Ice Particle Impacts on a Flat Plate

Mario Vargas, Charles Ruggeri, Peter M. Struk,

Mike Pereira, Duane Revilock, Richard E. Kreeger

National Aeronautics and Space Administration

Glenn Research Center

Outline

- Background
- Objectives
- Approach
- Experiment Set-up
- Data Analysis
- Results
- Conclusions

Background

- Ice crystal impacts are fundamental to understanding ice accretion on internal engine parts
- Research efforts have been directed to study the physics of ice particles impacting on a surface
- The experiments are part of NASA efforts to study the physics involved in engine power-loss events due to ice crystal ingestion and ice accretion formation inside engines

Learning Objectives

- Learn how to conduct the experiment
  - Ice particles vs. ice crystals
  - Size of ice particles for initial tests and their fabrication
  - Delivery of the ice crystals, pressure gun
  - Optical requirements, resolution needed and how to obtain it, camera frame rates
  - Target material and positioning
  - Experimental set-up
  - Parameters to be measured

Technical Objectives

- Gain understanding of the basic impact characteristics and main qualitative features of the impact and fragmentation
- Identify main parameters that govern impact characteristics and assess their relative importance
- Determine post impact particle size distributions (histogram)
- Measure velocity of the fragment in selected cases

Approach

Why conduct Research with Simple Geometries First and with Ice Particles

Why Ice particles:

- Even if we know the type of ice crystals encountered in nature we don't want to start with them

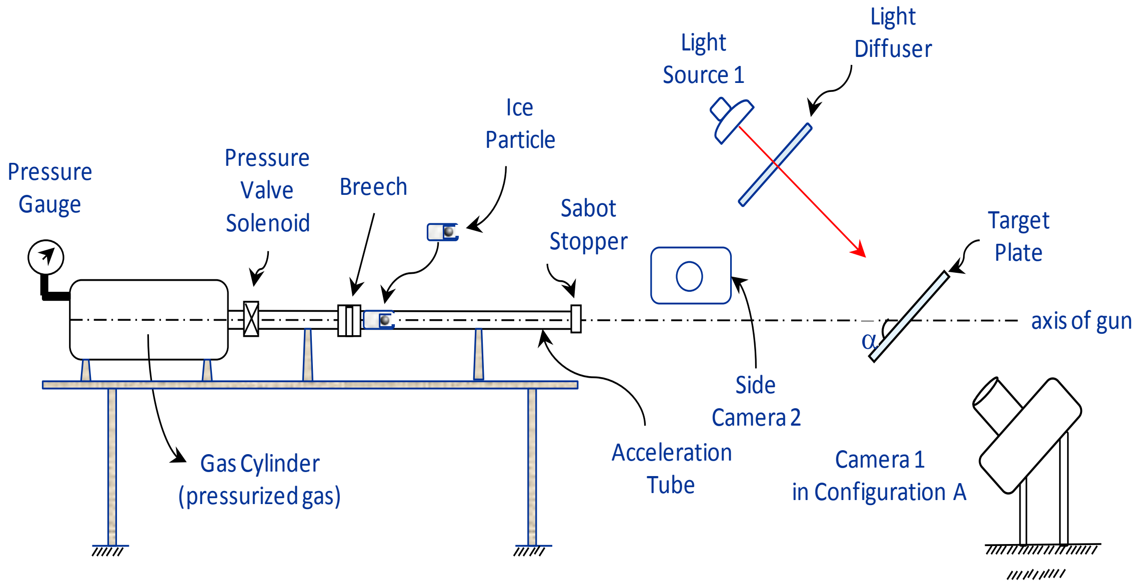
Why to work with simple geometries first:

- The nature of the impacts is very complex and dependent on air flow, fan or core element geometry and rotational speed

- We need to isolate the effects of all the variables involved; to do it we need to begin studying the characteristics of impacts on simple geometries and then move to the more complex ones

