SPHIR Facility and Recently added Diagnostics

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PSAAP Site Visit
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Overview: Major push in instrumentation

• Facility Overview and major instrumentation Improvements
  • Laser Side-lighting and CGS Results
  • Preliminary Side-Lighting Analysis
  • Preliminary Capture Pack Results
  • Spectrometer Update
  • Legacy Data Database Update
Experimental Facility

Current Instrumentation

- High-Speed Cameras
- Conoscope Profilometer
- Velocity Interferometer System for Any Reflector (VISAR)
- Two-stage Light Gas Gun
  - 1.8 mm (0.07”) bore diameter
  - 22.7 mg 440C steel spheres at 2–3 km/s
  - 5.5 mg nylon 6/6 cylinders at 5–10 km/s
  - 3.6 mg nylon 6/6 spheres at 5–6 km/s
Velocimetry: 5 – 10 km/s

- Impactor ionizes atmosphere, producing plasma sheath
- Impact speed determined from tracking of plasma sheath

**Photron SA1 Camera**
- 150,000 fps

**Camera FOV**

**Photron**
- 150000 fps
- Center

**FASTCAM SA1.1 mode**
- 1/150000 sec
- Frame: -30

**Nylon cylinder**
- L/D = 1
- 5.25 mg
- 5.8 km/s
Laser Side-Lighting Facility Setup

CORDIN 214-8 Model Camera

CORDIN 214-8

High-intensity laser light source

CORDIN triggered off of Impact Flash

(Not to scale)
Laser Side-Lighting Facility Setup

Coherent Verdi V6

Beam Expander 1

Beam Expander 2

Free Beam

Flight Tube

Target Tank

Target

Zoom Lens

Beam Reducer

Cordin 214-8

V_{\text{impact}}

ejecta
debris

(Not to scale)
Side-Lighting: Thick vs. Thin

\[ V_{\text{impact}} = 5.4 \text{ km/s} \]

\[ h = 1.5 \text{ mm, } \alpha = 0^\circ \]

\[ t_{\text{exposure}} = 25\text{ns} \]

\[ V_{\text{impact}} = 5.4 \text{ km/s} \]

\[ h = 3.0 \text{ mm, } \alpha = 0^\circ \]

Target

\[ t = t_{\text{trigger}} + 0.2 \mu\text{s} \]
Laser Side-Lighting Results

\[ V_{\text{impact}} = 5.4 \text{ km/s} \]
\[ h = 1.5 \text{ mm}, \quad \alpha = 0^\circ \]
\[ t_{\text{exposure}} = 25\text{ns} \]
\[ t = t_{\text{trigger}} + 1.0 \mu\text{s} \]

\[ V_{\text{impact}} = 5.4 \text{ km/s} \]
\[ h = 3.0 \text{ mm}, \quad \alpha = 0^\circ \]
\[ t = t_{\text{trigger}} + 1.0 \mu\text{s} \]
Laser Side-Lighting Results

\[ V_{\text{impact}} = 5.4 \text{ km/s} \]

\[ h = 1.5 \text{ mm}, \quad \alpha = 0^\circ \]

\[ t_{\text{exposure}} = 25 \text{ ns} \]

\[ V_{\text{impact}} = 5.4 \text{ km/s} \]

\[ h = 3.0 \text{ mm}, \quad \alpha = 0^\circ \]

\[ t = t_{\text{trigger}} + 2.0 \mu s \]
Laser Side-Lighting Results

\[ V_{\text{impact}} = 5.4 \text{ km/s} \]

\[ h = 1.5 \text{ mm}, \quad \alpha = 0^\circ \]

\[ t = t_{\text{trigger}} + 3.0 \mu\text{s} \]

\[ V_{\text{impact}} = 5.4 \text{ km/s} \]

\[ h = 3.0 \text{ mm}, \quad \alpha = 0^\circ \]

