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# Unsteady and Stochastic Behavior of Kerosene Concentration in Crossflow

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# Outline

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## □ Introduction

## □ Test

- Test system and principles
- Operating conditions

## □ Results and Discussion

- Unsteady characteristics of kerosene concentration
- Stochastic behavior of kerosene concentration

## □ Conclusions



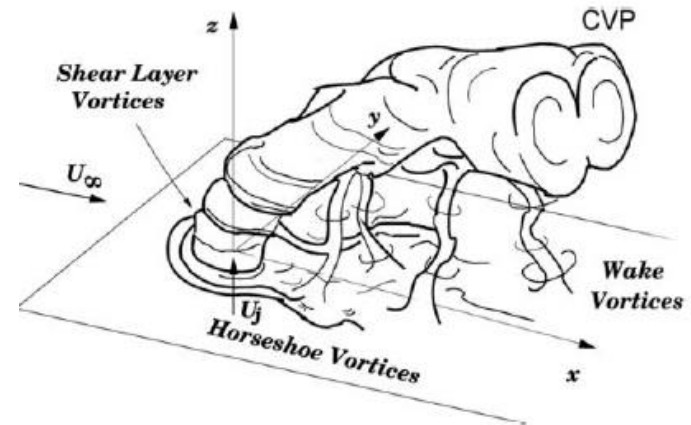
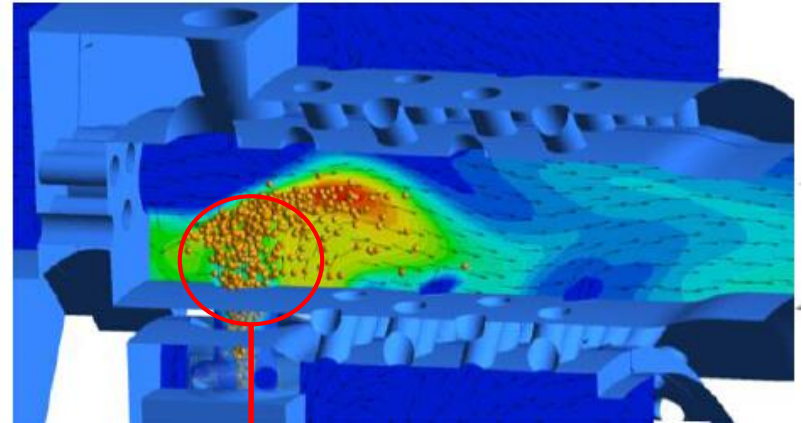
# Introduction

## Background

With the **LPP** combustion technology progress, the direct injection nozzle is used to directly inject kerosene into the premixed channel to achieve the mixture of fuel and air.

- the characteristics of the fuel concentration in crossflow play a decisive role in the full and efficient combustion of kerosene;
- its unsteady characteristics also determine the combustion stability.

The kerosene concentration in crossflow has been the focus of research in the field of aviation.



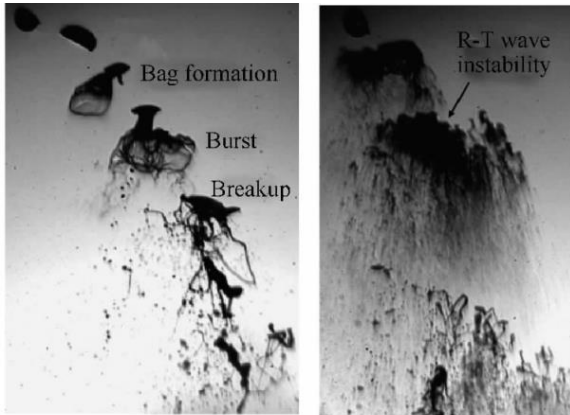


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# Introduction

## Research Status

### Atomization Mechanism



(a) Bag breakup

(b) Shear breakup

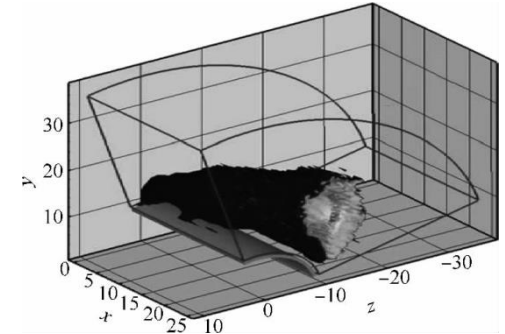
- Initial breakup and secondary breakup
- The high speed camera

### Penetration Depth



- Image processing and correlations of jet penetration trajectory;
- The high speed camera, PDPA and PLIF

### Spray Distribution



- Spray spatial distribution
- The high speed camera, PDPA and PLIF



# Introduction

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- the breakup mechanism of liquid column: the jet in crossflow is obviously **unsteady**;
- the concentration of spray: **the time averaged method** is often used;
- the existence of unsteady characteristics: the distribution of spray; concentration may exhibit **stochastic**.

