

# Ai-based evaluation of hybrid rocket combustion tests

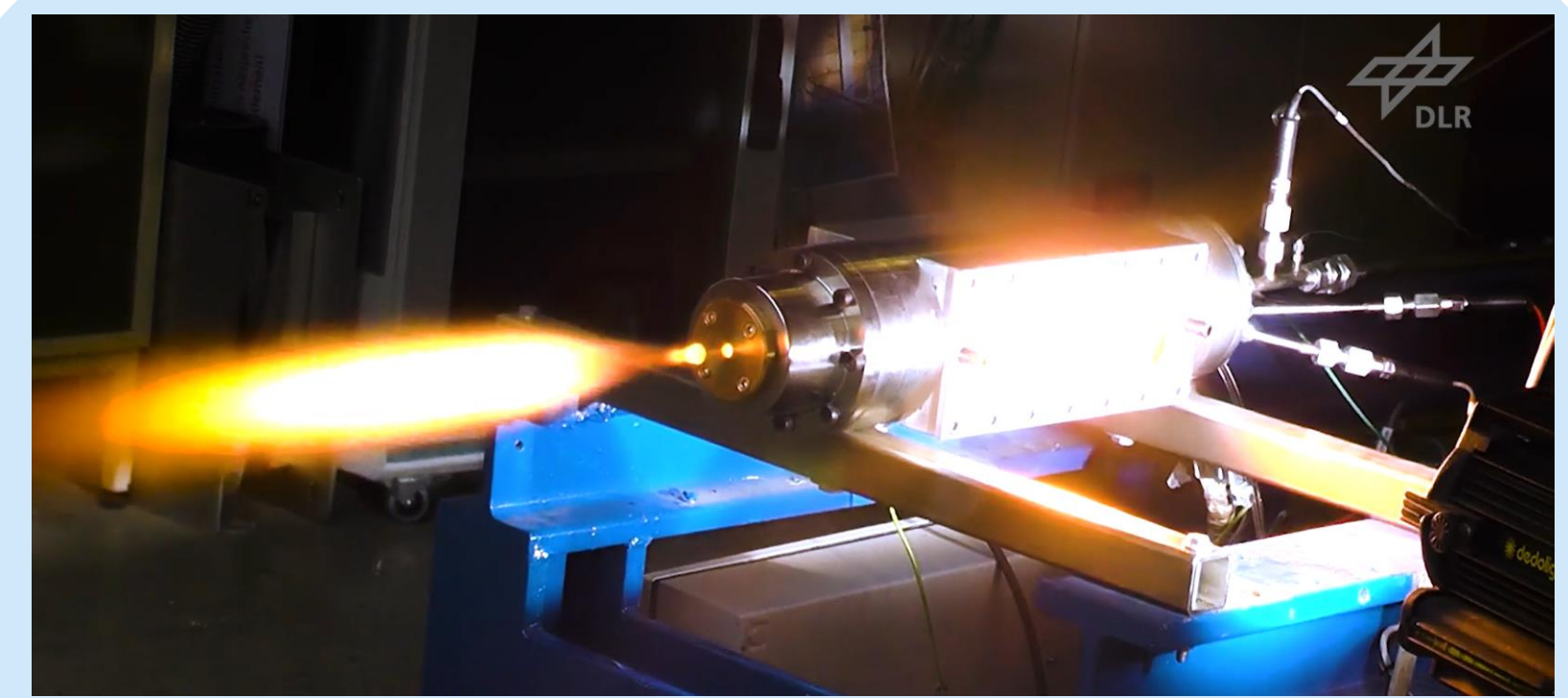
## Hybrid rocket engines

- Use chemical reaction of liquid oxidizer and solid fuel to generate thrust.
- Potential to be safer and cheaper alternative to other forms of chemical rockets.
- The **regression rate**, i.e. rate with which the solid fuel is consumed, is an important quantity for the design of hybrid rocket engines.

### Combustion tests of hybrid rocket fuels at DLR

- Liquid oxidizer is injected into a test chamber containing a solid fuel slab.
- The chamber has an optical access through which the combustion is recorded with a **high-speed camera** at 10 000 frames / second.
- Tests were performed with varying oxidizer mass flow rates and geometries/compositions of the fuel slab.

