Methodology for Yield Determination of Surface Shots Over Water

Film Scanning and Re-Analysis Project

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Lawrence Livermore National Laboratory

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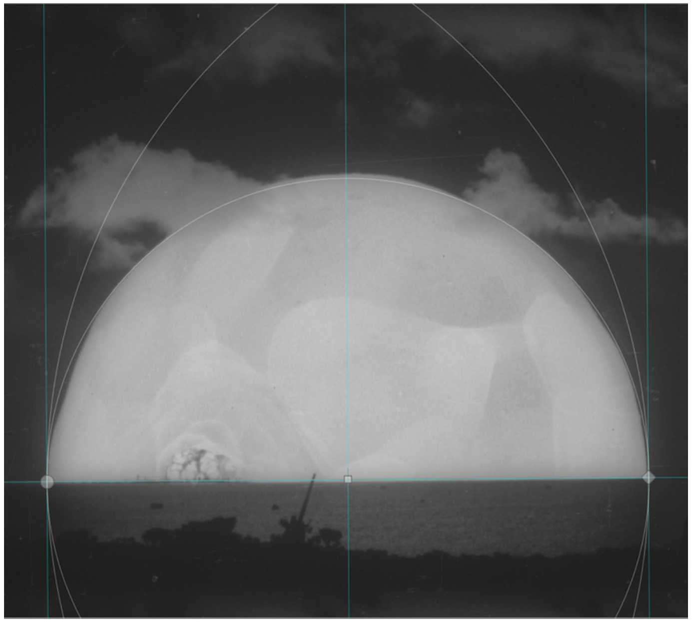
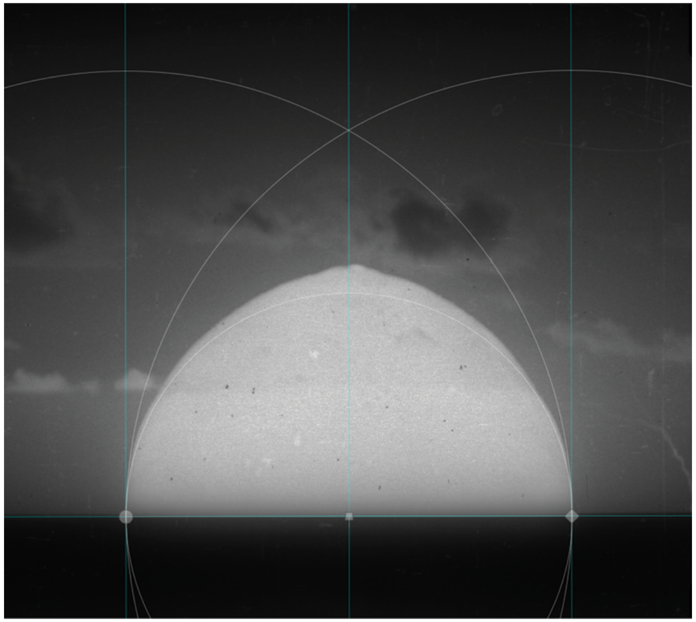
Presentation Breakdown

1. Introduction

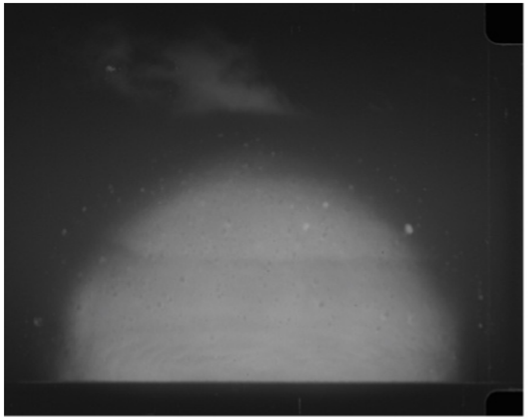
- Yield - measure of the amount of energy released by a detonation in equivalent tons of TNT
- Shockwave analysis is one of the many methods used to determine the yields of nuclear detonations
- All shockwave analysis techniques so far assume spherical shockwaves
- Yield is proportional to volume of the shockwave at a given reference time
- Shockwaves of surface shots were asymmetrical over water

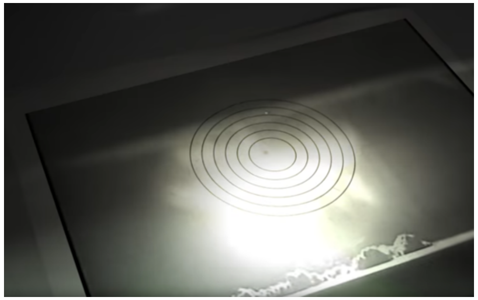


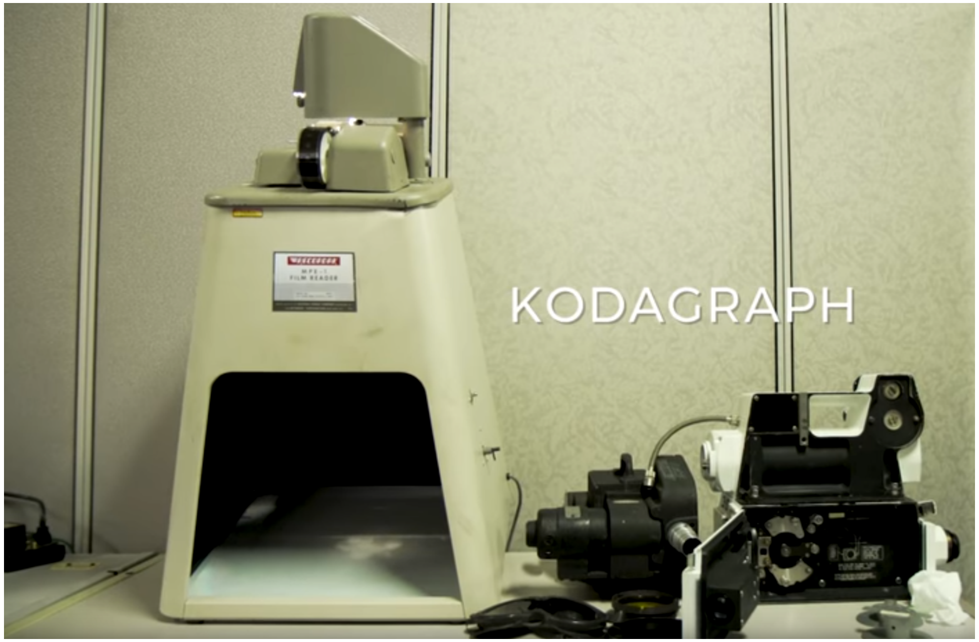


1. Introduction

- Existing data on shockwave radii:
  - EG&G may or may not have ignored the asymmetry
  - For most surface shots, EG&G used the arithmetic average of measured radii
- Deciding where the shockwave edge lies is a subjective measurement
  - Initial measurements were made on a Kodagraph