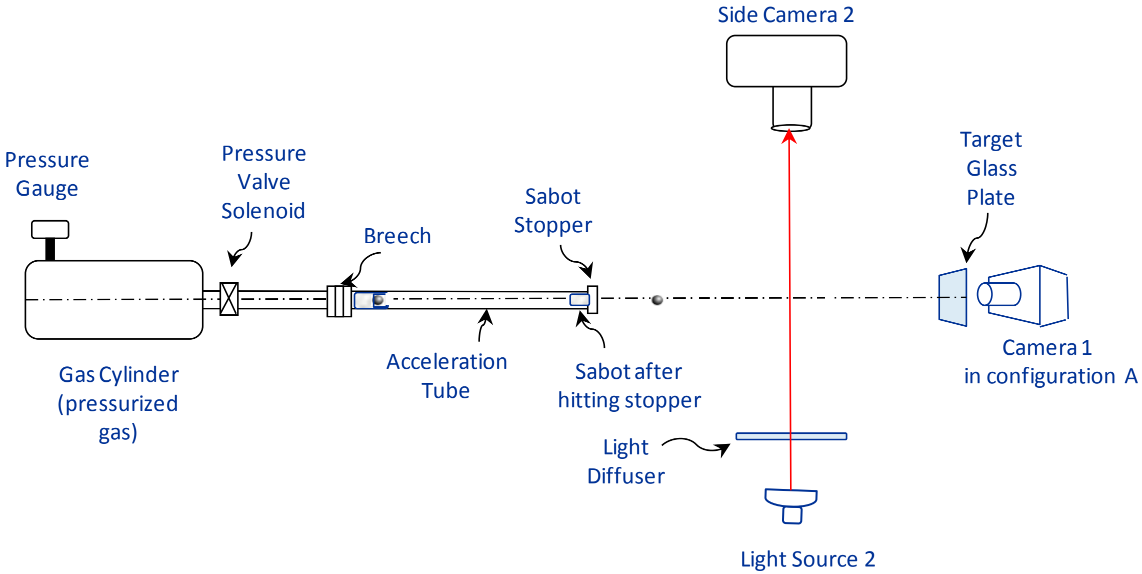
Approach

Conceptual View of Experiment – Side View



Approach

Conceptual View of Experiment – View from above



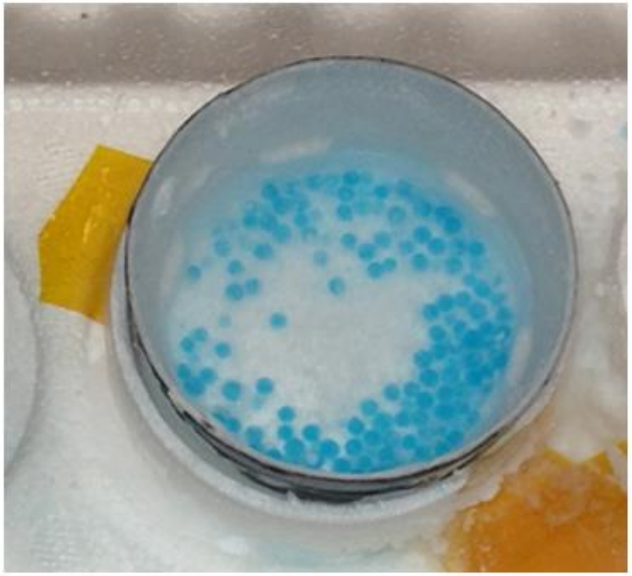
Approach

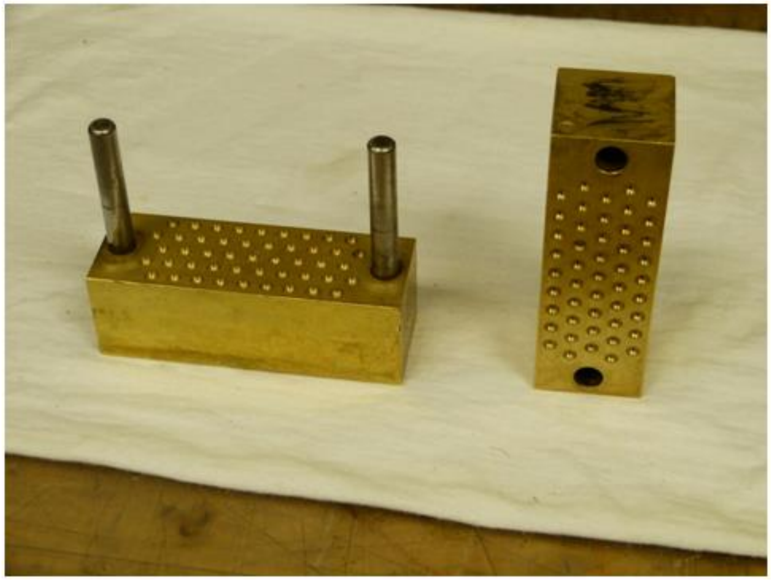
Camera Configurations

- Configuration A: camera below the target
  - Shimadzu HyperVision HPV-X, set to record at 1,000,000 frames per second
  - Photron FASTCAM SA-Z camera placed below the target, operated at 50,000 frames per second
- Configuration B: camera above the target
  - Allied Vision Prosilica GX6600 29 Megapixel camera
- Side Camera was used for both configurations
  - Photron SA-Z high speed digital camera at a frame rate of 62,500 frames per second

Experimental Setup

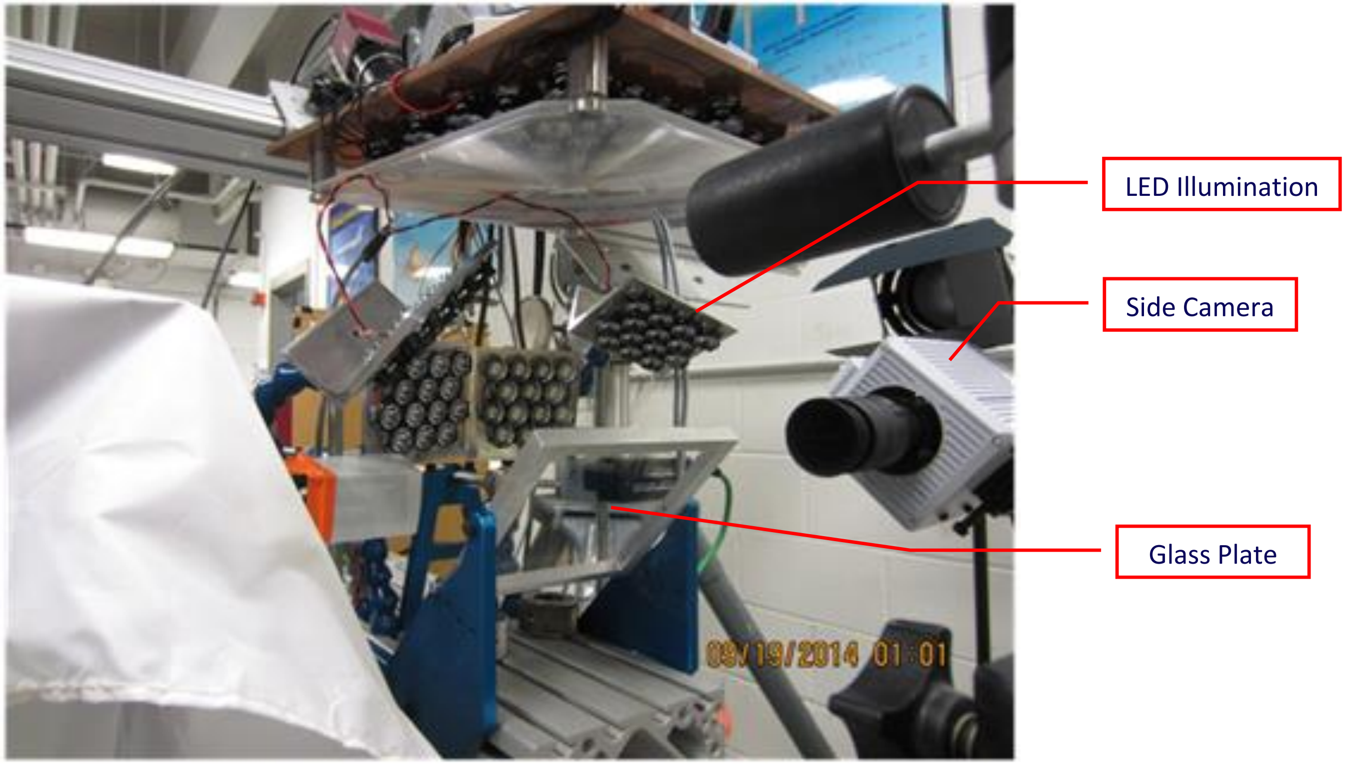
Experimental Setup
Fabrication of Ice Particles





