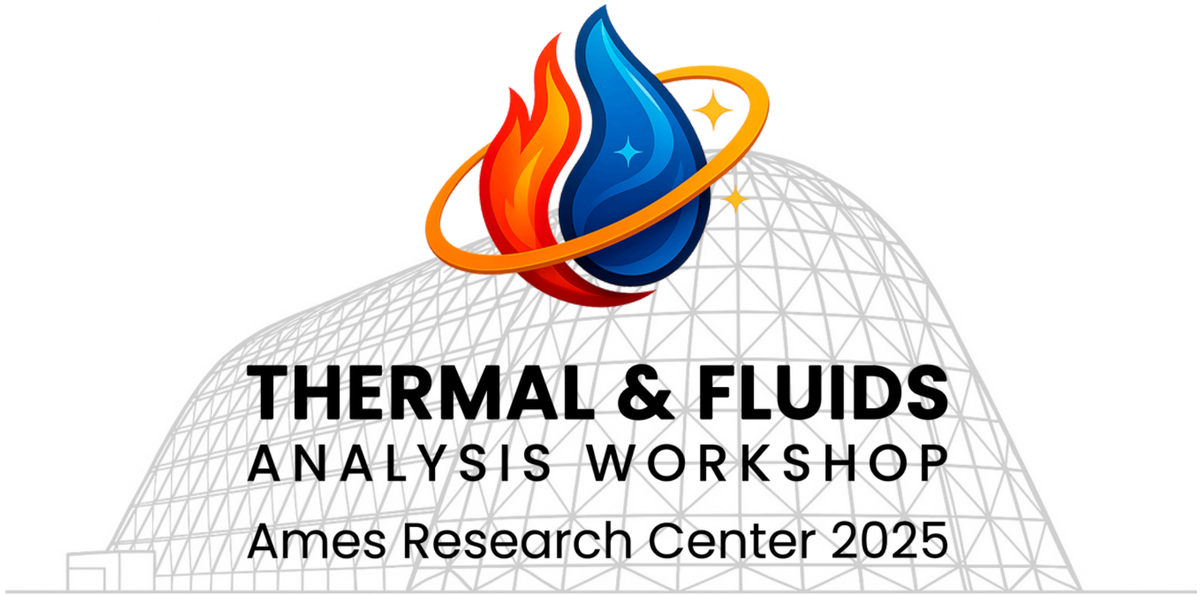
Calibration for Video Analysis with arcjetCV

Presented by: Alexandre Quintart



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Flying Squirrel

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1. Introduction

- NASA heatshields **require** extensive ground testing and modeling.

- Ground tests are **expensive** and **complex,** but they are **essential** for evaluating material behavior.

→ **Maximizing data** extraction from each test is important !

2. Motivations

Past capabilities:

→ arcjetCV (Since 2020):

- Automated recession analysis from video.
- 2D model validation.
- Time-resolved validation.

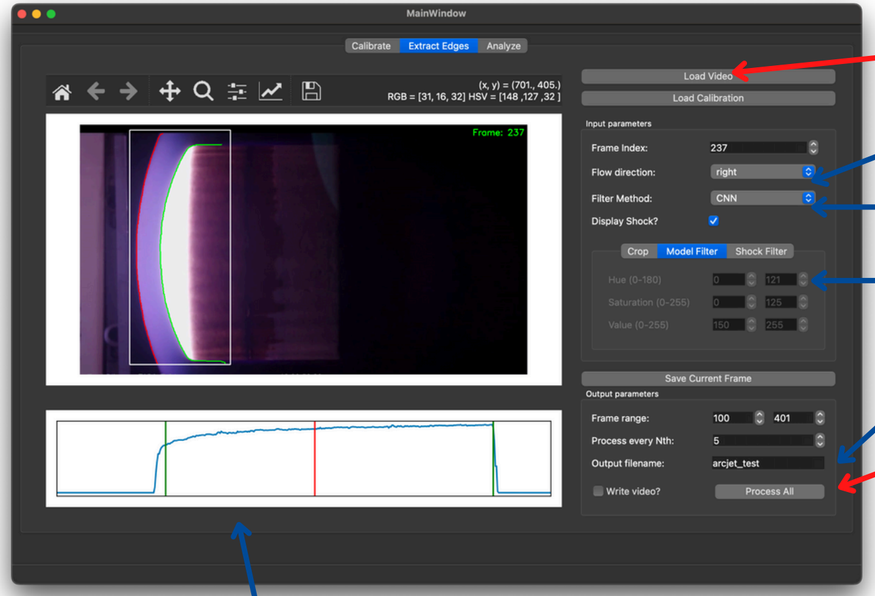
New capability :

→ arcjetCV 1.1:

- Improved machine learning model for recession tracking from videos.
- Simplified software distribution.
- Introduced a calibration module.

3. arcjetCV Overview

- **open-source software** tool for analyzing heatshield material performance during arcjet tests.
- **Machine learning** (CNN) models for automated video segmentation.
- Tracks **time-dependent** material **recession** and shock **standoff distance**.
- GUI for **user-friendly** operation and API for batch processing.



1. Load a video

Select flow direction

Select filter method

Crop & filter parameters

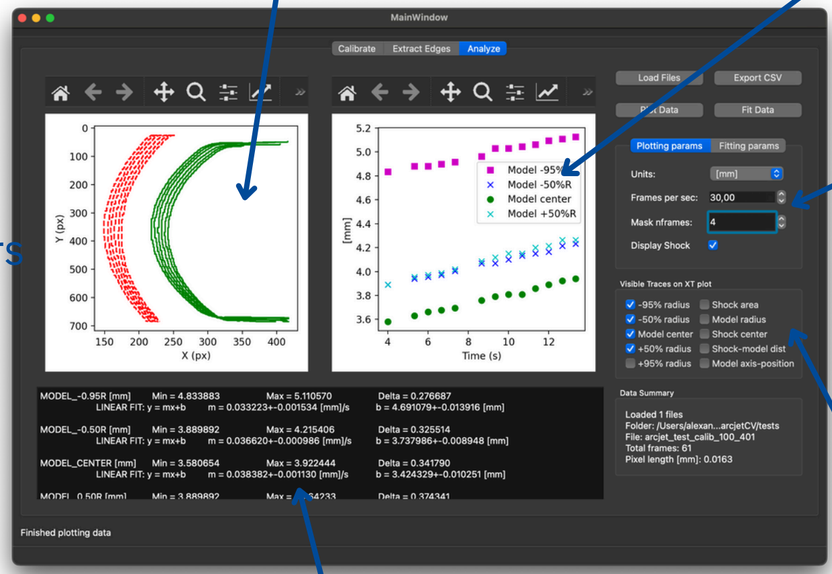
Output settings

2. Process all frames

Clickable navigation bar: displays integrated frame intensity, start/stop frames (green lines) and current frame (red line).

