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Tympanic Membrane Rupture Model Graphical User Interface

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TMRGUI User Guide

Sujeeta Bhatt, Felicia Sallis-Peterson, and Jessica Swallow

A. Introduction

Tympanic membrane rupture (TMR), an injury often caused by blast exposure, results from material failure when the tympanic membrane in the ear is subjected to traumatic loading (Clark 1991; Engles, Wang, and Gan 2017; Iyoho, Ho, and Chan 2020). Given the potential for TMR due to impulse noise exposure, a biomechanically based TMR model (TMRM) was developed with funding from the Joint Non-Lethal Weapons Directorate (JNLWD) to provide injury risk estimates for assessing TMR risk from impulse-noise exposures (Iyoho, Ho, and Chan 2020).

The TMRM is a fast-running, lumped-parameter model of the tympanic membrane with a probabilistic dose-dependent prediction of risk of injury. To develop the TMRM, the lumped-parameter model was fit to a previously developed finite element model (FEM) of the middle ear. Next, post-mortem human-subject (PMHS) data from James et al. (1982) were used to construct the injury probability response, and logistic regression was applied to create dose-response curves at moderate and severe eardrum rupture severities (Iyoho, Ho, and Chan 2020).

The TMRM solves the following differential equation to determine motion of the tympanic membrane upon exposure to an input impulse-noise recording:

$$mx'' + cx' + kx = P(t) * A$$

Here, m is the mass of the tympanic membrane, c is the damping coefficient, k is the spring constant, and A is the area of the membrane. $P(t)$ is the input pressure vs. time curve, and x, x', and x'' are the displacement, velocity, and acceleration of the tympanic membrane as a function of time, respectively, which are output from the model. Table 1 reproduces the table available in the TMRM documentation, specifying the values and units of each of the model's parameters.

Table 1. Parameters of the TMRM

Description	Symbol	Value	Units
Mass	m	8.0	mg
Spring constant	k	7629	N/m
Damping coefficient	c	0.0219	N-s/m
Surface area	A	57	mm^2

Source: (Adkins, Iyoho, and Chan 2019).

A graphical user interface (GUI) was later developed for the TMRM to facilitate easy use of the model. This User Guide explains how to work with the GUI. For further information on the TMRM development itself, we refer the reader to the article by Iyoho, Ho, and Chan (2020) and to the TMRM application programming interface (API) documentation (Adkins, Iyoho, and Chan 2019).

B. TMR User Interface

1. User Interface Development

The TMRGUI is a GUI developed by the Institute for Defense Analyses to enable both analysis of the TMRM and analysis using the model in either single-input or batch mode. Figure 1 shows a screenshot of the user interface (Swallow and Sallis-Peterson 2020).

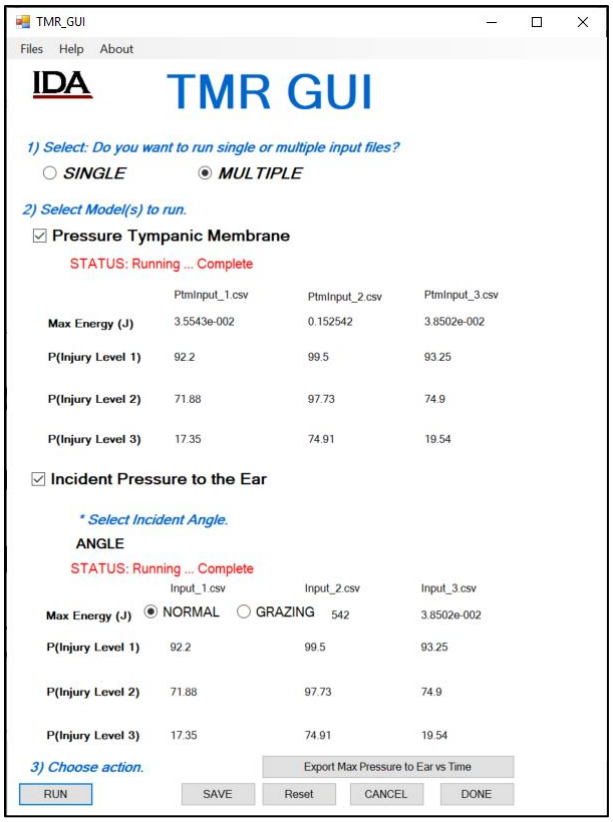

Figure 1. TMRGUI Interface

Written in C++ for the Microsoft Windows computer operating system, TMRGUI is an object-oriented design program. The interface design allows user interaction with the TMRM without affecting the model's basic functionality. Because TMRGUI is a wrapper function and separate from the TMRM itself, TMRGUI maintains the integrity of the guidance provided in the model's API while allowing for minimal modifications within the model software for interaction.