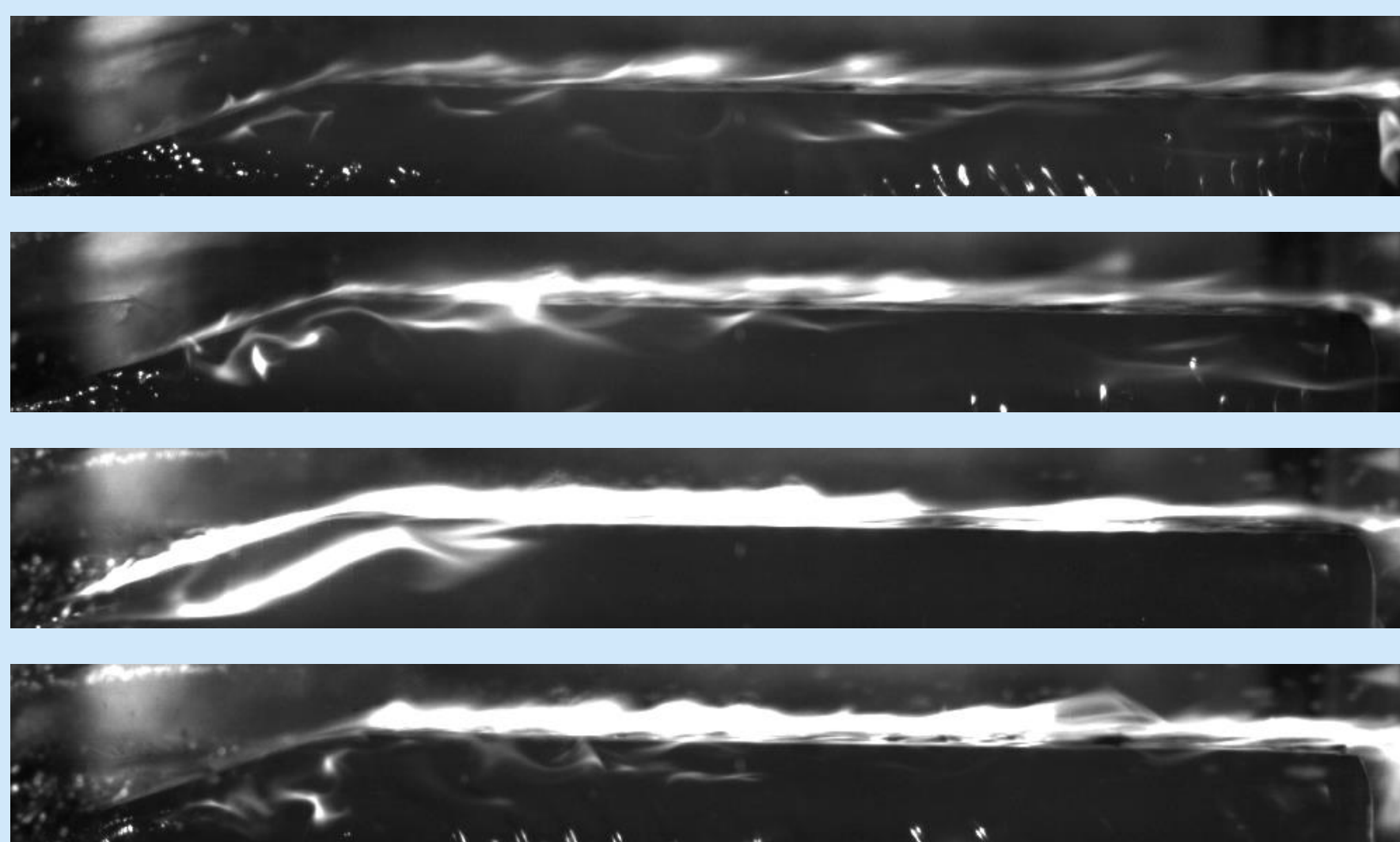
**Research question: How do you determine the regression rate from the high-speed video?**