\[ t = t_{\text{trigger}} + 3.0 \mu\text{s} \]
Laser Side-Lighting Results

\[ V_{\text{impact}} = 5.4 \text{ km/s} \]
\[ h = 1.5 \text{ mm, } \alpha = 0^\circ \]
\[ t = t_{\text{trigger}} + 4.1 \mu s \]

\[ V_{\text{impact}} = 5.4 \text{ km/s} \]
\[ h = 3.0 \text{ mm, } \alpha = 0^\circ \]
\[ t = t_{\text{trigger}} + 4.1 \mu s \]
Laser Side-Lighting Results

\[ V_{\text{impact}} = 5.4 \text{ km/s} \]

\[ h = 1.5 \text{ mm, } \alpha = 0^\circ \]

\[ t_{\text{exposure}} = 25\text{ns} \]

\[ V_{\text{impact}} = 5.4 \text{ km/s} \]

\[ h = 3.0 \text{ mm, } \alpha = 0^\circ \]

\[ t = t_{\text{trigger}} + 5.0 \mu s \]
Laser Side-Lighting Results

\[ V_{\text{impact}} = 5.4 \text{ km/s} \]
\[ h = 1.5 \text{ mm}, \quad \alpha = 0^\circ \]
\[ t_{\text{exposure}} = 25\text{ns} \]

\[ V_{\text{impact}} = 5.4 \text{ km/s} \]
\[ h = 3.0 \text{ mm}, \quad \alpha = 0^\circ \]
\[ t = t_{\text{trigger}} + 10.0 \mu s \]
Laser Side-Lighting Results

\[ V_{\text{impact}} = 5.4 \text{ km/s} \]
\[ h = 1.5 \text{ mm}, \ \alpha = 0^\circ \]
\[ V_{\text{debris}} = 2.2 \text{ km/s} \]
\[ \varepsilon_v = 0.3 \text{ km/s} \]
\[ V_{\text{ejecta}} = 3.5 \text{ km/s} \]
\[ \varepsilon_v = 0.3 \text{ km/s} \]
\[ t = t_{\text{trigger}} + 15.0 \mu s \]

\[ V_{\text{impact}} = 5.4 \text{ km/s} \]
\[ h = 3.0 \text{ mm}, \ \alpha = 0^\circ \]
\[ V_{\text{debris}} = 0.6 \text{ km/s} \]
\[ \varepsilon_v = 0.3 \text{ km/s} \]
\[ V_{\text{ejecta}} = 3.4 \text{ km/s} \]
\[ \varepsilon_v = 0.3 \text{ km/s} \]
\[ t = t_{\text{trigger}} + 15.0 \mu s \]
Side-Lighting Results: Thin Plates

Nylon 6/6 Cylinder
0.071” length, L/D =1

$V_{\text{impact}} = 5.7 \text{ km/s}$

$h_{1} = 0.96\text{mm}$
$h_{2} = 0.96\text{mm}$

$t = t_{\text{trigger}} + 0.2 \mu\text{s}$
Side-Lighting Results: Thin Plates

\[ h_1 = 0.96 \text{mm} \]
\[ h_2 = 0.96 \text{mm} \]
\[ v_{\text{impact}} = 5.7 \text{ km/s} \]
\[ t = t_{\text{trigger}} + 0.2 \mu s \]
Side-Lighting Results: Thin Plates

$h_1 = 0.96\text{mm}$
$h_2 = 0.96\text{mm}$
$v_{\text{impact}} = 5.7 \text{ km/s}$