XY Traces of Shock and Sample Edge plot

Time-dependence plot



3. Export

Parameters

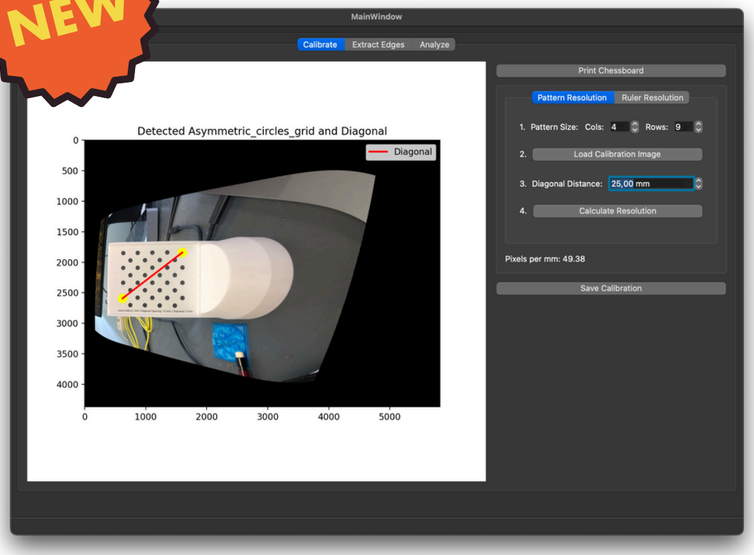
Plot options

Linear fits

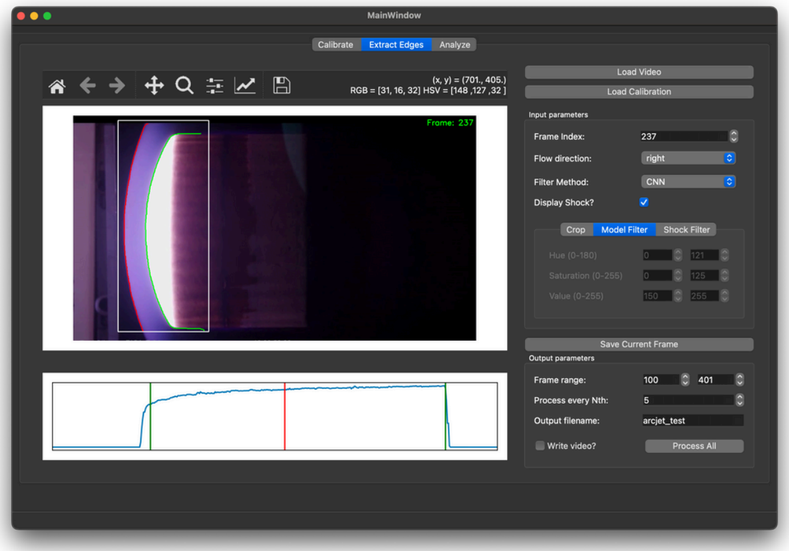
4. arcjetCV 1.1 Calibration Tool

1. Calibration Tool

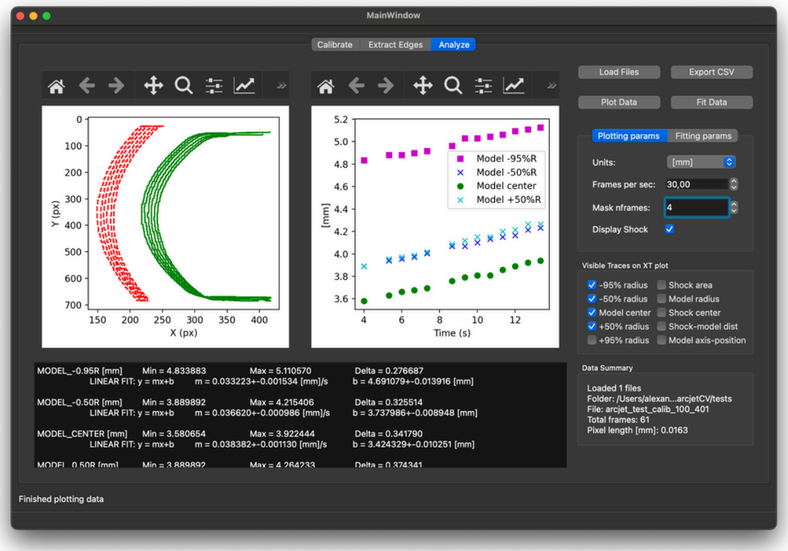
NEW



2. Data Extraction Tool



3. Analysis Tool



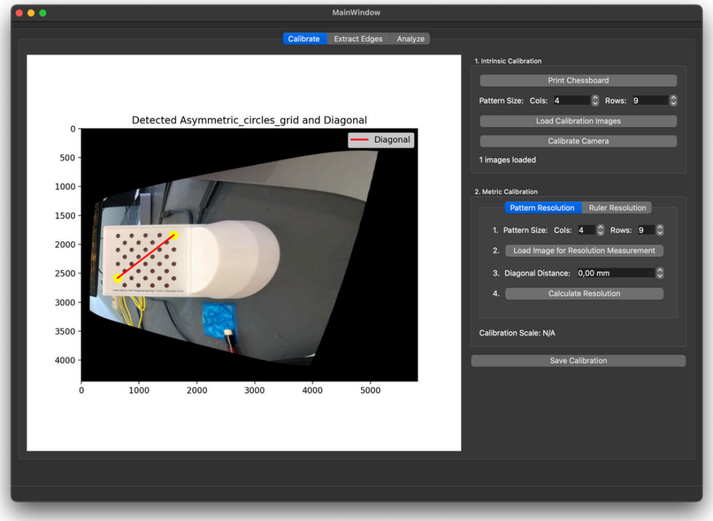
4. arcjetCV 1.1 Calibration Tool

Problem: Frames are distorted, misaligned, and lack an accurate pixel-to-millimeter ratio.