Combustion Chamber with optical access



Fuel slab before and after combustion



Example frames from one test

## General approach

1. Detect height of the fuel slab in each frame.
2. Compute the rate of change of this height.

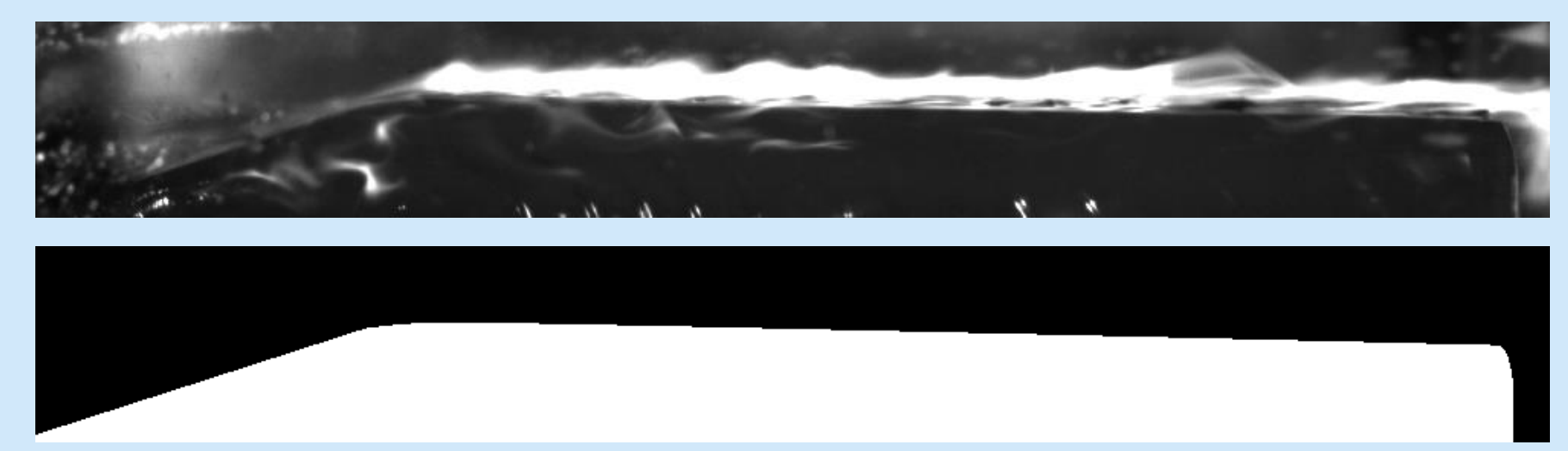
### Challenges:

- Soot, melted fuel or reflections on the access window.
- Flames at the side of the slab.
- Heuristics may fail for unforeseen flow behaviors.

**Methods for detecting the height of the fuel with edge detection or thresholding can not reliably deal with these obstructions.**

