Experimental study of a strongly shocked gas bubble

D. Ranjan, J. Niederhaus, J. Oakley, M. Anderson, R. Bonazza

Wisconsin Shock Tube Laboratory
Fusion Technology Institute
University of Wisconsin-Madison
Overview

- Planar shock wave accelerates a spherical soap bubble: Ar inside, N₂ outside, $A=0.176$

- Vortex velocity defect and circulation measurements

- Time evolution of geometrical properties

- Mach numbers
  - $M=2.88$, $u_p=745$ m/s
  - $M=3.38$, $u_p=907$ m/s
The Wisconsin Shock Tube

- Vertical
- Large internal cross-section (25 cm square)
- Total length 9.2 m, driver length 2 m
- Pressure load capability: 20 MPa
- Modular driven section
Details of R-M Experiment

Planar shock wave
Spherical soap bubble $D = 5$ cm
Driver: He  Driven: N$_2$  Test: Ar

Initial conditions:
Continuous white light from the front
Motion picture at 220 fps
Resolution (256×256)

Post shock:
Mie-scattering from the soap film acting as flow tracer
2 laser pulses
2 images per run on same frame
Resolution (1024×1024)
Initial Conditions

Formation of a ~5 cm diameter bubble and controlled release of bubble
Shock Accelerated Bubble $M#2.88$

$t = 25 \mu s$

$t = 65 \mu s$

$t = 170 \mu s$

$t = 280 \mu s$

$t = 295 \mu s$

$t = 400 \mu s$

$12.07 \text{ cm}$
Shock Accelerated Bubble $M\#2.88$

57th APS DFD Meeting
Seattle, 21-23 November, 2004

Wisconsin Shock Tube Laboratory
University of Wisconsin-Madison
Vortex Velocity Defect

- Bubble diameter $D$
- Time scale: $\tau = D/u_p$  
  ($u_p =$ particle velocity behind shock)
- $V_v = [(X_1 + X_2)/2]/(\Delta t)$ (for early times)
- $V_v = X/(\Delta t)$ (for later times)
Circulation Measurements, $M\#2.88$

\[ \Gamma \approx u_p (1 - \frac{u_p}{2W})D \ln\left(\frac{\rho_\infty}{\rho_b}\right) \]

Picone & Boris (1988)

Initial circulation

\[ \Gamma = -8.6 \text{ m}^2/\text{s} \ (D=5 \text{ cm}) \]

Haas & Sturtevant (1987)

Vortex ring circulation

<table>
<thead>
<tr>
<th>$t/\tau$</th>
<th>$\Gamma$ (m$^2$/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.0</td>
<td>-3.7</td>
</tr>
<tr>
<td>8.7</td>
<td>-4.8</td>
</tr>
</tbody>
</table>

Experimental values
Height Growth Rate, $M#2.88$

![Graph showing height growth rate with markers for $H/D$, $t/\tau$, and bubble compression.](image)
Width Growth Rate, $M\#2.88$
Vortex Growth Rate, $M#2.88$
Comparison($M#2.88$ & $M#3.38$)
Comparison($M#2.88$ & $M#3.38$)
Conclusions

- Developed new bubble-release technique
- Used strong \((M>2.5)\) shocks
- Observed bubble distortion, formation of vortex ring
- Measured growth rates of relevant large scale features
- \(\tau = \frac{D}{u_p}\) appears to be appropriate time scale

- Develop experiment to measure species concentration