The interactions between the GUI and TMRM are diagrammed in Figure 2. User actions within the GUI are indicated by solid blue arrows; the red dashed arrows show the embedded functionality of the GUI and the TMRM. Internally, the TMRGUI creates directives based on the user's interactions within TMRGUI and sends these directives to the TMRM. When the TMRM execution is complete, the TMRGUI then retrieves and displays the TMRM results. In addition, the TMRM has been set up to run using a DOS command-line script batch file so that the user can modify the batch file by designating all the required parameters to run the model without using the TMRGUI (Swallow and Sallis-Peterson 2020).

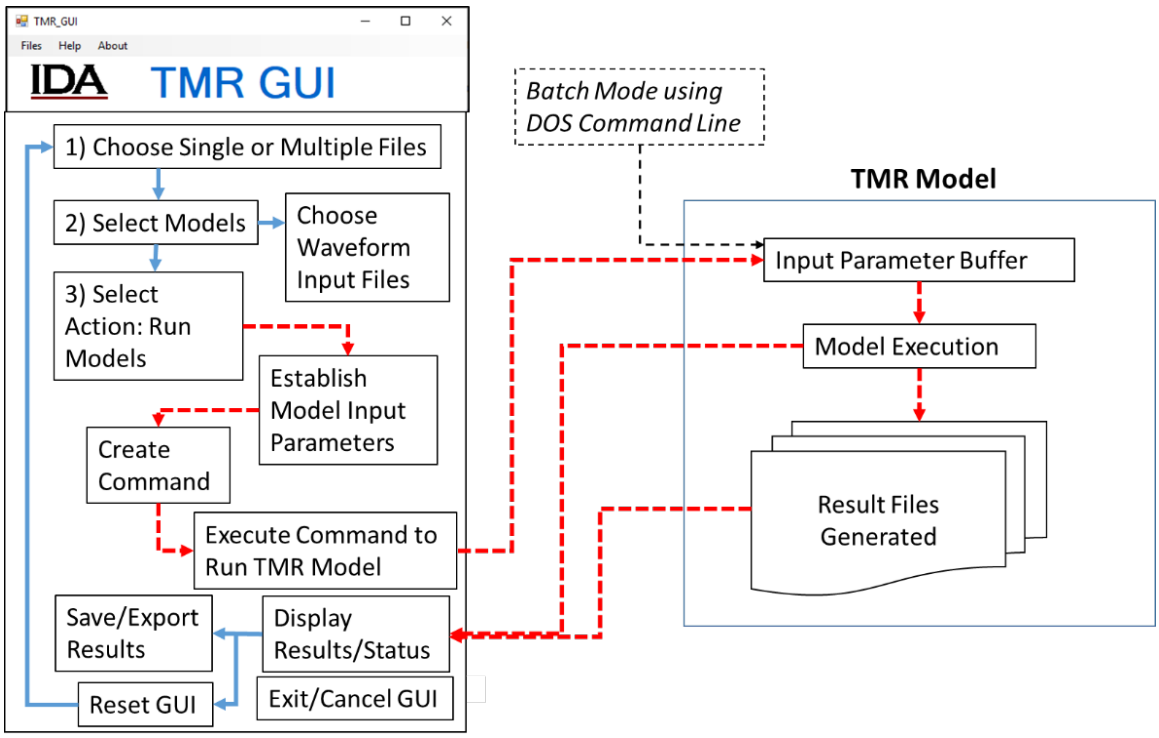

Figure 2. TMRGUI–TMR Model Interaction Design. Solid blue arrows indicate the user actions within the GUI, and red dashed arrows show the embedded functionality of the GUI and the TMR model.

2. System Requirements

The TMRGUI program requires a personal computer running the Microsoft Windows operating system. In addition, the following hardware and software specifications are recommended to run both the TMRGUI and the TMR model.

Hardware:

Operating system	Microsoft Windows 10
Computer and processor	64-bit PC with a 3.2 GHz processor
Memory	16 GB RAM or higher
Hard disk	At least 90 MB of disk space that includes 85 MB of storage for the model input files
Display	1024×768 or higher resolution monitor

Software:

Adobe Acrobat Reader	For the model documentation
Visual C++ Redistributable for Studio version 2015 or later	C++ libraries required for MS Visual Studio Built Applications
Winzip v. 23.0	For TMRGUI and TMR model installation

3. Installation

Installation of TMRGUI can be completed in three steps:

1. The user should save the compressed zip file TMRGUI.zipx onto the computer's local drive.
2. Extract the file by launching WinZip, and decompress the .zipx file to the computer's local drive.
3. The user must check for previous installations of the Visual C++ Redistributable libraries, by accessing the System, Add/Remove Software application on the Windows Operating System (OS). The OS must have version 2015 or later. If the OS has an older version, then run both the VC_redist.x64.exe and VC_redist.x86.exe files included in the TMRGUI folder.