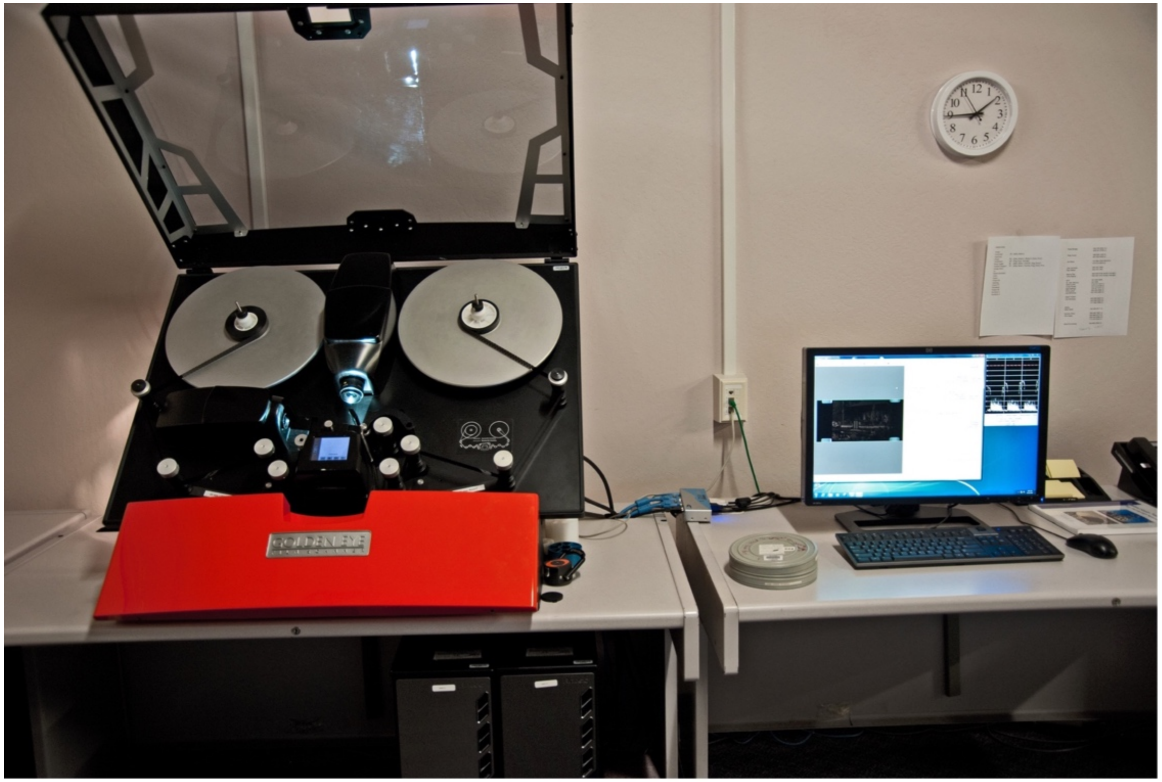






1. Introduction

- Film Scanning and Re-Analysis Project here at LLNL has digitized ~4200 of these scientific nuclear test films
- We live in the 21st century where advanced image processing algorithms and powerful supercomputers are at our disposal

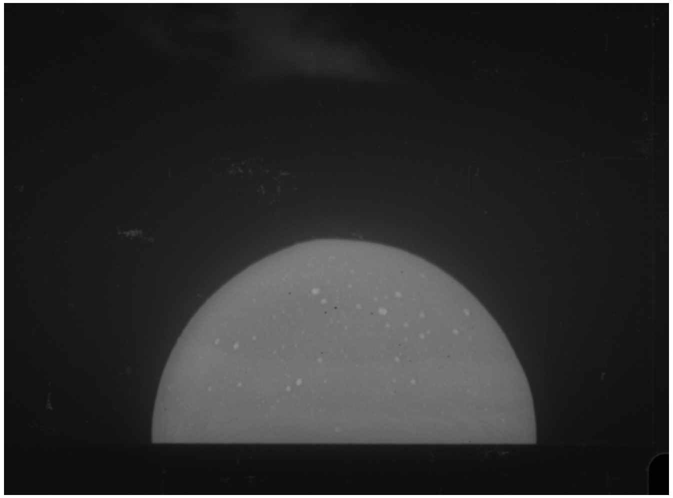


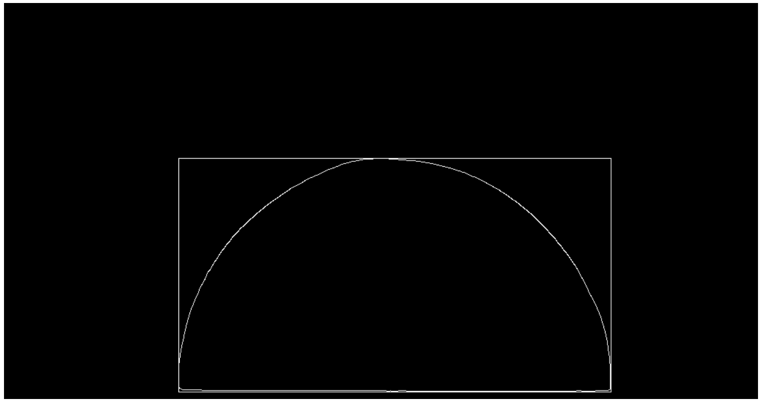
2. Objectives

- Image Processing
  - Devise an image processing pipeline which can segment the shockwave of the detonation from the rest of the frame
  - Measure the dimension of the shockwave contour
- Yield Determination
  - Create a method to reduce the 2-D contour to a single value which can be used in existing shockwave analysis equations
  - Compare yields and radius measurements to the past models and hope that they're better
- Resource Limitation
  - No army of interns