*In this paper:*

the high-frequency, high-precision liquid control device and the high-speed camera shadow method:

- study the unsteady characteristics of kerosene concentration in crossflow;
- to verify whether there is a stochastic behavior through statistical experimental means;



# Test

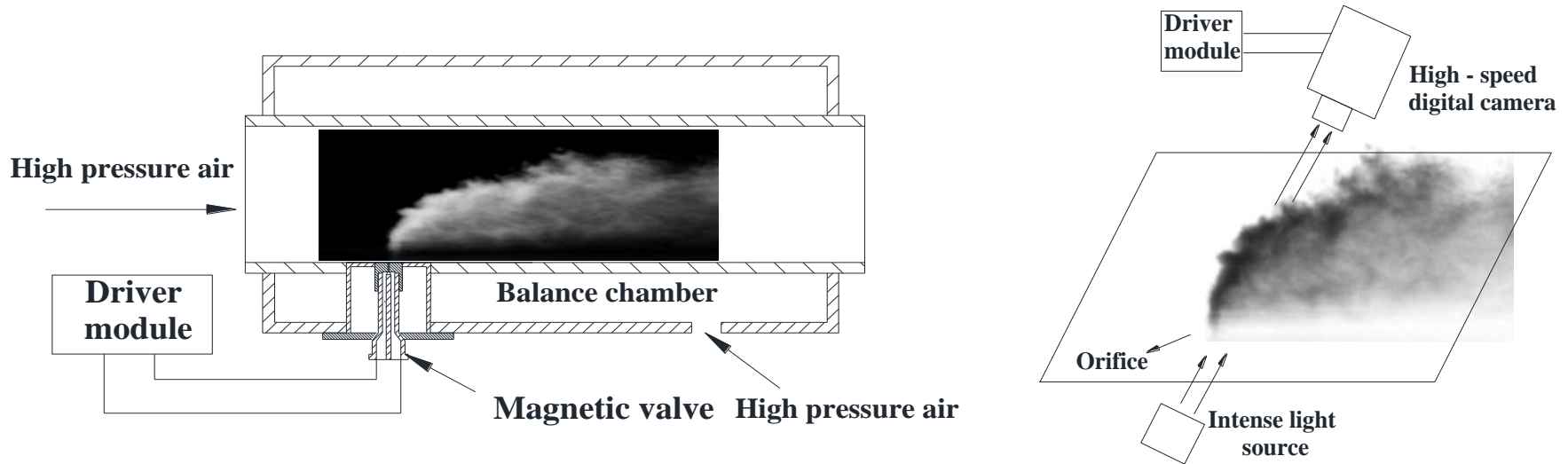
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- ◆ The unsteady characteristics: a certain physical quantity changes with time.
- ◆ The stochastic behavior: a certain physical quantity changes in repetitive experiments.
- ◆ Two characteristics: **High precision time resolution and Repeatability.**



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# Test system and principles



- A high-frequency, high-precision liquid injection control device;
    - the nozzle, solenoid valve and drive module
    - the time accuracy can be controlled within **0.1ms**
  - The high speed camera: the X-stream V ISIONXS-3 manufactured;
  - A strong light source: 300W tungsten halogen lamp;
- The exposure time ranges from 10 to 30 $\mu$ s and the acquisition frequency is 10KHZ.



