Duke UNIVERSITY | BIOMEDICAL ENGINEERING

BME 590
Neurotrauma
Head Impact Brain Simulation Project, Fall 2023
DUE: In-Class – [15% of Final Grade]

Project Overview: The Simulated Injury Monitor (SIMon) is a finite element brain model used to assess brain injury. Using head kinematics produced by previous simulations, students will use the SIMon model to assess brain injury criteria and brain deformations.

Assignment: Using the head kinematics from impacts simulated in Group Project 2, assess brain deformation and brain injury criteria using the SIMon finite element head model. You should assess Cumulative Strain Damage Measure (CSDM) and 95th percentile Maximum Principal Strain (MPS). Command files are provided for CSDM, and an experimental command file for MPS. CSDM is defined as the volume fraction of the brain meeting or exceeding a given strain threshold, for example, a strain of 0.15. MPS is calculated as the 95th percentile of the maximum principal strain (in Dyna, we can use the Effective plastic strain measure). Some details on how to calculate MPS are given below, as well as both a Python and MATLAB script. In addition, please find 1-2 papers in the literature that have used SIMon or similar finite element brain models to assess risk of brain injury, and compare those with the results of your project here.

SIMon Tutorial:

NHTSA provides the SIMON model through their website. The .k file can additionally be found on the class Sakai site. Note that the SIMon model uses units of TON, MM, SEC, while the Hybrid III and helmet models used previously use units of MM, MSEC, KG. A sample loadcurve file (from NHTSA) is provided as well. The SIMon model is driven with 6 input kinematics, applied to the skull of the model (part 8): X,Y,Z linear motion (displacement, velocity, or acceleration) as well as X,Y,Z angular motion (again, displacement, velocity, or acceleration). Here, we will use linear acceleration and angular velocity, as measured at the Head CG. To prepare your previous model results for use with SIMon, and to run this model:

1. Open your previous LS-DYNA model results
2. Run the provided *bme590f23_curves.cfile* command file to produce curve files from the model output
    a. This will save the X, Y, Z linear acceleration and angular rate to .crv files you can load into SIMon.
    b. This cfile converts units from the HIII model units to those used by SIMon
    c. Note that, in addition, the cfile adjusts the coordinate system of the output results. The HIII model uses a "Z-down" reference frame, while SIMon uses "Z-up"
3. Close the previous model result.
4. Open a **new** copy of the SIMon model (make sure this is a new copy, so you don't mess up the original model by accident). There will be a few errors – you can ignore these for the moment.
5. Open the Keyword manager, and open the DEFINE*CURVE dialog.
    a. Create curves for all 6 of the kinematics you previously exported, using the Load XY Data button
    b. You should load X,Y,Z linear acceleration as curves 3,4,5 respectively, and X,Y,Z angular velocity as curves 6,7,8 respectively.
6. Ensure the BOUNDARY_PRESCRIBED_MOTION_RIGID cards 1-6 are configured properly

a. Card 1 should use LCID 3, and should be set with DOF = 1 (X-linear), VAD = 1 (acceleration)
b. Card 4 should use LCID 6, and be set with DOF = 5 (x-rotational), VAD = 0 (velocity)

7. Add a CONTROL_TERMINATION card with the appropriate termination runtime for your simulation (in seconds)
8. Run the model

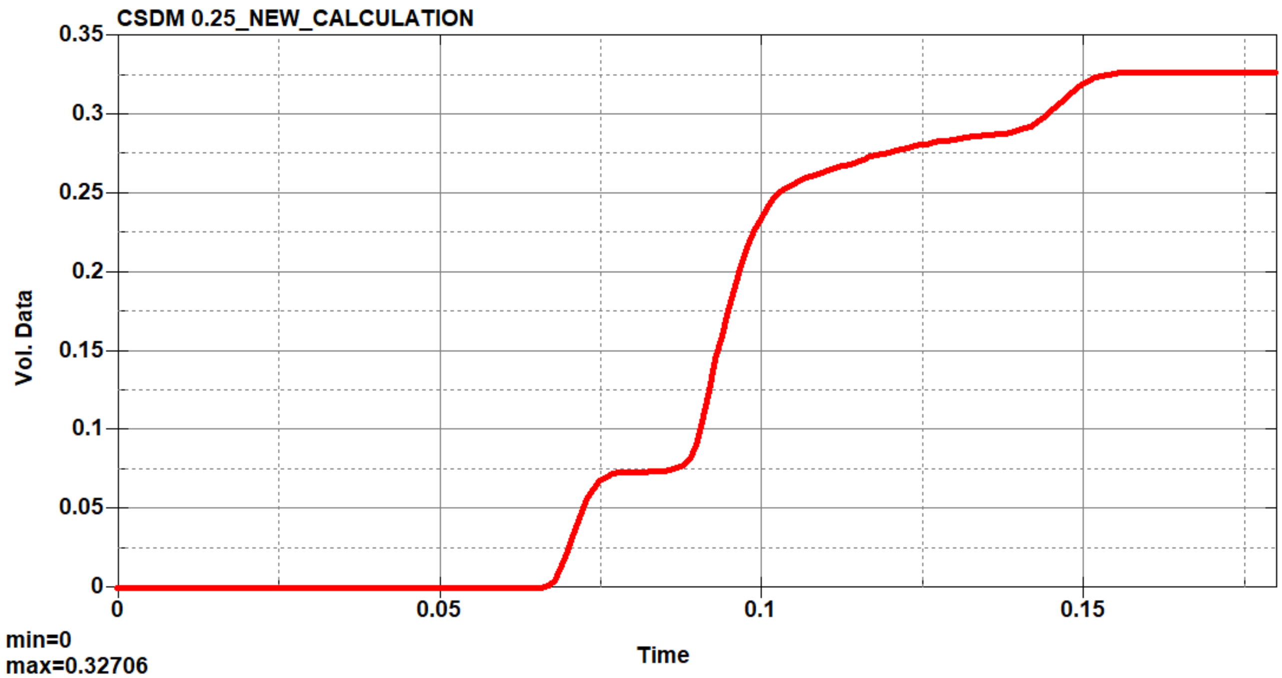
To assess brain deformation injury metrics, use the Cumulative Strain Damage Measure. We have provided command files from NHTSA that, assesses CSDM-15 and CSDM-25, the 0.15 and 0.25 strain thresholds. You can modify these command file to use any other strain level.