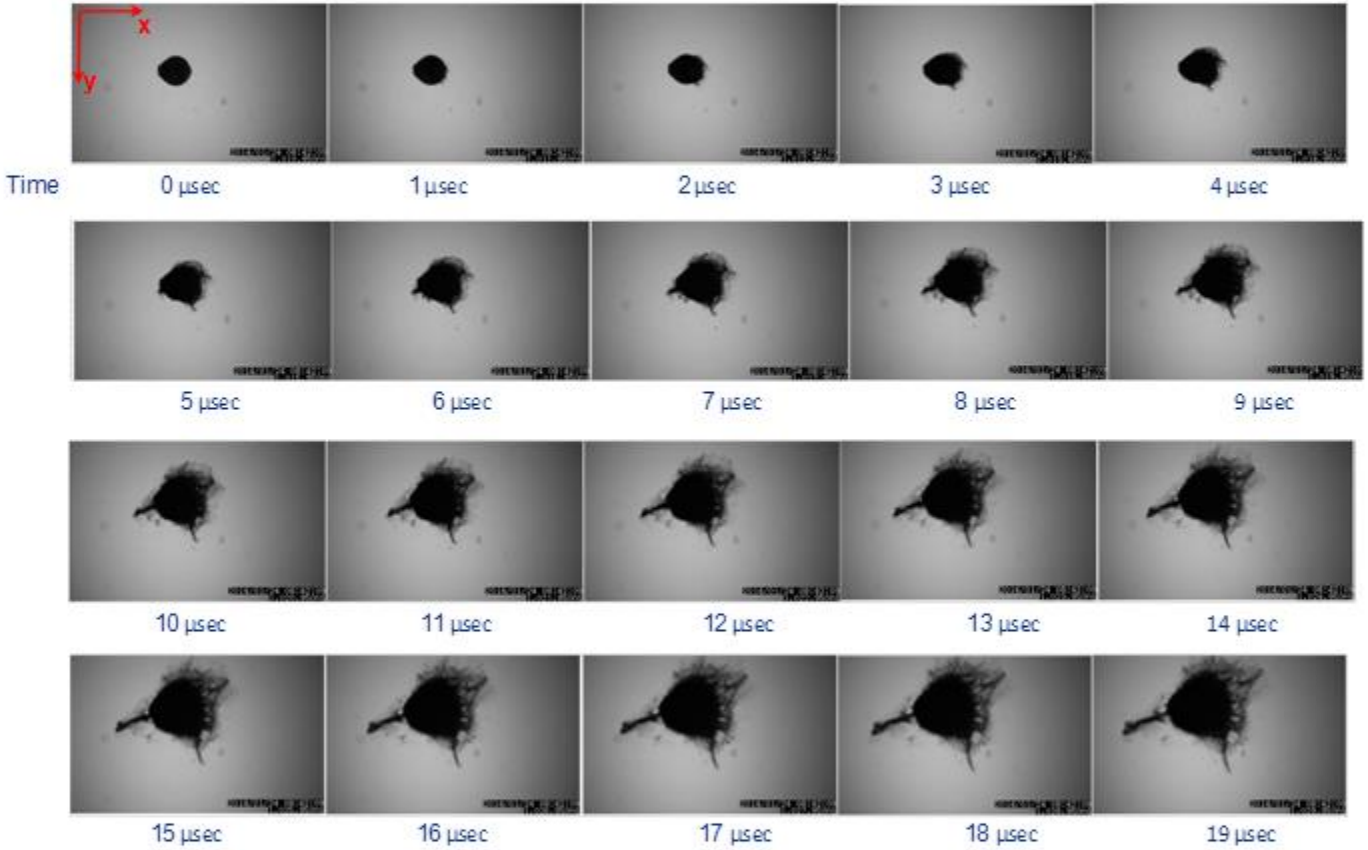
Experimental Setup
Target and Laser Triggering

Experimental Setup
Target, LED Illumination, Side Camera



RESULTS
Configuration A -Shimadzu HyperVision HPV-X

Particle Diameter = 4.6 mm, Velocity 163 m/sec, frame rate = 1,000,000 fps

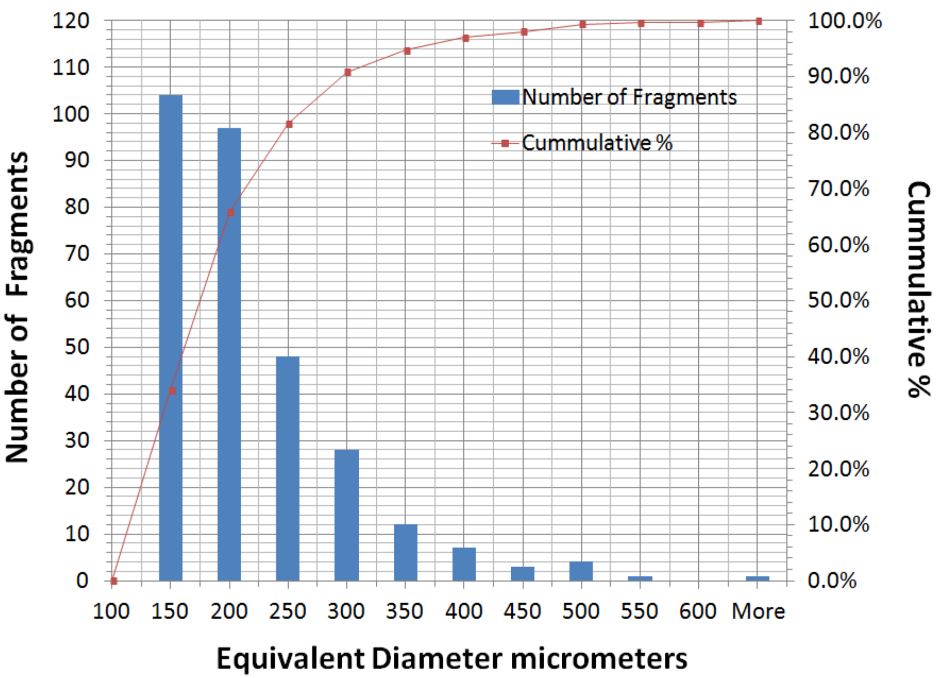


RESULTS
Configuration A -Shimadzu HyperVision HPV-X

Particle Diameter = 4.6 mm, Velocity 163 m/sec, frame rate = 1,000,000 fps

Mean Equivalent Diameter = 190 micrometers

Median Equivalent Diameter = 157 micrometers

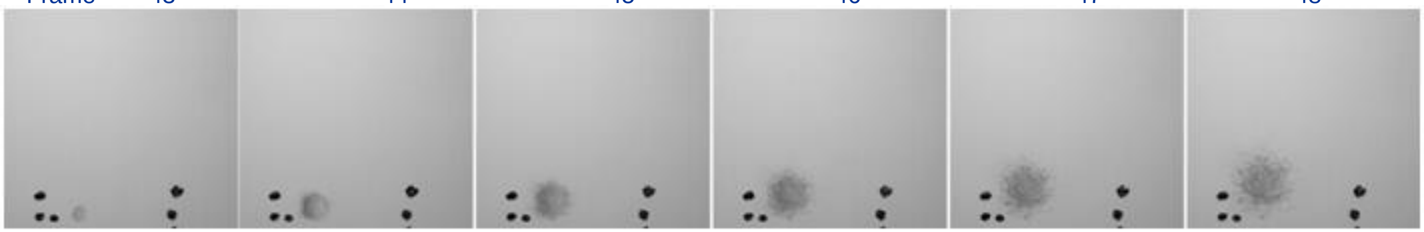


RESULTS
Configuration A –Photron FASTCAM SA-Z

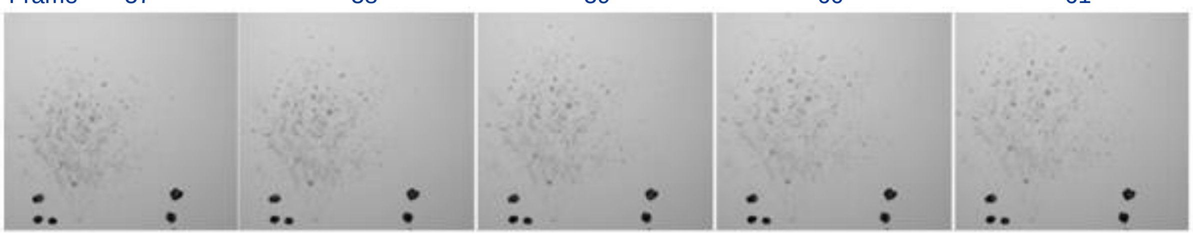
Particle Diameter = 3.2 mm, Velocity 99.5 m/sec, frame rate = 50,000 fps