3. Methodology – Image Processing

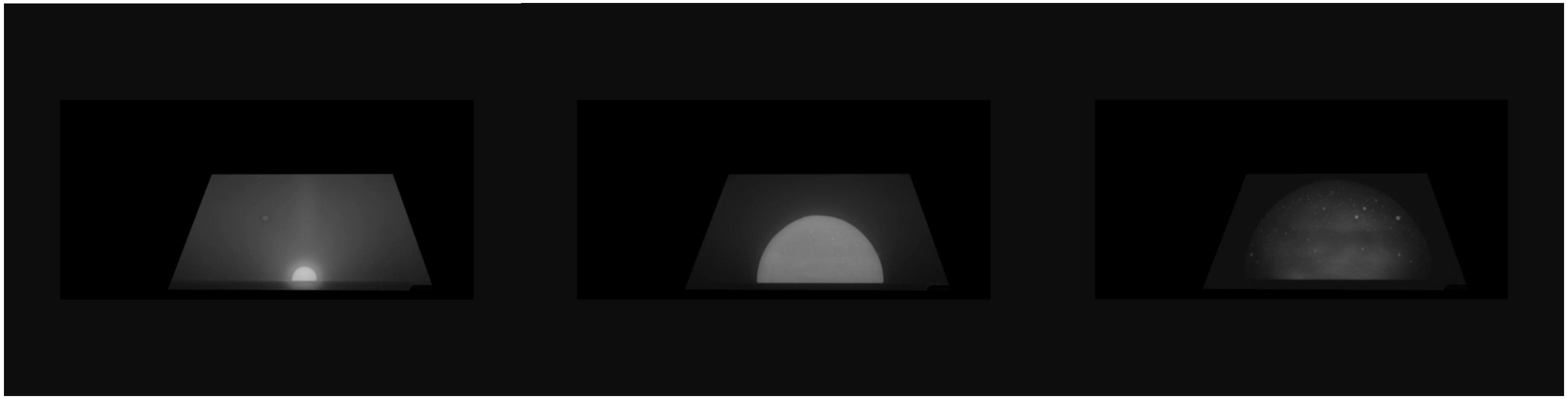
- Determining the contour of the shockwave from a noisy, scientific film yields an image segmentation problem
- Pipeline for performing this image segmentation can be broken down into three steps:
  - Image Preprocessing
  - Image Segmentation
  - Image Postprocessing
- Minimal amount of human input





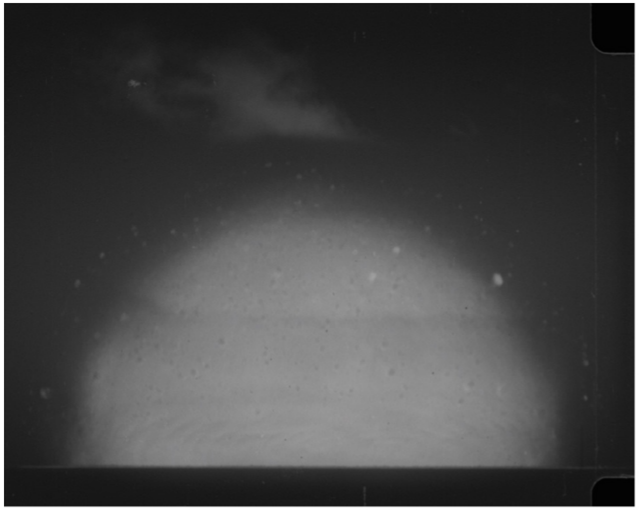
3. Methodology – Image Preprocessing

- Overall Goals:
  - Gather as much preliminary data from the original image as possible
  - Apply some transformations which should make the later steps easier
- Issues to Address:
  - Incorrect exposure of each image
  - Noise in the original image
- First steps
  - Cropping and Down sampling
  - Median Blur – Noise Reduction
  - Morphological Opening – Despeckling and noise reduction