The TMRGUI folder contains the following items:

- TMRGUI.exe—the TMRGUI executable
- TMR_local.exe—the TMR model executable
- TMR_Model_1p0_API_Documentaion.pdf—the TMR model API documentation
- TMRGUI_UsersGuide.pdf—A copy of this user guide
- Input_Sample.csv— Incident Pressure model sample input file
- PtmInput_Sample.csv--Tympanic Pressure model sample input file
- Incident Pressure folder—example input files to run the Incident Pressure model
- Tympanic Pressure folder—example input files to run the Tympanic Pressure model

- outputs folders—sample output folders, one each located in the Incident Pressure and Tympanic Pressure folders
- TMRGUI_defaults.txt—Currently set input and output directories
- AcroRd32_shortcut—Shortcut to Adobe Acrobat to enable viewing of documentation from the GUI
- VC_redist_x64 folder--Visual C++ Redistributable for Visual Studio installer for 64-bit computers
- VC_redist_x86 folder--Visual C++ Redistributable for Visual Studio version 2015 for 32-bit computers

4. Input Data Format

The model takes input in the form of a pressure vs. time waveform. This is input as a .csv file with the first column as time (units of milliseconds) and the second column pressure (units of kilopascals, kPa). The model also expects that the sampling frequency of the input data is 200 kHz, according to TMRM documentation; consequently, the time column of the input .csv file should increment by 0.005 ms from line to line.[1] The input file should not include a header line, although the units and arrangement of the columns should meet this description. Example input files are available in the Tympanic Pressure and Incident Pressure folders delivered with the model software.

5. Output Data Format

TMRGUI produces multiple different output files. Each input .csv produces one output file that reports the computed membrane motion and energy for that input file. These individual output files are named following the input file name with "_output.csv" appended. Each single or batch run also produces a summary .csv file called either TMRPI_summary.csv or TMR_summary.csv, based on which one of the Incident Pressure to the Ear or Tympanic Membrane Pressure models was run (see Section C). These summary files contain the computed doses and probabilities of injury for each input file submitted for the run. These output files do include column headers. Table 2 describes the data available in the output files, including associated units.

[1] The model developer was uncertain of whether this 200 kHz input frequency was actually a *requirement* for running the fast-running TMRM accurately (whether it had been hard-coded), so we recommend following this guideline for the time being.

Table 2. Outputs of the TMR Model with TMRGUI Interface

Output Name	Output Units	Output Location From User Interface
Time	ms	Time column of individual output .csv
Displacement as a function of time, $x(t)$	m	Displacement column of individual output .csv
Velocity as a function of time, $x'(t)$	m/s	Velocity column of individual output .csv
Acceleration as a function of time, $x''(t)$	m/s^2	Acceleration column of individual output .csv
Energy as a function of time, $E(t)$	J	Energy column of individual output .csv
Dose, D	J	Max energy (J) column of summary output .csv
Probability of injury (TMR levels 1, 2, and 3)	%	P(Injury Level X) columns of summary output .csv
Peak pressure at the eardrum	kPa vs. ms	PeakPressureAtEarDrum output .csv, only if Incident Pressure to the Ear model was run *and* Export Max Pressure to the Ear vs Time was selected

If the user is running the Incident Pressure to the Ear model and elects to export the maximum pressure to the ear, an additional output file with "TMR_PeakPressureAtEarDrum.csv" appended to the input file name will be saved in the Incident Pressure to the Ear output folder. This file has two columns—Time (ms) and Eardrum Peak Pressure (kPa)—that represent the results of the TMRM's transformation of the input pressure at the ear to pressure at the tympanic membrane.

C. Operating the TMRGUI

Through the selection of the appropriate models and the waveform-input files (see steps below), the GUI builds a DOS command that executes the model software. While the model is executing, TMRGUI monitors the run status, retrieves data on the model output, and displays the model results within the TMRGUI window. TMRGUI then allows the user to SAVE the results, RESET the GUI, or continue to run additional cases at the user's discretion. In addition, the user can choose to export and save the computed maximum pressure to the ear vs. time for each case.

The TMRGUI should be run from a local drive (e.g., desktop of a computer), rather than from network drives. This ensures correct timing of command execution.

