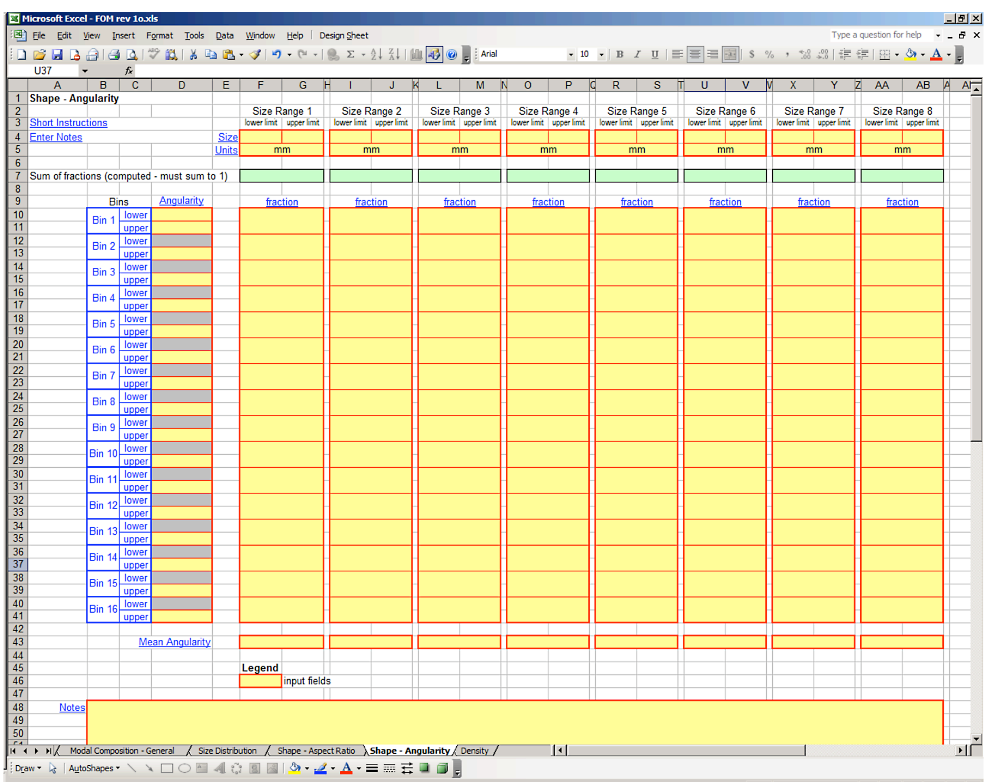


Figure 16. Shape—Angularity worksheet.

Bin values for the angularity distribution must be contiguous. Also, bins must be specified in order of increasing angularity. The user enters the upper bin value for a given bin. This value also becomes the lower bin value for the next bin. A lower and upper bin value must be specified for the first bin.

5.3.6.1 Specific Instructions Angularity distribution is specified as an RFD histogram. If the data are not in RFD form, they must first be converted to this form.

Step 1: Enter the particle size range lower and upper limits into the cells in the row labeled Size, under the heading Size Range *i* for the *i*th size range set of data.

Note: If angularity data is not a function of size, or if the particles span all sizes, then the size fields may be left blank. This data is currently not used for any computations and is for informational purposes only; however, it may be used in the future.

Step 2: Enter the units for the sizes in the fields below the size fields in the row labeled Units.

Note: Both the sizes (lower size limit and upper size limit) must be in the same units.

Note: This field features a drop down menu from which the μm, mm, and cm units may be selected. This data is currently not used for any computations and is for informational purposes only; however, it may be used in the future.

Step 3: For the size ranges defined in steps 1 and 2, enter the lower and upper bin angularity values for the first bin in the column labeled Angularity. Continue to enter upper bin angularity values for the second and succeeding bins until upper bin angularity values have been entered for every bin for which data exists.

Note: Lower bin angularity values for bins other than the first are obtained from the upper bin angularity values of the preceding bins.

Step 4: Enter the fraction of particles whose angularities fall within the first angularity bin in the column labeled Fraction. Fraction must be a number between zero and 1. Continue to enter fractions for the second and succeeding angularity bins until fractions have been entered for every bin for which data exists.

Note: The fractions for all bins must sum to unity.

Step 5: If the angularity distribution is unknown, the user may enter just the mean angularity into the field labeled Mean Angularity. If angularity distribution data is known, it is used to compute Mean Angularity.

Note: Do not enter both RFD angularity data and mean angularity data.

Step 6: Notes for the worksheet may be entered in the block titled Notes.

5.3.6.2 Example. In this example, shown in figure 17, the angularity distribution is unknown. However, a mean angularity of 28.3 has been determined. Therefore, the user enters the mean value into the field labeled Mean Angularity.

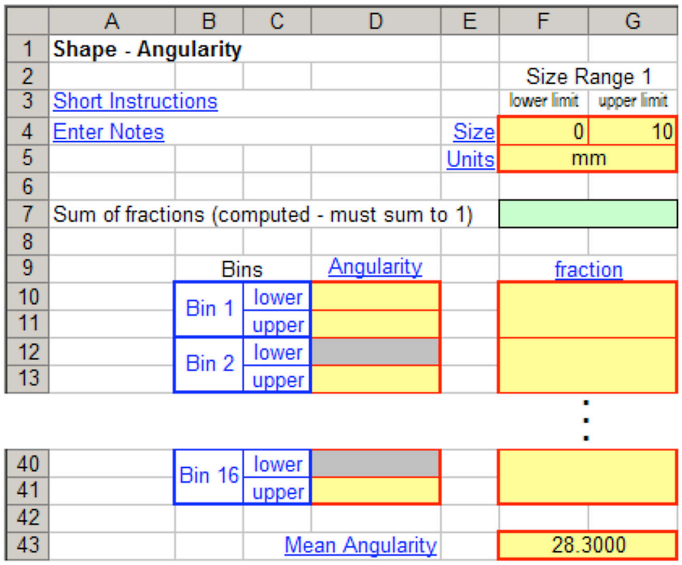


Figure 17. Shape—Angularity example.

5.3.7 Density Worksheet

This worksheet is used to enter the density data. Density is the ratio of the material's mass to volume. However, because the materials being compared are particulate, various volumes may be considered in the definition including volume with or without interparticle void volume and internal pore volume. As a result, three different measures of density (i.e., mean specific gravity, minimum bulk density, and maximum bulk density) are defined. Precise definitions of these terms may be found in reference 1. These are entered into the Density worksheet shown in figure 18.

5.3.7.1 Specific Instructions.

Step 1: Enter the mean specific gravity of the material into the field labeled Mean Specific Gravity. Since this is a ratio, it is a dimensionless quantity and has no units.

Step 2: Enter the minimum bulk density of the material into the field labeled Minimum Bulk Density.

Step 3: Enter the units for minimum bulk density into the field labeled Units under Minimum Bulk Density. Note that units must be either g/cm^3 or kg/m^3.

Step 4: Enter the maximum bulk density of the material into the field labeled Maximum Bulk Density.

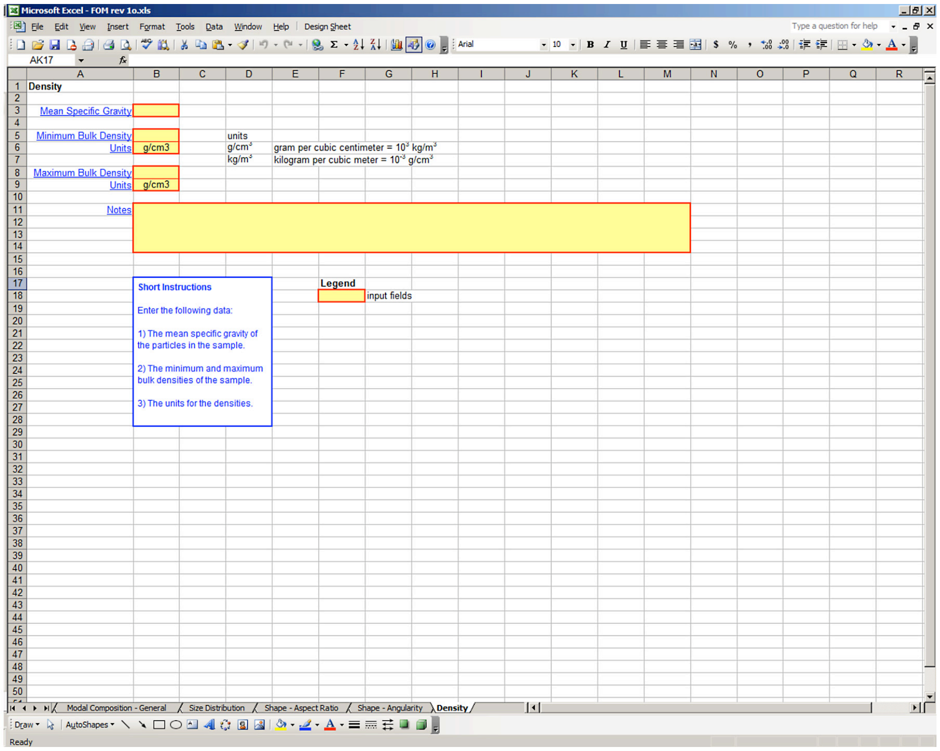


Figure 18. Density worksheet.

Step 5: Enter the units for maximum bulk density into the field labeled Units under Maximum Bulk Density. Note that units must be either g/cm^3 or kg/m^3.

Note: The Units cell features a drop-down menu from which the g/cm^3 or kg/m^3 units may be selected.

Step 6: Notes for the worksheet may be entered in the block titled Notes.

5.3.7.2 Example. In this example, shown in figure 19, the mean specific gravity of a material is 2.345, the minimum bulk density is 2.102 g/cm^3 and the maximum bulk density is 2.789 g/cm^3.

5.4 Creating a Reference or Simulant Data File

Once data for a reference and simulant material is collected, it must be entered into an Excel file with the exact structure as the FoM Template.xlt file installed with the FoM software. The steps for creating a reference or simulant data file are identical; therefore, this section will refer to either file as the sample data file.

Note: The following steps show two different methods for creating a sample data file. Either method may be used but both methods should not be used simultaneously.

	A	B
1	**Density**	
2		
3	Mean Specific Gravity	2.345
4		
5	Minimum Bulk Density	2.102
6	Units	g/cm3
7		
8	Maximum Bulk Density	2.789
9	Units	g/cm3

Figure 19. Density example.

Note: The c:\ in the pathnames represents the Windows' volume. The user may need to use a different drive designator if the Windows' volume on your computer is not c:\.

Step 1: Create an empty sample data file from the FoM Template.xlt in the default FoM data folder using one of the following methods:

- Method 1: Directly from an Excel application:
  - Open the c:\FoMData\FoM Template.xlt with an Excel file by double-clicking the file or using the File>>Open menu item from within Excel.
  - Use the File>>Save As… menu item from within Excel to save the template in a new file.
    - Double click the folder or use the Save in line of the Save As dialog box to specify where the file should be saved.
    - Use the File name line in the dialog box to specify the sample data file name.
    - Click the Save button in the dialog box. This will save an empty sample data file without the read-only attribute that the FoM Template.xlt file has.

- Method 2: From within the FoM application:
  - Open the FoM application from the Start>>All Programs>>Figures of Merit list item.
  - From within the FoM application, select the File>>New… menu item.
    - Double click the folder or use the Save in line of the dialog box to specify where the file should be saved.
    - Use the File name line in the dialog box to specify the sample data file name.
    - Click the Save button in the dialog box. This will save an empty sample data file without the read-only attribute that the FoM Template.xlt file has. A confirmation dialog box will appear stating that a new sample data file has been created.

Step 2: Edit and save the sample data file using one of the following methods:

- Method 1: Directly from an Excel application:
  - Open the newly created sample data file with an Excel file by double-clicking the file or using the File>>Open menu item from within Excel.

- Enter data in the yellow highlighted fields.
- Use the File>>Save menu item from within Excel to save the entered data.

- Method 2: From within the FoM application:
  - From within the FoM application, select the File>>Open>>Reference or File>>Open>>Simulant menu item, depending on whether the file should be interpreted as reference material or simulant material.
    - Double click the new sample data file or type the name into the File name line in the dialog box. Excel will be launched and the selected file will appear. If the selected data file does not appear, you may need to click the Excel button on the task bar to bring the window to the front.
  - Use the File>>Save menu item from within Excel to save the entered data.
  - As an alternative, use the File>>Close>>Reference or File>>Close>>Simulant menu item in the FoM application. The user will be asked to confirm saving the data before the file is closed.

6. USING THE FREQUENCY OF MERIT SOFTWARE

6.1 Selecting Reference and Simulant Data Files for Figure of Merit Calculations

Both a reference and a simulant data file must be selected prior to performing any FoM calculations. Any Excel data file adhering to the exact format of the FoM Template.xlt file may be used as a reference or a simulant data file; therefore, a file that was originally created as a simulant may be selected as a reference if the user desires to compare two simulants.

When the FoM software is first opened, no reference or simulant data is selected. The fields titled Reference and Simulant, as shown in figure 20, on the main window of the FoM software indicate this.

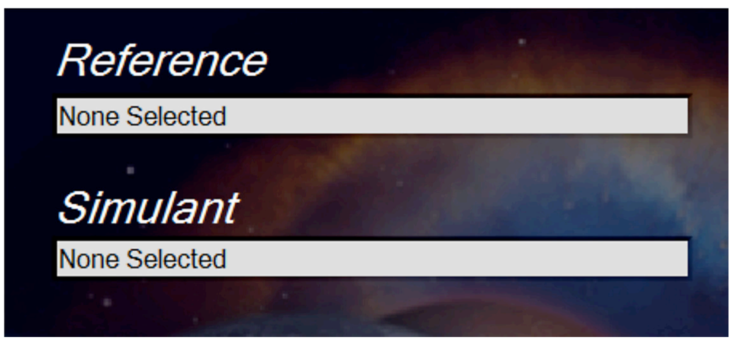


Figure 20. Reference and Simulant data file selection fields.

Once a reference and/or simulant data file is selected, it can only be unselected by selecting another file or exiting the FoM software. The None Selected appears in these fields only until a file is selected for the first time.

There are two ways to select a Reference or Simulant data file; both are from within the FoM software.

Method 1: Select and open the data file for viewing as follows:

- Select the File>>Open>>Reference or File>>Open>>Simulant menu item. A file select dialog box will appear.
- Double click the desired sample data file or type the name into the File name line in the dialog box. Excel will be launched and the selected file will appear. If the selected data file does not appear, the user may need to click the Excel button on the task bar to bring the window to the front.