# Operating conditions

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Case	P/MPa	T/K	J	We
1	1.7	300	55	258
2	1.7	300	72	258

✓ **The unsteady characteristics:** the fuel is injected continuously for 20ms

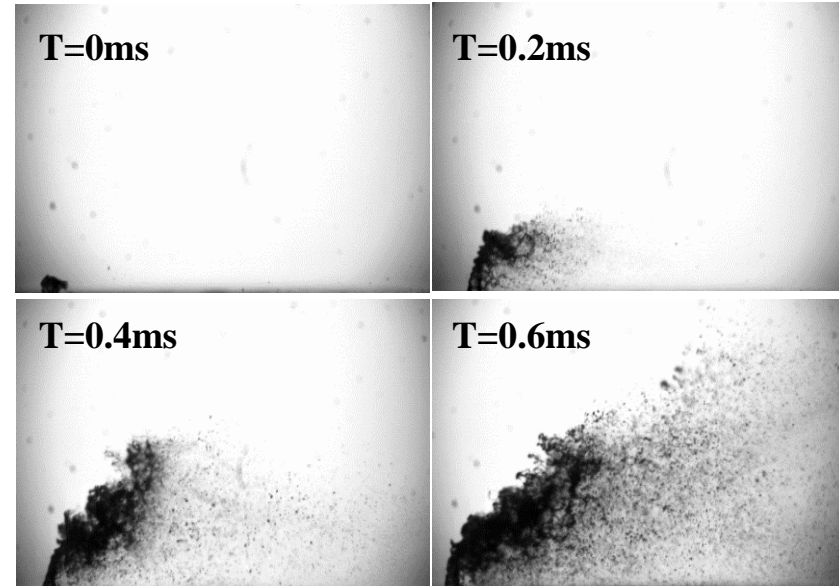
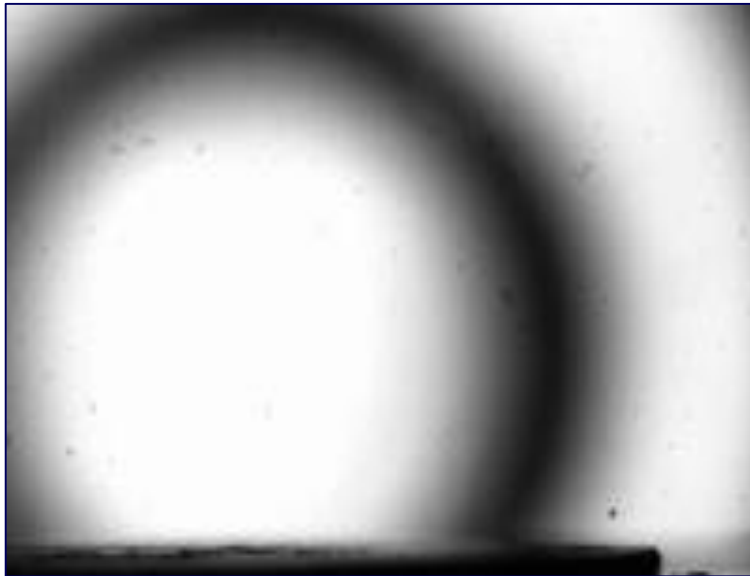
✓ **The stochastic behavior :** 100 experiments are carried out in the same operating conditions





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# Unsteady characteristics

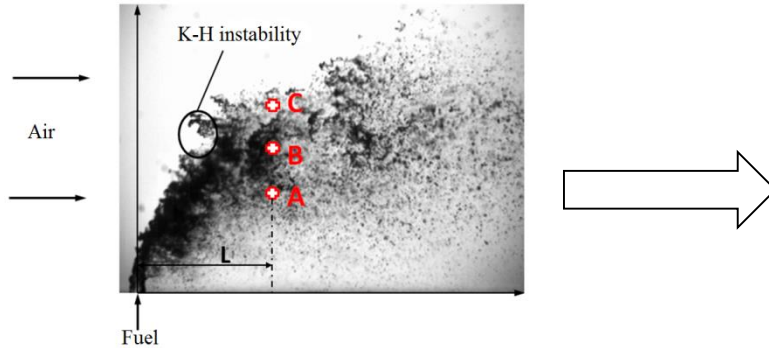


- The whole process from the spray begins injection into the test section to fill up the entire oil spray test area;
- the spray covers the test area after 0.6ms.