Camera FOV= 46.7x43.8mm, Resolution 73.2 μm/pixel

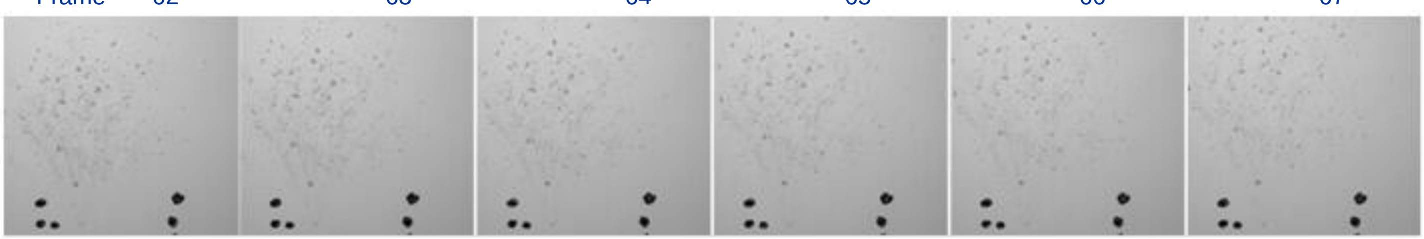
t = μsec	840	860	880	900	920	940
Frame	43	44	45	46	47	48



t = μsec	1120	1140	1160	1180	1200
Frame	57	58	59	60	61

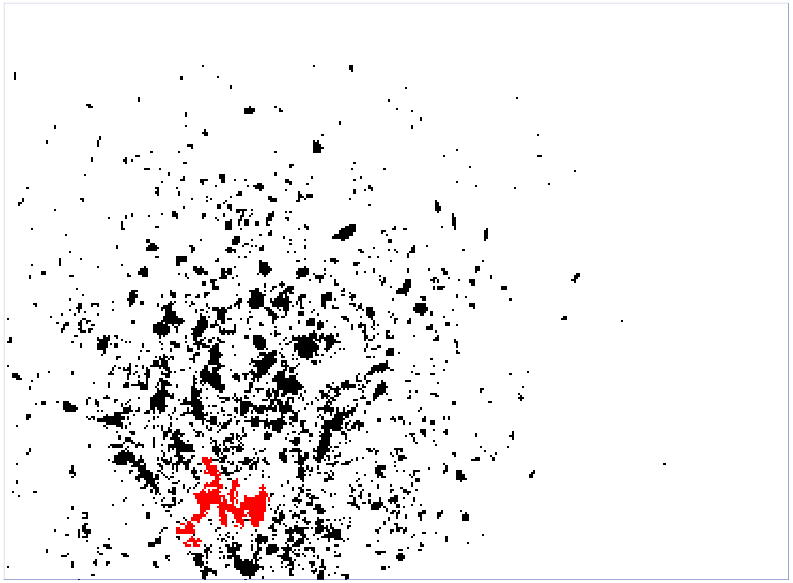


t = μsec	1220	1240	1260	1280	1300	1320
Frame	62	63	64	65	66	67



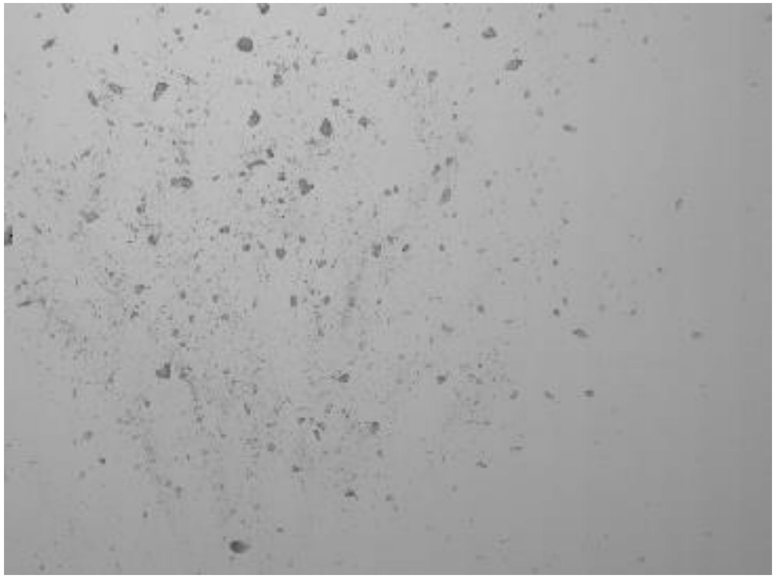
RESULTS
Configuration A -Photron FASTCAM SA-Z
Frame Rate = 50,000 fps

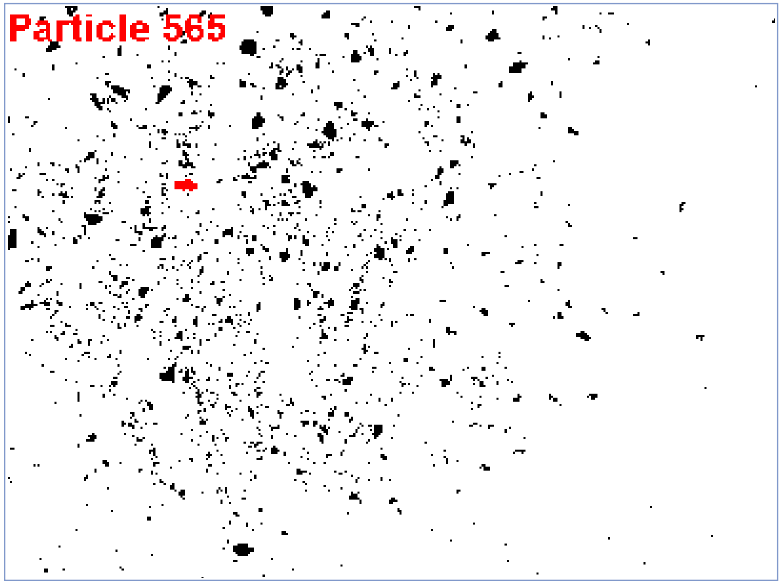
. Fragments 280 microseconds after impact , frame 57, Res 73.2 μm/pixel