Solution: Add a calibration section to:

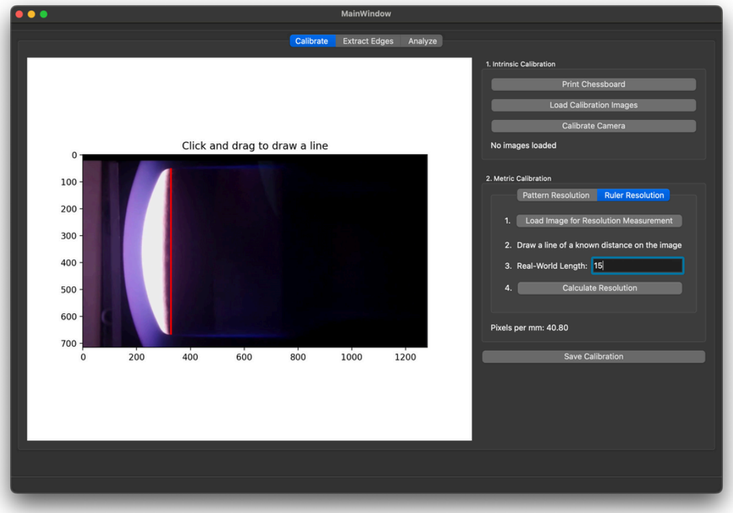
- Correct lens distortion
- Improve frame alignment
- Accurately determine the pixel/mm ratio for metric measurements

Pattern Calibration



OR

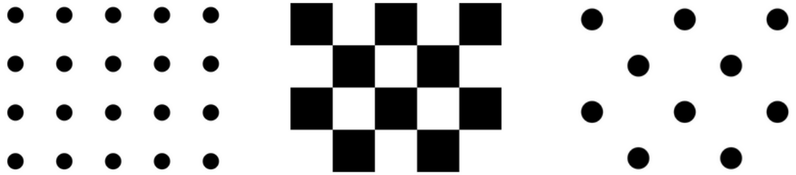
Ruler Calibration



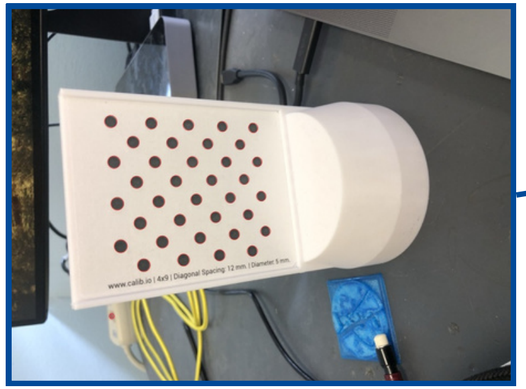
Pattern Calibration

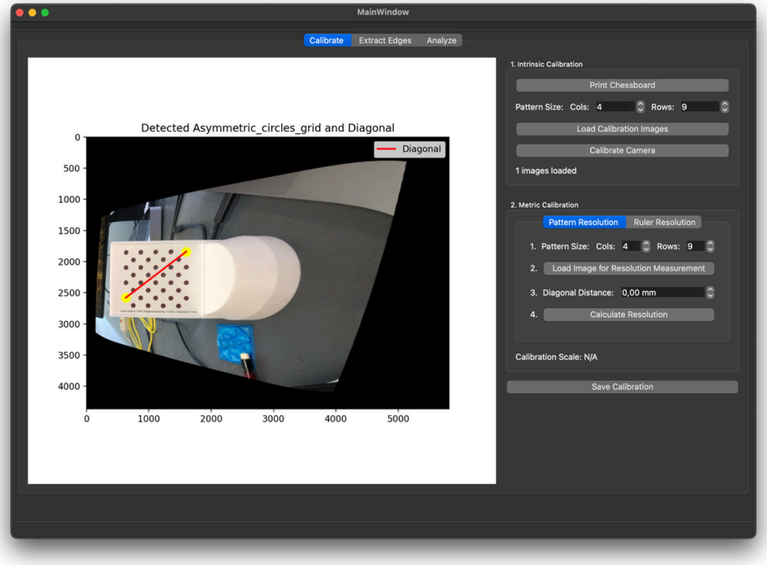
A full calibration workflow using printed checkerboards or dot grids:

- Detects structured patterns (checkerboard, circle, asymmetric grid).
- Computes:
  - Lens undistortion: corrects radial/tangential distortion.
  - Homography: aligns grid with image axes (planar rectification).
  - Metric scale: derived from known grid size.



circles checkerboard asymmetric circles





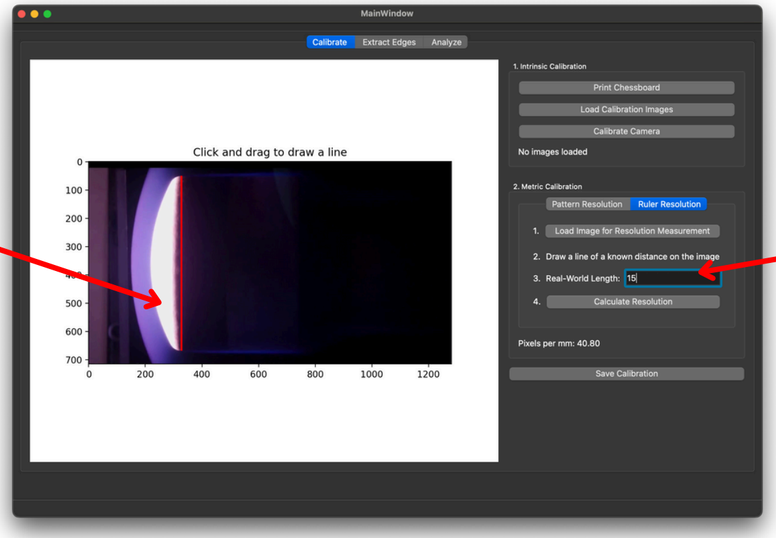
Ruler Calibration

A fast, practical method for test videos without calibration patterns:

- User draws a line over a known-length object.
- arcjetCV computes the **pixel-to-mm scale** from the drawn segment.
- **No lens correction:** only metric scaling, sufficient when distortion is minimal

➜ Interesting for **legacy videos** where pattern calibration hasn't been performed.

1. Draw a known distance



2. Real-world length

5. arcjetCV 1.1 Improvements

Goals:

- Increase the accuracy of the convolutional neural network detection.
- Simplify software distribution.

Improvements:

- New edge class
- New architecture
- Expanded training dataset
- Distribution on pypi (Python Package Index)
- Available as an executable for Windows (.exe) and macOS (.app).

arcjetCV 1.1: New Edge class

Problem:

- Standard CNN architectures may **struggle** with accurate **edge detection** in samples where boundary details are critical.
- Misclassification or blurring of edge regions can lead to **errors** in measuring **recession**.

Solution:

- Introduce a **dedicated class** for sample edges.

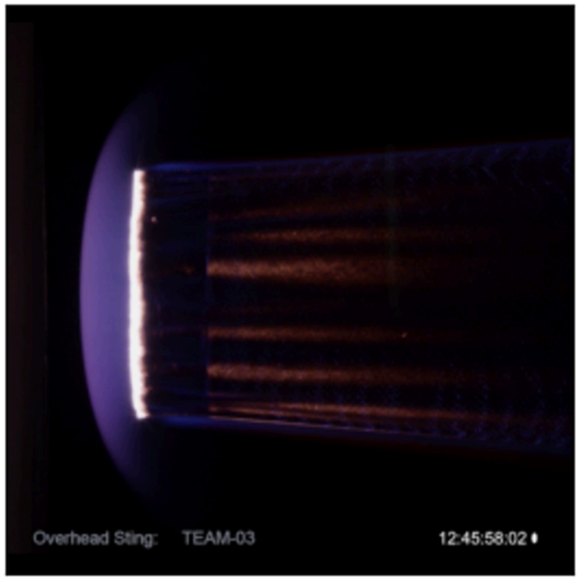
→ This class specifically labels boundary areas where material recession occurs, allowing the model to **focus** on fine **edge** details.