The TMRGUI contains a mixture of user selection and buttons. The buttons, which are dynamic in usability, are only active when key events occur as the program is run. There are three menu selections in the GUI:

- Files—used to set up default input and output directories
- Help—a link to the TMR model API documentation
- About—the TMRGUI developer contact information

1. Getting Started

There are a number of steps to successfully run the TMRGUI:

1. Launch TMRGUI by double clicking the TMRGUI.exe file. The main window will become active (see Figure 3).

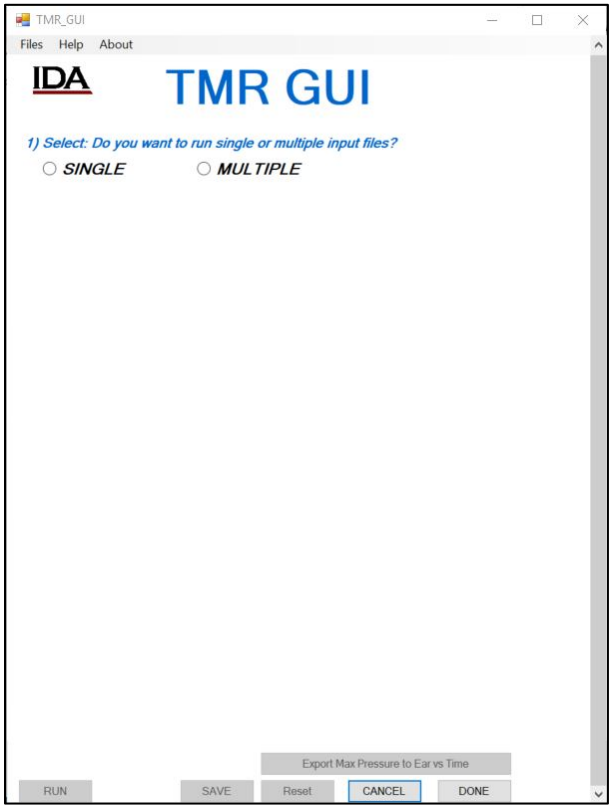

Figure 3. Opening Screen of TMRGUI

2. Select input and output directories. **Note, the software input and output directories initially default to the user's C: drive, but TMRGUI needs to have read/write privileges to these directories. You will need to specify input and output directories for TMRGUI depending on your computer's security policies.** When TMRGUI is opened for the first time the user should:

   a. Set up default input and output directories of the TMR models by selecting the *Files* menu and choosing Set Defaults (see Figure 4).

      1) An input directory and an output directory can be set for each model (Pressure Tympanic Membrane and Incident Pressure to the Ear).

      2) The currently set default directories can be checked at any time by selecting the Files menu and choosing Show Default Directories. A dialog box will appear

that shows the current input and output directories for the Pressure Tympanic Membrane and Incident Pressure to the Ear models.

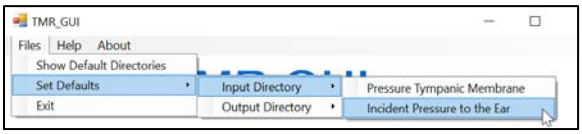

Figure 4 Setting up Input and Output Directories in TMRGUI

b. The TMR Model API documentation and this User Guide are located under the Help menu item (see Figure 5).

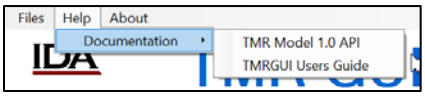

Figure 5. The Help Menu Item in TMRGUI

2. Running the TMRGUI

1. Select whether the TMR model should run *SINGLE* or *MULTIPLE* input files (see Figure 6). This selection gives the user the flexibility to run cases singly for individual analyses or multiple cases for a comparative analyses (batch mode).
2. Select the models. The two “models” or functions distinguish between different types of inputs. The user can select the Pressure Tympanic Membrane model, the Incident Pressure to the Ear model, or both in one run.
    a. Pressure Tympanic Membrane requires an input representative of pressure at the tympanic membrane to output the maximum energy at the tympanic membrane (the dose). Pressure Tympanic Membrane may be run directly when the user’s inputs represent pressure at the tympanic membrane.
    b. Incident Pressure to the Ear uses an input that is representative of a free-field recording and outputs pressure to the tympanic membrane. Note that when choosing the Incident Pressure to the Ear model, the user must select the incident angle (i.e., NORMAL or GRAZING). TMRGUI will not execute this model without user input regarding the incident angle to be simulated. The output of the Incident Pressure to the Ear model (peak pressure at the tympanic membrane) is then automatically input to Pressure Tympanic Membrane to yield the final TMRM output of probability of injury. In this case, output files will be saved in the Incident Pressure to the Ear directory.