• The selected data file name will appear in the box under Reference or Simulant in the main FoM window.

Method 2: Select the data file, but do not open for immediate viewing as follows:

• Move the mouse cursor over the label Reference or Simulant that appears on the main window of the FoM software. When the word becomes a highlighted yellow color, click the mouse once as shown in figure 21. A file select dialog box will appear.

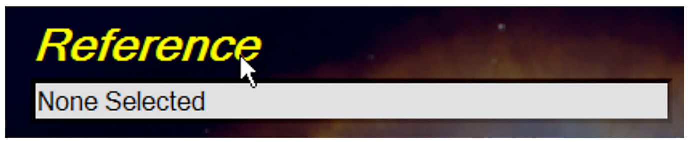


Figure 21. Selection of a reference material data file.

• Double click the desired sample data file or type the name into the File name line in the dialog box. Excel will be launched and the selected file will open but will be minimized as a button on the task bar.

• The selected data file name will appear in the box under Reference or Simulant in the main FoM window as shown in figure 22.

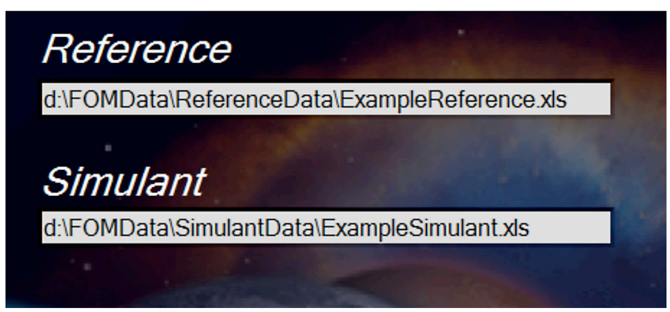


Figure 22. Filled in fields for reference and simulant material data files.

After both a reference and simulant data file have been selected, the FoM calculation functions may be executed.

6.2 Computing Figures of Merit

6.2.1 Introduction

Once the input data files for the FoM software have been opened, computation of the FoMs may proceed. In addition to the data about the reference material and the simulant material, the user must supply various other inputs. One of these has already been described, namely the Importance Vector for Modal Composition and the Importance Weighting Function for Size Distribution. Although not an intrinsic property of the reference material, Importance was included in the reference material workbook for convenience since the Importance has the same dimensions as, and must match, the data that it weighs. This made data entry a little easier than requiring a third workbook or prompting the user for the data in the application proper. Other inputs that the user must supply are described in the FoM sections where the input is appropriate. FoM computation may be initiated by one of two methods.

Method 1: Using the Window menu, select the Window>>FoM>> and then one of the following menu items: The Modal Composition, Size Distribution, Shape, or Density.

Method 2: Selecting the desired FoM computation in the main application window, move the mouse cursor over the FoM that you wish to compute that appears on the main window of the FoM software. Modal Composition and Shape have a second tier of choices that may be selected by moving the cursor first over Modal Composition or Shape and then over the second tier to be selected. When the word becomes a highlighted yellow color, as shown in figure 23, click the mouse once. The example in section 6.2.2 shows how to initiate a Modal Composition—General computation.

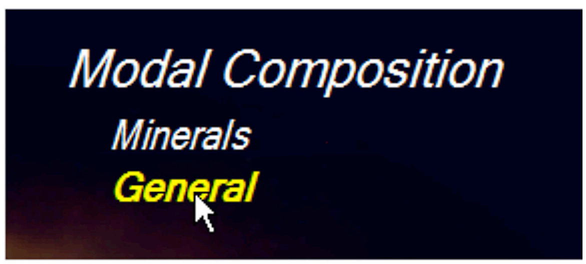


Figure 23. Color change indicating a selection.

Either method will result in a dialog box appearing that will allow further option selection. The specific details for each FoM follow.

6.2.2 Modal Composition—Minerals

Selection of the Modal Composition—Minerals FoM computation causes the Modal Composition FoM—Minerals dialog box, shown in figure 24, to appear.

Pressing the Close button closes the dialog box and terminates FoM computation.

Pressing the Start Calculation button initiates computation of up to eight different modal composition FoMs corresponding to the eight different size ranges on the Modal Composition—Minerals worksheet in which data may have been provided.

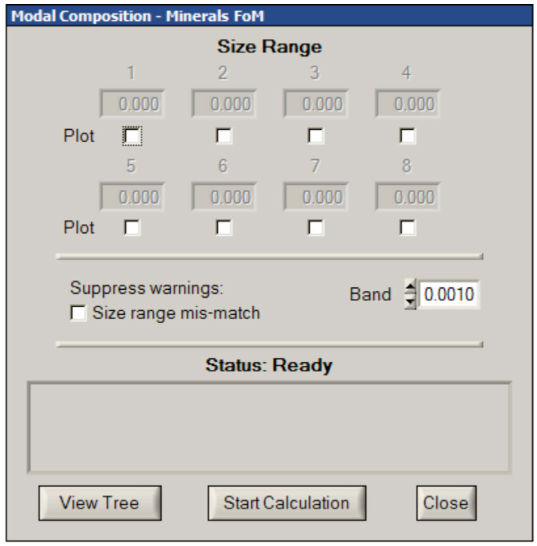


Figure 24. Modal Composition—Minerals FoM dialog box.

The dialog box also allows the user to suppress a 'Size Range Mis-match' warning. If 'Size Range Mis-match' warnings are not suppressed, then a warning results when a given size range in the reference material worksheet does not match the corresponding size range in the simulant worksheet. The purpose of this warning is to alert the user to the fact that data for inconsistent size ranges are being compared. While small mismatches may not matter, large ones may be indicative of a data entry error. The warning appears as shown in figure 25.

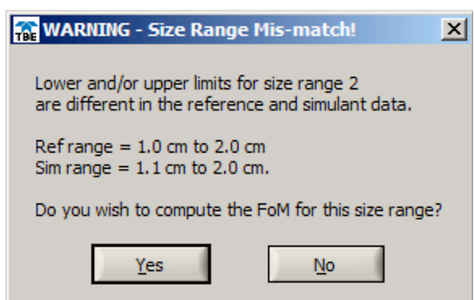


Figure 25. Size Range Mis-match warning dialog box.

Selecting Yes allows the FoM computation to proceed. Selecting No terminates the calculation for that size range.

If 'Size Range Mis-match' warnings are suppressed, then size range mismatches are ignored and the FoMs will be computed for all size ranges for which data exists in both the reference and simulant data files.

Composition fractions for modal composition are required to sum to unity. In practice however, fractions may not sum to exactly unity because of numerical round off. Therefore, a band has been defined around unity that is considered unity for summing purposes. Thus, sums that fall within the range 1 ± Band are considered to be 1. The default value for Band is 0.001 so that all sums between 0.999 and 1.001 are considered to be 1. The value of Band may be set to different values if the default is not appropriate.

Checking the box labeled Plot under each size range will produce a set of bar graphs that show the reference fractional modal composition, the simulant fractional modal composition as separate plots, the reference and simulant fractional modal composition in a combined plot, and the difference of the reference and simulant fractional modal composition. These plots are provided as visual aids to the FoM computation. Examples are shown in figures 26 and 27.

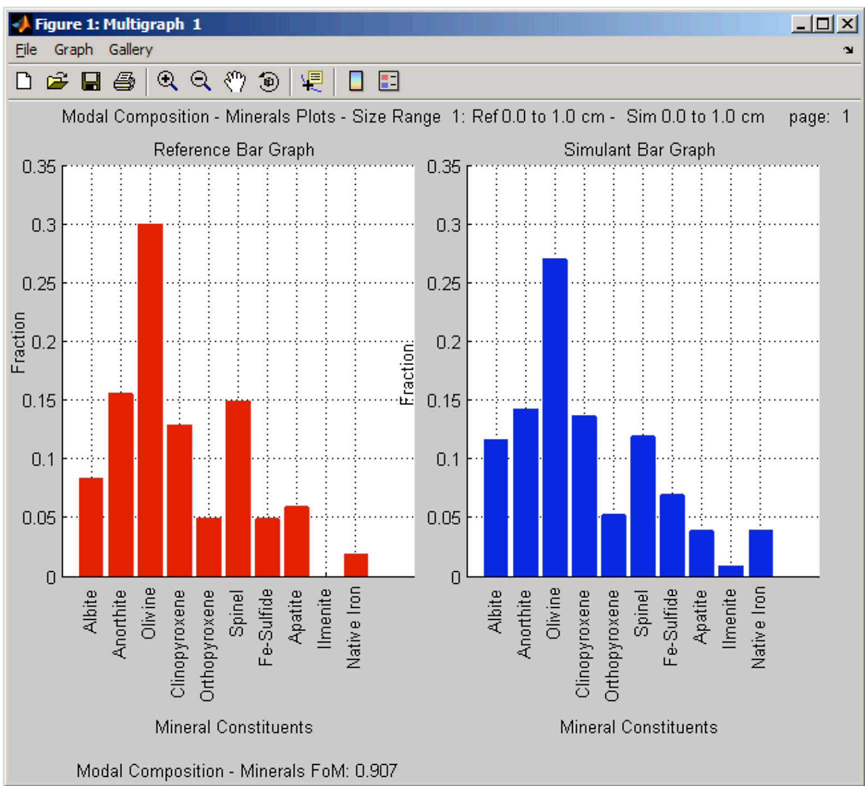


Figure 26. Modal Composition—Minerals reference and simulant bar graphs.

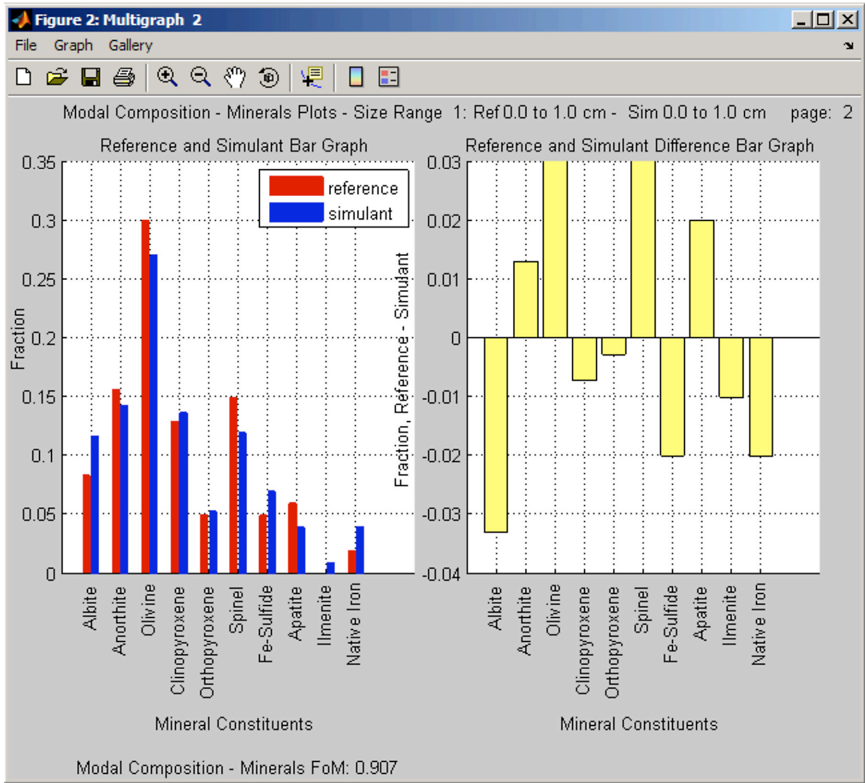


Figure 27. Modal Composition—Minerals joint and difference bar graphs.

Finally, pressing the View Tree button brings up the Modal Composition Tree—Minerals window. This window, shown in figure 28, shows the modal compositional data in hierarchical view for each size range. The user may select to view the various fractions as fractions of the whole (Fraction of Total) or as fractions of the parents at a particular level (Fraction of Level).

The refresh button will initiate a reread of the Modal Composition—Minerals Excel worksheet. If the tree window is open when the user edits the worksheet, the software should detect the change and automatically close the tree window. Whenever the tree window is opened, it checks to see if the worksheet has been changed since the last read. If it has been changed, the file will be reread. The refresh button forces a new read of the worksheet even if the software thinks the file has not changed since the last read. Under nominal conditions, this button should never have to be used; however, it may be used if, for any reason, the user believes that the latest updates to the worksheet have not been loaded into the tree window.

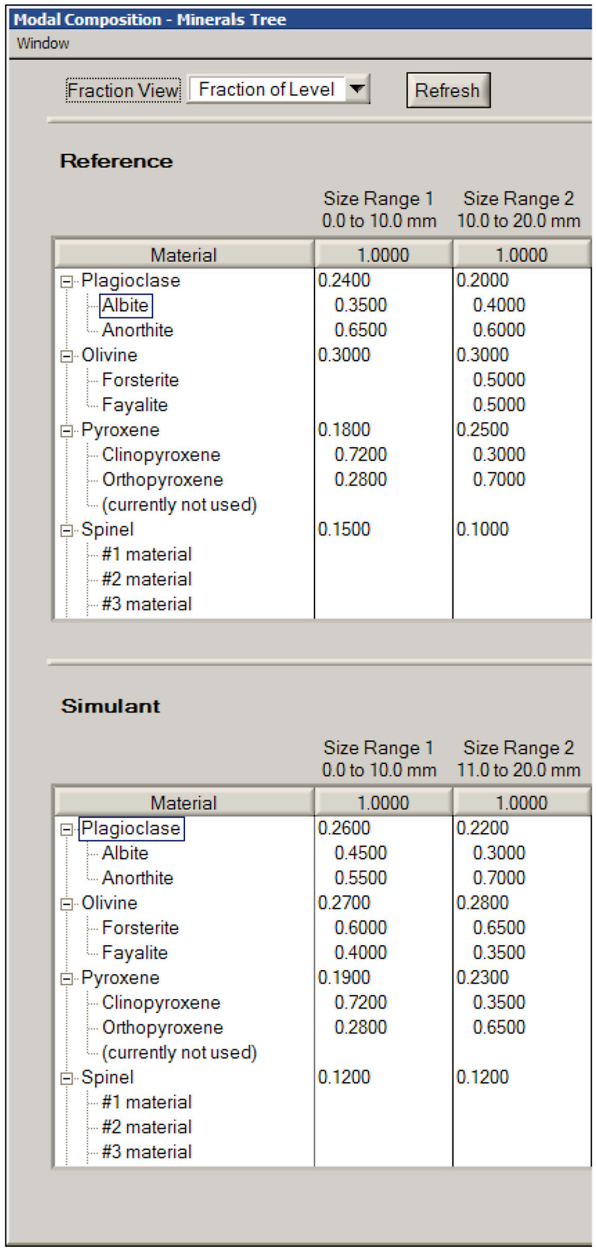


Figure 28. Modal Composition—Minerals data tree view.