Advantage:

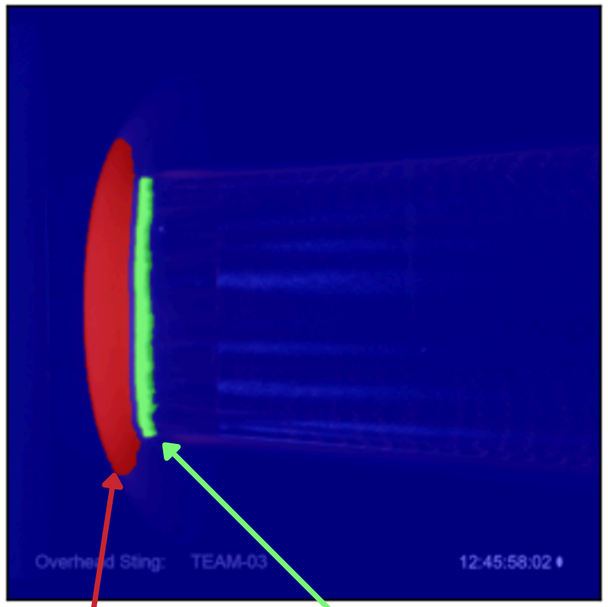
- **Reduced misclassification**: By distinguishing edge from non-edge pixels more effectively, minimizing errors in recession measurement.

arcjetCV 1.1: New Edge class

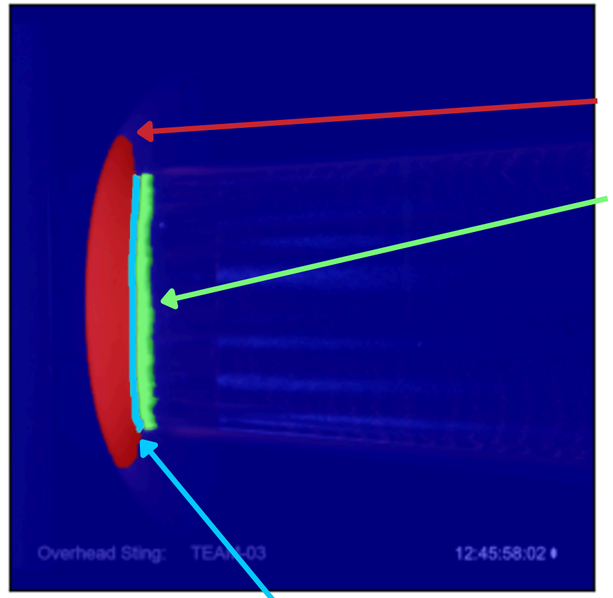
Original frame



Old training mask



New training mask



arcjetCV 1.1: New architecture

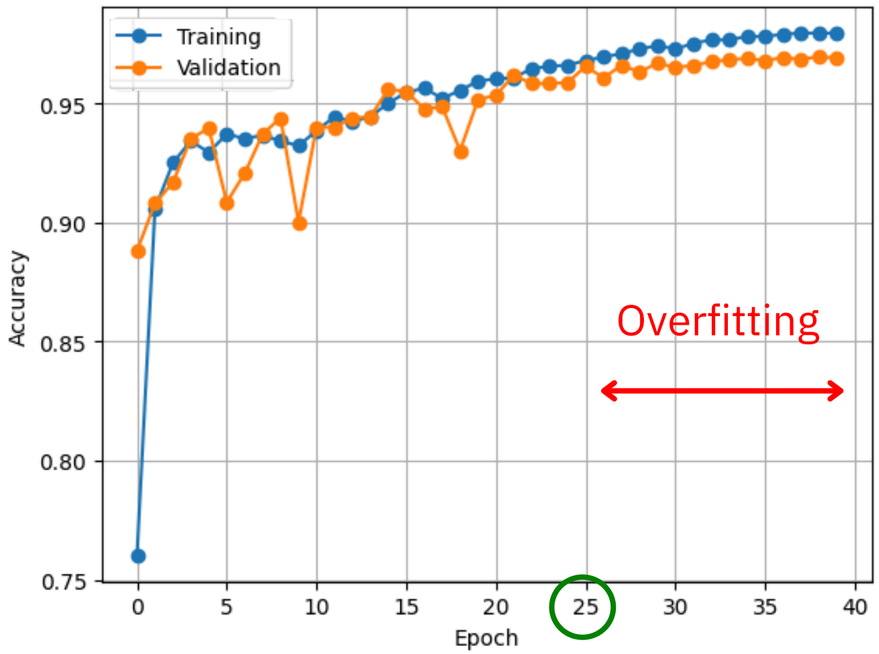
Xception

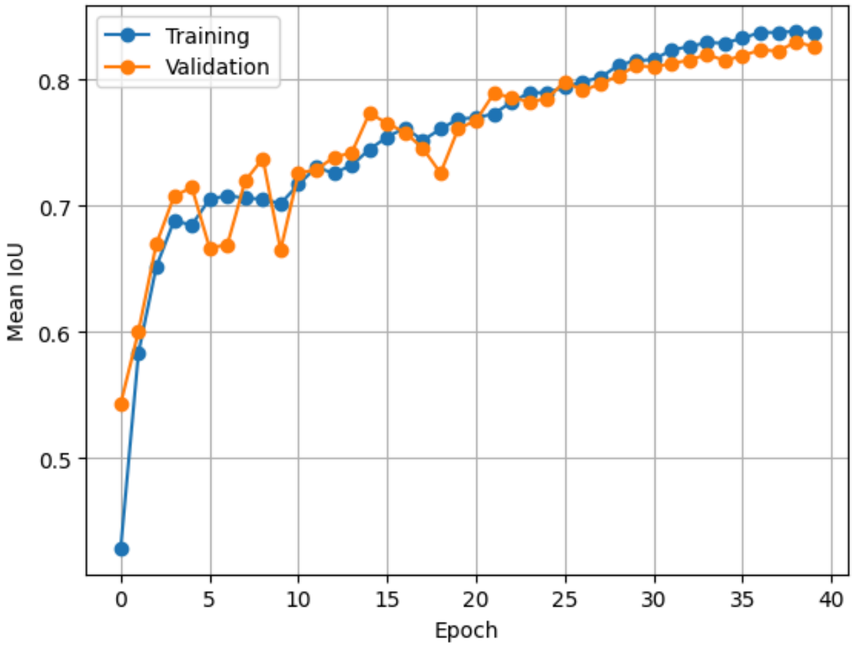
Key Advantages:

- **Improved Edge Detection:** Xception captures fine details, making it ideal for tasks needing precise segmentation.
- **Superior Feature Extraction:** Residual connections in Xception improve feature learning over VGG16's standard convolutions.
- **Higher Accuracy & Lower Cost:** Xception delivers better accuracy and is computationally more efficient, despite its deeper architecture.

