Preliminary Simulations of the Ullage Dynamics in Microgravity during the Jet Mixing Portion of Tank Pressure Control Experiments

Kevin Breisacher

NASA Glenn Research Center, Cleveland, Ohio

Jeffrey Moder

NASA Glenn Research Center, Cleveland, Ohio

Joint Propulsion Conference
Orlando, Florida
July 2015

Tank Pressure Control Experiment (TPCE)

- Get-Away Special experiment flown on the Space Shuttle in 1991

Objectives

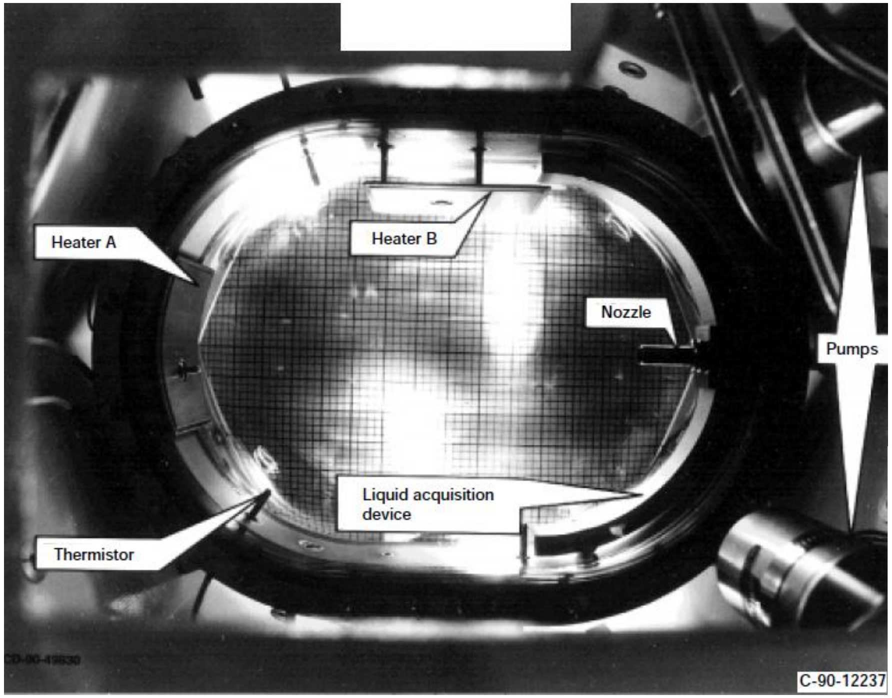
- characterize the dynamics of jet induced mixing processes in microgravity

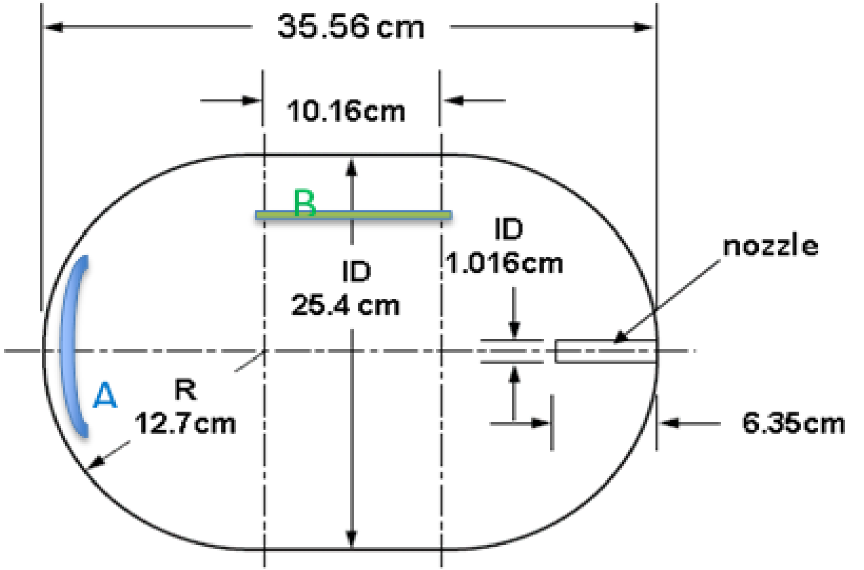
- provide data to validate CFD models of jet mixing in microgravity