6.2.2.1 **Window Menu.** The Window menu contains the following menu items (see figure 29):

- Print: Opens the standard dialog box for printing files to print the tree window.
- Close: Closes the tree window.

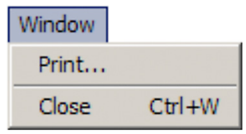


Figure 29. Window menu.

The user may also right click in the tree window, which brings up a control menu shown in figure 30 from which the user can perform a search (Find), expand or collapse the entire tree or a subset thereof (this can also be performed with the ± icons), and can change the font size. Font size changes are remembered so the user can set and forget them.

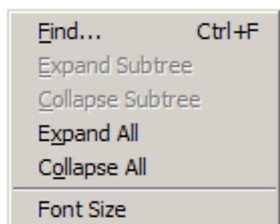


Figure 30. Modal Composition—Minerals tree control menu.

Pressing the Close button (not shown) closes the window.

6.2.3 Modal Composition—General

Selection of the Modal Composition—General FoM computation causes the Modal Composition FoM—General dialog box shown in figure 31 to appear.

This dialog box and its behavior are identical to the dialog box Modal Composition—Minerals FoM, so the reader is referred to section 6.2.2 for further information.

6.2.4 Size Distribution

Selection of a Size Distribution FoM computation causes the Size Distribution FoM dialog box to appear (fig. 32).

Pressing the Close button closes the dialog box and terminates FoM computation.

Pressing the Start Calculation button initiates computation of the Size Distribution FoM.

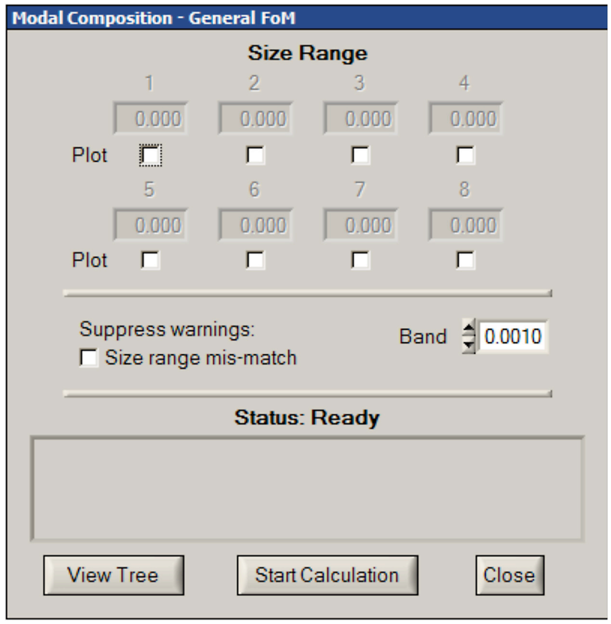


Figure 31. Modal Composition—General FoM dialog box.

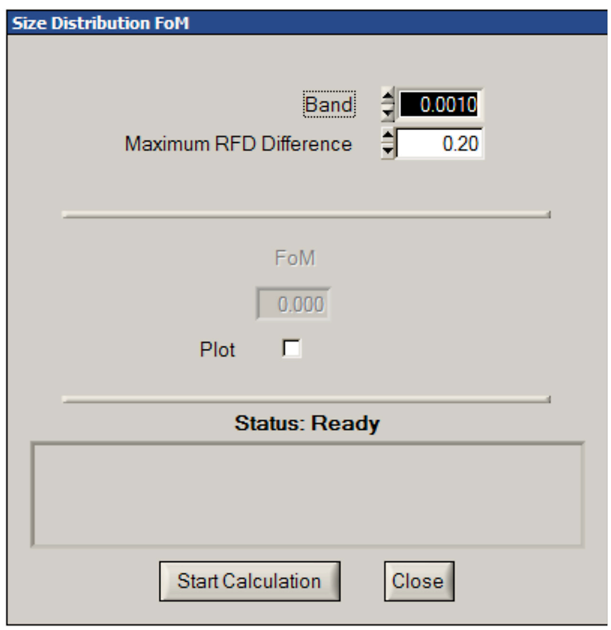


Figure 32. Size Distribution FoM dialog box.

Fractions for size distribution are required to sum to unity. In practice however, fractions may not sum exactly to unity because of numerical round off. Therefore, a band around unity may be defined that is considered unity for summing purposes. Thus, sums that fall in the range 1 ± Band are considered to be 1. The default value for Band is 0.001 so that all sums between

0.999 and 1.001 are considered to be 1. The value of Band may be set to different values if the default is not appropriate.

The dialog box also allows the user to specify a Maximum RFD Difference. Recall that the Size Distribution FoM is computed by comparing two RFDs and that such FoMs are subject to a maximum error constraint. If the difference between the reference RFD and the simulant RFD exceeds the Maximum RFD Difference, then the FoM is set to zero. The default value for the Maximum RFD Difference is 0.2. This dialog box allows the user to specify a different value. The actual largest difference between the reference RFD and the simulant RFD is computed and displayed on a graph if the Plot option is checked.

Checking the box labeled Plot generates a series of plots of the reference RFD, the simulant RFD, and the difference of the reference and simulant RFDs. Additionally, the largest difference between the reference RFD and the simulant RFD is computed and displayed. These plots (fig. 33) are provided as visual aids to the FoM computation.

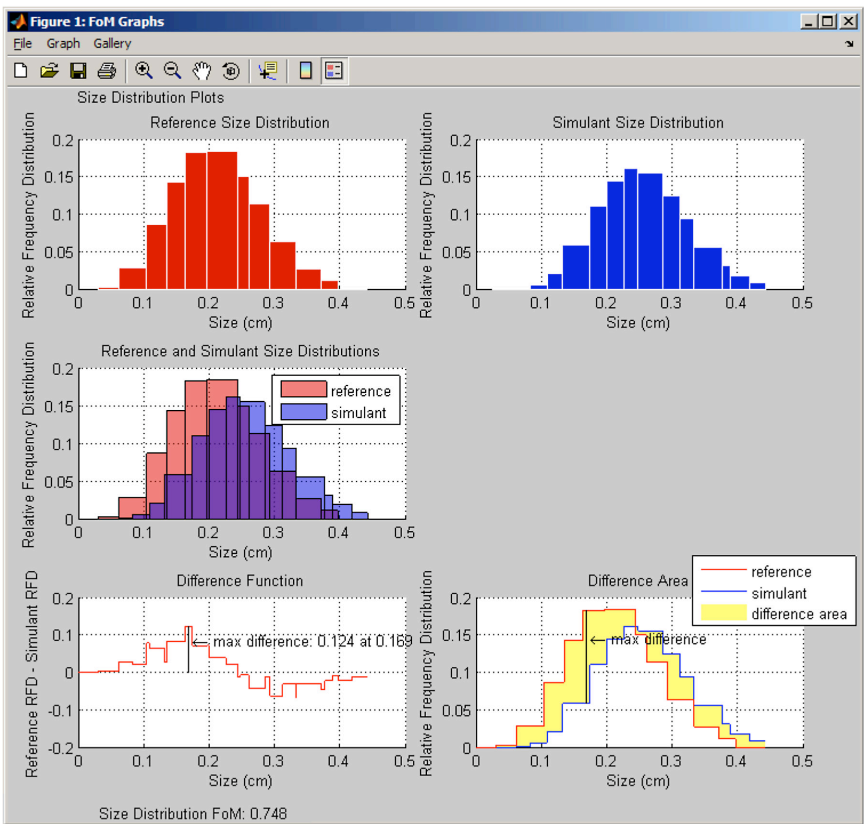


Figure 33. Size Distribution histogram plots.

6.2.5 Shape—Aspect Ratio

Selection of a Shape—Aspect Ratio FoM computation causes the Shape—Aspect Ratio FoM dialog box shown in figure 34 to appear. This FoM computation is an RFD computation just like the Size Distribution FoM computation; therefore, this dialog box is just like the Size Distribution Dialog box, with the exception that the computations can occur over multiple size ranges.

Pressing the Close button closes the dialog box and terminates FoM computation.

Pressing the Start Calculation button initiates computation of the Size Distribution FoM.

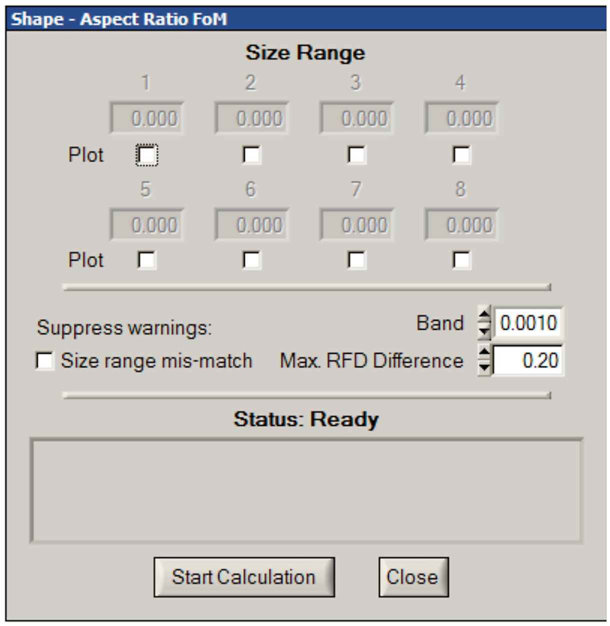


Figure 34. Shape—Aspect Ratio FoM dialog box.

Fractions for size distribution are required to sum to unity; in practice however, fractions may not sum exactly to unity because of numerical round off. Therefore, a band around unity may be defined that is considered unity for summing purposes. Thus, sums that fall in the range 1 ± Band are considered to be 1. The default value for Band is 0.001 so that all sums between 0.999 and 1.001 are considered to be 1. The value of Band may be set to different values if the default is not appropriate.

The dialog box also allows the user to specify a Maximum RFD Difference. Recall that the Shape—Aspect Ratio FoM is computed by comparing two RFDs and that such FoMs are subject to a maximum error constraint. If the difference between the reference RFD and the Simulant RFD exceeds the Maximum RFD Difference, then the FoM is set to zero. The default value for the Maximum RFD Difference is 0.2. This dialog box allows the user to specify a different value. The actual largest difference between the reference RFD and the simulant RFD is computed and displayed on a graph if the Plot option is checked.

Checking the box labeled Plot generates a series of plots of the reference RFD, the simulant RFD, and the difference of the reference and simulant RFDs. Additionally, the largest difference between the reference RFD and the simulant RFD is computed and displayed. The plots in figure 35 are provided as visual aids to the FoM computation and are similar to the ones shown for Size Distribution in figure 33.

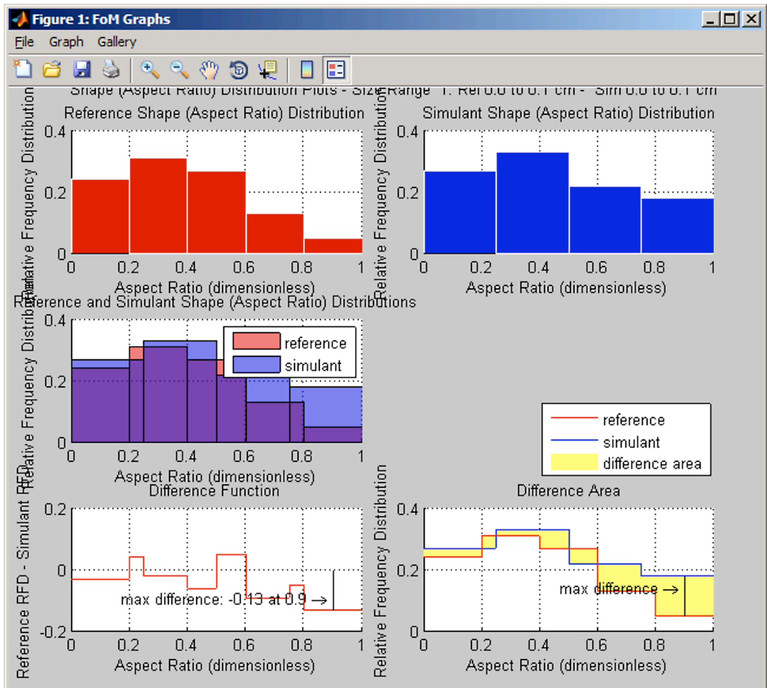


Figure 35. Shape—Aspect Ratio FoM graphics output.

6.2.6 Shape—Angularity

Selection of a Shape—Angularity FoM computation causes the Shape—Angularity FoM dialog box shown in figure 36 to appear.

This dialog box and its behavior are identical to the dialog box Shape—Aspect Ratio FoM, so the reader is referred to section 6.2.5 for further information. Figure 37 presents examples of the Shape—Angularity FoM graphics output.

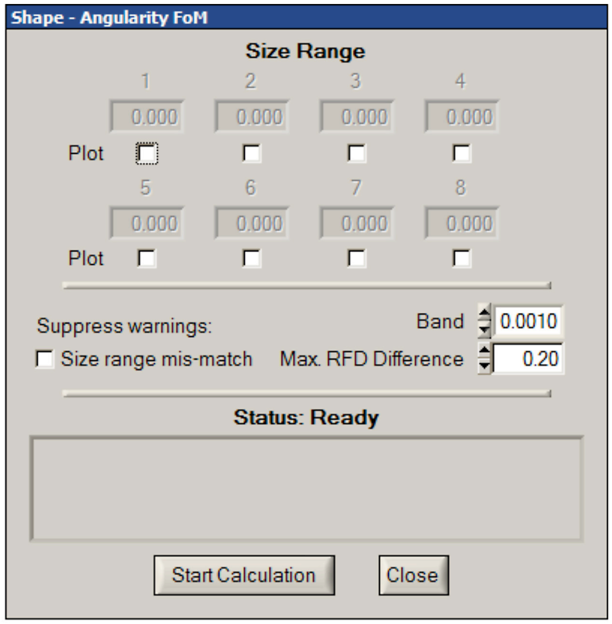


Figure 36. Shape—Angularity FoM dialog box.