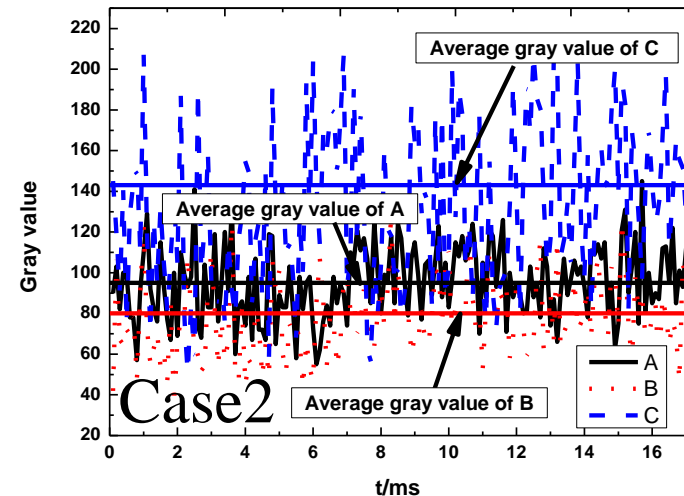
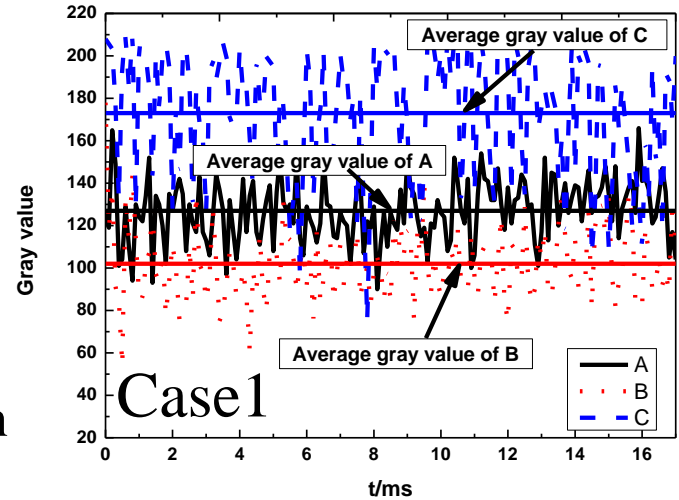


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# Unsteady characteristics



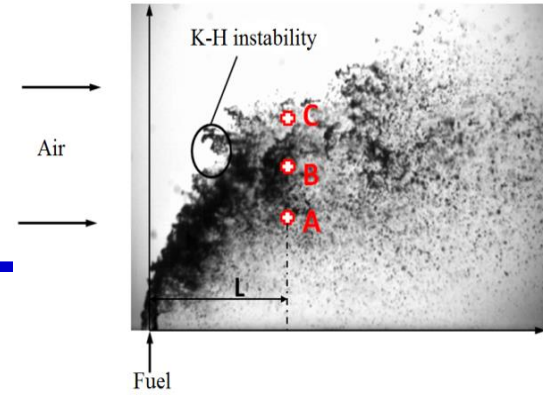
- with the change of time, the concentration distribution of the spray is **unsteady**;
- the maximum concentration is in the center of spray, and the concentration at the inner edge of the spray is greater than that at the outer edge;
- the concentration of spray increases with the momentum ratio;
- the uniformity of the spray will be better with the momentum ratio increasing.



