1. **Introduction**
   1. The fundamental understanding and industrial application of shape memory alloys (SMAs) continues to grow.
   2. The process for developing and integrating a shape memory alloy engineering system can be divided into six main steps (detailed graphically in figure 1).
   3. For proper/rigorous system design, the full thermomechanical constitutive response must be captured via a material model.
   4. Each stage of the development process detailed above requires significant time and effort, but the greater SMA community has developed tools to speed certain development stages.
   5. However, a laborious workflow of experimental analysis and constitutive model calibration is still commonly required for rigorous SMA characterization. This is especially difficult for newcomers to the field or those engaged in multi-disciplinary efforts.
   6. In this work, we detail a streamlined open-source tool to help both material scientists and design engineers analyze their thermomechanical data and calibrate an appropriate SMA constitutive model.
   7. The pre-processing GUI extracts data from multiple inputs such as tensile test data and external thermocouples and automatically synchronize them onto the same time series.
   8. Furthermore, the calibration GUI finds the best fit of constitutive model parameters (martensitic elastic modulus, austenite start temperature, etc.) given filtered and synchronized experimental data.
   9. Need metatext paragraph?
2. **Method description**
   1. **Data pre-processing**
   2. **Model calibration**
      1. SMA Constitutive Model Calibration, or Parameter Identification, describes the process of finding the set of model parameters (Martensite Start Temperature, Maximum transformation strain, etc.) that best fit material experimental data in the mode of operation relevant for the engineering component of interest (e.g., tension, compression, torsion, or a combination thereof).
      2. An appropriately calibrated constitutive model is essential for design of complex systems with SMAs.
      3. Historically, SMA model calibration has been performed analytically, based on analysts’ best-guesses of appropriate properties, and via numerical optimization.
      4. For this work, due to the inherent interdependence of so many material properties, and assuming that the driving factor for calibration is proper fit of experimental data, we can approach the calibration problem as a numerical optimization problem.
      5. Because of the aforementioned material property interdependence, we use a hybrid optimization scheme to best balance global searches with local optima; when multiple experiments are conducted, this optimization problem is overdetermined so there may exist many local optima.
      6. Our tool leverages the genetic algorithm NSGA-II for the global search and then SLSQP implemented in SciPy for the local search, although the tool is modular and other optimization algorithms can be easily inserted in lieu of the ones discussed herein.
   3. **1-D Lagoudas SMA Constitutive Model**
      1. The Lagoudas shape memory alloy constitutive model uses the Gibbs' free energy to derive a thermodynamically consistent relationship between stress and strain.
      2. Alternatively, we can discuss the model from the lens of how the calibrated parameters affect constitutive response.
      3. As mentioned earlier, the seventeen material properties that define shape memory alloy constitutive response are unique but interdependent.
      4. Many other material properties are interrelated as well; changing transformation strain properties will change both the strain-temperature response and the shape of the transformation surfaces.
   4. **Calibration via numerical optimization**
      1. The current implementation of the tool, in a GUI-based format, allows the SMA designer to specify both optimization parameters and material property bounds and values.
      2. Each calibration routine can be executed in less than 10 minutes, depending on the size of the optimization, and the results are easily digestible for those who are not innately familiar with the Lagoudas SMA constitutive model.
   5. **Post-processing and outputs**
3. **Implementation example**
   1. **Experimental data**
      1. To calibrate an accurate SMA constitutive model to capture actuator behavior, *n* isobaric (constant force thermal cycling) tests, where *n* is preferably greater than 4, are required.
   2. **Conventional calibration procedure**
      1. Calibration of the 17 unknown parameters that define the Lagoudas SMA constitutive model can be calibrated without a global optimization strategy by estimating parameter groups (e.g., transformation temperatures, thermoelastic properties, etc.) sequentially
      2. First, transformation temperatures for each tested stress level can be estimated via the tangent method or similar.
      3. With transformation temperatures and stress-influence coefficients estimated, thermoelastic properties and transformation strain properties can be calculated.
      4. At this point, the analyst has two choices in terms of calculating the rest of the thermoelastic and transformation strain properties.
      5. Both of these approaches to calculate the remaining thermoelastic properties and transformation strain properties may introduce modeling errors.
      6. At this point, all material properties are estimated; to fully capture the true strain-temperature response, iterative calibration of each smooth hardening coefficient is necessary until a satisfactory fit is accomplished.
   3. **Calibration via numerical optimization**
4. **Conclusions and further refinements**