Conclusion: Xception is a more effective model for high-precision tasks like edge segmentation.

ML architecture performance





Model with 25 epochs	Pixel Accuracy	mIoU
VGG16 (Old model)	0.9411	0.7311
ResNet18	0.9413	0.7543
Xception	**0.9687**	**0.8005**

$$\text{Pixel Accuracy} = \frac{\text{Number of Correctly Classified Pixels}}{\text{Total Number of Pixels}}$$

Mean Intersection over Union (mIoU):

$$\text{mIoU} = \frac{1}{N}\sum_{i=1}^{N} \text{IoU}_i$$

$$\text{IoU}_i = \frac{\text{TP}_i}{\text{TP}_i + \text{FP}_i + \text{FN}_i}$$

→Handles Class Imbalance

where N = Total number of classes.

where:

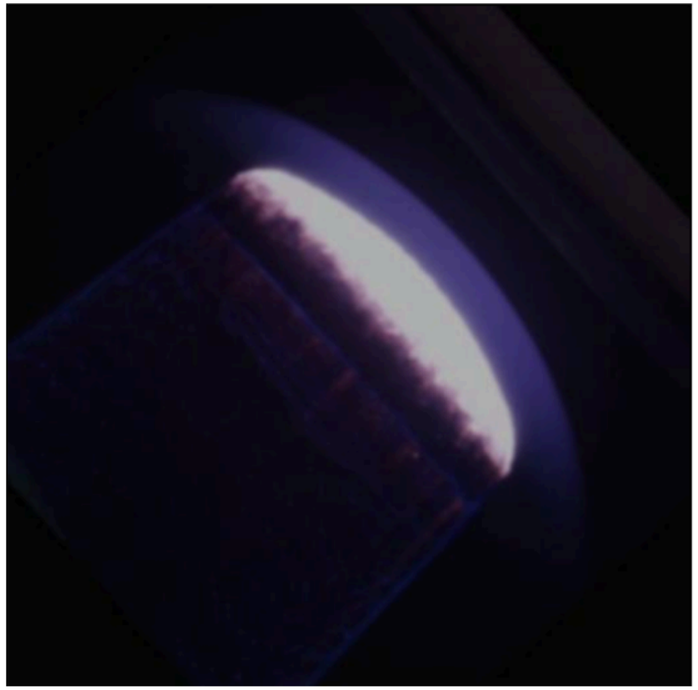
- True Positive (TP) = Pixels correctly predicted for class i,
- False Positive (FP) = Pixels incorrectly predicted as class i,
- False Negative (FN) = Pixels of class i that were missed.

arcjetCV 1.1: Augmented training dataset

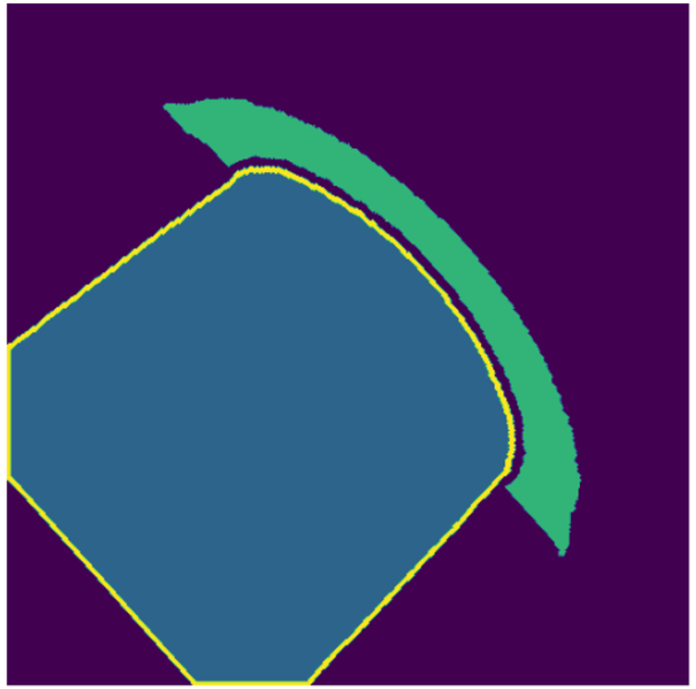
- New frames from different facilities.
  - VKI
  - UIUC
- New frames from new tests.

→ Size of the new dataset: **1778** training frames.

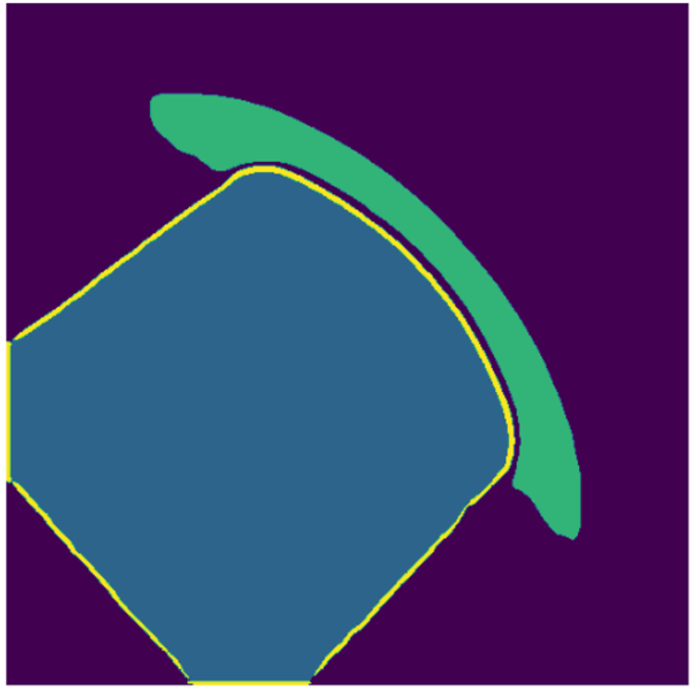
arcjetCV: New model result



Challenging video frame



Ground truth masks



Xception prediction

arcjetCV 1.1: installation

PyPi

1) Open your terminal

2) Install arcjetCV

```
pip install arcjetCV
```

3) Run arcjetCV:

```
arcjetCV
```

Git

1) Open your terminal

Prerequisites:

- git-lfs
- Miniconda or Anaconda
- Xcode Command Line Tools (macOS)