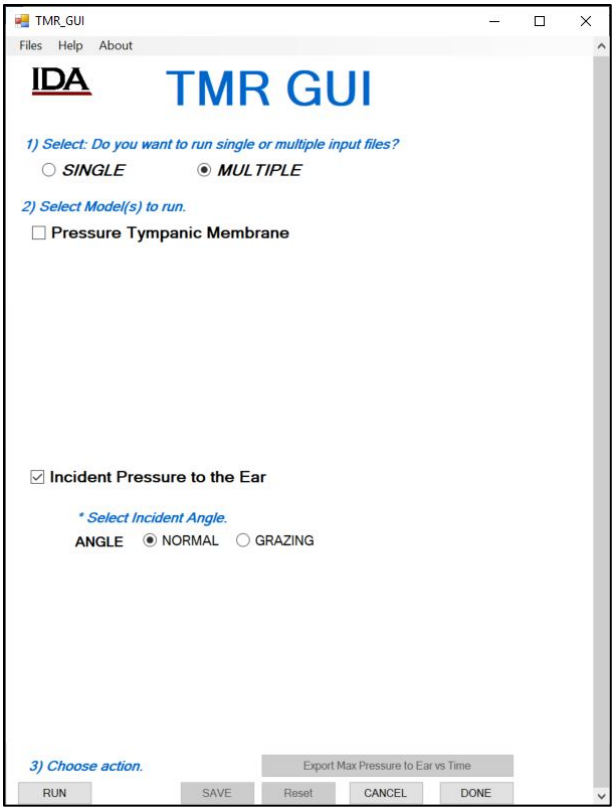

Figure 6. Selecting Incident Pressure to the Ear in TMRGUI

3. Choose action to perform. After the models are selected, the TMRGUI activates the RUN command. At this point, the user can run the TMRM(s) or exit the GUI by selecting CANCEL or DONE.

4. Selecting the RUN command button will activate the input file dialog window(s) (Figure 7) for the model(s) chosen above. It may take a few seconds for the window(s) to appear. If the user previously set up the default input and output folders, then the dialog window will automatically navigate to the models' input file folders. The user will be prompted to select the files to run. Once the files are selected, the user should press OPEN, returning to the TMRGUI. If the user selected *MULTIPLE* in step one, then multiple files can be selected during this step. If the user selected both models (Pressure Tympanic Membrane and Incident Pressure to the Ear), then TMRGUI will first request that the user select input files for Pressure Tympanic Membrane. After executing the Pressure Tympanic Membrane model on those files, TMRGUI will then request the user to select input files for Incident Pressure to the Ear. TMRGUI will then execute the model on those files.

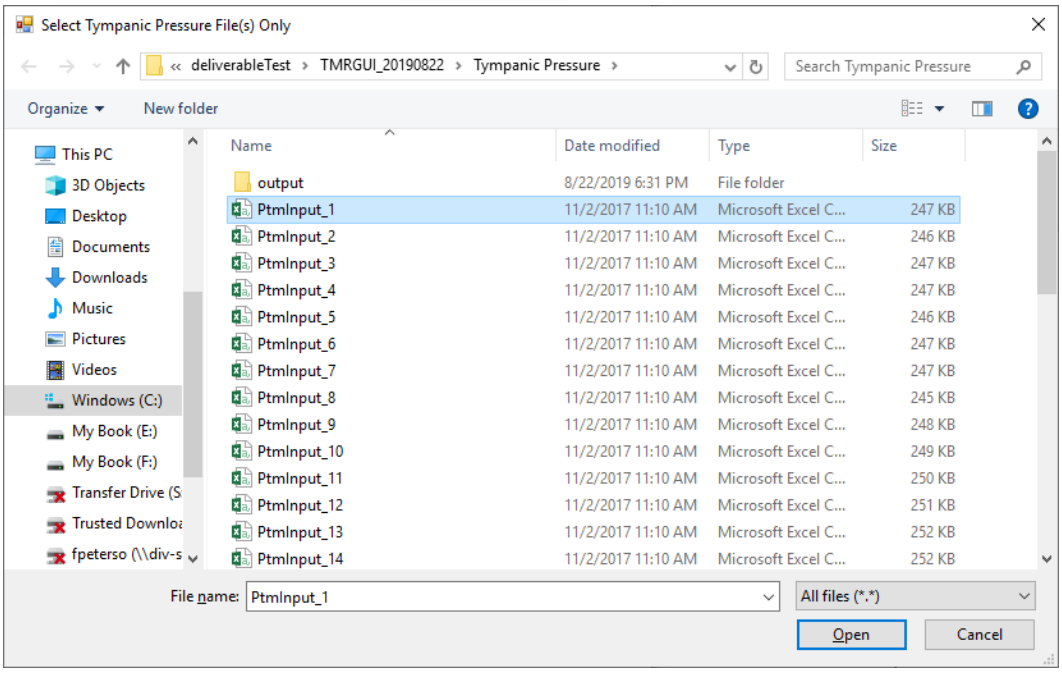

Figure 7. Selecting Input Files in TMRGUI

5. The RUN command will build the directories and launch the TMR model. While the program is running, temporary files will appear in the directory where the model's executable file (.exe) is located. The run time is dependent on the number of files selected.
6. Results. After the TMR model completes, the TMRGUI displays the results for up to three data files for each model. Figure 8 is an example of multiple comparative results for both models.