Troubleshooting:

- If the model error terminates because of Error 40508 (SOL+508), "time X falls outside the range of load curve N", ensure that your TERMINATION card is set to the maximum time in your load curve inputs

Making sure you can run SIMon:

Before you use your own data, try to run SIMon using the provided sample data from NHTSA. Open *loadcurv_thor9042P.txt* as a k-file, and run the SIMon model. Make sure you understand what keywords the THOR loadcurve file is changing or adding. You should get the following for CSDM25:



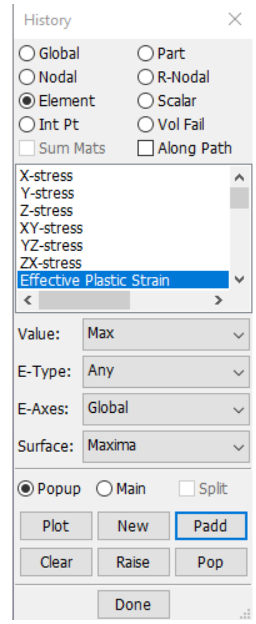
You should additionally get MPS95 = 0.3829

Consider:

- The D3Plot output frequency is by default set to 1ms. You can adjust this in the DATABASE_BINARY_D3PLOT card
- Before calculating MPS, CSDM, or anything else, view the animation of the SIMon run alongside the original model run, to ensure the kinematics are the same.

Calculating MPS-95:

- MPS-95 is calculated from the solid elements when using SIMon. The relevant parts are 1, 2, 3, 11, 12, 13.
- I have yet to find an efficient way to calculate MPS-95 in LS-Dyna. You can calculate the absolute maximum using the History plot (see below), but this is suspect due to computational instability, and is applied across all parts. The 95th percentile of the maximum values is generally accepted as avoiding computational instability, and provides a more accurate value.



- There is an EXPERIMENTAL command file provided for your use. Proceed with caution… This command file takes a long time to run, and may or may not crash LS-DYNA. If this takes more than an hour, something has probably gone wrong and you should email Mitchell, or try again.
- When you use the *mps_calculation.cfile* command, you will get a very large CSV file with broken headers. You will need to open it in a text editor (something like Notepad++ on Windows) and delete the header rows due to some strangeness in how Dyna chooses to export the element names. Then, you can load it in with either MATLAB or python and calculate MPS-95. Use the provided *calculateMPS.m* or *calculateMPS.py* scripts to do this.
  - Make sure you change the file path in either script to load the correct CSV file
  - Note: The Python script requires both the pandas and numpy libraries
- Alternatively, you can do the following, although I would not recommend it:
  - Deactivate all parts EXCEPT 1,2,3,11,12,13
  - In the Select window, select all Active elements
  - In the history window, change the Value from Max to Elm, and press plot
  - This will freeze, Dyna may crash, you may get sad at how frustrating this is. If nothing else, it will definitely take a long time to process all 30130 elements. Every time you click, this will redraw all the lines…
  - Go to the Save tab, if Dyna will let you, and save all outputs as a CSV file with a single x-axis. This takes a long time. Go grab some coffee, multitask, or stare at your screen while you wait…
- You will not be able to open this CSV with Excel, as it has too many columns. You'll need to use MATLAB, Python, or some similar tool to load and work with the data here.
- You can then calculate the 95th percentile strain across all elements for each timestep.