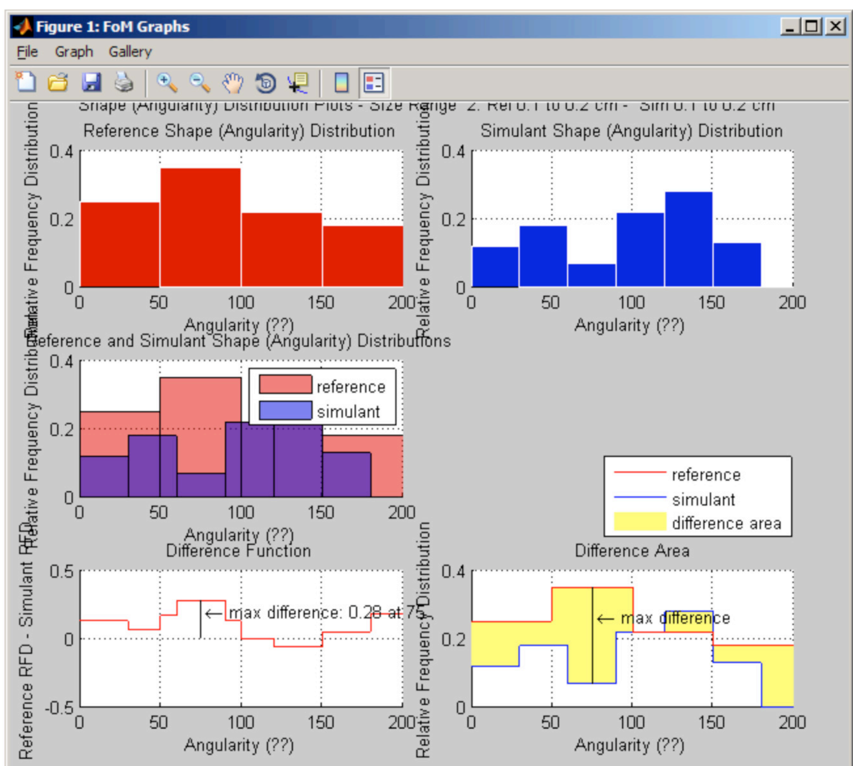


Figure 37. Shape—Angularity FoM graphics output.

6.2.7 Density

Selection of a Density FoM computation causes the FoM Messages (see section 6.3) and Density FoM dialog box shown in figure 38 to appear.

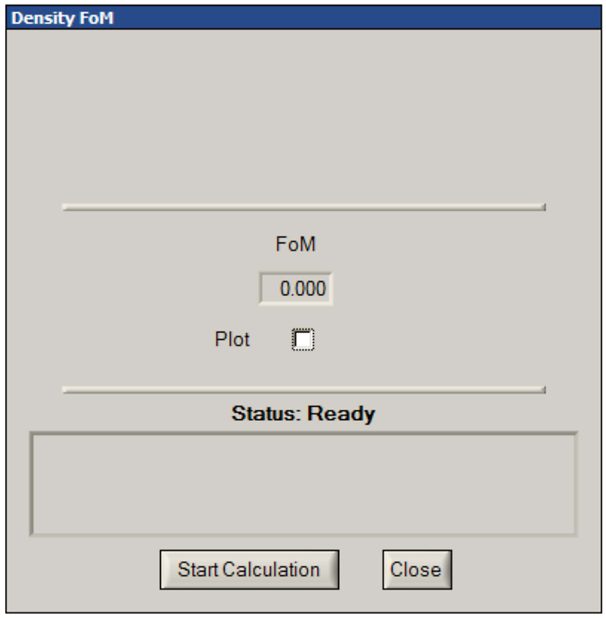


Figure 38. Density FoM dialog box.

Pressing the Close button closes the dialog box and terminates FoM computation.

Pressing the Start Calculation button initiates computation of the Density FoM.

Checking the box labeled Plot will produce a set of bar graphs as shown in figures 39 and 40. The reference density categories (mean specific gravity, minimum bulk density, and maximum bulk density) and the simulant density categories as separate plots are shown in figure 39. The reference and simulant density categories in a combined plot and the difference of the reference and simulant density categories are shown in figure 40. These plots are provided as visual aids to the FoM computation and are similar to the ones shown for modal composition in figures 26 and 27.

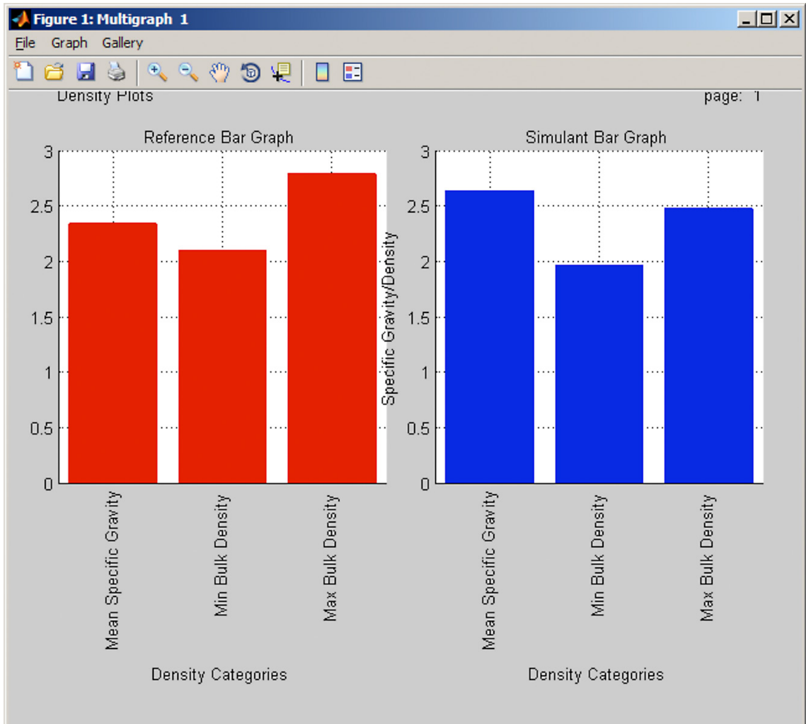


Figure 39. Density FoM graphics output, page 1.

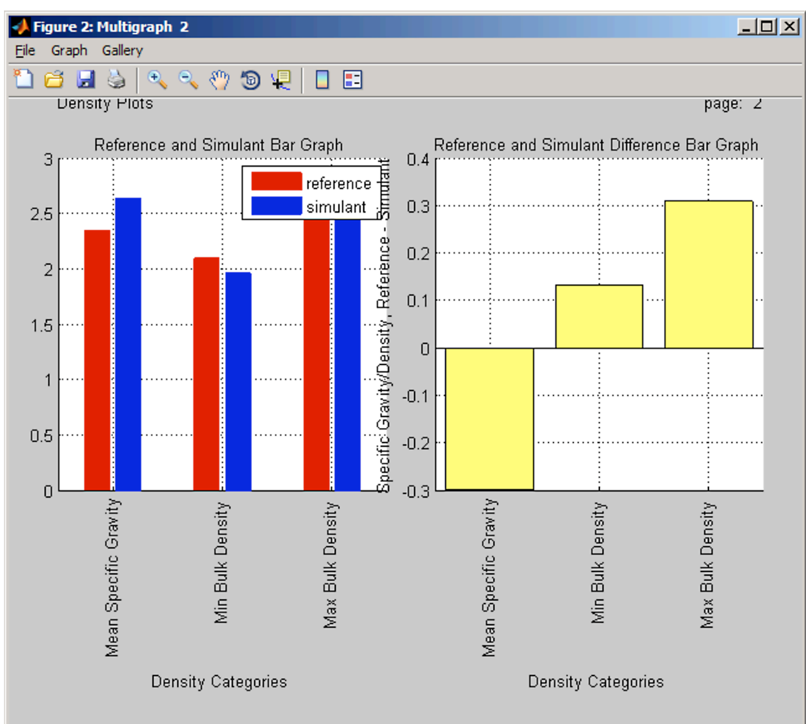


Figure 40. Density FoM graphics output, page 2.

6.3 Figure of Merit Messages and Saving Results

When an FoM calculation is initiated, any messages resulting from the calculation and the results of the calculation are displayed in the scrolling FoM Messages window shown in figure 41.

This window captures errors, warnings, and informational messages. It also contains the results of the FoM calculation by default.

This window has two menus, Window and Options, that contain the menu items described in sections 6.3.1 and 6.3.2.

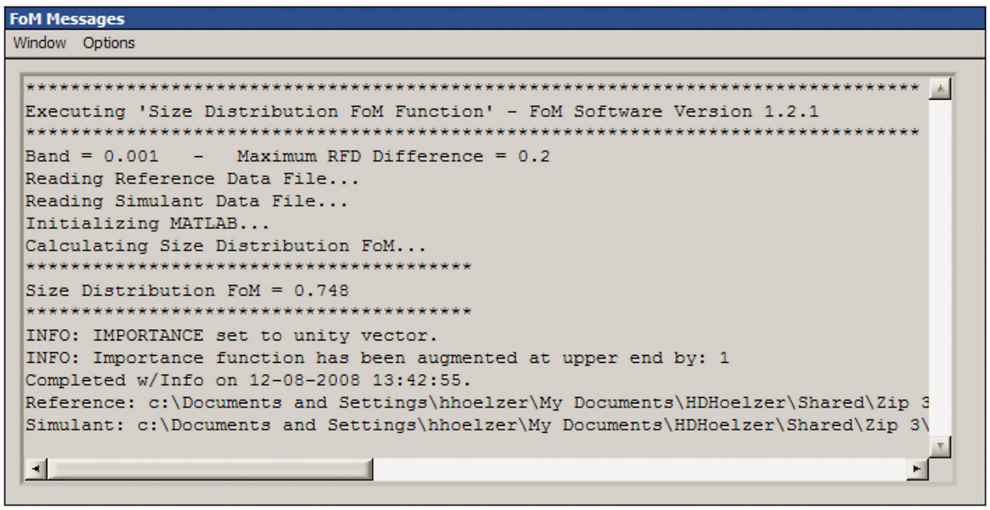


Figure 41. FoM Messages window.

6.3.1 Window Menu

Figure 42 is a depiction of the Window menu.

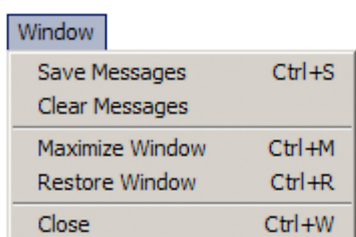


Figure 42. Window menu.

The Window menu contains the following menu items:

- Save Messages: Saves the contents of the window to a text file, so that a record of the FoM computations may be made.

• Clear Messages: Clears the contents of the window.

• Maximize Window: Maximizes the FoM Messages window. The window may also be resized by grabbing and dragging the top or bottom borders. Dragging on the title bar moves the window.

• Restore Window: Restores the FoM Messages window to its default size and location.

• Close: Closes the FoM Messages window. It may be reopened by selecting the Window>>Messages menu item.

6.3.2 Options Menu

Figure 43 is a depiction of the Options menu.

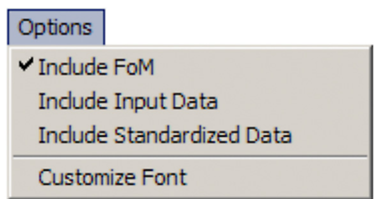


Figure 43. Options menu.

The Options menu contains the following menu items:

• Include FoM: Includes the FoM computation result in the FoM Message window. This is checked by default.

• Include Input Data: Input data refers to the composition vectors, the size distribution vectors, the shape distribution data, and the density data as read from the reference and simulant work sheets. By checking 'Include input data' the raw inputs that were used for the FoM calculation can be captured in the FoM Messages window. These may then be saved for output if the user saves the contents of the FoM Messages window.

• Include Standardized Data: Raw input data is manipulated in various ways within the FoM software, such as converting to common units or adjusting composition vectors so that the reference and simulant vectors are commensurate. Input data that has been manipulated in some form or fashion is referred to as standardized data. By checking Include Standardized Data, these data are included in the FoM Messages window.

• Customize Font: Allows the user to choose the font and font size for text displayed in the FoM Messages window. Choosing a monospaced font (default) allows columns to line up. Font type and size selections are remembered between each execution of the FoM software.

6.4 Figure of Merit Menu Descriptions

6.4.1 File Menu

The FoM File menu is depicted in figure 44.

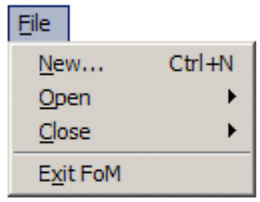


Figure 44. FoM File menu.

The File menu contains the following menu items:

- New…: Creates a new empty template file and prompts the user where to save this file. File may subsequently be opened by clicking on the label Reference or Simulant in the main window of the FoM software or externally with Excel.

- Open: This menu item contains the following submenus:
  - Reference: If no reference file has been opened (the reference file field containing the path to reference file under the label Reference is blank), this opens the standard dialog box for retrieving files. Otherwise, if a reference file has been opened (field containing path to reference file under the label Reference contains a path), it opens the file in the reference file field under the label Reference.
  - Simulant: If no simulant file has been opened (the simulant file field containing path to simulant file under the label Simulant is blank), this opens the standard dialog box for retrieving files. Otherwise, if a simulant file has been opened (field containing path to simulant file under the label Simulant contains a path), it opens the file in the simulant file field under the label Simulant.

- Close: This menu item contains the following submenus:
  - Reference: Closes the reference file but leaves the name and path to the reference file in the reference file field.
  - Simulant: Closes the simulant file but leaves the name and path to the simulant file in the simulant file field.

- Exit FoM: Terminates execution of the FoM software.

6.4.2 Window Menu

The FoM Window menu is depicted in figure 45.

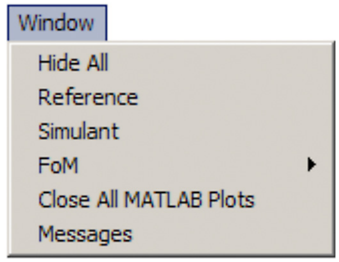


Figure 45. FoM Window menu.

The FoM Window menu contains the following menu items:

- Hide All: Hides all open dialog windows.

- Reference: Maximizes the Excel Reference file window.

- Simulant: Maximizes the Excel Simulant file window.

- FoM: This menu item contains the following submenus:
  - Modal Composition: This menu contains the following submenus.
    - Minerals: Opens the Modal Composition—Minerals dialog box, see section 6.2.2.
    - General: Opens the Modal Composition—General dialog box, see section 6.2.3.
  - Size Distribution: Opens the Size Distribution dialog box, see section 6.2.4.
  - Shape: This menu contains the following submenus.
    - Aspect Ratio: Opens the Shape—Aspect Ratio dialog box, see section 6.2.5.
    - Angularity: Opens the Shape—Angularity dialog box, see section 6.2.6.
  - Density: Opens the Density dialog box, see section 6.2.7.