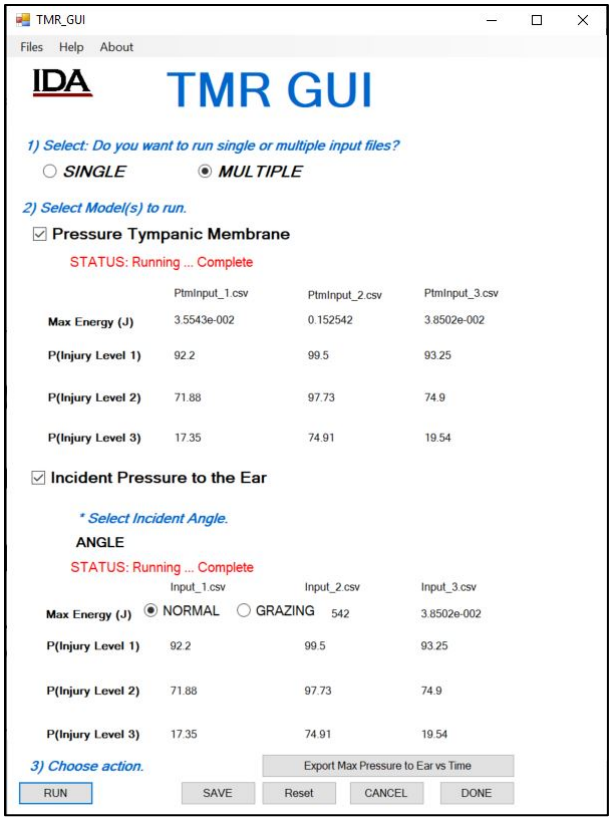

Figure 8. Results of a Multiple Comparative Results Run of TMRGUI

7. Saving the results. TMRGUI then allows the user to either SAVE the results, RESET all selections in the TMRGUI, or continue to run additional cases at the user's discretion. In addition, the user can choose to export and save the computed maximum pressure to the ear vs. time for each case (if the Incident Pressure to the Ear model was run) by selecting Export Max Pressure to the Ear vs Time. If SAVE is selected, TMRGUI will save not only the computed doses and risks of injury for all files in a batch run but also the output tympanic-membrane displacement, velocity, acceleration, and energy vs. time results (refer to Section 1.B.5). Be sure to take note of step (9) below to avoid overwriting of the summary output file(s).

8. Confirmation messages (Figure 9 and Figure 10) are displayed when files are saved to the default output folders successfully.

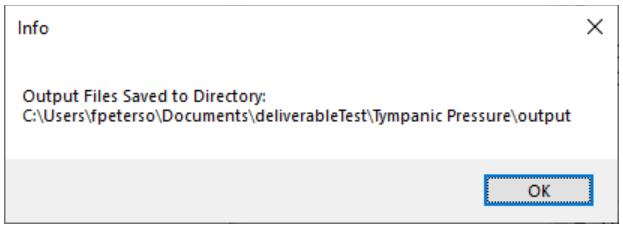

Figure 9. Confirmation Message for Saving TMRGUI Results Files

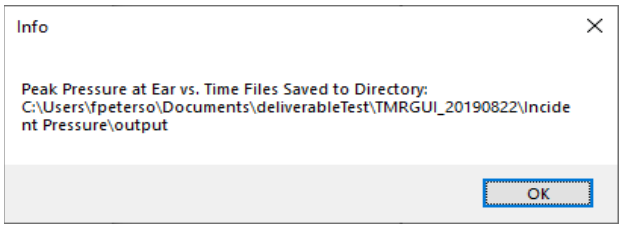

Figure 10. Confirmation for Saving Peak Pressure at Ear vs. Time Files

9. Avoiding overwriting summary files. To prevent overwriting of files:
    a. Create a separate folder for each batch run that is conducted.
    b. If the Pressure Tympanic Membrane model was used, cut and paste the saved output files, including the summary file TMR_summary.csv, from the default save directory into the new folder you created for that batch run.
    c. If the Incident Pressure to the Ear model was used, cut and paste saved output files, including the summary file TMRPI_summary.csv, into the new folder you created for that batch run.
10. Running new file(s). To run a new file or batch of files, select RESET and follow the aforementioned steps. *Note*: This will delete all temporary files.