2) Install arcjetCV

```
git clone https://github.com/magnus-haw/arcjetCV.git
cd arcjetCV
conda env create -f env/arcjetCV_env_[cpu/gpu].yml
conda activate arcjetCV
python -m pip install -e .
```

3) Run arcjetCV:

```
conda activate arcjetCV
arcjetCV
```

see the Git

arcjetCV 1.1: Executable Installation

Download the executable .exe or .app here:

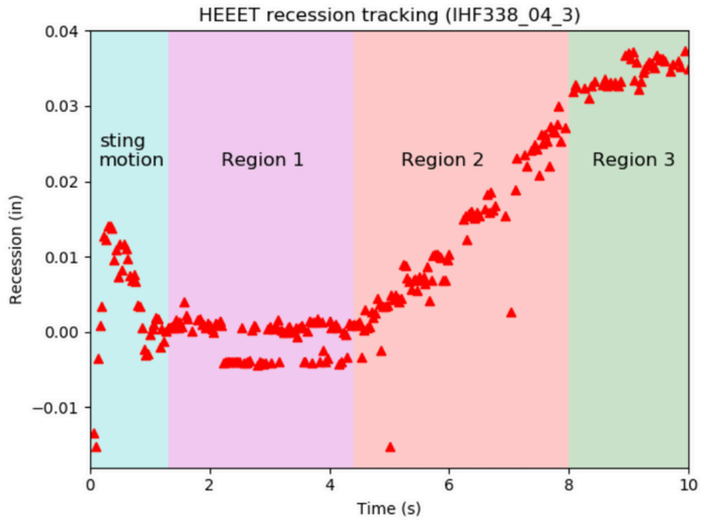
Windows Version 1.1 Available **Soon**

6. arcjetCV: Observations

1. Non-linear Recession

With arcjetCV: 3 Regions:

- *Region 1:* Nearly no recession
- *Region 2:* Constant recession rate
- *Region 3:* reduced recession rate



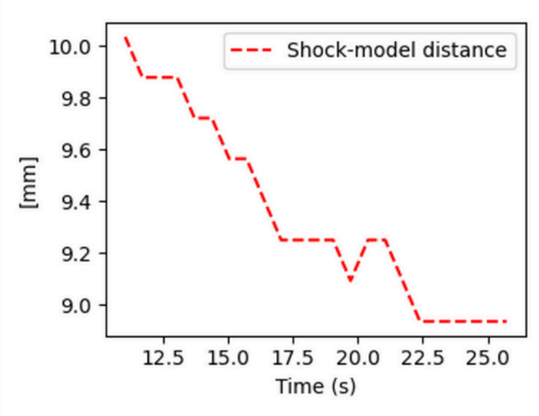
2. Shock standoff

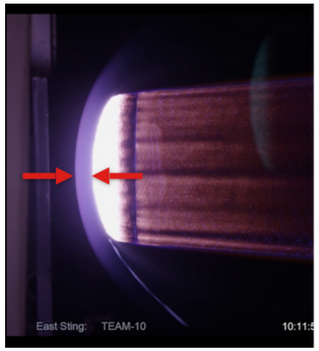
Shock-sample distance decrease implies that the pressure at the sample surface is changing with time:

→ Aerothermal conditions are changing

→ The sample is becoming more porous

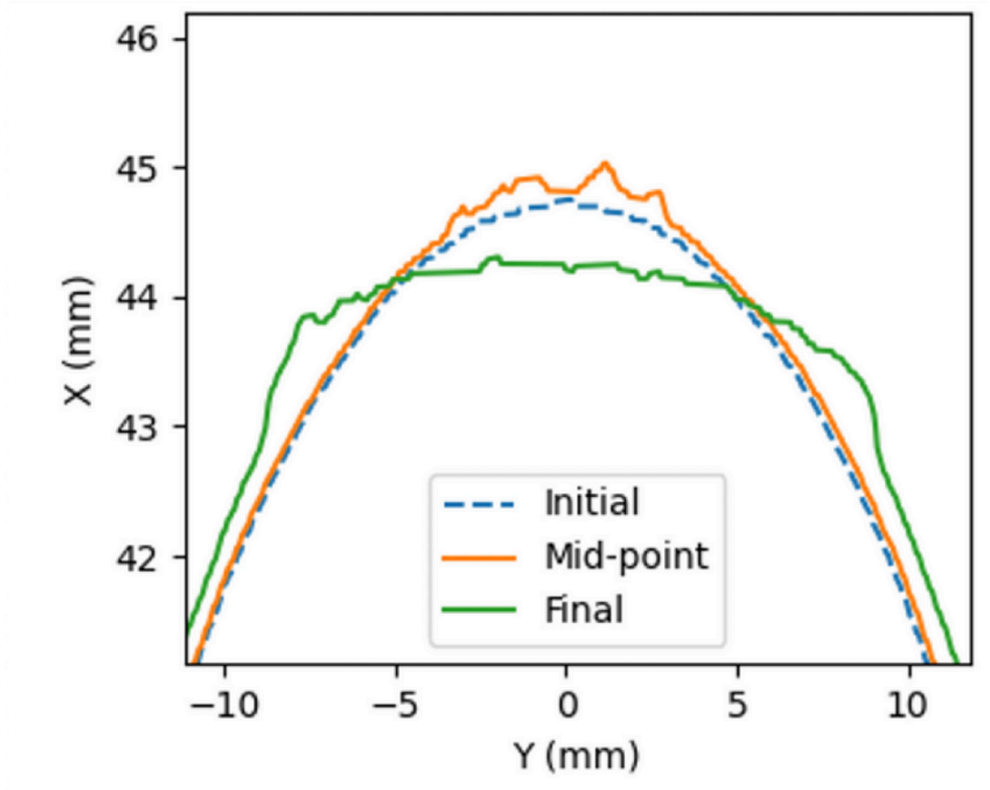
→ Pyrolysis gas pressure is changing

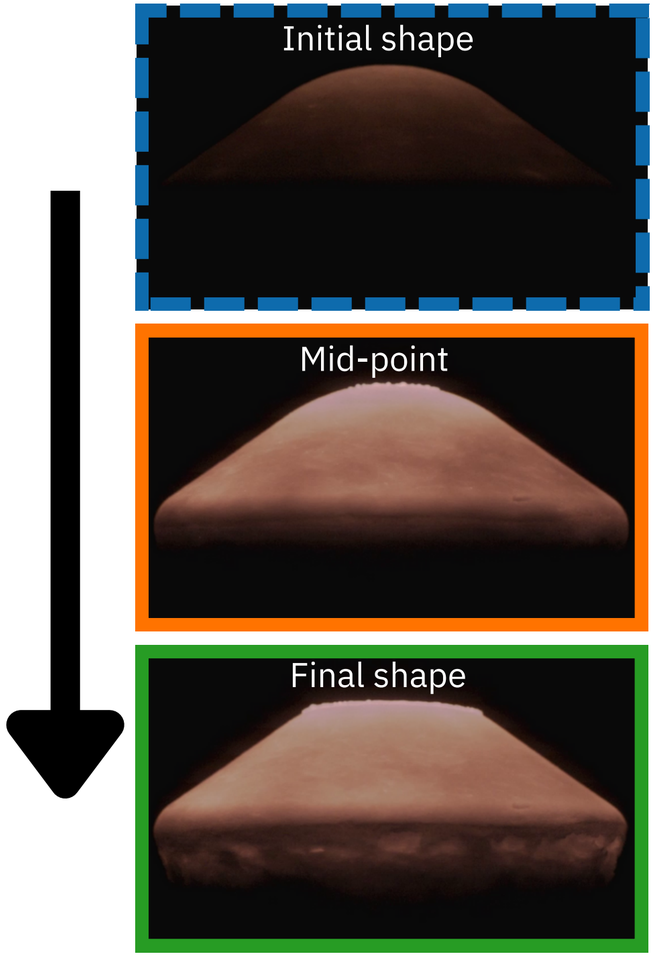




arcjetCV: Observations

3. Shape change





- Surface develops millimeter scale ripples/bubbles

- Sample deforms/flattens at the nose.
- The entire sample is expanding (e.g. negative recession at the edges).

7. Future Work

1. Integrated Physical Reference Markers

- Add fixed visual markers (e.g., laser dots, sample holder markage). That can be used as a reference for the recession.

➜ Improve robustness to camera shifts.

2. Integrate a Kalman Filter for Resolution Improvement

- Tracks edge motion smoothly across video frames.
- Reduces noise and small fluctuations in edge detection.
- Helps get cleaner, more precise results — even if the video is noisy.

7. Future Work

3. 3D arcjetCV Using Photogrammetry

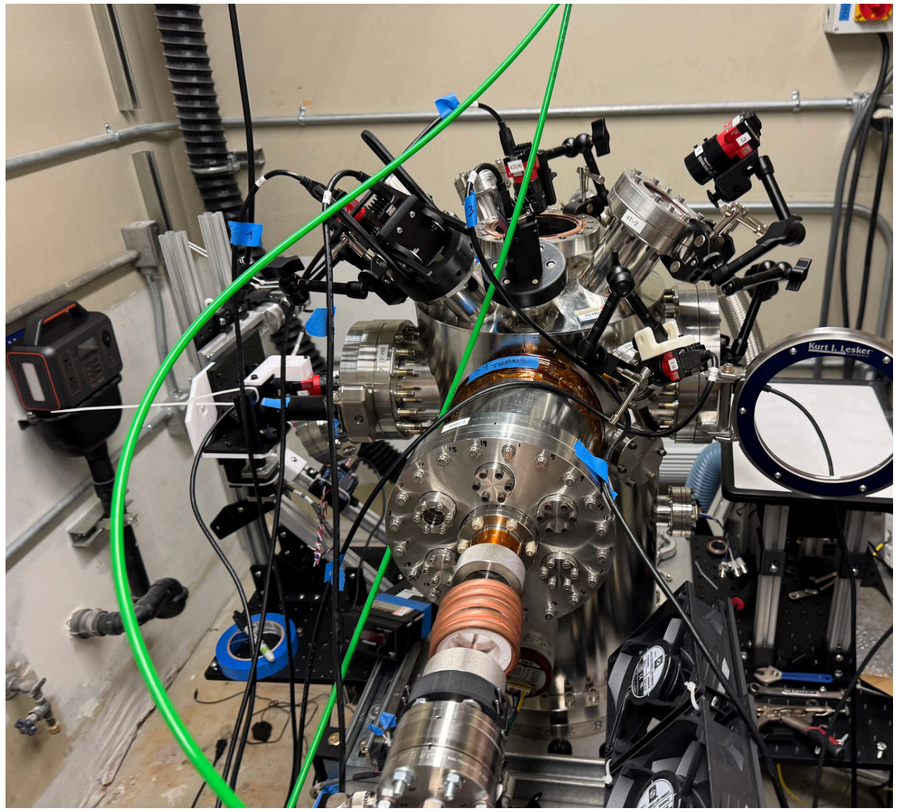
STARscan

arcjetCV

3D Scan of sample **before/after** test

2D recession analysis **during** test

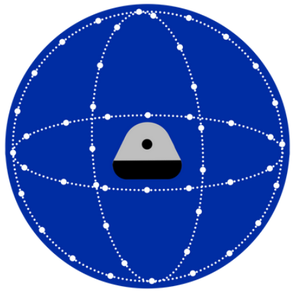
3D Reconstruction **during** test



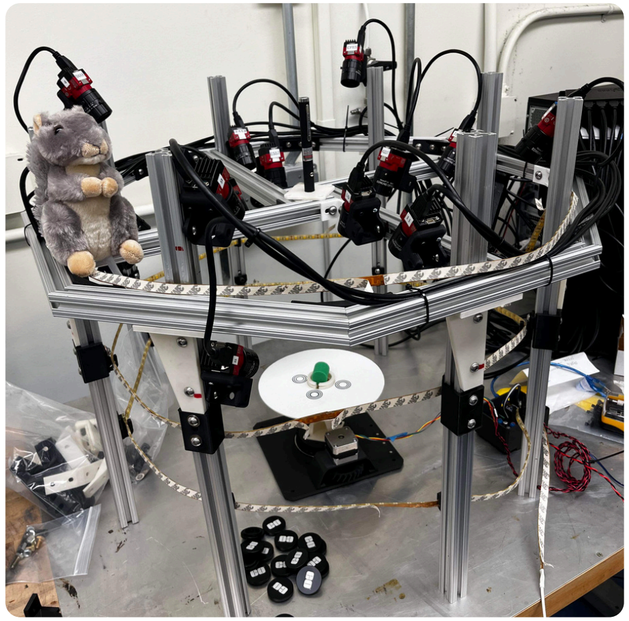
Inspired by Loehle et al. (2014), who used photogrammetry for ablative surface tracking in high-enthalpy flows.