$t = t_{\text{trigger}} + 5.0 \mu s$
Side-Lighting Results: Thin Plates

$h_1 = 0.96\text{mm}$
$h_2 = 0.96\text{mm}$
$v_{\text{impact}} = 5.7 \text{ km/s}$
$t = t_{\text{trigger}} + 10.0 \mu\text{s}$
Side-Lighting Results: Thin Plates

\[ V_{\text{debris}} = 3.7 \text{ km/s} \]
\[ \varepsilon_v = 0.2 \text{ km/s} \]

\[ h_1 = 0.96\text{mm} \]
\[ h_2 = 0.96\text{mm} \]
\[ v_{\text{impact}} = 5.7 \text{ km/s} \]

\[ t = t_{\text{trigger}} + 20.0 \mu\text{s} \]
Side-Lighting Results: Thin Plates

\[ h_1 = 0.96 \text{mm} \]
\[ h_2 = 0.96 \text{mm} \]
\[ v_{\text{impact}} = 5.7 \text{ km/s} \]
\[ t = t_{\text{trigger}} + 30.0 \mu\text{s} \]
Side-Lighting Results: Thin Plates

$h_1 = 0.96\text{mm}$

$h_2 = 0.96\text{mm}$

$v_{\text{impact}} = 5.7\text{ km/s}$

$t = t_{\text{trigger}} + 50.0\text{ µs}$
Metric: Debris Cloud Shot-Line Velocity

Isolated Debris Cloud image

\[ h = 0.97 \text{mm}, \quad \alpha = 0^\circ \]
\[ v_{\text{impact}} = 5.35 \text{ km/s} \]

\[ v_{\text{debris}} = \frac{pS}{t} \quad p = \text{inter-frame distance} \]
\[ S = \text{mm/pixel scale} \]
\[ T = \text{inter-frame time} \]

\[ \varepsilon_v = \sqrt{\left(\frac{p}{t} \varepsilon_s\right)^2 + \left(\frac{S}{t} \varepsilon_p\right)^2 + \left(\frac{pS}{t^2} \varepsilon_t\right)^2} \]

\( \varepsilon_v \) conservatively between 0.1 km/s and 0.3 km/s
Side-Lighting Results: Obliquity

$V_{\text{impact}} = 5.2 \text{ km/s}$
$h = 1.5\text{mm}, \alpha = 45^\circ$

Nylon 6/6 SPHERE
0.072” diameter

$t = t_{\text{trigger}} + 0.1 \mu s$
Side-Lighting Results: Obliquity

\[ V_{\text{impact}} = 5.2 \text{ km/s} \]
\[ h = 1.5\text{mm}, \alpha = 45^\circ \]

\[ t = t_{\text{trigger}} + 1.0 \mu\text{s} \]
Side-Lighting Results: Obliquity

\[ V_{\text{impact}} = 5.2 \text{ km/s} \]
\[ h = 1.5 \text{ mm}, \alpha = 45^\circ \]

\[ t = t_{\text{trigger}} + 2.0 \mu s \]
Side-Lighting Results: Obliquity

$V_{\text{impact}} = 5.2 \text{ km/s}$

$h = 1.5\text{ mm}, \alpha = 45^\circ$

$t = t_{\text{trigger}} + 3.0 \mu\text{s}$
Side-Lighting Results: Obliquity

\[ V_{\text{impact}} = 5.2 \text{ km/s} \]
\[ h = 1.5 \text{mm}, \alpha = 45^\circ \]

\[ t = t_{\text{trigger}} + 4.0 \mu\text{s} \]
Side-Lighting Results: Obliquity

\[ V_{\text{impact}} = 5.2 \, \text{km/s} \]
\[ h = 1.5 \, \text{mm}, \, \alpha = 45^\circ \]

\[ t = t_{\text{trigger}} + 5.0 \, \mu\text{s} \]
Side-Lighting Results: Obliquity

\[ V_{\text{impact}} = 5.2 \text{ km/s} \]

\[ h = 1.5 \text{mm}, \alpha = 45^\circ \]

\[ t = t_{\text{trigger}} + 10.0 \mu\text{s} \]
Side-Lighting Results: Obliquity

\[ V_{\text{impact}} = 5.2 \text{ km/s} \]
\[ h = 1.5\text{mm}, \ \alpha = 45^\circ \]