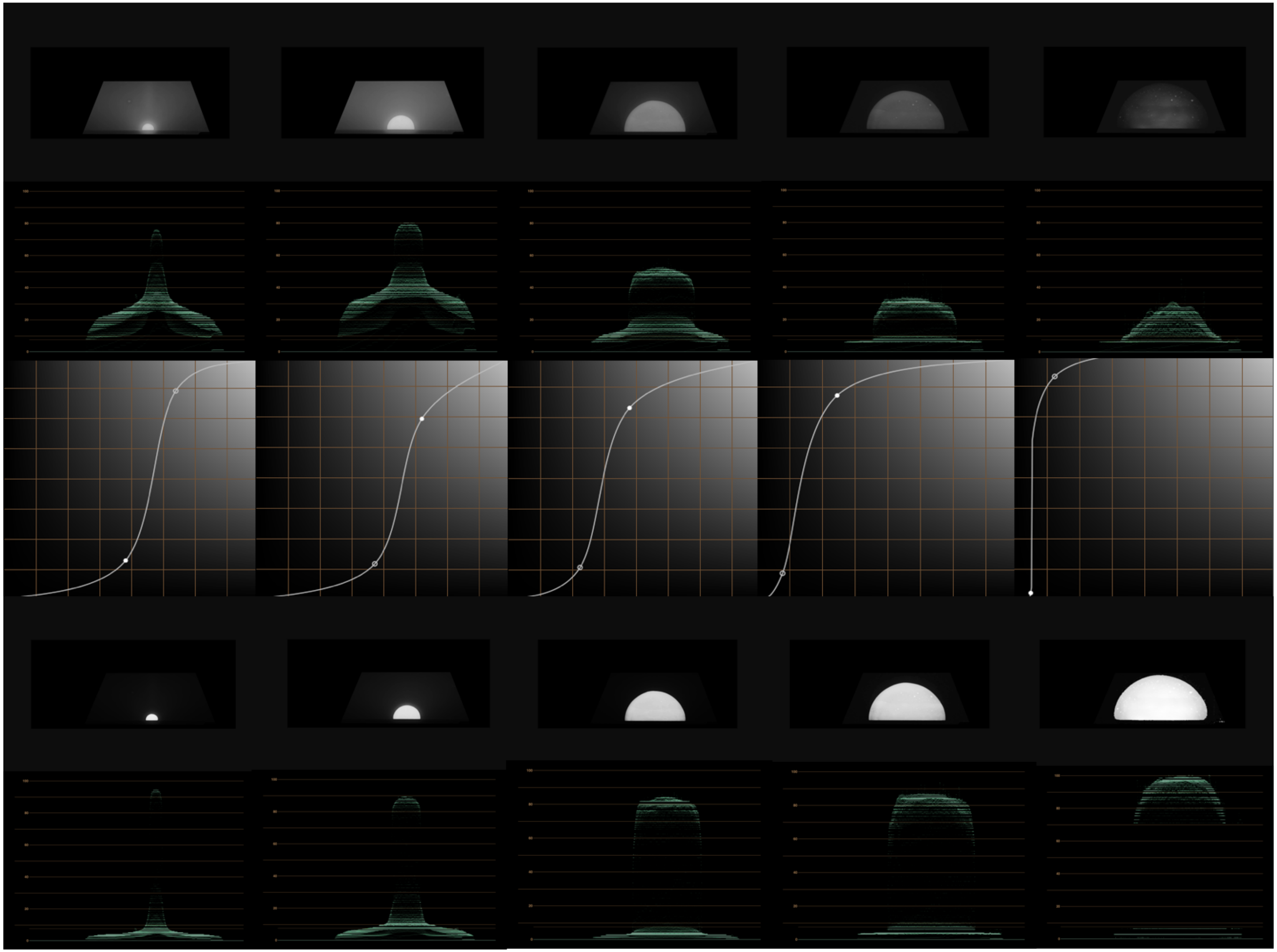
3. Methodology – Image Preprocessing

- Automatic Exposure Compensation
  - Curve Adjustment similar to other Image Processing tools ex. Photoshop, Lightroom, etc.
  - Dynamic generation of Look Up Tables (LUTs) to help correct exposure
- Necessary since films have a fixed sensitivity
  - Early stages of the shockwave have extremely high amounts of light output resulting in a washed out frame
  - Late stages when shockwave drops below the Draper Temperature and stops emitting visible light



3. Methodology – Image Preprocessing

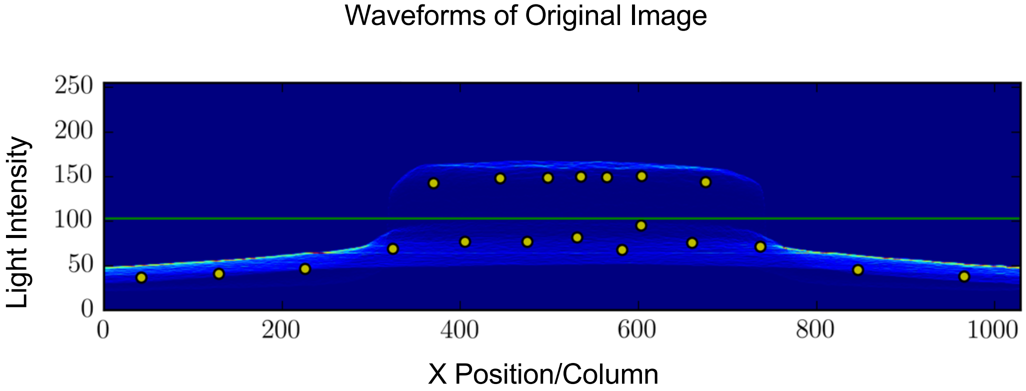
Time →

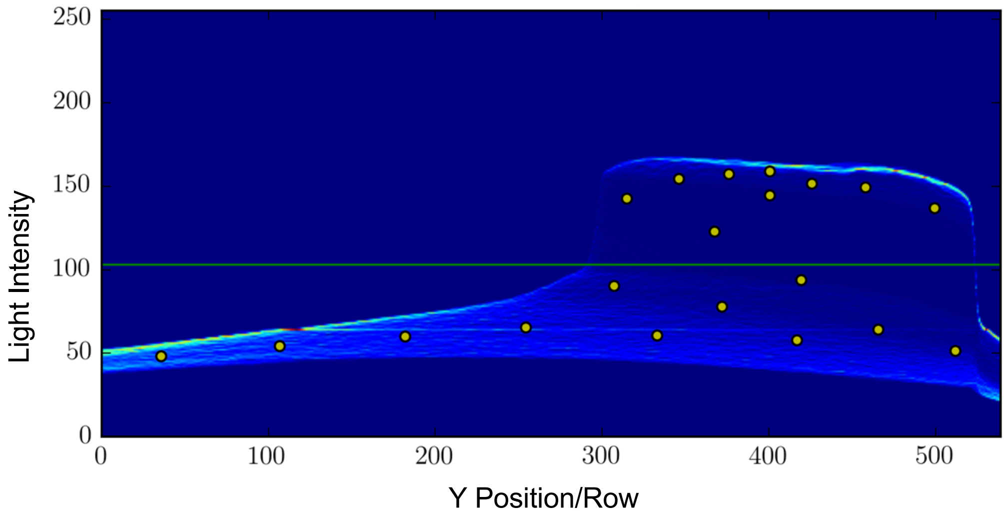


3. Methodology – Image Preprocessing

- Separate image into distinct regions which will allow the application to cut out unnecessary parts of the image
- Determine a preliminary threshold value through waveform analysis:
  - Waveform – A plot displaying the light intensity of each row/column of an image
  - K-Means clustering to get discreet points which describe the high density regions of the waveform
  - Take directional gradient to find edge points corresponding to the shockwave
  - Find the midpoint of the edge points
- Dilate and erode the thresholded image to form regions we know for sure are:
  - The background (0-black)
  - The fireball or foreground (255-white)
  - The area containing the shockwave