D. Advanced TMRGUI

An advanced, "expert" version of TMRGUI was also developed that allows the user to modify the values of the TMRM parameters (*m*, *A*, *c*, and *k*), which enables sensitivity analyses. In the advanced TMRGUI, the user can modify the values of the TMRM parameters within predetermined ranges. The model is then run using these modified parameters. Note, however, that this does not modify the TMRM source code, so that a restart of the "expert" TMRGUI will leave these parameters in their default values. All parameter combinations in the allowed ranges were not tested, so this GUI is not recommended for distribution to most users of the TMRM. Figure 11 shows a screen shot of the opening screen of the advanced TMRGUI. The advanced TMRGUI installs the same way as the standard TMRGUI, but contains the executable TMRGUI_EXPERT.exe to launch the GUI, rather than TMRGUI.exe and installs from the zip "TMRGUI_EXPERT.zipx" rather than TMRGUI.zipx.

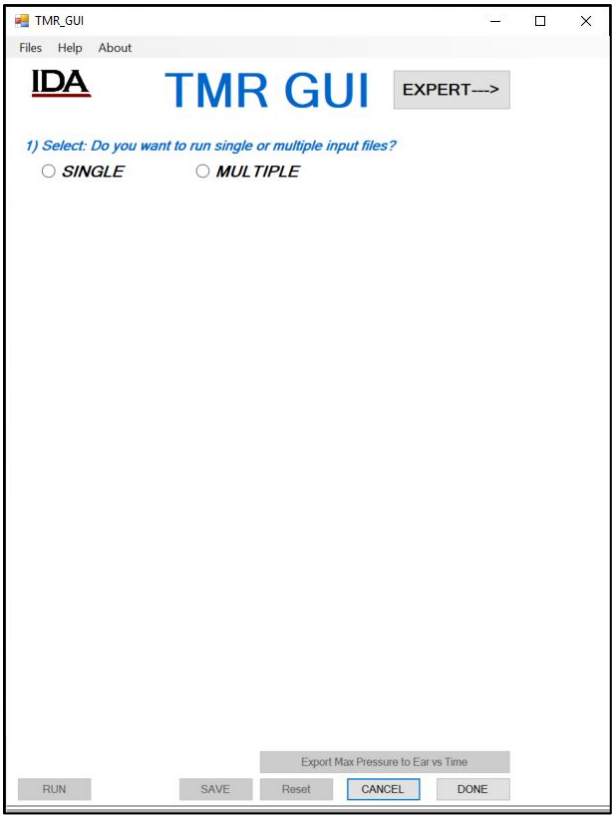

Figure 11. Opening Screen of Advanced TMRGUI

- To change the TMRM parameters (*m*, *A*, *c*, and *k*), select EXPERT to open a new window (the "Expert Panel"), where these changes can be made. Figure 12 shows the Expert Panel of the advanced TMRGUI.

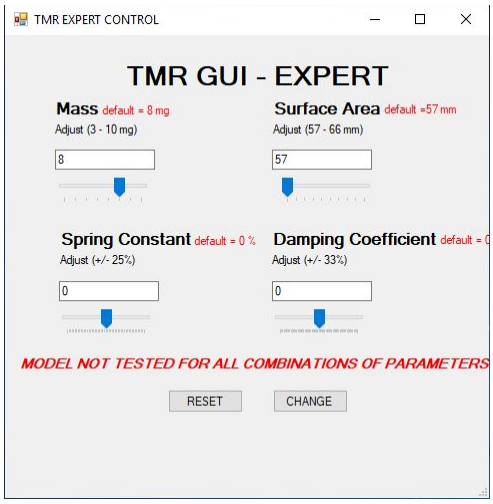

Figure 12. Expert Panel of Advanced TMRGUI

- Either slide the bars or directly enter the changes to the TMRM parameters. The allowed range of changes and default values are listed on the Expert Panel in the GUI. *Note*: for mass (*m*) and area (*A*) parameters, the displayed number represents the value of the parameter. For the spring constant (*k*) and damping coefficient (*c*), the value shown represents a percent change in the parameter relative to the default value (i.e., if 25 is selected for *k*, the model will be run with $k = 1.25*k_{default}$).
- Select CHANGE to implement the new parameter values in the model. A warning dialog box will appear confirming the change in values.
- Select OK to continue, and close the Expert Panel. The main GUI screen will show the current settings of the four parameters in the upper right corner, as shown in Figure 13. You can now run the TMRGUI as usual. *Note*: The injury correlates contained in TMRM were calibrated to the default parameter values and do not update upon changing the model parameters with the expert GUI. Users should not make use of probability of injury values output by TMRGUI with non-default model parameter values. Instead, users can observe changes in computed membrane motion and energy. The injury correlates can be recalibrated using procedures described in Swallow and Sallis-Peterson (2020).
- The summary output files for the Advanced TMRGUI contain extra columns (not present in the Standard TMRGUI summary outputs) that report the settings of the four parameters during the model run for each input file. These columns are labeled according to the four parameters (Mass *m* (mg), Surface Area *A* (mm^2), Damping Coefficient *c* (relative variation), and Spring Constant *k* (relative variation)).