\[ t = t_{\text{trigger}} + 15.0 \mu s \]
Metric Provided to Analysts
Measure gradient of refractive index due to changes of temperature and density around the impact site

\[ S = \text{optical path difference} \]
\[ \Delta = \text{grating spacing} \]
\[ p = \text{pitch of grating} \]

\[ \frac{\partial S}{\partial x_\alpha} = \frac{n\Delta}{p} \]

\[ \alpha = \{1, 2\} \]
CGS by Transmission Results

Nylon 6/6 Cylinder
0.071” length, L/D =1
Vertical CGS Gradient

\[ \Delta = 1.25 \text{ in (31.75 mm)} \]

\[ t = t_{\text{trigger}} + 0.1 \mu s \]

\[ V_{\text{impact}} = 4.7 \text{ km/s} \]

\[ h_{\text{target}} = 0.063” \]

\[ p_{\text{tank}} = 52.0 \text{ Torr} \]
CGS by Transmission Results

\[ t = t_{\text{trigger}} + 0.1 \, \mu s \]

\[ V_{\text{impact}} = 4.7 \, \text{km/s} \]
\[ h_{\text{target}} = 0.063'' \]
\[ p_{\text{tank}} = 52.0 \, \text{Torr} \]
CGS by Transmission Results

\[ t = t_{\text{trigger}} + 1.0 \, \mu s \]

\[ V_{\text{impact}} = 4.7 \, \text{km/s} \]

\[ h_{\text{target}} = 0.063'' \]

\[ p_{\text{tank}} = 52.0 \, \text{Torr} \]
CGS by Transmission Results

\[ t = t_{\text{trigger}} + 2.0 \ \mu s \]

\[ V_{\text{impact}} = 4.7 \ \text{km/s} \]

\[ h_{\text{target}} = 0.063” \]

\[ \rho_{\text{tank}} = 52.0 \ \text{Torr} \]
CGS by Transmission Results

\[ t = t_{\text{trigger}} + 3.0 \, \mu s \]

\[ V_{\text{impact}} = 4.7 \, \text{km/s} \]

\[ h_{\text{target}} = 0.063'' \]

\[ p_{\text{tank}} = 52.0 \, \text{Torr} \]
CGS by Transmission Results

\[ t = t_{\text{trigger}} + 4.1 \, \mu s \]

\[ V_{\text{impact}} = 4.7 \, \text{km/s} \]

\[ h_{\text{target}} = 0.063'' \]

\[ p_{\text{tank}} = 52.0 \, \text{Torr} \]
CGS by Transmission Results

\[ t = t_{\text{trigger}} + 5.0 \, \mu s \]

\[ V_{\text{impact}} = 4.7 \, \text{km/s} \]

\[ h_{\text{target}} = 0.063'' \]

\[ p_{\text{tank}} = 52.0 \, \text{Torr} \]
CGS by Transmission Results

\[ V_{\text{impact}} = 4.7 \text{ km/s} \]
\[ h_{\text{target}} = 0.063'' \]
\[ p_{\text{tank}} = 52.0 \text{ Torr} \]

\[ t = t_{\text{trigger}} + 10.0 \mu s \]
CGS by Transmission Results

\[ t = t_{\text{trigger}} + 15.0 \mu s \]

\[ V_{\text{impact}} = 4.7 \text{ km/s} \]

\[ h_{\text{target}} = 0.063'' \]

\[ p_{\text{tank}} = 52.0 \text{ Torr} \]
CGS by Transmission Results

\[ V_{\text{norm}} = 1.3 \text{ km/s} \]

\[ \varepsilon_v = 0.2 \text{ km/s} \]

\[ V_{\text{int}} = 1.1 \text{ km/s} \]

\[ \varepsilon_v = 0.2 \text{ km/s} \]

\[ V_{\text{impact}} = 4.7 \text{ km/s} \]

\[ h_{\text{target}} = 0.063'' \]

\[ p_{\text{tank}} = 52.0 \text{ Torr} \]

\[ t = t_{\text{trigger}} + 15.0 \mu\text{s} \]
Debris Capture Diagnostic
Capture Pack and Measurement