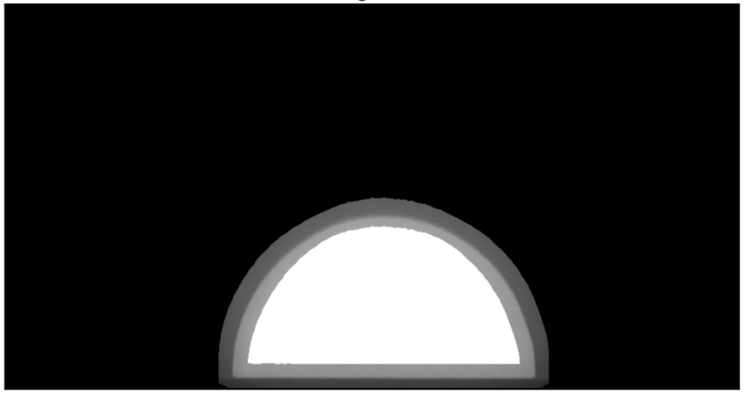
3. Methodology – Image Preprocessing





Original 207

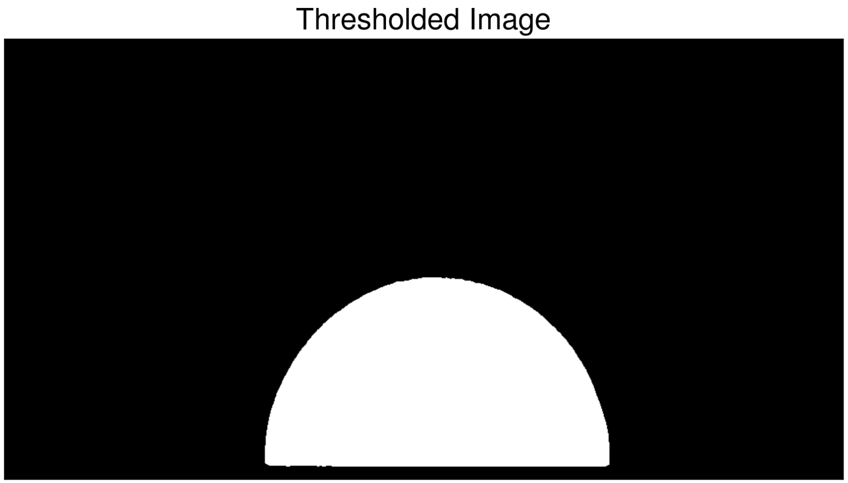
Regions

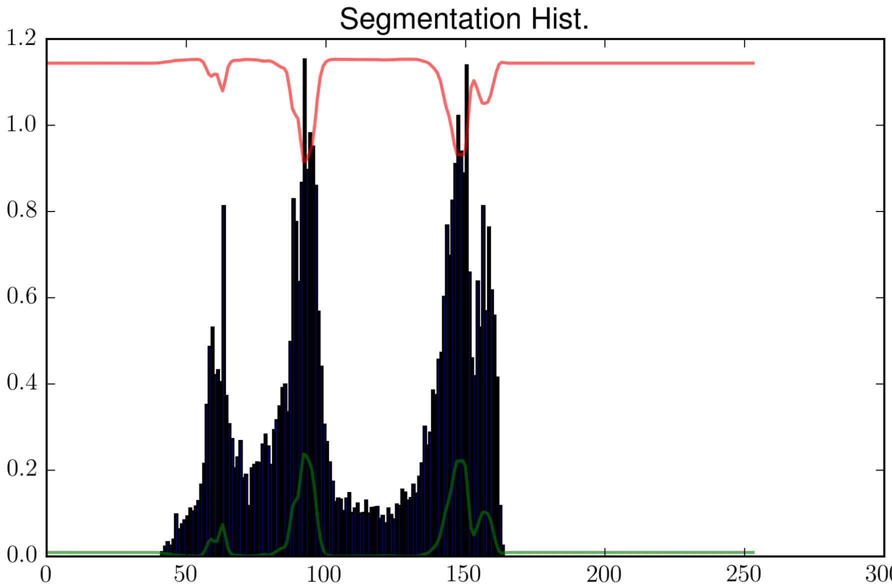


3. Methodology – Image Segmentation

- Finding a more refined threshold value which will binarize the image exactly on the shockwave front (hopefully)
- This is done by analyzing the histogram of the region where the shockwave lies
  - Histogram – A plot showing the distribution of light intensities for an image
  - By examining the histogram of light intensities from 1-254, we are looking at the distribution of light intensities of just the shockwave interface region
  - Use Kernel Density Estimation to get a smoothed function of the histogram
  - Apply Peak Detector to find the two maxima of the plot that describe only the interface region
  - Run Otsu's Thresholding Algorithm on this specific region of the histogram to get a final threshold
    - Maximize Inter-Class Variance
    - Minimize Intra-Class Variance