- Close All MATLAB Plots: Closes all open plot windows, also see section 6.5.

- Messages: Opens the FoM Messages dialog box, see section 6.3.

6.4.3 Help Menu

The FoM Help menu is depicted in figure 46.

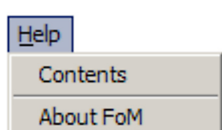


Figure 46. FoM Help menu.

The FoM Help menu contains the following menu items:

- Contents: Opens the Help window from which further help for the FoM software may be obtained.

- About FoM: Opens the About dialog box.

6.5 Plot Windows Help

FoM plot windows contain three menus, File, Graph, and Gallery that may be used to fiddle with the plots. FoM plot windows also contain a toolbar known as the Plot Toolbar. In the parlance of the MathWorks, plot windows are known as figure windows and the Plot Toolbar is known as the Figure Toolbar. Further descriptions are found in sections 6.5.1 through 6.5.4.

6.5.1 File Menu

The FoM plot windows File menu is depicted in figure 47.

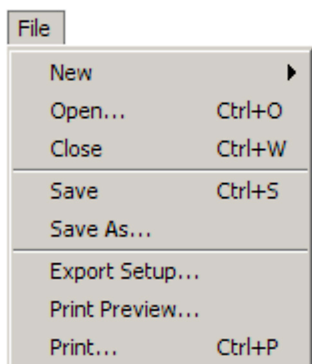


Figure 47. FoM plot windows File menu.

The FoM plot windows File menu contains the following menu items:

- New: Contains the submenu Figure, which opens a new plot window.

- Open…: Opens the standard dialog box for retrieving files.

- Close: Closes the current plot window.

- Save: Saves the current plot window. If window has not been saved before, opens the standard dialog box for saving files.

- Save As…: Opens the standard dialog box for saving files.

• Export Setup…: Allows saving a plot in a format that can be used by another application such as the standard graphics file formats TIFF or EPS. For additional information see: <http://www.mathworks.com/help/techdoc/index.html>.

• Print Preview…: Opens a dialog box for previewing and selecting options for printing a plot window. For additional information see: <http://www.mathworks.com/help/techdoc/index.html>.

• Print…: Opens the standard dialog box for printing files to print the plot window.

6.5.2 Graph Menu

The FoM plot windows Graph menu (fig. 48) contains the menu items listed below. Certain menu items are graph specific, meaning that the function is performed on a selected graph. Graph selection occurs by clicking on the graph of interest. Selecting the menu item then performs the action.

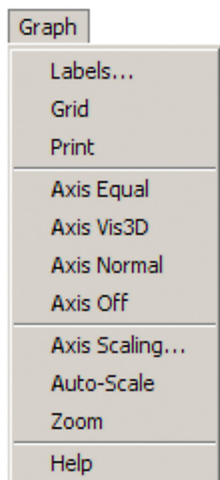


Figure 48. FoM plot windows Graph menu.

• Labels…: For a selected graph, brings up a dialog box, shown in figure 49, where the user may specify a graph title, an X axis label, and a Y axis label (and Z axis label for three-dimensional (3-D)).

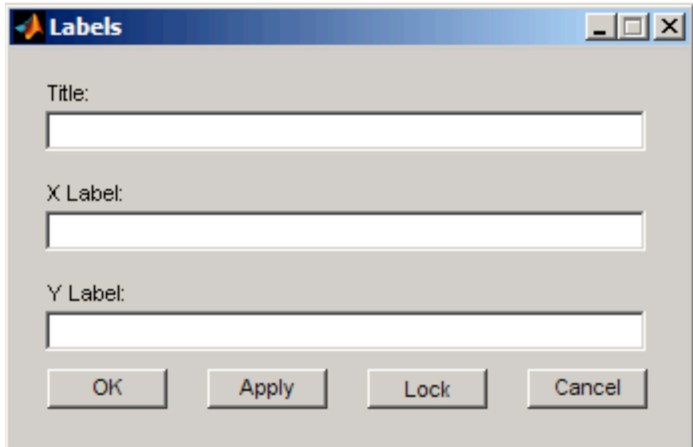


Figure 49. Labels dialog box.

If labels already exist, then the labels fields will be populated with the respective labels from the graph. Selecting another graph while the Labels dialog box is open causes the label fields to become repopulated with the labels from the new graph unless the Lock button is depressed. If the Lock button is depressed, then the labels are locked. In this case, pressing OK or Apply causes the locked labels to be applied to the new graph.

- OK: Applies the labels to the graph and closes the Labels dialog box.
- Apply: Applies the labels to the graph but leaves the Labels dialog box open.
- Lock: Locks the text in the labels fields if depressed. If not depressed, then fields repopulate when a new graph is selected.
- Cancel: Closes the Labels dialog box without changing any labels.

• Grid: For a selected graph, toggles grid lines on the graph.

• Print: Opens the standard dialog box for printing files to print the plot window.

• Axis Equal: For a selected graph, causes the axis scale factors (data length/physical length) to be the same in X and Y (and Z for 3-D plots) so that circles (spheres) plot like circles instead of ellipses (ellipsoids). Changes the axes data length but keeps the physical length the same.

• Axis Vis3D: For a selected graph, causes the axis scale factors (data length/physical length) to be the same in X and Y (and Z for 3-D plots) so that circles (spheres) plot like circles instead of ellipses (ellipsoids). Changes the axes physical length but keeps the data length the same.

• Axis Normal: For a selected graph, restores the axes to their original scaling if changed by Axis Equal or Axis Vis3D.

• Axis Off: Toggles the visibility of the axes and grid if one exists. Note that making the axes invisible also makes any labels invisible including the graph title, X-axis label, and Y-axis label.

- Axis Scaling: For a selected graph, brings up the Axis Scaling dialog box, shown in figure 50, where the user may manually specify axes data limits. For the X and Y axes (and Z axes if a 3-D plot), the minimum and maximum axes limits may be specified. When the dialog box opens, the axes limit data fields are populated with the current graph axes limits. The current graph may be designated by clicking in it. Selecting another graph with the Axis Scaling dialog box open causes the axes limit data fields to become repopulated with the limits from the new graph unless the Lock button is depressed. If the Lock button is depressed, the axes limit data is locked. In this case, pressing OK or Apply causes the locked data values to be applied as axes limits to the new graph.

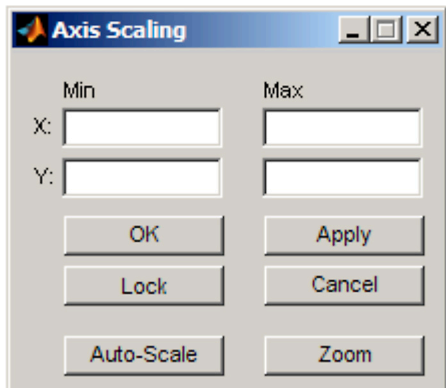


Figure 50. Axis Scaling dialog box.

  - OK: Applies the axes data values to the graph and closes the Axis Scaling dialog box.
  - Apply: Applies the axes data values to the graph but leaves the Axis Scaling dialog box open.
  - Lock: Locks the axes data values in the axes limit data fields if depressed. If not depressed, then fields repopulate when a new graph is selected.
  - Cancel: Closes the Axis Scaling dialog box without changing any axes limits.
  - Auto-Scale: Causes the axes to be automatically scaled.
  - Zoom: See Zoom below.

- Auto-Scale: For a selected graph, causes the axes to be automatically scaled.

- Zoom: Changes the cursor to a cross-hairs cursor and allows zooming in on a portion of the graph. Dragging the cross-hairs cursor creates a zoom box to which the axes will rescale. Right clicking causes rescaling to the previous zoom box. Pressing the Enter key on the keyboard terminates zooming and leaves the graph at the last zoom box scaling.

Note that while the cross-hairs cursor is displayed, different graphs may be zoomed by dragging within them. The zooming function remembers the level of zooming for each graph, so they may be individually unzoomed. However, once zooming is terminated with the Enter key, unzooming information is lost.

- Help: Displays the help text.

6.5.3 Gallery Menu

The FoM plot windows Gallery menu (fig. 51) contains the menu items listed below. These menu items are graph specific, meaning that the function is performed on a selected graph. Graph selection occurs by clicking on the graph of interest. Selecting the menu item then performs the action.

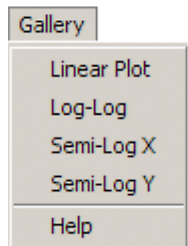


Figure 51. Gallery menu.

- Linear Plot: For the selected graph, changes the axes scaling to linear scaling.
- Log-Log: For the selected graph, changes the X- and Y-axes scaling to logarithmic.
- Semi-Log X: For the selected graph, changes the X-axis scaling to logarithmic.
- Semi-Log Y: For the selected graph, changes the Y-axis scaling to logarithmic.
- Help: Displays this help text.

6.5.4 Plot Toolbar

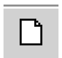
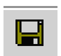
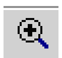
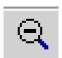
The Plot toolbar shown in figure 52 is provided by The MathWorks, Inc. In MathWorks parlance, this is also known as the Figure toolbar. Certain tools are graph specific, meaning that they work on a selected graph. Graph selection occurs by clicking on the graph of interest either with the tool or with the mouse pointer.

Figure 52. Plot toolbar.

Further help on the use of the Plot toolbar may be found at: <http://www.mathworks.com/help/techdoc/index.html>.

The icons from left to right in figure 52 have the following names and functions listed in table 1:

Table 1. Plot toolbar icon names and functions.

	New Plot: Creates a new plot window.
	Open File: Displays the open file dialog box for opening a file.
	Save Plot: Displays the save file dialog box for saving the FoM graphs.
	Print Plot: Displays the print dialog box for printing the FoM graphs.
	Zoom In: Allows zooming in on a portion of the graph by clicking or dragging to create a zoom box (scale of axes is changed). Right clicking with this tool displays a drop-down menu from which further options may be selected, including Reset to Original View.
	Zoom Out: Allows zooming out by clicking on a graph (scale of axes is changed). Right clicking with this tool displays a drop-down menu from which further options may be selected, including Reset to Original View.
	Pan: Allows a graph to be panned (axes limits are changed but scale is not). Right clicking with this tool displays a drop-down menu from which further options may be selected, including Reset to Original View.
	Rotate 3D: Allows 3-D rotation of the plot axes and associated plot. This works for two-dimensional plots also. Right clicking with this tool displays a drop-down menu from which further options may be selected, including Reset to Original View.
	Data Cursor: Allows pickoff of data values on a graph. Clicking on a portion of a curve displays the abscissa (X) and ordinate (Y) values. Right clicking with this tool displays a drop-down menu from which further options may be selected.
	Insert Colorbar: Inserts a color bar for a selected graph. A color bar is a legend with values for graphs containing items whose colors indicate values.
	Insert Legend: Inserts a legend for a selected graph. The legend text may then be edited by double clicking on the default text.

6.6 Limitations of Using Excel With the Figure of Merit Software

The FoM software accesses the Excel data files via ActiveX Automation. Limitations of this interface require that only one instance of Excel is running while the FoM software is running. The FoM software must launch this instance of Excel.

If an instance of Excel.exe is running when the FoM software is started, the error message of figure 53 will display and the user will be prompted to terminate the Excel.exe process before running the FoM software.

If the Excel process was initiated from Windows, it should be terminated by using the File>>Exit option from within Excel.

If the FoM software terminates abnormally, it is possible that an Excel.exe process will be left running. If this is the case, the only way to terminate this process is to use the Windows Task Manager to end the Excel.exe process tree. This termination may possibly cause loss of any unsaved changes in the Excel data files.

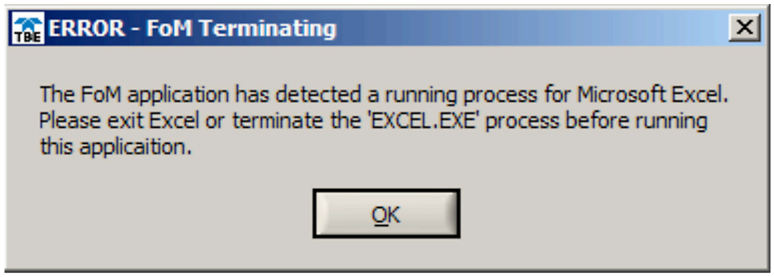


Figure 53. Excel is already running error message.

6.7 Copyrights

The following copyrights are germane to this Technical Memorandum (TM):

7. INSTALLATION NOTES

FoM Software is a Microsoft Windows-based application developed and maintained by TBE, Huntsville, Alabama for Marshall Space Flight Center (MSFC).

7.1 Minimum System Requirements

Minimum system requirements have not been established at this time; however, the FoM software has been tested with the following system configurations:

- Microsoft Windows 2000® and Windows XP®.
- 512 MB RAM.
- Microsoft Excel 2000® and Microsoft Excel 2003®.
- Mass storage requirements are minimal (<0.5 GB).

7.2 Required Components for Execution of Figure of Merit Software

The following components are required for the execution of FoM software:

- FoM software is a National Instruments LabWindows™/CVI™ 8.5-based custom graphical user interface with MATLAB-based custom FoM functions used to compute FoMs.
- National Instruments LabWindows™/CVI™ 8.5 Run-Time Environment (RTE) is automatically installed in the application directory with the FoM software during installation. This RTE will automatically be uninstalled when the FoM software is uninstalled.

MATLAB Compiler Runtime (MCR) 7.9 is licensed and installed separately. TBE distributes the MCR at no cost to the FoM software user. This is a one-time installation and does not need to be repeated for new releases of the FoM software.

- Excel 2000 (or later) is used to generate input data for the FoM software and must be installed on the system with the FoM software. It is the responsibility of the system owner to purchase and install the Excel software.

7.3 Installation Instructions

The FoM software package consists of two separate software components that require two installations:

(1) The FoM software proper, herein denoted as FoM software.

(2) An engine from The MathWorks, Inc. known as the MATLAB MCR that powers the numerical routines in the FoM software.

Additionally, the FoM software uses the Excel software, which the user must acquire and install separately. The National Instruments LabWindows™/CVI™ RTE is automatically installed when the FoM software is installed.

Once the MCR has been installed, it will not be necessary to install it again for future FoM software releases, except if the future software release requires a newer version of the MCR.

7.4 Installation of MATLAB Compiler Runtime

This installation step may be skipped if the user has previously installed the MCR version 7.9 on the PC that the FoM software is being installed, or if MATLAB, version 7.7 (release 2008b) is already installed on the PC that the FoM software is being installed. The version of MATLAB installed on a PC may be ascertained by launching MATLAB, then entering the command '>> ver' at the command line. The Command Window shown in figure 54 will appear.

