Cavitation is a common problem for many engineering devices in which the main working fluid is in liquid state. In turbomachinery applications, cavitation generally occurs on the inlet side of pumps. The deleterious effects of cavitation include: lowered performance, load asymmetry, erosion and pitting of blade surfaces, vibration and noise, and reduction of the overall machine life.

Cavitation models in use today range from rather crude approximations to sophisticated bubble dynamics models. Details about bubble inception, growth and collapse are relevant to the prediction of blade erosion, but are not necessary to predict the performance of pumps. An engineering model of cavitation is proposed to predict the extent of cavitation and performance. The vapor volume fraction is used as an indicator variable to quantify cavitation. A two-phase flow approach is employed with the assumption of the thermal equilibrium between liquid and vapor. At present velocity slip between the two phases is selected. Preliminary analyses of 2D flows shows qualitatively correct results.
CURRENT STATUS IN CAVITATION MODELING

by

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for Presentation at:
11th Workshop for CFD Applications in Rocket Propulsion
NASA Marshall Space Flight Center, AL

April 20-22, 1993
BOILING VS CAVITATION

Boiling is phase change at constant pressure due to addition of external heat.

Cavitation is phase change due to lowering of hydrodynamic pressure under adiabatic conditions.
## HIERARCHY OF CAVITATION MODELS

<table>
<thead>
<tr>
<th>LEVEL</th>
<th>METHODOLOGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Single-phase flow analysis; identify cavitated zones where $P &lt; P_V$</td>
</tr>
<tr>
<td>2</td>
<td>Single-phase flow analysis; Set $P = P_V$ in regions where $P &lt; P_V$; iteratively identify cavitated zones</td>
</tr>
<tr>
<td>3</td>
<td>Two-phase flow analysis with a vapor source equation</td>
</tr>
<tr>
<td>4</td>
<td>Two-phase flow analysis with bubble-dynamics equations</td>
</tr>
</tbody>
</table>
COMMENTS

- Level 1 Approach: O.K. but too conservative
- Level 2 Approach: too weak, and can be misleading
- Level 3 Approach: Acceptable and sufficient for performance prediction; Accuracy depends on Vapor Source Equation
- Level 4 Approach: Needed for accurate prediction of local damage sites of bubble bursting, etc.
- Selected Approach: Level 3
# TWO-PHASE FLOW METHODS

<table>
<thead>
<tr>
<th>Method</th>
<th>Governing Equations</th>
<th>Velocity Slip</th>
<th>Interphase Friction</th>
</tr>
</thead>
</table>
| Homogenous        | Mixture momentum  
                     | Mixture continuity  
                     |                 |                     |
| Algebraic slip    | Same as homogenous but with velocity-slip terms              | 0             | -                   |
| Two-fluid         | Phasic momentum  
                     | Mixture and/or  
                     | Needs to be modeled |                     |
| Eulerian-Lagrangian | Continuum equations for continuous phase  
                         | $U_g - U_c$   | Needs to be modeled |                     |

$U_g$ - $U_c$
DENSITY CHANGES IN ENGINEERING FLOWS

\[ \frac{\partial \rho}{\partial p} \approx \frac{1}{C^2} \]

\( C = \text{Sound Speed} \)

<table>
<thead>
<tr>
<th>FLOW TYPE</th>
<th>( \rho_{\text{max}}/\rho_{\text{min}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buoyant Flows</td>
<td>1.1</td>
</tr>
<tr>
<td>Transonic Flows</td>
<td>2.0</td>
</tr>
<tr>
<td>Supersonic Flows</td>
<td>10.0</td>
</tr>
<tr>
<td>Reacting Flows</td>
<td>20.0</td>
</tr>
<tr>
<td>Cavitating Flows</td>
<td>1000.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Medium</th>
<th>Sound Speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>300</td>
</tr>
<tr>
<td>2( \phi ) Diesel</td>
<td>1.6</td>
</tr>
</tbody>
</table>

- Large density variations give rise to stiff equations
- Smaller sound speed slows down information propagation
- Cavitating flows offer a very stringent challenge to numerical schemes
Geometry: Axisymmetric Orifice; D/d = 3

Fluid: Diesel

Flow Conditions: \( P_{\text{exit}} = 1 \text{ Bar}; T = 187^\circ \text{C}; \frac{\rho_f}{\rho_v} = 283 \)

Study 1: Effect of varying inlet pressure

Study 2: Effect of geometry change (rounded entrance; \( \gamma/R = 15\% \))
CATERPILLAR INJECTOR ORIFICE

Steady State Analysis  Pinlet = 2.5 bar

a. STREAMLINES

b. STATIC PRESSURE

c. VAPOR FRACTION
CATERTILLAR INJECTOR ORIFICE

Steady State Analysis  Pinlet = 3.0 bar

a. STREAMLINES

b. STATIC PRESSURE

c. VAPOR FRACTION

0.000131
0.000117
0.000104
9.14e-05
7.83e-05
6.53e-05
5.22e-05
3.92e-05
2.61e-05
1.31e-05
3.64e-12

0.929
0.836
0.743
0.65
0.557
0.464
0.372
0.279
0.186
0.0929
1.49e-08
CATERPILLAR INJECTOR ORIFICE

Steady State Analysis  Pinlet = 10.0 bar

a. STREAMLINES

b. STATIC PRESSURE

c. VAPOR FRACTION
Effect of Edge Shape on Void Fraction Pin=4 bar

Sharp Edge

Rounded Edge
SUMMARY

- Test Problem Results:
  1) As inlet pressure increases, state of cavitation changes from subcritical to supercritical.
  2) The rounded entrance reduces cavitation.

- Preliminary results are encouraging

- Considerable future work needed for:
  1) Robustness and accuracy improvements of basic method.
  2) Adaptation for complex geometries with additional body forces (e.g. due to rotation)
  3) Validation under a variety of flow conditions.