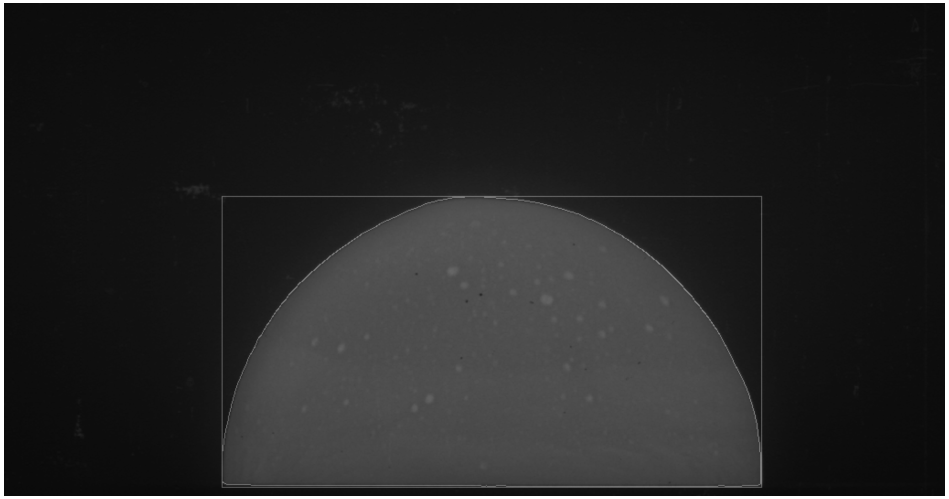
3. Methodology – Image Segmentation

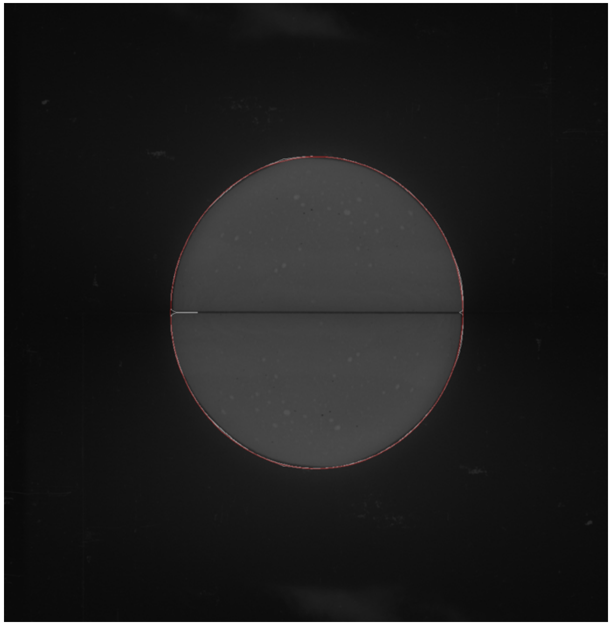




3. Methodology – Image Postprocessing

- Find the contours of the segmented image
- Measure a dimension of the final contour via shape fitting
  - Generally a bounding box works well
    - Height and (half) the width of the bounding box describe the asymmetry of the shockwave
  - Fit an ellipse to the asymmetric shockwave
    - Major and Minor Radii of the resulting ellipse is used