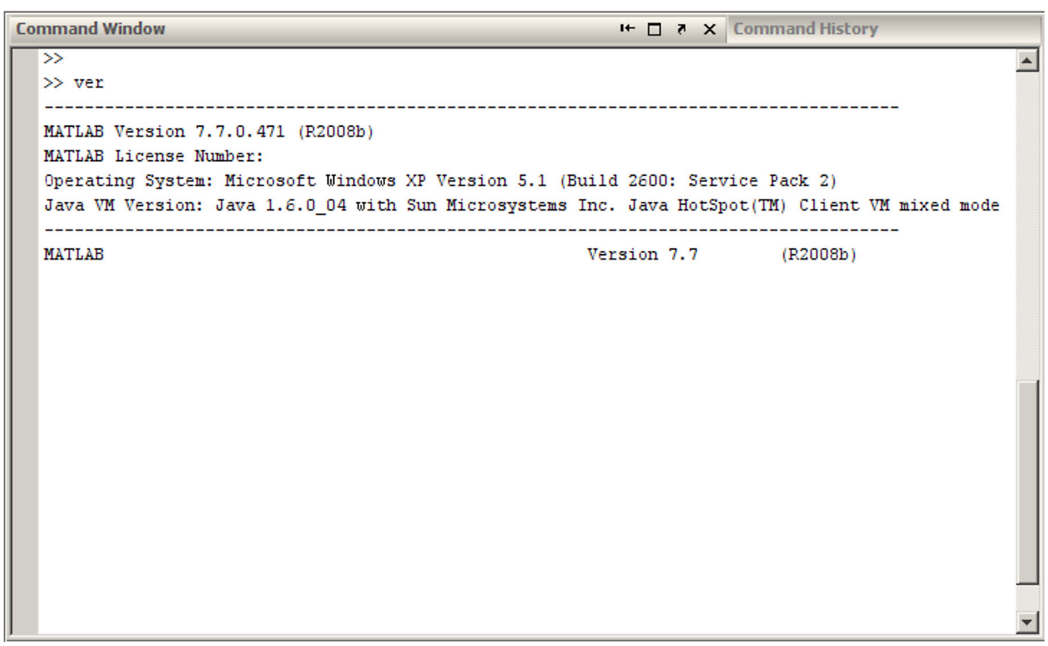


Figure 54. MATLAB responds with version information.

7.5 Specific Steps

Step 1: The user must have administrative privileges to install the MCR on a target machine since it modifies both the system registry and the system path. Running the MCRInstaller after the MCR has been set up on the target machine requires only user-level privileges.

Step 2. In the FoM Installation folder, open the folder titled MCRInstaller. In this folder, open the folder titled MCR installer XXXXx (XXXXx is the release version of the installer). Launch the application MCRInstaller shown in figure 55.

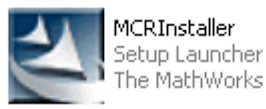


Figure 55. MCRInstaller.

Step 3. The initial prompt will be Choose Setup Language. Select English or Japanese and click on OK to continue. The Choose Setup Language dialog box in figure 56 will appear.

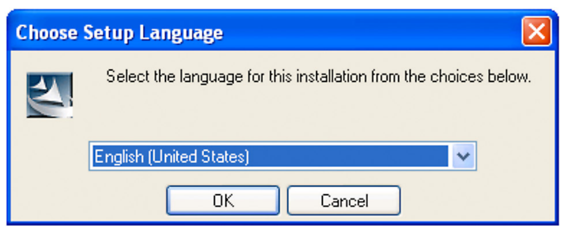


Figure 56. Choose Setup Language.

Step 4. If the Microsoft Visual C++ Redistributable Package is already installed on the machine that the MCR is being installed, then the dialog box in figure 57 will not appear and the user may proceed to the next step. Otherwise, click on Install to continue.

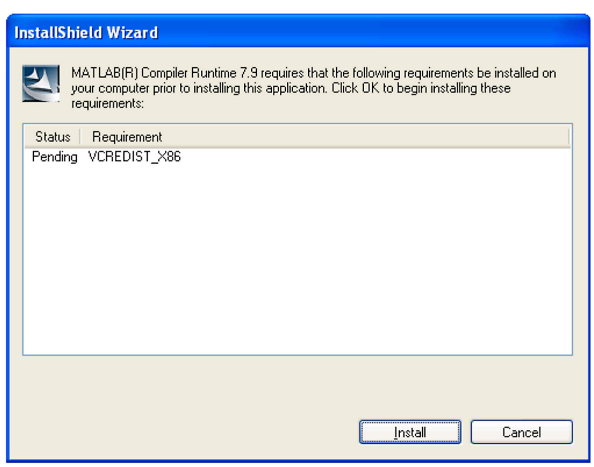


Figure 57. InstallShield Wizard MATLAB(R).

Step 5: This will bring up the dialog boxes shown in figures 58 and 59 in sequence, as the installation gets under way. No action is required by the user until step 6 unless the user wishes to cancel the installation.

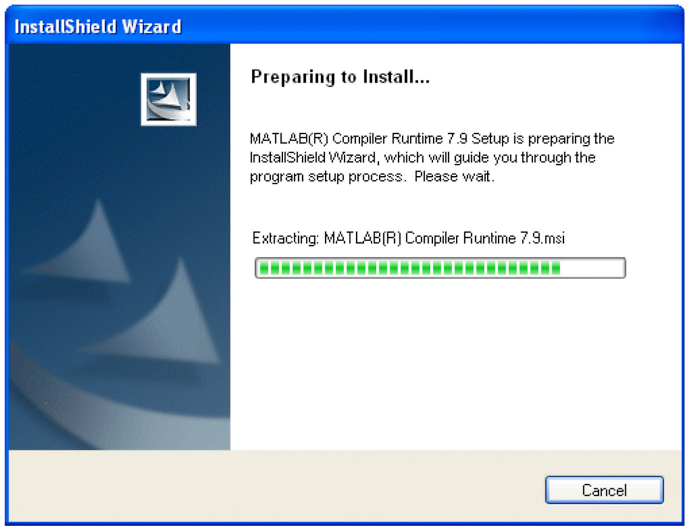


Figure 58. InstallShield Wizard (prepare to install).

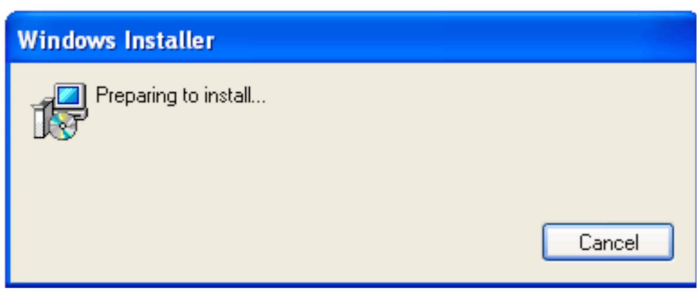


Figure 59. Windows Installer.

Step 6: The InstallShield Wizard will now unpack the MCRInstaller, which will bring up the InstallShield Wizard for MATLAB Compiler Runtime box shown in figure 60. Select Next > to continue.

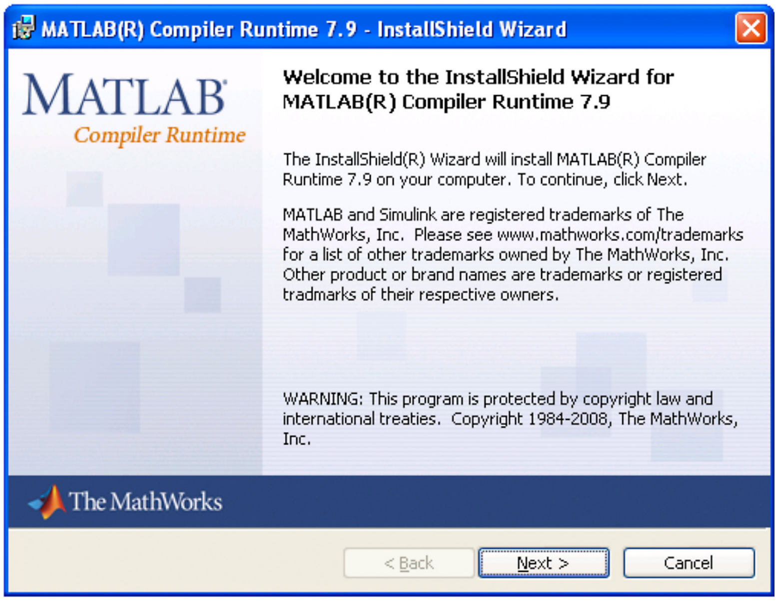


Figure 60. MATLAB(R) Compiler Runtime 7.9.

Step 7: Enter the User Name and Organization when reaching the Customer Information prompt (fig. 61). Then press Next >.

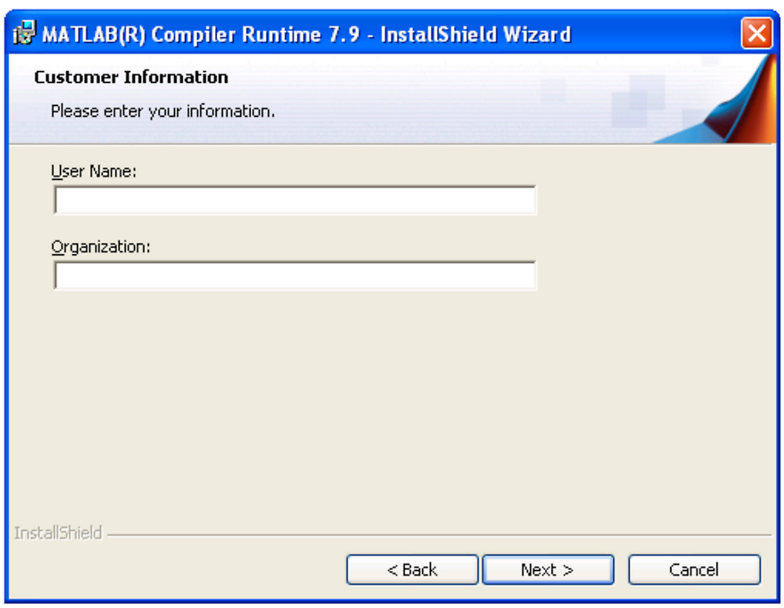


Figure 61. MATLAB(R) Customer Information.

Step 8: This will bring up the Destination Folder (fig. 62) prompt for installation of the MCR. The default destination is …\Program Files\MATLAB\MATLAB Compiler Runtime\. Change the destination if the default is unacceptable, then press Next >.

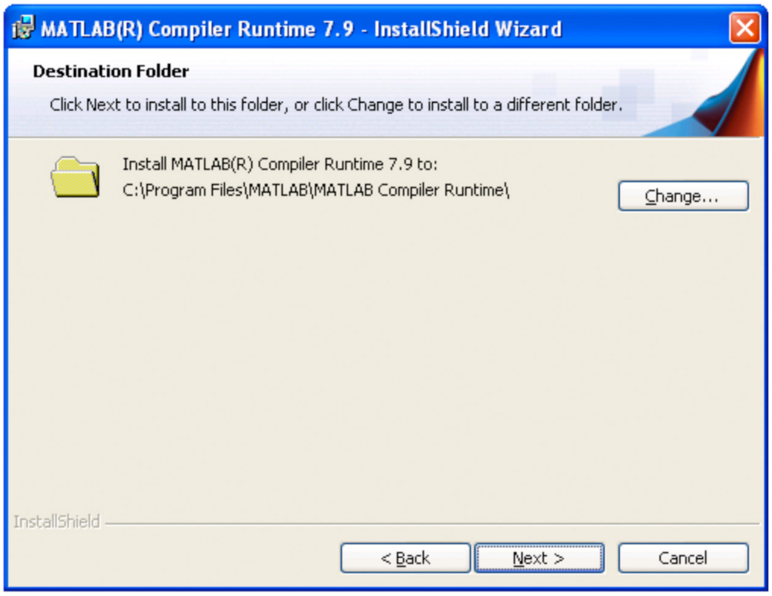


Figure 62. MATLAB(R) Destination Folder.

Step 9: This brings up the Ready to Install the Program (fig. 63) prompt. Press Install to begin the installation.

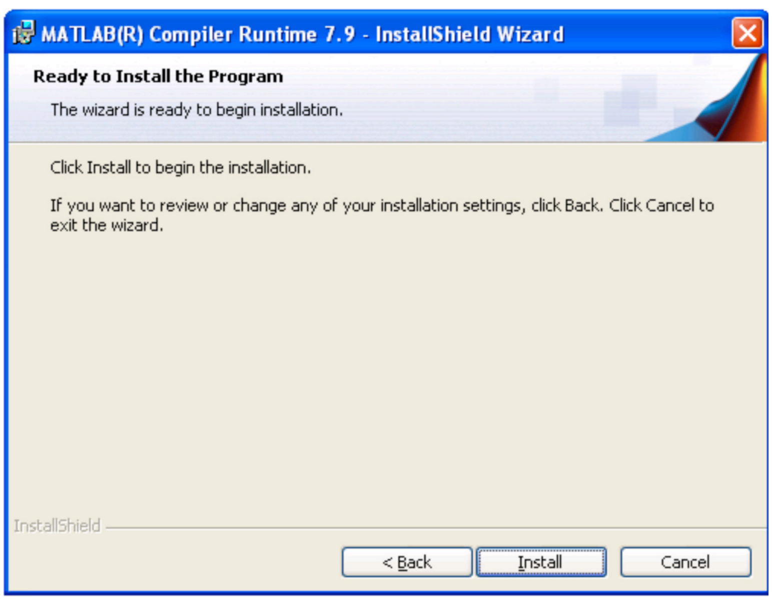


Figure 63. MATLAB(R) Ready to Install the Program.

Step 10. Installation begins (fig. 64).

The user may be notified that .NET Framework is not installed (fig. 65). If this prompt is received, press OK to continue. The FoM software does not currently require .NET Framework.

Figure 64. Installing MATLAB(R) Computer Runtime 7.9.