Stack of alternating foam plates and plastic films

- Architectural Foam
  - 1 lb/ft³
  - inexpensive
  - highly engineered (controlled pts)

Opaque plastic film

- Film sheet after test

Light Box

Film

Camera

Computer Image Analysis

Measurements

1. X-Y position of debris particle perforations on each film [dispersion of debris]
2. Size of debris particle perforations [debris particle size]
3. #1 combined with film distance from target perforation site gives debris particle direction and penetration path length in foam [related to mass & velocity of debris particle]
4. Recovery of debris material from selected tests
Characterizing Debris Cloud Mass & Trajectory
D26 – thick target

FOV before experiment

Experiments for Spatial and Temporal Characterization of Impact Flash
D26 – thick target

\( P_{\text{tank}} = 3.0 \text{ Torr} \)

\( V_{\text{impact}} = 5 \text{ km/s} \)

\[
\begin{align*}
  t_{\text{start}} & = t_{\text{trigger}} + 0.2 \mu\text{s} \\
  t_{\text{exp}} & = 1 \mu\text{s}
\end{align*}
\]
D26 – thick target

\[ P_{\text{tank}} = 3.0 \text{ Torr} \]

\[ V_{\text{impact}} = 5 \text{ km/s} \]

\[ t_{\text{start}} = t_{\text{trigger}} + 2.0 \mu\text{s} \]

\[ t_{\text{exp}} = 1 \mu\text{s} \]
D26 – thick target

$P_{\text{tank}} = 3.0 \text{ Torr}$

$V_{\text{impact}} = 5 \text{ km/s}$

\[
t_{\text{start}} = t_{\text{trigger}} + 4.1 \mu s
\]
\[
t_{\text{exp}} = 1 \mu s
\]
D26 - thick target

$P_{\text{tank}} = 3.0 \text{ Torr}$

$V_{\text{impact}} = 5 \text{ km/s}$

$t_{\text{start}} = t_{\text{trigger}} + 6.0 \mu\text{s}$

$t_{\text{exp}} = 1 \mu\text{s}$
D26 – thick target

\( P_{\text{tank}} = 3.0 \text{ Torr} \)

\( V_{\text{impact}} = 5 \text{ km/s} \)

\( t_{\text{start}} = t_{\text{trigger}} + 8.0 \mu\text{s} \)