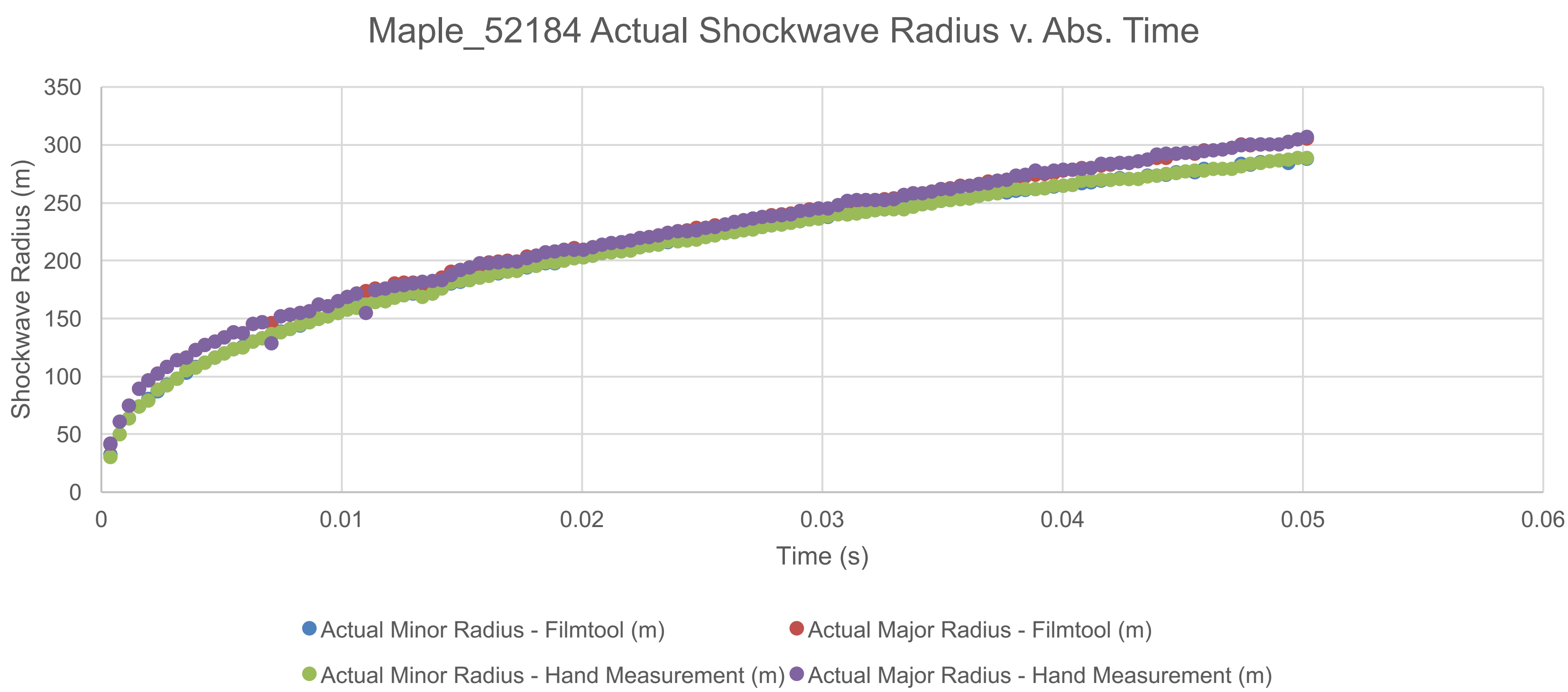


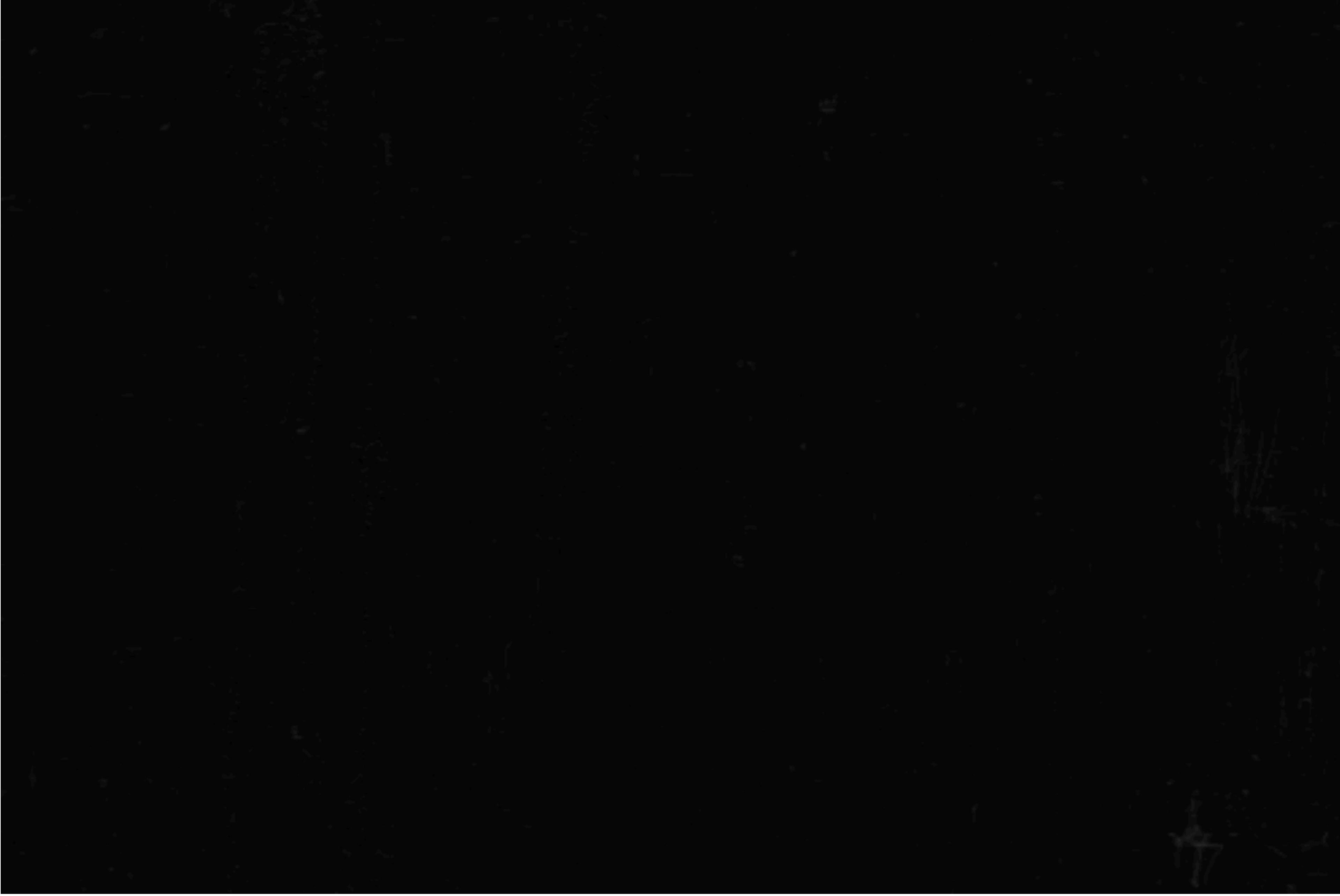
3. Methodology – Yield Determination

- Taylor's Equation is used in shockwave analysis to determine the yield of these shots
  - $R = \frac{1}{2K^{1/5}}\left(\frac{\theta Y_{SW}}{\rho_0}\right)^{1/5} t^{2/5}$
  - Only has a single radius parameter
- To simplify our shockwave measurements to a single value which can be used in yield determination the following methods are tested:
  - Arithmetic Average
    - $\bar{r} = \frac{a+b}{2}$
  - Radius of an equivalent volume sphere
    - $\frac{4}{3}\pi\bar{r}^3 = \frac{4}{3}\pi abc, a = b$
    - $\bar{r} = \sqrt[3]{a^2c}$

4. Results

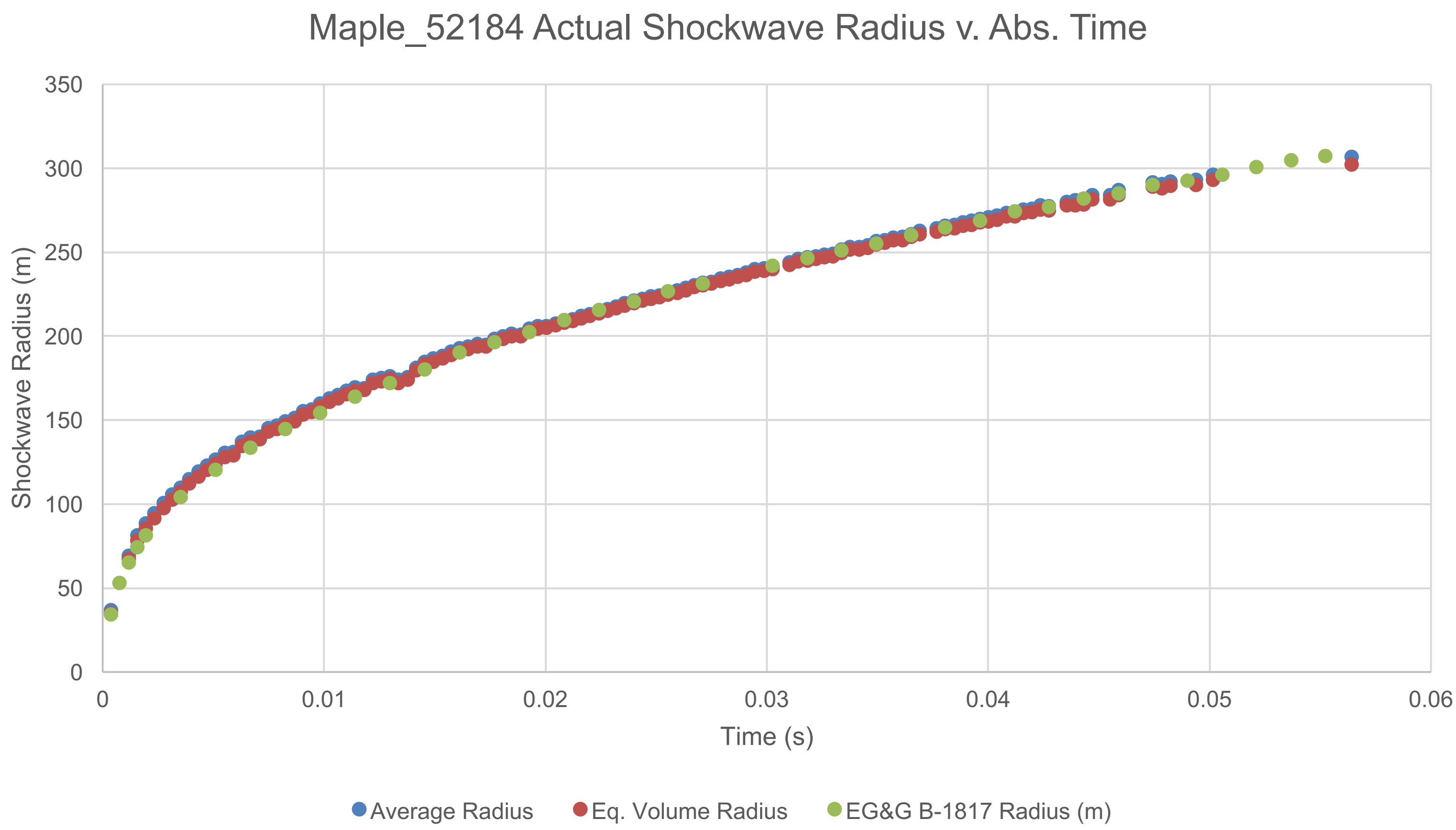
- 50 films analyzed so far with some fiddling here and there
- Film Analysis Application required only minimal human input
  - Frame of first light
  - Cropping Bounds cutting our extra parts of the film ex. film perforations
  - Measurement Fit Type: Bounding Box or Ellipse