RESULTS
Configuration A -Photron FASTCAM SA-Z
Frame Rate = 50,000 fps

. Fragments 480 microseconds after impact , frame 67, Res 73.2 μm/pixel



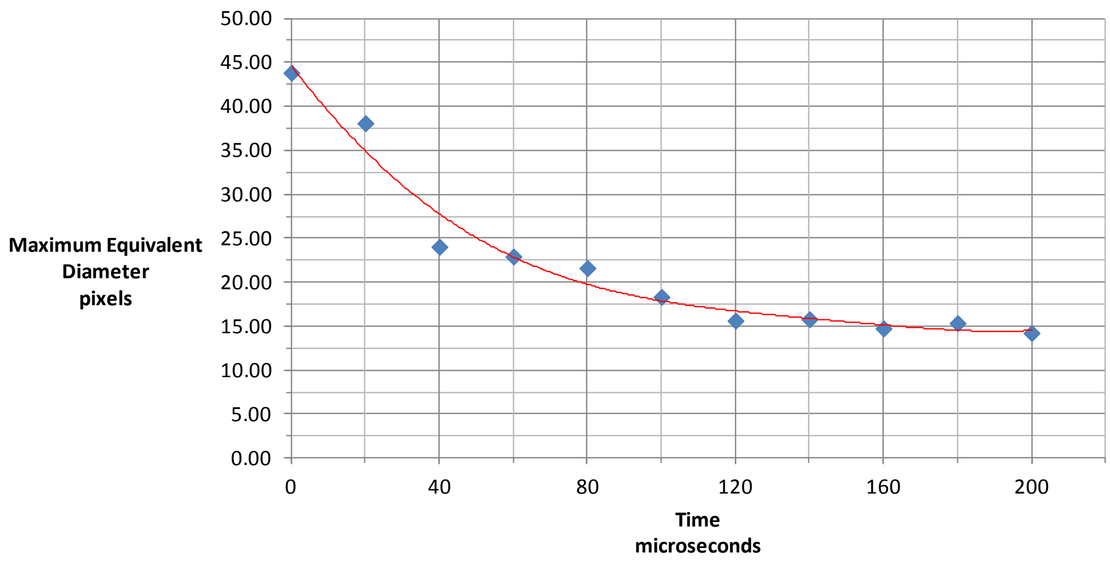


RESULTS
Configuration A -Photron FASTCAM SA-Z

Particle Diameter = 3.2 mm, Velocity 99.5 m/sec, frame rate = 50,000 fps

Maximum Equivalent Diameter for frames 57 to 67

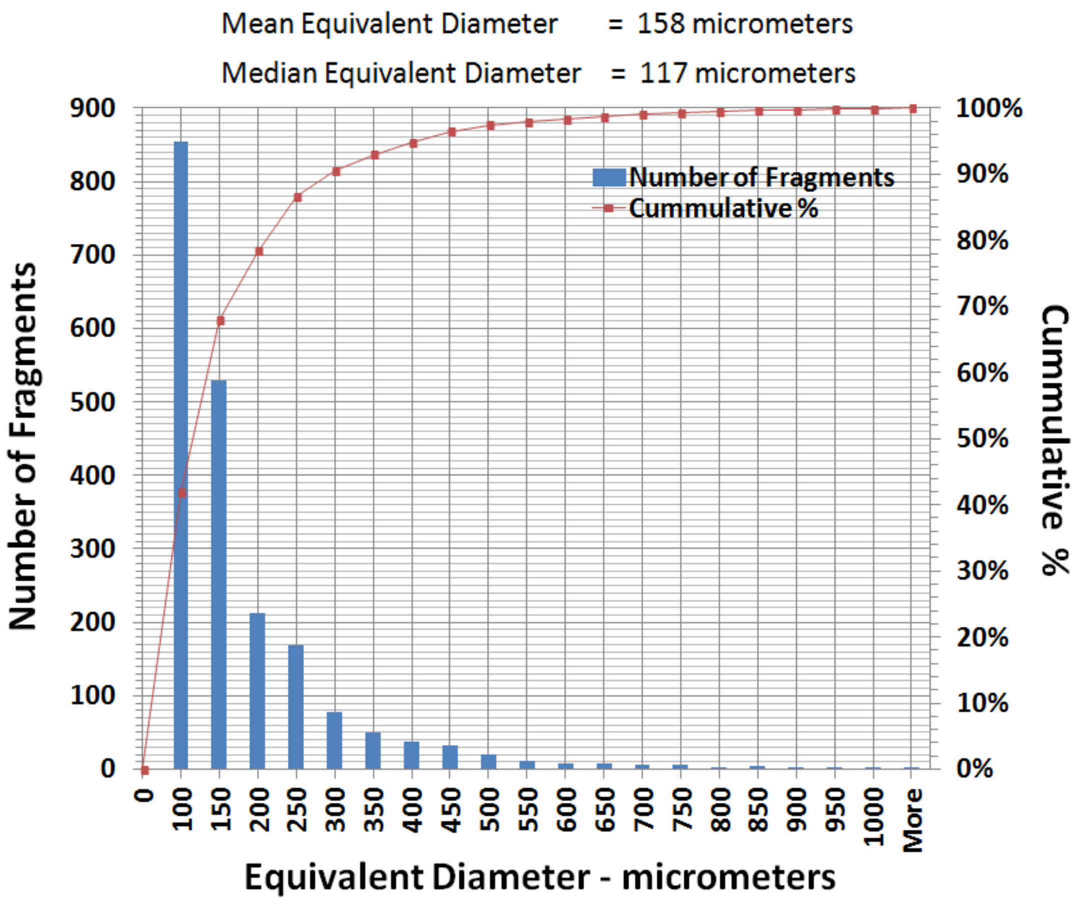
Resolutions = 73.2 µm/pixel; 14 pixels = 1.02 mm