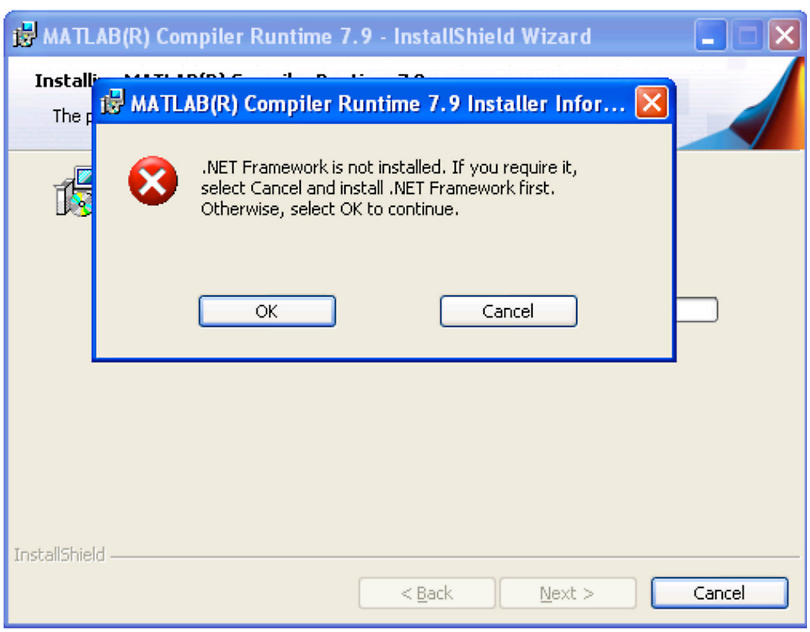


Figure 65. Installing MATLAB(R) Computer Runtime (.NET Framework not installed).

Step 11. Upon notification that the installation has completed, press Finish to finish (fig. 66).

Figure 66. MATLAB(R) Installation Wizard Completed.

7.6 Installation of Figure of Merit Software

If the user has previously installed the FoM software, the old version of the software should be uninstalled before a new version is installed. To uninstall a previous version of the FoM software, go to the Start button, then Settings, then Control Panel and open the Add or Remove Programs control panel. Scroll through the list of currently installed programs until Figures of Merit is found. Select Figures of Merit and press Remove to uninstall the program. If Figures of Merit is not found in the list of currently installed programs, then it is not installed and no further uninstallation is necessary.

7.7 Specific Steps

Step 12: The user must have administrative privileges to install the FoM software on a target machine since it modifies both the system registry and the system path. Running the FoM software after it has been set up on the target machine requires only user-level privileges.

Step 13: In the FoM Installation folder, open the folder titled FoM Installer (fig. 67). Launch the application setup.

Figure 67. FoM setup Installer.

Step 14: The installer responds with the initialization screen shown in figure 68 after launching.

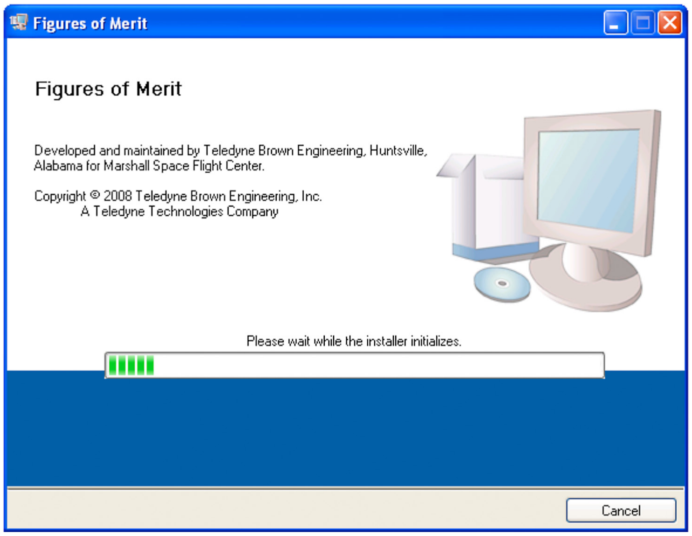


Figure 68. Figures of Merit.

Step 15: The initial prompt will be Destination Directory (fig. 69). Change the destination if the default is unacceptable, then press Next >>.

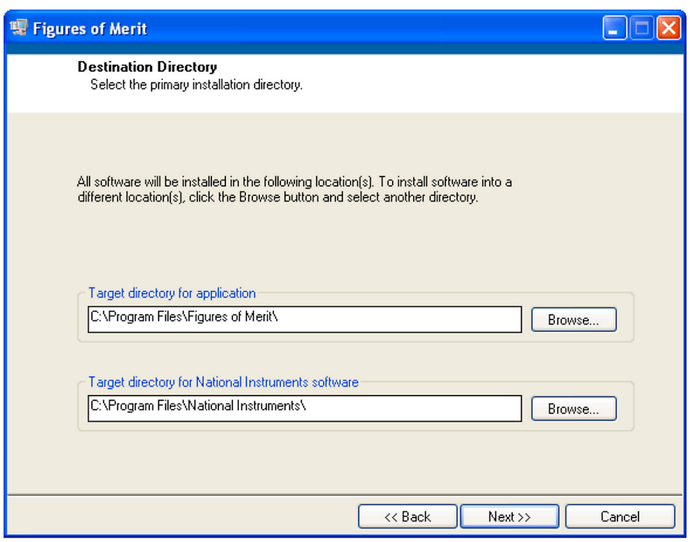


Figure 69. Destination Directory.

Step 16: This brings up the License Agreement (fig. 70). Note the restriction on redistribution of the MCR. The user may not further distribute the MCR. Each copy of the MCR must be requested from one of the points of contact in the section Contact Information. In order to install the FoM software, the user must agree to the terms of the License. Press Next >> to continue.

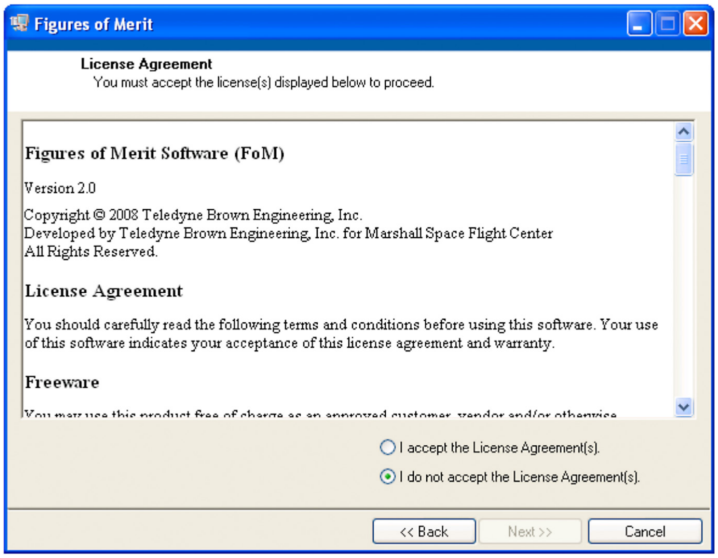


Figure 70. License Agreement.

Step 17: This brings up the Start Installation prompt (fig. 71). Select Next >> to begin installation.

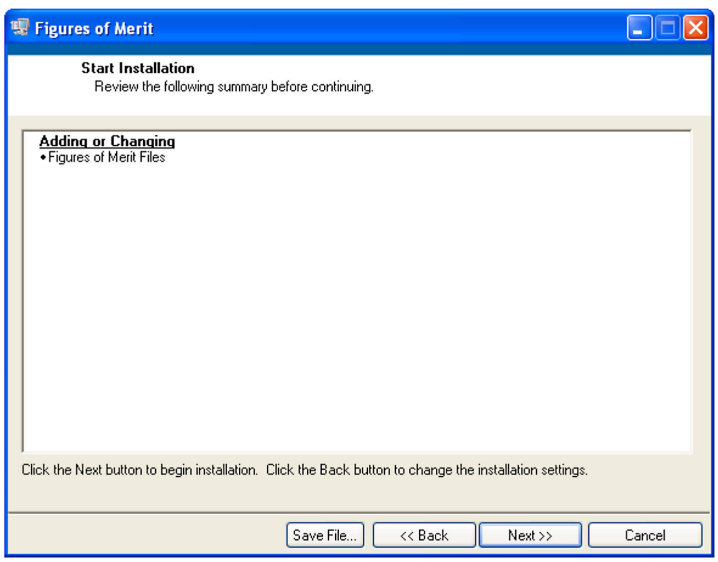


Figure 71. Start Installation.

Step 18: Installation begins as indicated by the screen shown in figure 72.

Step 19: Upon notification that the installation has completed, press Finish to finish (fig. 73).

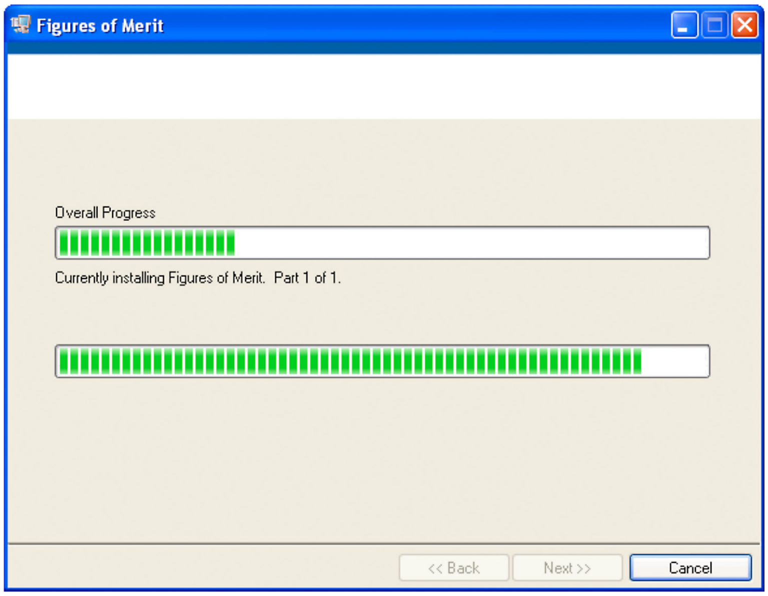


Figure 72. Overall Progress.

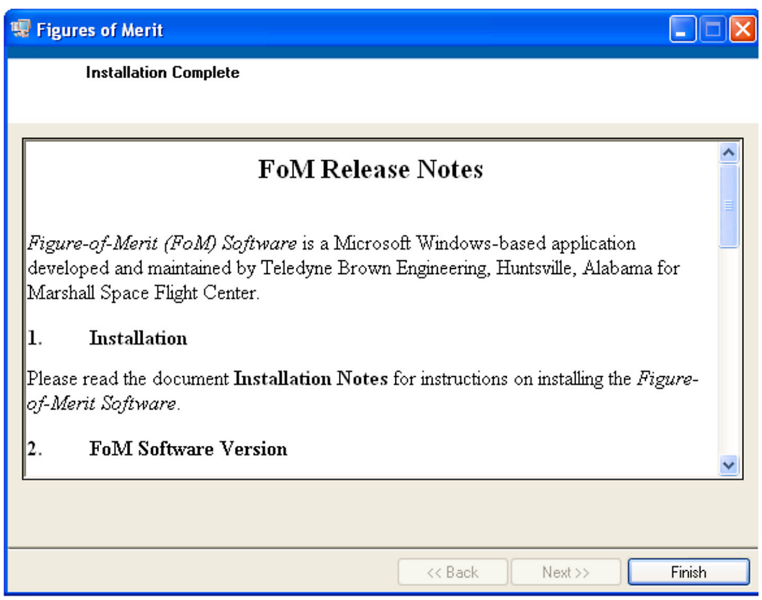


Figure 73. Installation Complete.

7.8 Messages/Errors

During installation of the MATLAB MCR, the user may receive the following error messages. Please respond accordingly.

If the message in figure 74 is received:

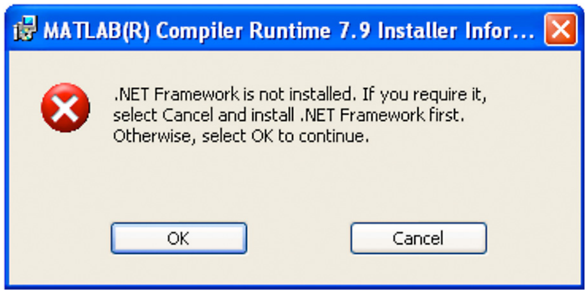


Figure 74. .NET Framework is not installed.

Recommended response:

- Select OK to continue. The FoM software does not currently require .NET Framework.

When attempting to execute the FoM software, you may receive these system messages. Please respond accordingly.

A popup dialog containing the message shown in figure 75 (or similar) appears when attempting to execute the FoM software. This message occurs if the MCR is not installed.

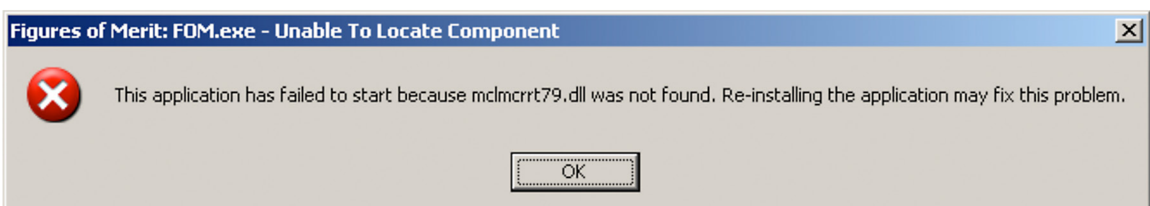


Figure 75. Unable to Locate Component.

Recommended response:

- Press the OK button, then install the MathWorks MCR by running the MCRInstaller.exe application. See section 7.4.

Popup dialogs containing the messages shown in figures 76 and 77 (or similar) appear when attempting to open a reference or simulant Excel file. These messages occur if Excel is not installed.

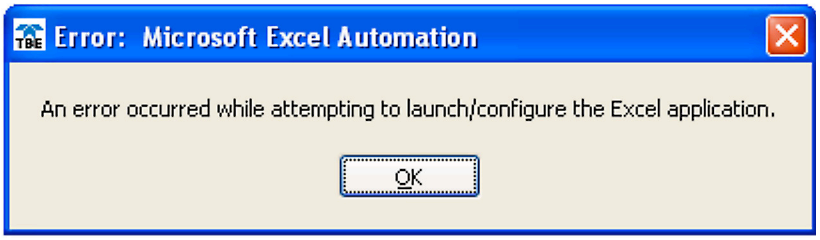


Figure 76. Microsoft Excel Automation.

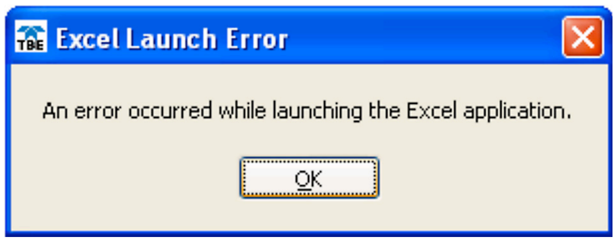


Figure 77. Excel Launch Error.