\( t_{\text{exp}} = 1 \mu\text{s} \)
D26 – thick target

$P_{tank} = 3.0$ Torr

$V_{impact} = 5$ km/s

$t_{start} = t_{trigger} + 10.0 \mu s$

$t_{exp} = 1 \mu s$
D26 – thick target

$P_{\text{tank}} = 3.0 \text{ Torr}$

$V_{\text{impact}} = 5 \text{ km/s}$

$t_{\text{start}} = t_{\text{trigger}} + 12.0 \mu s$

$t_{\text{exp}} = 1 \mu s$
D26 – thick target

$P_{\text{tank}} = 3.0 \text{ Torr}$

$V_{\text{impact}} = 5 \text{ km/s}$

$t_{\text{start}} = t_{\text{trigger}} + 14.0 \mu s$

$t_{\text{exp}} = 1 \mu s$
D27 — thick target

FRONTAL VIEW of target impact flash

6”
$D_{27} \rightarrow \text{thick target}$

$P_{\text{tank}} = 3.1 \, \text{Torr}$

$V_{\text{impact}} = 5 \, \text{km/s}$

$t_{\text{start}} = t_{\text{trigger}} + 0.2 \, \mu\text{s}$

$t_{\text{exp}} = 1 \, \mu\text{s}$
D27 – thick target

$P_{\text{tank}} = 3.1 \text{ Torr}$

$V_{\text{impact}} = 5 \text{ km/s}$

$t_{\text{start}} = t_{\text{trigger}} + 6.0 \mu\text{s}$

$t_{\text{exp}} = 1 \mu\text{s}$
D27 – thick target

$P_{\text{tank}} = 3.1 \text{ Torr}$

$V_{\text{impact}} = 5 \text{ km/s}$

$t_{\text{start}} = t_{\text{trigger}} + 8.0 \mu\text{s}$

$t_{\text{exp}} = 1 \mu\text{s}$
D27 – thick target

$P_{\text{tank}} = 3.1 \text{ Torr}$

$V_{\text{impact}} = 5 \text{ km/s}$

$t_{\text{start}} = t_{\text{trigger}} + 14.0 \mu\text{s}$

$t_{\text{exp}} = 1 \mu\text{s}$
Visible-UV High-Speed Camera (PI-MAX 3)
- 1024 x 256 pixel, gated, intensified CCD camera
- 3 ns fast gate
- Spectral coverage of 200 nm to 850 nm

Acton VM-504 500 mm focal length (0.05 nm resolution) spectrograph

LightField 64 bit Data Acquisition Software

Infrared Imaging Camera (OMA V)
- Spectral coverage of 0.9 μm to 1.7 μm
- 2.2 μs response time

Lens systems for field of view

WinSpec 32 bit Data acquisition software
All components operated by integrated computer control software
Spectrometers Installed
Post Mortem Profilometry

**Optimet MiniConoscan 3000**

- Produces surface map as \{x,y,z\} coordinate table
- Scans 101mm x 101mm area
- 25 micron resolution in x, y, & z

Accurately measures post-test target deformation features for comparison with numerical simulation

- **Target Perforation area**
- **Back-surface slope map**

MiniConoscan Image courtesy of Optimet Optical Metrology
Nylon Impactor on 6061-T6 Aluminum Targets

45 experiments, 40 useful perforation area data points
Legacy Perforation Area Data

6061-T6 Al Targets, 0 degrees obliquity, cylinder impactor

Perforation Area [mm²] vs Impact Speed [km/s]

- h = 0.55mm
- h = 0.96mm
- h = 1.58mm
- h = 2.03mm
- h = 2.29mm
- h = 3.07mm
- h = 4.06mm

PSAAP: Predictive Science Academic Alliance Program
VISAR (Recently Operational)

Velocity Interferometer System for Any Reflector

**Metric Provided to Analysts**
Normal surface velocity of entire deformation event at 4 selected points with high < 10 ns resolution

- **High temporal definition** (entire impact event with <1 μs resolution)
- **Limited spatial resolution** (data taken at 4 points)

**Coherent Verdi-V6 6 Watt, 532 nm laser**
Current Diagnostics Summary

**Diagnostic Technique**

- **Post Mortem Profilometry**
  - **Routine**
  - **Operational**

- **In Situ Side-Lighting Shadowgraphs**
  - **Operational**

- **In Situ CGS by Transmission**
  - **Operational**

- **In Situ VISAR**
  - **Delivered**

- **In Situ Spectrometry**
  - **Delivered**

**Performance Measures**

- Perforation Area
- Target back-surface slope
- ...

- Bulge formation
- Ejecta/debris cloud formation
- Ejecta/debris cloud distribution

- Index of refraction gradient of Ejecta and Debris cloud

- Back-surface normal velocity

- Emission spectra
- Thermal distribution of target/debris cloud
The following metrics will be used on each experiment and delivered:

- Perforation Area
- Debris Cloud Shot-Line Velocity
- Debris Cloud Trajectory
- Debris Cloud Penetration Depth
- Ejecta Velocity
- Debris Cloud Temperature
- Emission Spectra