RESULTS
Configuration A -Photron FASTCAM SA-Z

Particle Diameter = 3.2 mm, Velocity 99.5 m/sec, frame rate = 50,000 fps

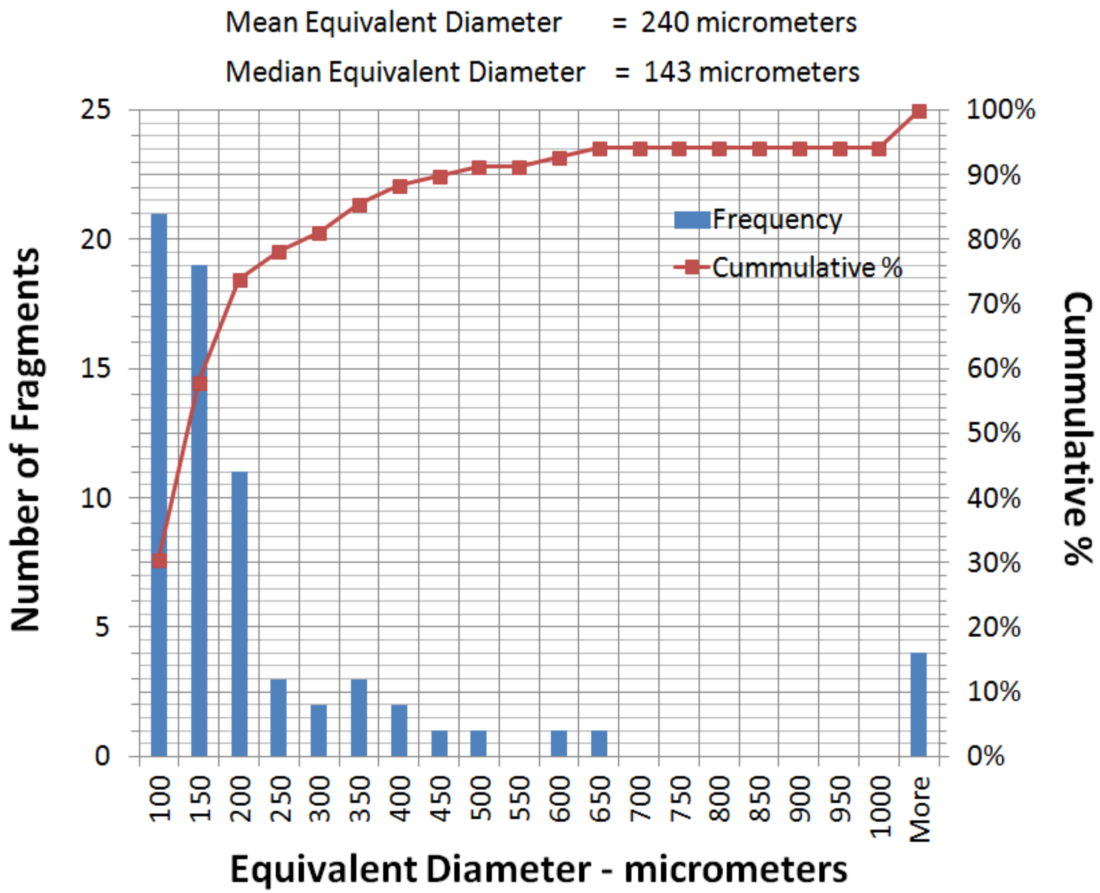
Histogram of frame 67, Resolutions = 73.2 µm/pixel