Recommended response:

- Press the OK button then install Microsoft Excel.

Complete uninstallation of the FoM software package will require uninstallation of the MCR and the FoM software.

7.9 Uninstallation of the Figure of Merit Software

To uninstall the FoM software, go to the Start button, then Settings, then Control Panel and open the Add or Remove Programs control panel. Scroll through the list of currently installed programs until Figures of Merit is found. Select Figures of Merit and press Remove to uninstall the program. If Figures of Merit is not found in the list of currently installed programs, then it is not installed and no further uninstallation is necessary.

7.10 Uninstallation of the MathWorks MATLAB Compiler Routine

To uninstall the MCR, go to the Start button, then Settings, then Control Panel and open the Add or Remove Programs control panel. Scroll through the list of currently installed programs until MATLAB Compiler Runtime X.X is found (where X.X is the version number). Select MATLAB Compiler Runtime X.X and press Remove to uninstall the program. If MATLAB Compiler Runtime X.X is not found in the list of currently installed programs, then it is not installed and no further uninstallation is necessary.

8. TROUBLESHOOTING

8.1 Installation Troubleshooting

During installation of the MCR or FoM software or when the FoM software is executed, the user may receive the following system messages. Please respond accordingly.

(1) The following message is received: .NET Framework is not installed. If the user requires it, select Cancel and install .NET Framework first. Otherwise, select OK to continue.
  (a) Recommended response: Select OK to continue. The FoM software does not currently require .NET Framework.

8.2 Execution Troubleshooting

When attempting to execute the FoM software, the user may receive the following system messages. Please respond accordingly.

(1) The popup dialog of figure 78 (or similar) appears when attempting to execute the FoM software. This message occurs if the MathWorks MCR is not installed.
  (a) Recommended response: Press the OK button, then install the MathWorks MCR by running the MCRInstaller.exe application.

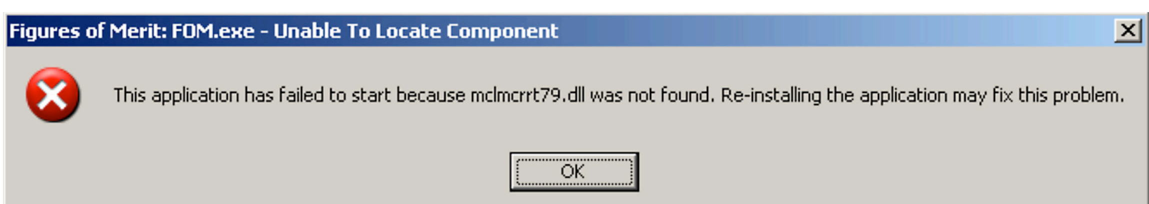


Figure 78. Unable to locate FoM DLL error message.

(2) The popup dialog of figure 41 appears when attempting to execute the FoM software. This message occurs if Excel is running when the FoM software starts.
  (a) Recommended response:
    i. Press the OK button.
    ii. If Excel is running, exit Excel.
    iii. Otherwise, launch Windows Task Manager by right clicking on the task bar at the bottom of the window and selecting Task Manager from the popup menu.
    iv. In Task Manager, go to the Processes tab, find the running Excel process (EXCEL.EXE), select it, and press the End Process Tree button to terminate the process.

(3) The popup dialog of figure 79 may appear when attempting to select a reference (or simulant) data file. This message occurs if the pathname of the data file exceeds the Windows limitation of 256 characters. Note: The Simulant Data.xls in this example popup is the selected filename without the full pathname.
   (a) Recommended response:
      i. Press the OK button.
      ii. Move the data file to a folder at a higher level to shorten the full pathname, or shorten the folder name(s) in the path of this file.

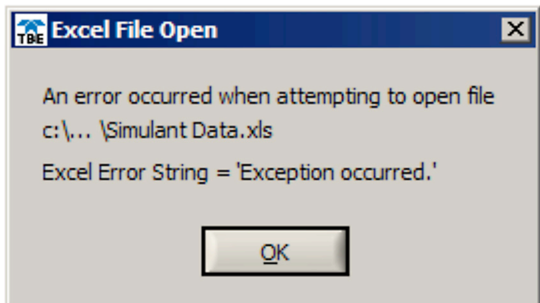


Figure 79. Path depth error message.

9. VERSION DESCRIPTION DOCUMENT

FoM software is a Microsoft Windows-based application developed and maintained by TBE, Huntsville, AL for the MSFC. This TM records the versions of the components that form a complete package for release. It also describes the versions of software that were used to create the FoM software.

9.1 Figure of Merit Software Version

This TM describes component versions for version 2.0 of the FoM software.

9.2 Figure of Merit Software Package Components

The FoM software package is comprised of a primary application and two dynamic link libraries (DLLs) developed by TBE under two separate development systems: MATLAB by The MathWorks and LabWindows/CVI by National Instruments.

9.2.1 MATLAB Figure of Merit Dynamic Link Library (fom_lib.dll) Software Components

The MATLAB software (fom_lib.dll) component version numbers are listed in table 2.

Table 2. DLL package.

Software File	Type	Version	Date
fom_lib_release_26.zip	DLL Archive	26	December 15, 2008

9.2.1.1 MATLAB Figure of Merit Dynamic Link Library Code. The MATLAB FoM DLL source code files are not assigned individual version numbers except for the two primary components. The files that comprise Version 26 of the MATLAB FoM DLL are dated and time-stamped (Central Time Zone) as shown in tables 3 and 4.

Table 3. Matlab FoM DLL primary components.

Software Files	Type	Version	Date
fom_bar.m	m Function	Rev 4	December 15, 2008
fom_rfd.m	m Function	Rev 4	December 15, 2008

Table 4. Matlab FoM DLL support components.

Software Files	Type	Date	Time
isnumericscalar.m	m Function	September 09, 2008	2:45 pm
isnumericvector.m	m Function	September 09, 2008	2:46 pm
multigraph.m	m Function	August 29, 2007	2:31 pm
multigraph_init_fom.m	m Function	October 29, 2007	9:15 am
plot_menus_fom	m Function	June 02, 2008	3:16 pm
textf.m	m Function	August 29, 2006	11:44 am
time_stamp.m	m Function	February 27, 2004	5:05 pm
xticklabel_rotate.m	m Function	November 07, 2008	10:35 am
Gallery Menu fom.mht	HTML Help	March 21, 2008	1:08 pm
Graph Menu fom.mht	HTML Help	March 21, 2008	1:10 pm

9.2.2 LabWindows/C for Virtual Instrumentation Figure of Merit Software Components

The LabWindows/CVI software component version numbers are shown in tables 5 and 6.

Table 5. LabWindows/CVI primary components.

Software Files	Type	Version	Date
FoM Application (FoM.exe)	Application	2.0 (TBE)	December 22, 2008
FoM_MATLAB (FoM_MATLAB.dll)	Application Extension	2.6 (TBE)	December 22, 2008

Table 6. LabWindows/CVI support components.

Software Files	Type	Version	Date
excel2000.fp	Instrument	CVI 8.5	October 23, 2007
animate.fp	Instrument	CVI 8.5	October 23, 2007
toolbox.fp	Instrument	CVI 8.5	October 23, 2007
Psapi.lib	Library	CVI 8.5	October 23, 2007
version.lib	Library	CVI 8.5	October 23, 2007
fom_lib.dll (from Matlab Software in section 2.1)	Application Extension	26 (TBE)	December 15, 2008
FoM Help File.chm	Compiled HTML Help File	From Rev 1 of FoM UG	December 22, 2008

9.2.2.1 Figure of Merit Application (FoM.exe) Code. The FoM Application (FoM.exe) source, include, and user interface files are not assigned individual version numbers. The files that comprise Version 2.0 of the FoM Application code are dated and time stamped (Central Time Zone) as shown in table 7.

9.2.2.2 Figure of Merit MATLAB Dynamic Link Library (FoM_Matlab.dll) Code. The FoM MATLAB DLL (FoM_Matlab.dll) Version 2.6 is the application extension used with the FoM Application Version 2.0. FoM_Matlab.dll Version 2.6 code is comprised of files dated and time stamped as shown in table 8.

Table 7. Files that comprise Version 2.0 of the FoM application code.

Source Files	Date	Time
FoM_Main.c	December 19, 2008	4:50 pm
FoM_Menu.c	December 10, 2008	3:13 pm
FoM_Composition.c	December 09, 2008	3:45 pm
FoM_SizeDist.c	November 10, 2008	10:09 am
FoM_Shape.c	December 09, 2008	3:45 pm
FoM_Density.c	November 10, 2008	10:09 am
FoM_ExcelFunctions.c	October 14, 2008	12:55 pm
FoM_SharedFunctions.c	December 09, 2008	3:13 pm
Include Files	**Date**	**Time**
FoM_Globals.h	December 09, 2008	3:21 pm
FoM_Displays.h	December 08, 2008	2:53 pm
FoM_ExcelFunctions.h	October 14, 2008	12:55 pm
FoM_MATLAB.h	October 21, 2008	8:46 am
User Interface Files	**Date**	**Time**
FoM_Displays.uir	December 10, 2008	2:59 pm

Table 8. FoM Matlab DLL (FoM_Matlab.dll) Version 2.6.

Source Files	Date	Time
fom_lib.c (glue code for fom_lib.dll)	December 18, 2008	1:35 pm
mclmcrrt.c (glue code for mclmcrrt79.dll)	December 18, 2008	3:38 pm
FoM_Matlab.c	December 18, 2008	3:42 pm
Include Files	**Date**	**Time**
fom_lib.h	December 18, 2008	1:34 pm
mclmcrrt.h	December 08, 2008	1:26 pm
FoM_MatlabDisplays.h	November 09, 2008	11:51 pm
FoM_Matlab.h	October 21, 2008	8:46 am
User Interface Files	**Date**	**Time**
FoM_MatlabDisplays.uir	November 09, 2008	11:52 pm

9.2.3 Excel Workbook

The Excel workbook version number is shown in table 9.

Table 9. Excel workbook version number.

Workbook File	Version	Date
FoM Template_1.2.1.xls	1.2.1 b	December 12, 2008

9.2.4 Documentation

Document version numbers are shown in table 10.

Table 10. Document version numbers.

Document Files	Version	Date
Figures-of-Merit Algorithm Description	Rev 1	December 31, 2008
Figures-of-Merit Software User's Guide	Rev 1	December 31, 2008
Figures-of-Merit Software Installation Notes	Rev 1	December 31, 2008
Figures-of-Merit Software License Agreement	2	–
Figures-of-Merit Software Release Notes	–	December 31, 2008
Figures-of-Merit Software Version Description Document	–	December 31, 2008

9.3 Ancillary Software (Development Environment)

This section lists the versions of software tools used to develop the FoM software.

9.3.1 MATLAB Software

The software file number for Compile Script is listed in table 11.

Table 11. Compile script.

Software File	Version	Date
mcc_lib_script.m	–	December 05, 2008

The MathWorks software is identified in table 12.

Table 12. MathWorks software.

Software	Version	Date
Matlab Compiler	4.9	–
Lcc-win32 C (C compiler)	2.4.1	–
Matlab Compiler Runtime (MCR)	7.9	–

9.3.2 LabWindows/ C for Virtual Instrumentation Software

Workspace and Project Files software files are listed in table 13.

Table 13. Workspace and project files.

Software File	Type	Date
FoM.cws (includes both .prj files)	Workspace	December 29, 2008
FoM.prj (Build for FoM.exe)	Project	December 22, 2008
FoM_Matlab.prj (Build for FoM_Matlab.dll)	Project	December 22, 2008

National Instruments software is listed in table 14

Table 14. National Instruments software.

Software	Version	Date
LabWindows/CVI Development System	8.5	–
LabWindows/CVI Runtime Environment	8.5	–

10. SUPPORT

10.1 About Figures of Merit Software

FoM software is a Microsoft Windows-based application developed and maintained by TBE, Huntsville, AL for MSFC.

The FoM software is comprised of and/or uses the following custom and commercially available software components that must be installed on the target system:

- FoM software is a National Instruments LabWindows™/CVI™ 8.5-based custom graphical user interface and MATLAB-based custom FoM functions used to generate FoM.
  – LabWindows/CVI, © 2008 by National Instruments. All rights reserved.

- National Instruments LabWindows/CVI 8.5 RTE is automatically installed in the application directory with the FoM software during this installation. This RTE will automatically be uninstalled when the FoM software is uninstalled.

- MathWorks MCR is licensed and installed separately. The MCR is distributed by TBE at no cost to the FoM software user. This is a one-time installation and does not need to be repeated for new releases of the FoM software.
  – MATLAB, © 1984–2008 by The MathWorks, Inc.

- Microsoft Excel 2000 (or later) is used to generate input data for the FoM software and must be installed on the system with the FoM software. It is the responsibility of the system owner to purchase and install the Microsoft Excel software.
  – Microsoft is a registered trademark of Microsoft Corporation.

11. CONTACT INFORMATION

For technical support, contact:

Douglas L. Rickman
Global Hydrology and Climate Center
NSSTC/MSFC/NASA
ph. 256–961–7889 (fax –7389, alt. fax –7788)
Douglas.L.Rickman@nasa.gov

For algorithm and software support, contact:

Hans D. Hoelzer
Teledyne Brown Engineering
ph. 256–726–1632
hans.holzer@tbe.com

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Teledyne Brown Engineering, Inc.
P. O. Box 070007
Huntsville, AL 35807-7007

Attn: H. D. Hoelzer
hans.hoelzer@tbe.com

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14. ABSTRACT
Figures of Merit (FoMs) and the FoM software provide a method for quantitatively evaluating the quality of a regolith simulant by comparing the simulant to a reference material. FoMs may be used for comparing a simulant to actual regolith material, specification by stating the value a simulant's FoMs must attain to be suitable for a given application and comparing simulants from different vendors or production runs. FoMs may even be used to compare different simulants to each other. A single FoM is conceptually an algorithm that computes a single number for quantifying the similarity or difference of a single characteristic of a simulant material and a reference material and provides a clear measure of how well a simulant and reference material match or compare. FoMs have been constructed to lie between zero and 1, with zero indicating a poor or no match and 1 indicating a perfect match. FoMs are defined for modal composition, particle size distribution, particle shape distribution, (aspect ratio and angularity), and density. This TM covers the mathematics, use, installation, and licensing for the existing FoM code in detail.

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