Photogrammetry scanner

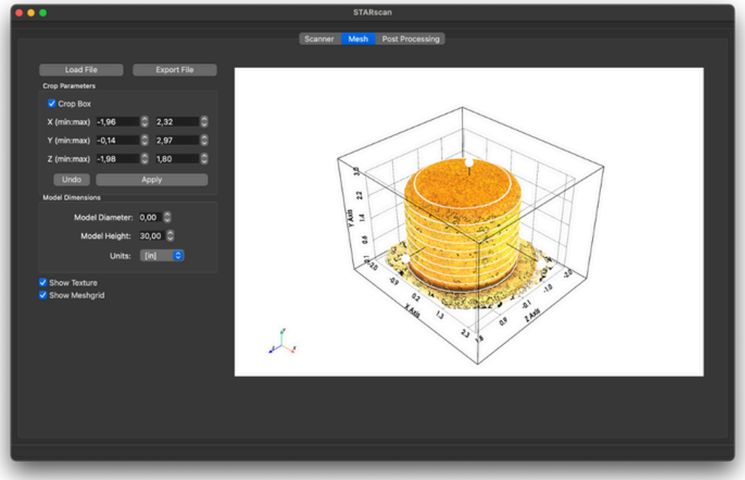
STARscan



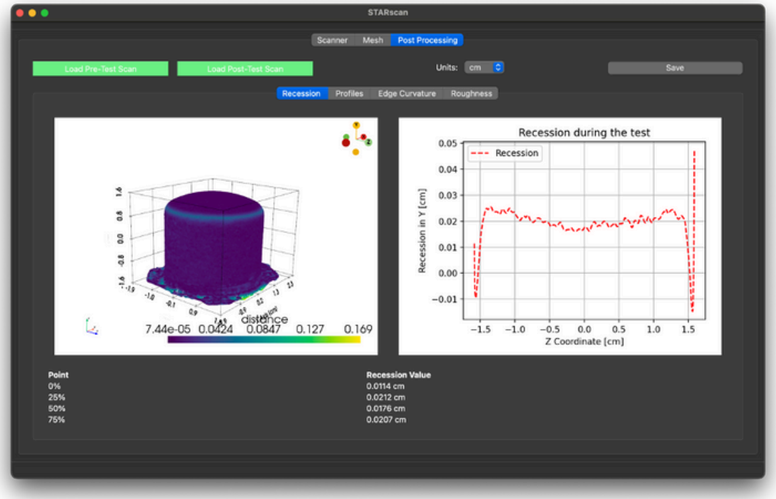
Scan sample before and after test



- 3 custom **3D scanning systems** built to accelerate and streamline scanning and analysis of arcjet test articles.
- **Software** that provides analysis of the shoulder **curvature**, **roughness** and **recession**.
- **Principle:** Photogrammetry
- **Accuracy:** ~ 0.35mm
- **Scan time:** 2 min

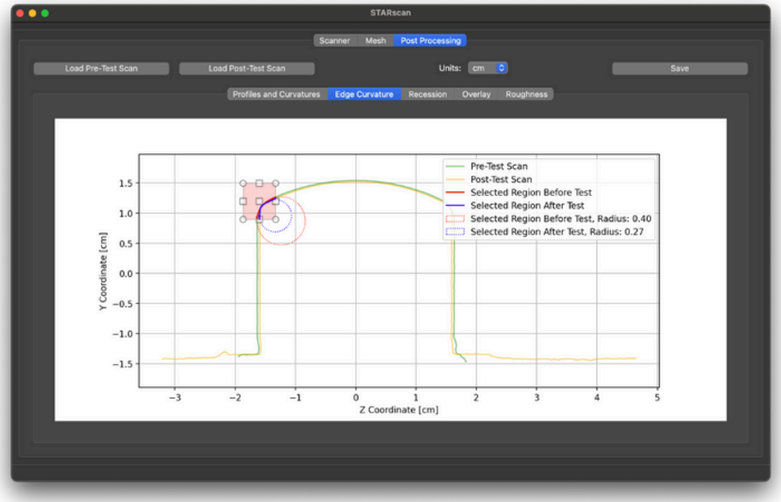


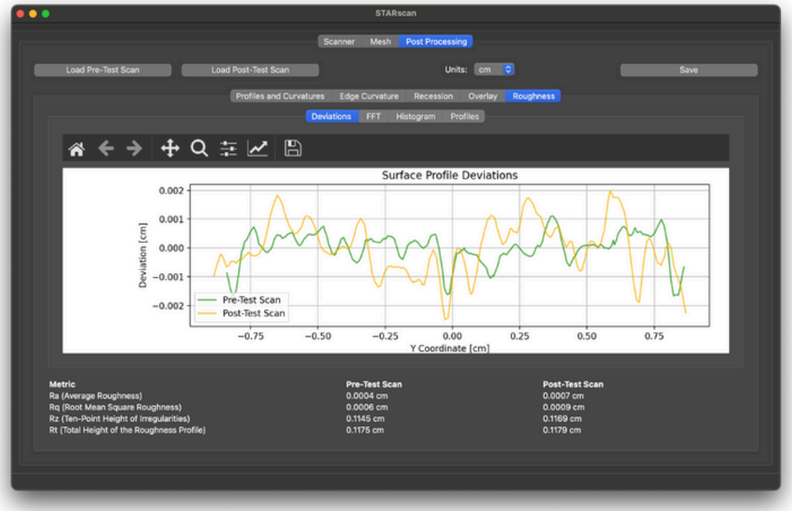
STARscan GUI



Recession

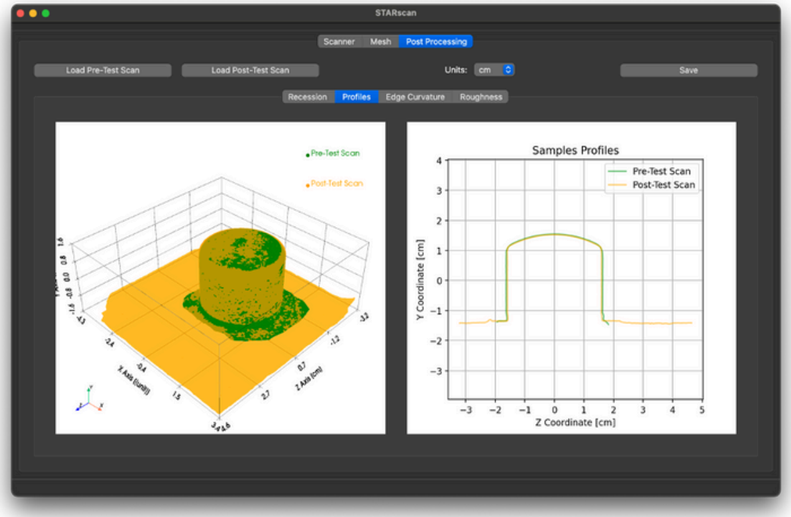
Shoulder Curvature





Roughness

Profiles



8. Conclusion

arcjetCV enables:

- Automated recession statistics.
- 2D model validation.
- Time resolved validation.

arcjetCV users :

- Ames arcjet facilities
- Orion
- MSR
- von Karman Institute

arcjetCV 1.1

- New Class
- Expanded Dataset
- New Architecture
- 3 Installation Methods
- New Calibration

→ Better mission planning and risk management.

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- TSM Branch IRAD

Thank you for your attention !

Get updates on **arcjetCV**