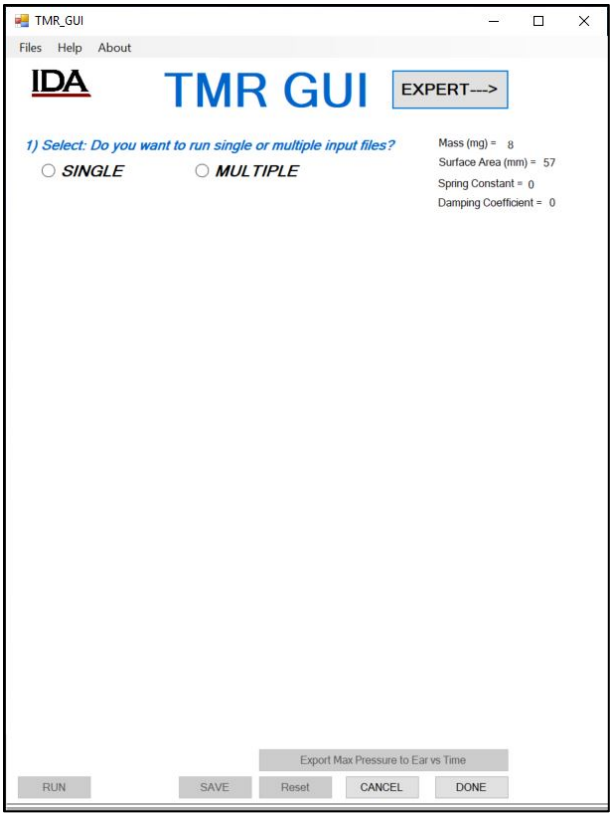

Figure 13. Advanced TMRGUI Screen After Closing the Expert Panel. The settings of the four parameters are shown in the upper right corner of the GUI.

- To return all parameters to default values, reopen the Expert Panel and select Reset and Change. It is recommended that all users do this at the end of any working session with the TMRM
- *Note*: TMRM has not been tested for all combinations of input parameters. It is possible that some combinations of parameters will cause the model to crash. If this occurs, the TMRM may take a long time to run or may report infinite values for computed dose.

Relationship between the Expert and Standard TMRGUI

As a program design rule, the Expert and Standard versions of TMRGUI have identical program codes, with one exception. Both versions contain a variable called expertMode. It is a Boolean-type variable—its state can be either *true* or *false*. When the variable is set to *true*, the main TMRGUI window will reveal and enable the EXPERT button. Also, it will provide access to the subsequent functions that allow the user to modify the model parameters. When the variable is set to *false*, the main GUI window will not contain the EXPERT button. This button will not get enabled, and the subsequent functions to change model parameters are not accessible. For the Standard version of TMRGUI, the variable is set to *false*; for the Expert version, the variable is set to *true*.

E. References

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F. Abbreviations

API	application programming interface
GUI	graphical user interface
JNLWD	Joint Non-Lethal Weapons Directorate
PMHS	post-mortem human subject
TMR	tympanic membrane rupture
TMRM	tympanic membrane rupture model

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

The Tympanic Membrane Rupture Graphical User Interface (TMRGUI) was prepared by IDA to allow easy user operation of the Tympanic Membrane Rupture Model (TMRM), which estimates risk of tympanic membrane rupture due to impulse noise exposure. The TMRM was provided to IDA by the Joint Non-Lethal Weapons Directorate (JNLWD) for assessment, and was previously developed with funding from the JNLWD by another performer. TMRGUI allows the user to operate the TMRM in either single-input or batch mode, view results, and save output files recording results. An advanced version of TMRGUI also includes the ability to manipulate the values of parameters within the TMRM without affecting the TMRM source code. This deliverable includes the source code for both versions of the GUI (the advanced and the standard versions), the compiled TMRGUI software for both versions and supporting files, and user guides prepared by IDA for both versions of the TMRGUI.

15. SUBJECT TERMS

Auditory injury risk; Graphical User Interface (GUI); Non-Lethal Weapons (NLW); tympanic membrane rupture (TMR)

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