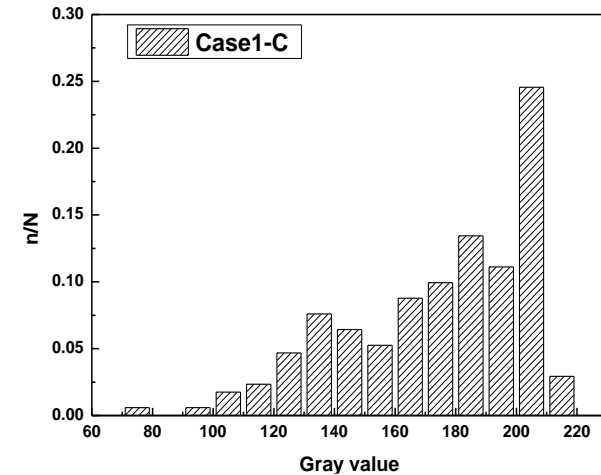
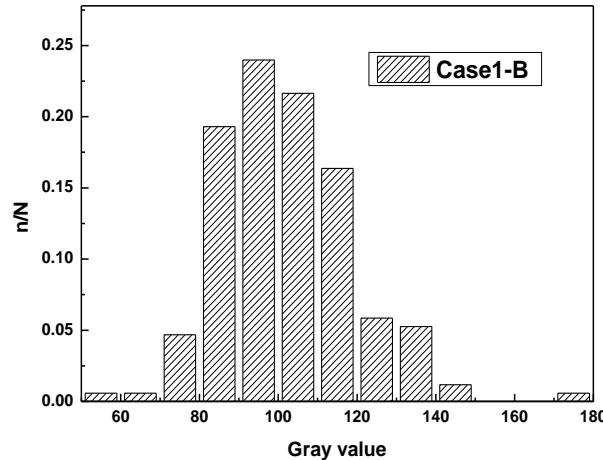
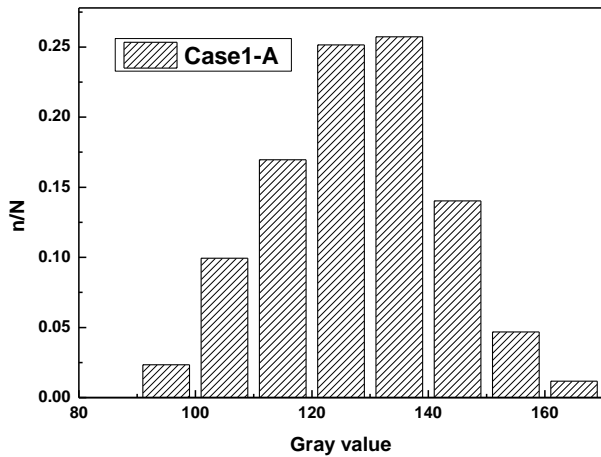


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# Unsteady characteristics



The PDF of the gray value:



- the gray values distribution of point A and B all approximately satisfies **Gaussian distribution**;
- the unsteady characteristics at the outer edge of the spray is more obvious



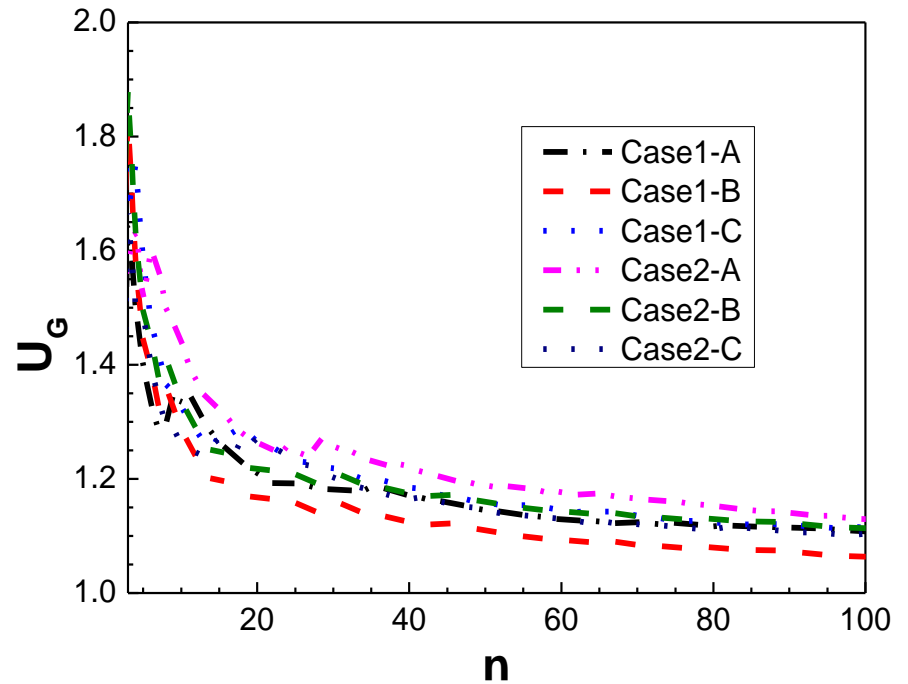
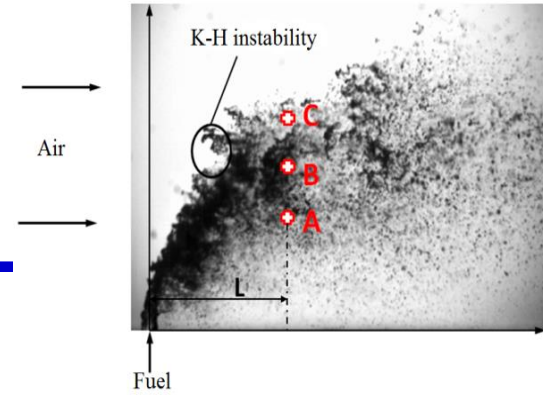
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# Stochastic behavior

□ In order to study the stochastic behavior, a statistical method is used to make multiple measurements of the same parameter under the same conditions.