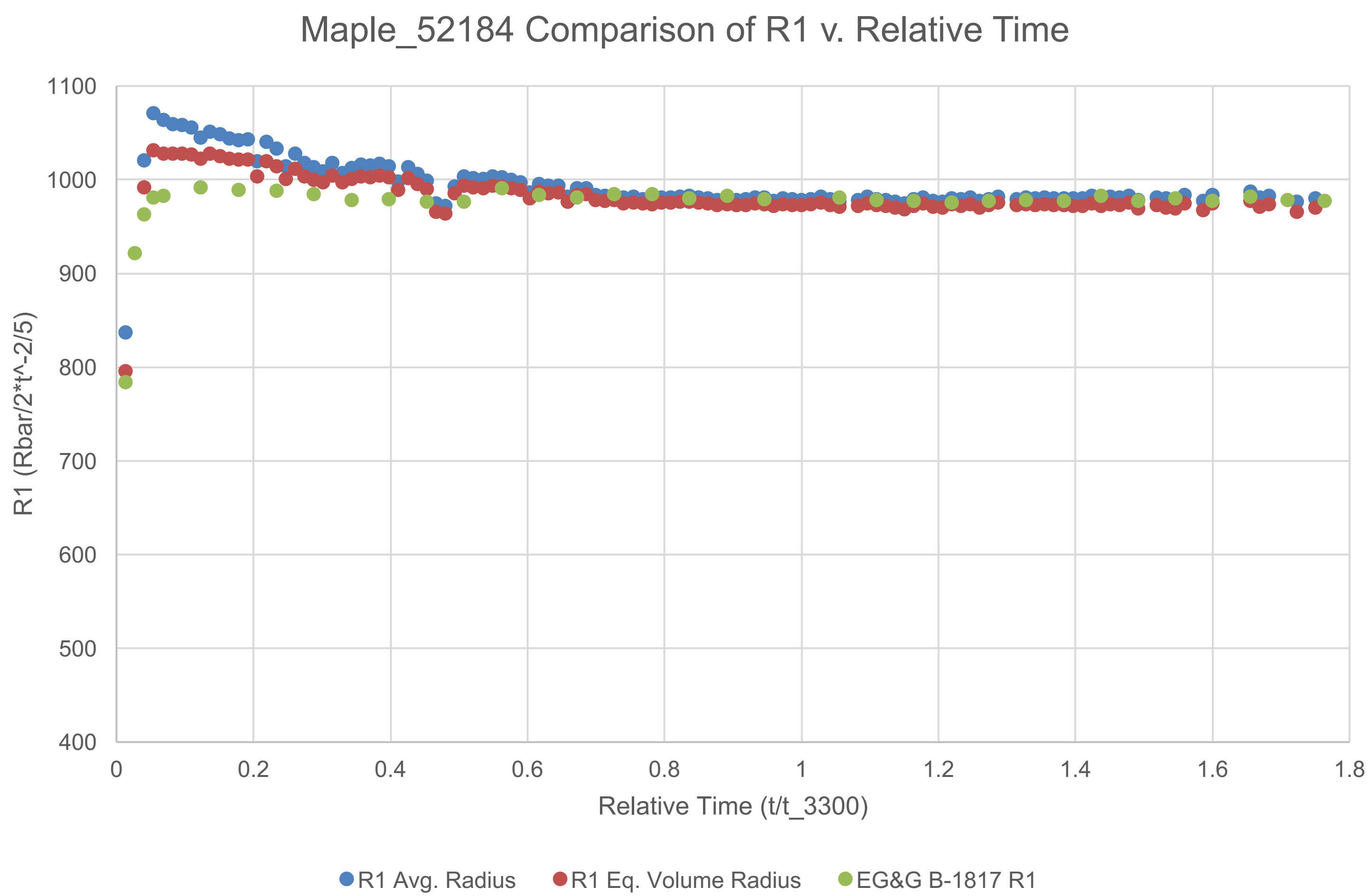
4. Results

- To reduce the dimension of our measurement we:
  - Took an arithmetic average
  - Used the radius of a sphere of equivalent volume to our fitted ellipsoid



4. Results

- Determining the Yield using Taylor’s Equation requires finding the values of R1 which correspond to the regime which Taylor’s Equation is valid



4. Results

- Original EG&G Yield: 215 KT
- EG&G Re-analysis Yield: 193.4 KT [Greg Spriggs]
  - Using original EG&G data
  - 10% difference with original EG&G Yield
- Current work:
  - Radius of Equivalent Volume Yield: 194.8 KT
    - 9.4% difference with original EG&G Yield
    - 0.7% difference with re-analyzed EG&G Yield
  - Average Radius Yield: 202.3 KT
    - 5.9% difference with original EG&G Yield
    - 4.6% difference with re-analyzed EG&G Yield

5. Discussion

- Primary goals of the film analysis application were met, no army required
- Tool is still very experimental with several necessary improvements ex:
  - Smarted exposure compensation
  - More feedback in each step and between steps to catch errors
- Generate accurate and repeatable benchmark data for use in:
  - Validating existing shockwave simulation codes
  - Creating new 2D or even 3D simulation codes
- The yields calculated with the described methods can also be used to benchmark our codes

6. Future Research

- Mass Entrainment effects as the shockwave moves over the water
- 3-D modeling of the shockwave using composites of the shockwave’s contour from multiple angles
- Novel methods for reducing radii dimensions to singular value for use with existing yield determination equations
- Yield Determination equations which take in 2-dimentional data
- Developing more accurate models and simulations which account for water entrainment effects and the asymmetrical shockwave

7. Thanks & Acknowledgements

- All LLNL employees involved in making our summer internships a great experience!
- Team: Gregory Spriggs, Jim Moye, Jason Bender, Peter Kuran
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