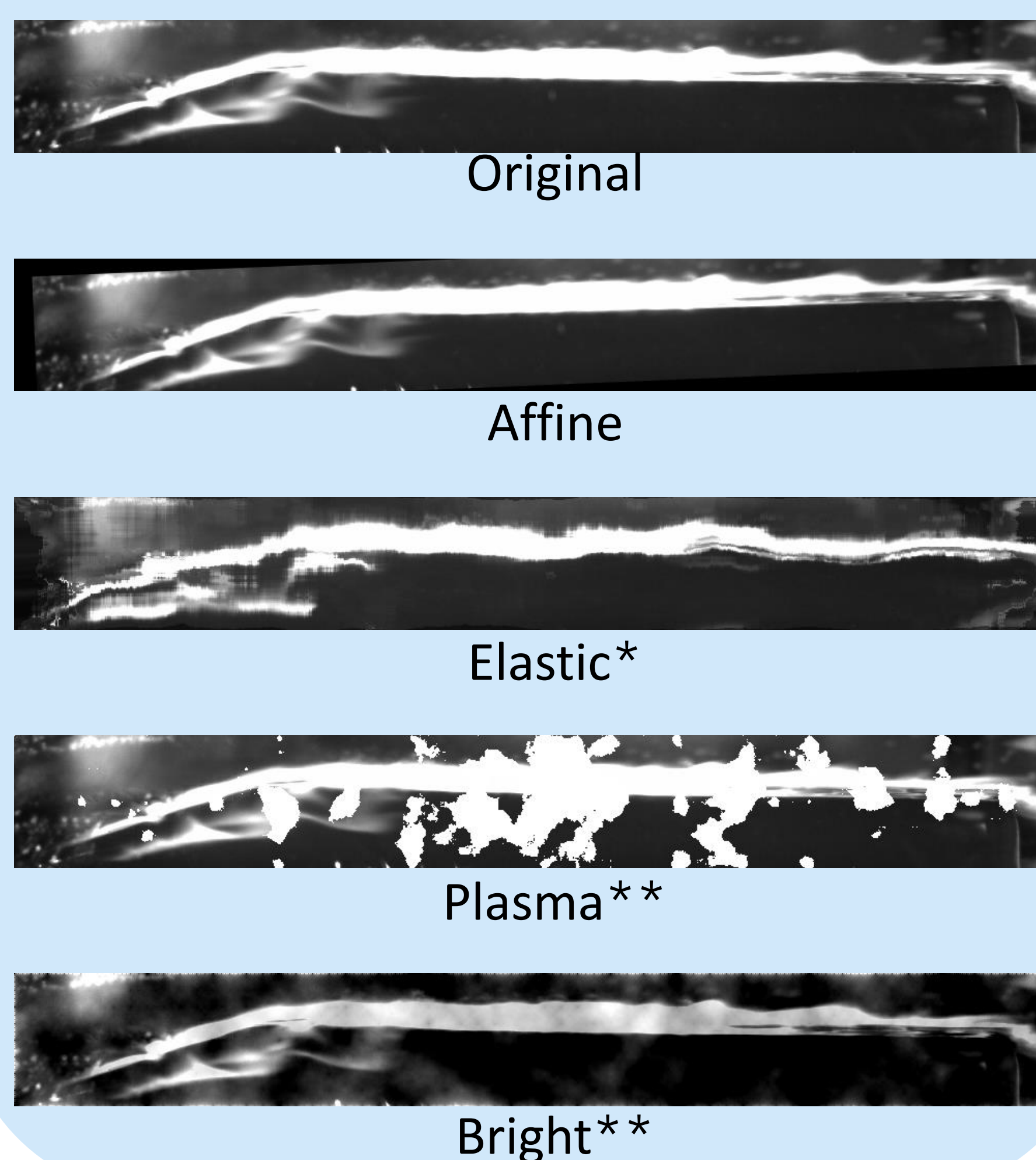
## ML approach

1. Manually segment the shape of the fuel for some examples.
2. Train a neural network on these examples.
3. Evaluate the trained network on the entire video.
4. Compute height and regression rate from the resulting binary masks.