□ 100 experiments are carried out in the same operating conditions.

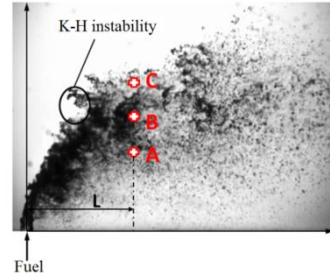
$$U_G(n) = \sqrt{\frac{\sum_{i=1}^n (\bar{G} - G)^2}{n(n-1)}}$$





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# Stochastic behavior

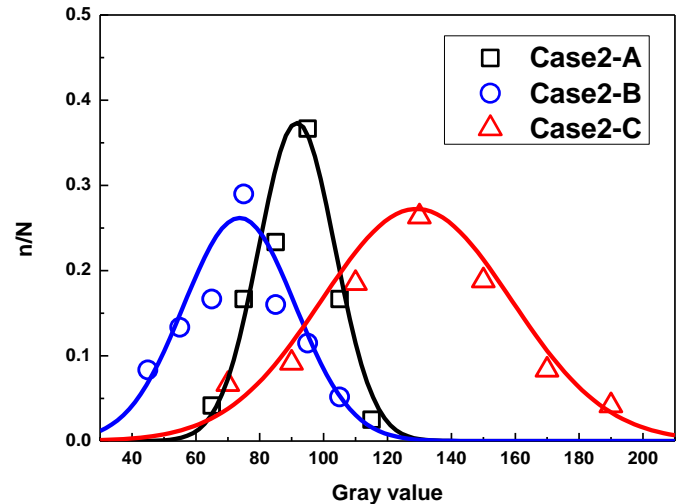
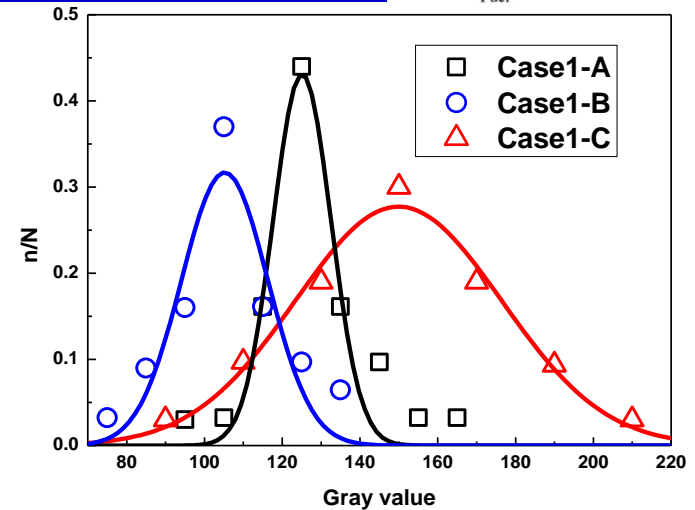


➤ the gray values at the same time and location are **different** in repeatability experiments **under the same operating conditions**;

➤ the probability distributions of gray values at point A, B and C in both case1 and case2 are fitted, and it is found that they all approximately satisfy Gaussian distribution;

➤ the spray concentration at the outer edge shows stronger stochastic behavior;

➤ with the increase of momentum ratio, the stochastic behavior of spray concentration distribution in crossflow is more obvious.





# Conclusions

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- In the time domain, the kerosene concentration in crossflow exhibits obvious **unsteady characteristics**. The unsteady characteristics will be more obvious with the increase of momentum ratio.
- The results of statistics show that the concentration distribution at the inner edge and the central trajectory of the jet conforms to **Gauss distribution**. The unsteady characteristics at the outer edge of the spray are more obvious.
- The statistical results of repeated tests show that the kerosene concentration in crossflow is **stochastic**, and its probability density distribution is **Gauss distribution**.
- The stochastic behavior at the outer edge is more obvious. With the increase of momentum ratio, the stochastic behavior will become stronger.



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Thank you for listening

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