RESULTS
Configuration A -Photron FASTCAM SA-Z

Particle Diameter = 2.2 mm, Velocity 23.4 m/sec, frame rate = 50,000 fps

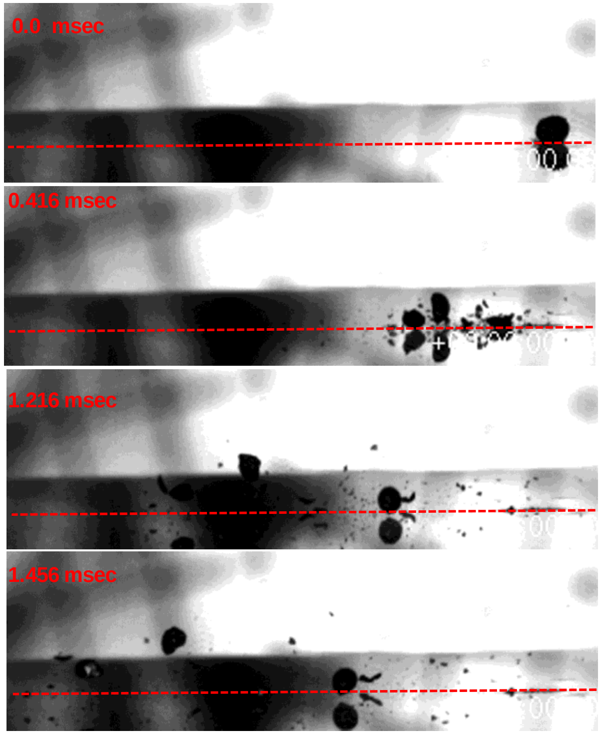
Resolutions = 73.2 µm/pixel



RESULTS
Configuration A –Side Camera

Particle Diameter = 2.2 mm, Velocity 23.4 m/sec, frame rate = 62,500 fps

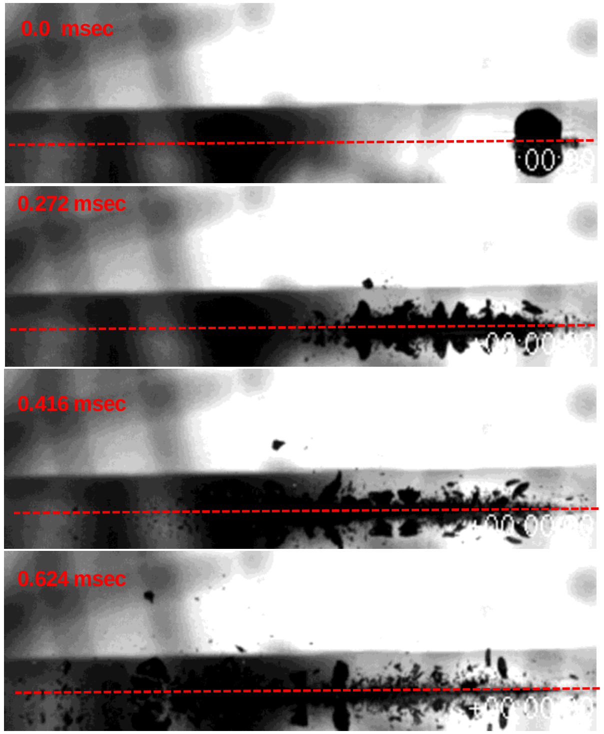
Resolutions = 123 µm/pixel



RESULTS
Configuration A –Side Camera

Particle Diameter = 2.9 mm, Velocity 47.9 m/sec, frame rate = 62,500 fps

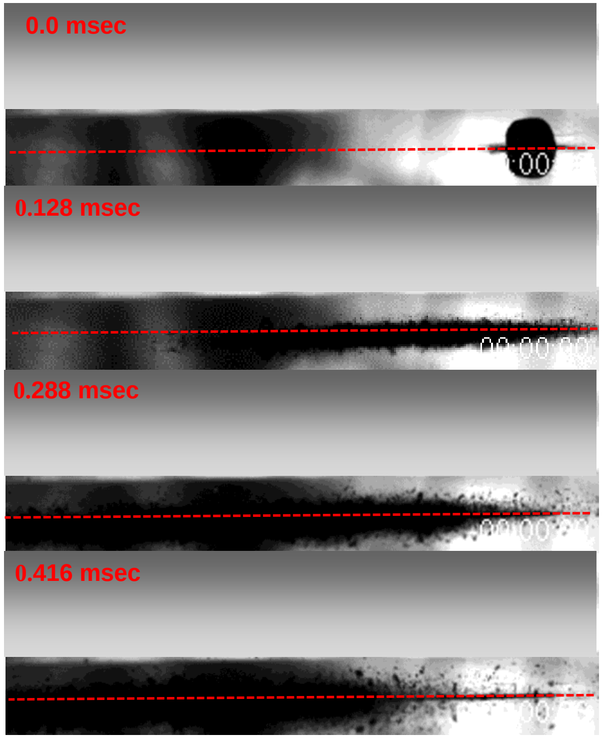
Resolutions = 123 µm/pixel



RESULTS
Configuration A –Side Camera

Particle Diameter = 2.9 mm, Velocity 130.1 m/sec, frame rate = 62,500 fps

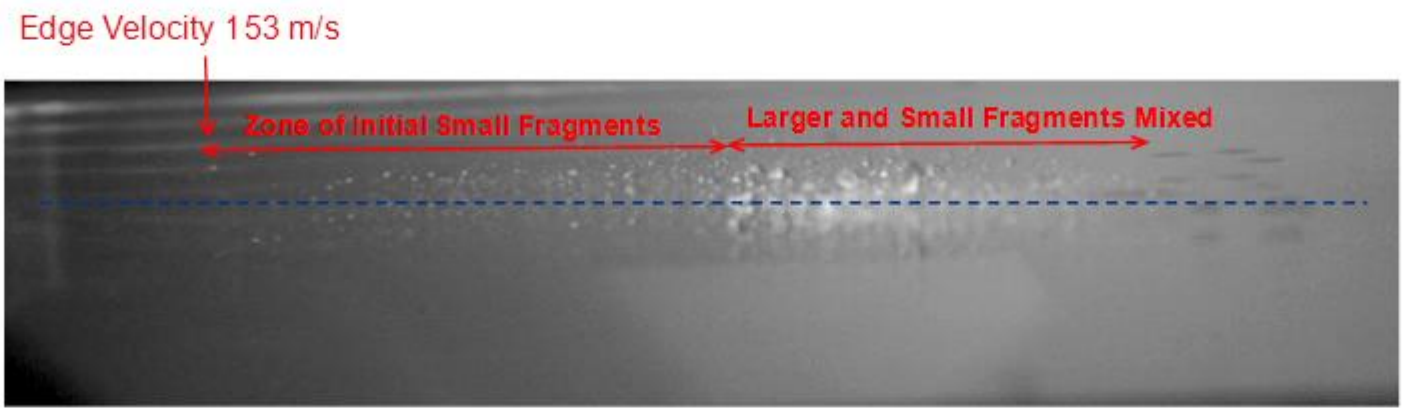
Resolutions = 123 µm/pixel



RESULTS
Configuration A –Side Camera

Particle Diameter = 2.0 mm, Impact Velocity 88.9m/sec

Edge Velocity of Fragments = 153 m/s

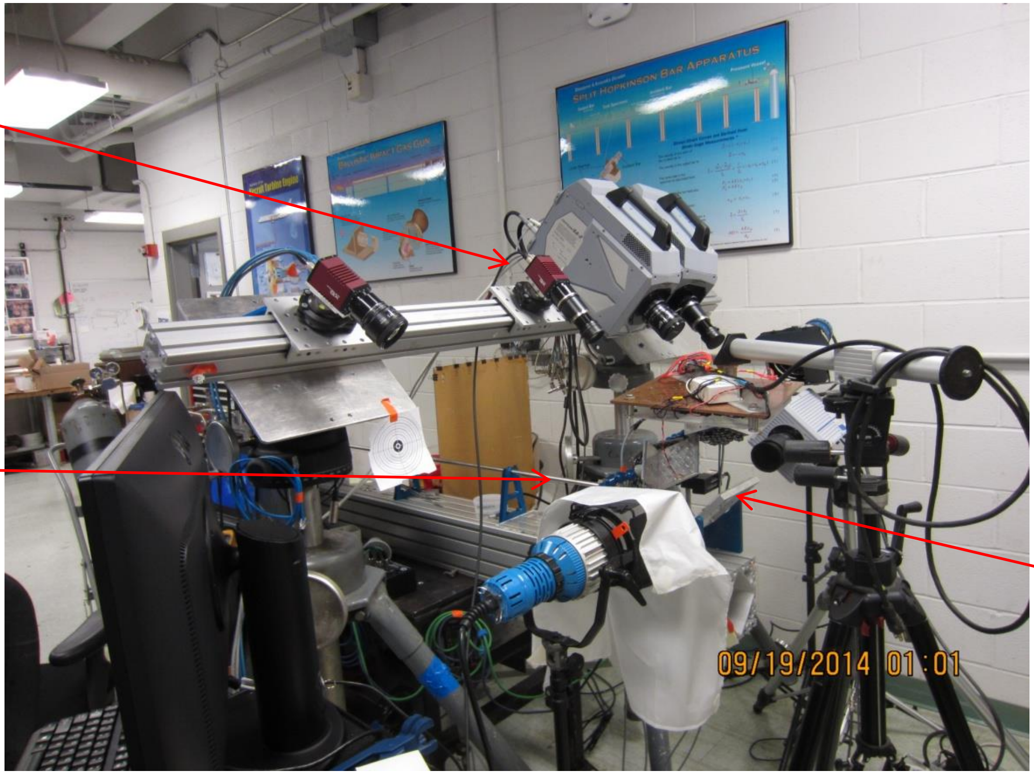


RESULTS
Configuration B -Allied Vision Prosilica GX6600 29 Megapixel camera

Resolutions = 22.4 µm/pixel

Camera Normal
to the Target

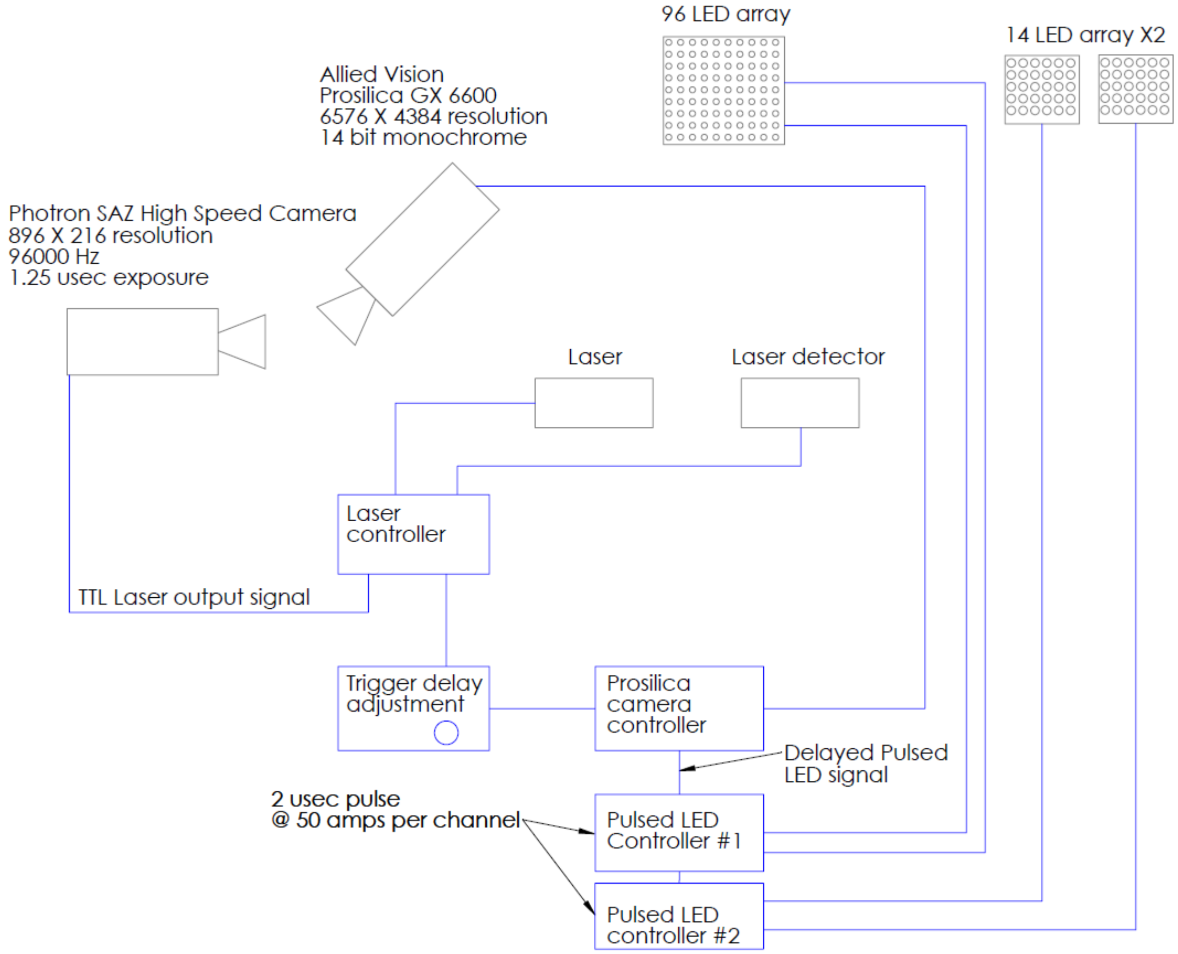
Pressure Gun
Barrel



Target

RESULTS
Configuration B -Allied Vision Prosilica GX6600 29MP

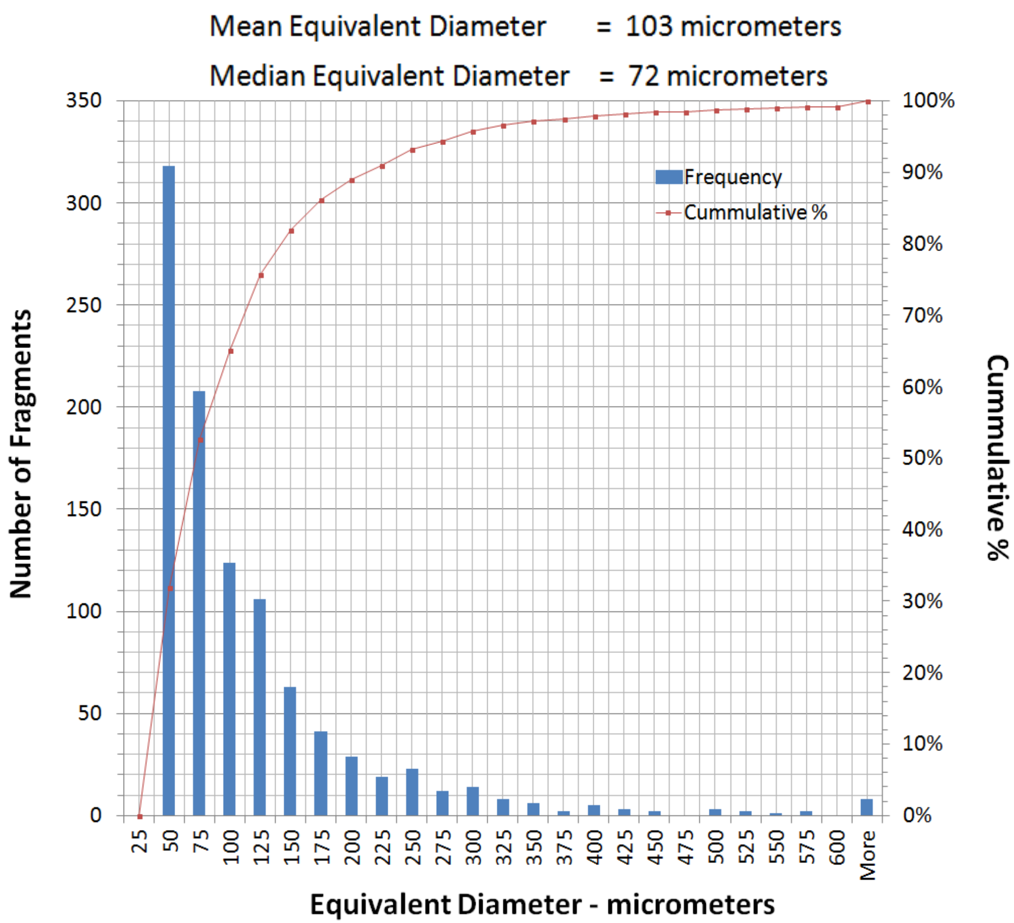
Schematic of pulsed LED and Prosilica camera system



RESULTS
Configuration B -Allied Vision Prosilica GX6600 29MP

Particle Diameter = 2.0 mm, Velocity 88.9 m/sec, Single Frame

Resolution = 22.4 µm/pixel



Conclusions

- Images captured with a high speed camera at 1,000,000 fps showed:
  - The area where the particle has the initial contact with the surface breaks up into very small particles that are ejected as a fragments cloud.
  - This initial fragments cloud precedes the development of cracks and the formation of larger fragments in the remainder of the impacting ice particle.
- The digital imaging processing data analysis methodology captured area and equivalent diameter distribution of the fragments, but a larger field of view and higher resolution are needed to capture smaller fragments
- In all the runs analyzed, the histogram of the fragments equivalent diameter followed the same pattern:
  - A non-normal distribution with a long tail, with most of the values concentrated near the resolution limit.

Conclusions (continuation)

- The threshold value influences the value obtained for the area and equivalent diameter of the fragments:
  - In the present work the Otsu method was used consistently.
  - Calibration of the threshold value is needed as part of the testing procedure in future tests.
- Future studies of ice particle impacts of diameters in the range of 250 to 600 micrometers, the median mass equivalent diameter size of actual ice crystals, will require major improvements in the optical system setup to obtain the resolution and field of view needed.
- Ice particle preparation methods will have to be modified to generate particles in the size of actual ice crystals.

END OF PRESENTATION