Example frame with manual segmentation

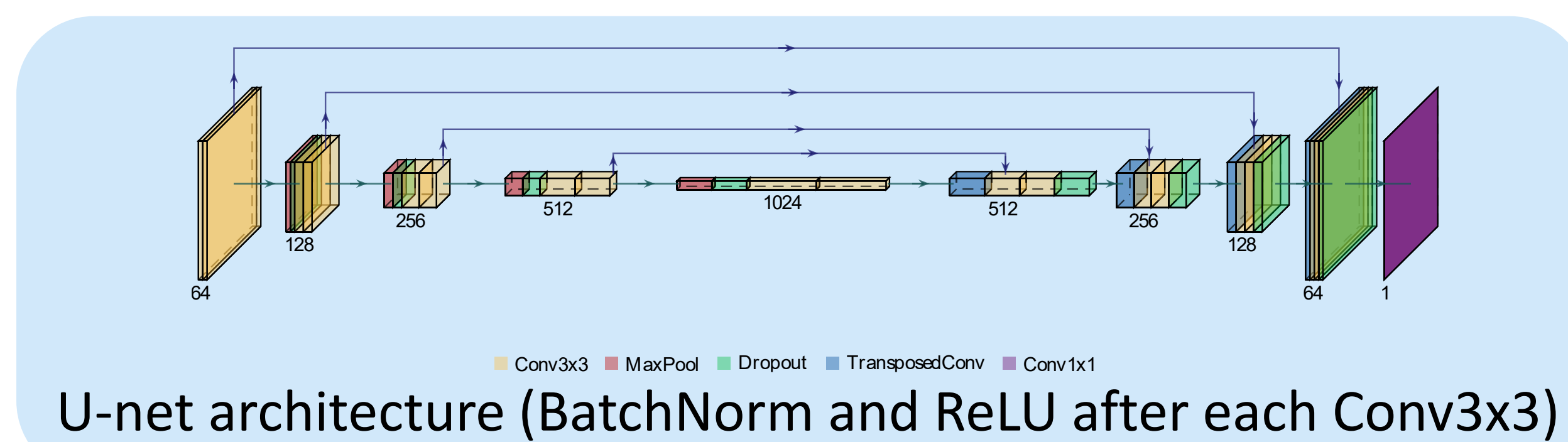
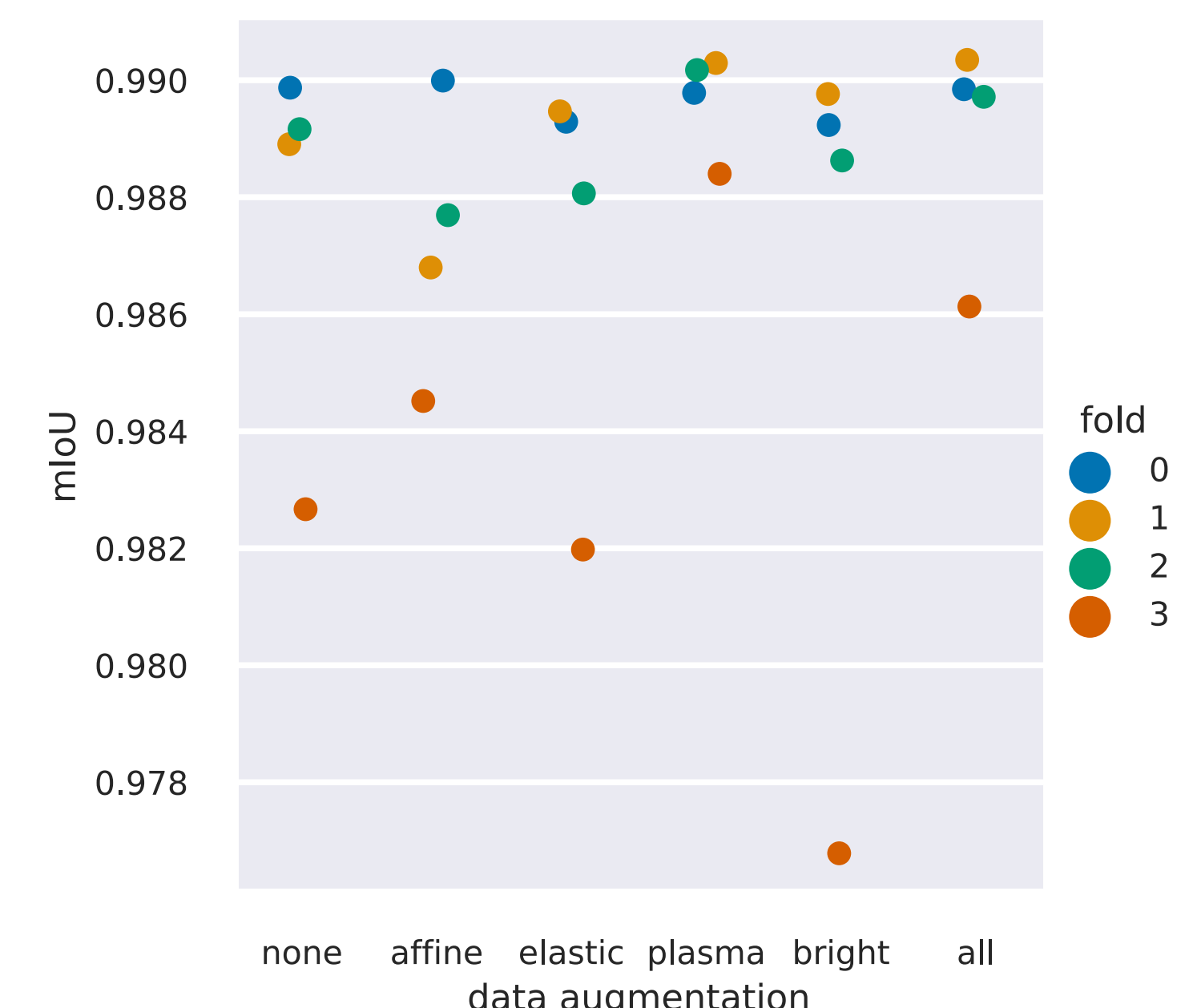
### Data Augmentation:



\* Simard et al, "Best practices for convolutional neural networks applied to visual document analysis", 2003, doi: 10.1109/ICDAR.2003.1227801.  
 \*\* Nicolaou et al, "TorMentor: Deterministic dynamic-path, data augmentations with fractals", 2022, doi: 10.1109/CVPRW56347.2022.00305.

## Training

- 176 masks created manually for one combustion test.
- U-net architecture (with Dropout and BatchNorm) implemented in Pytorch.
- 4-fold cross validation to test different data augmentations.



## Testing

- Use 3 different combustion tests as testing data.
- 110 manually segmented frames per test.