Our objective as part of the e-Cryo program is to evaluate current cryogenic fluid capabilities to support NASA efforts and to identify areas requiring further development

TPCE hardware

- clear acrylic tank for optical access
- 83 % fill with Freon (r-113)
- embedded jet nozzle
- two electrical heaters
- liquid acquisition device (LAD) to recirculate fluid





Cylindrical tank with hemispherical domes and jet nozzle along centerline.
Inner tank height/diameter = 35.56/24.5 = 1.45.
Inner tank diameter/jet nozzle ID = 25.4/1.016 = 25

- video cameras were used to record ullage interface
  (limited to 2 mins of heating 4 min mixing)

- temperatures and pressures in the tank were recorded

- cartesian grid placed behind the tank

The results of 38 tests were reported with jet flow rates ranging from 0.38 to 3.35 L/min. The jet Weber number used to characterize the TPCE tests was adopted from previous testing by Aydelott[3]:

$$We_j = \rho_l V_o^2 R_o^2 / (\sigma D_j)$$

where

D_j - is the diameter of the jet at the interface

R_o - is the radius of the liquid jet at the nozzle outlet

V_o - is the velocity of the liquid jet at nozzle outlet

ρ_l - is the density of the liquid jet

σ - is the surface tension at the interface

x - is the distance from jet nozzle outlet to liquid/vapor interface

and

$$D_j = 2R_o + 0.24x \quad (\text{for } x < 12.4\, R_o)$$

$$= 0.22R_o + 0.38x \quad (\text{for } x > 12.4\, R_o)$$

“Tank Pressure Control in Low Gravity by Jet Mixing”, Benz, M., NASA CR 191012, March 1993.

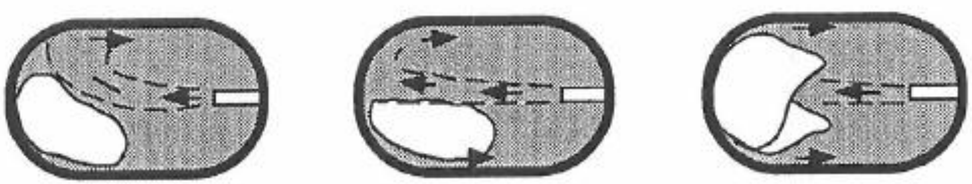
Nonpenetrating – jet doesn't penetrate the ullage

Asymmetric – jet forces ullage to one side of tank

Penetrating – jet penetrates and flows behind the ullage

Run Number	Flow Rate (l/min)	Weber Number	Flow Pattern
25	0.38	0.29	Nonpen.
32	0.38	0.30	Nonpen.
3	0.54	0.59	Nonpen.
11	0.59	0.71	Nonpen.
16	0.60	0.72	Nonpen.
8	0.60	0.73	Nonpen.
20	0.60	0.73	Nonpen.
23	0.62	0.77	Nonpen.
33	0.64	0.82	Nonpen.
27	0.80	1.29	Nonpen.
31	0.84	1.44	Nonpen.
29	1.24	3.10	Asym.
26	1.24	3.11	Asym.
4	1.53	4.73	Asym.
7	1.53	4.74	Asym.
15	1.53	4.74	Asym.
12	1.54	4.78	Penetr.
34	1.54	4.79	Asym.
24	1.57	4.96	Penetr.
19	1.58	5.06	Penetr.
28	1.71	5.90	Asym.
30	1.77	6.30	Penetr.
2	2.68	14.51	Penetr.
5	2.72	14.91	Penetr.
10	2.74	15.16	Penetr.
13	2.78	15.55	Penetr.
17	2.78	15.62	Penetr.
36	2.82	16.08	Penetr.
22	2.84	16.22	Penetr.
37	3.34	22.48	Penetr.
38	3.35	22.64	Penetr.

Figure 43: Flow Pattern versus Flow Rate and We_j



$3.1 < We_j < 4.8$ $4.8 < We_j < 6.3$ $14.5 < We_j < 22.6$

Figure from "Tank Pressure Control in Low Gravity by Jet Mixing", Benz, M, NASA CR 191012, March 1993

FLOW-3D

multi-physics, multi-dimensional, transient , CFD code

uses fractional area/volumes (FAVOR) for geometry definition (no arbitrary body fitted grid)

volume of fluid (VOF) for fluid interfaces

variety of surface tracking algorithms (split Lagrangian)

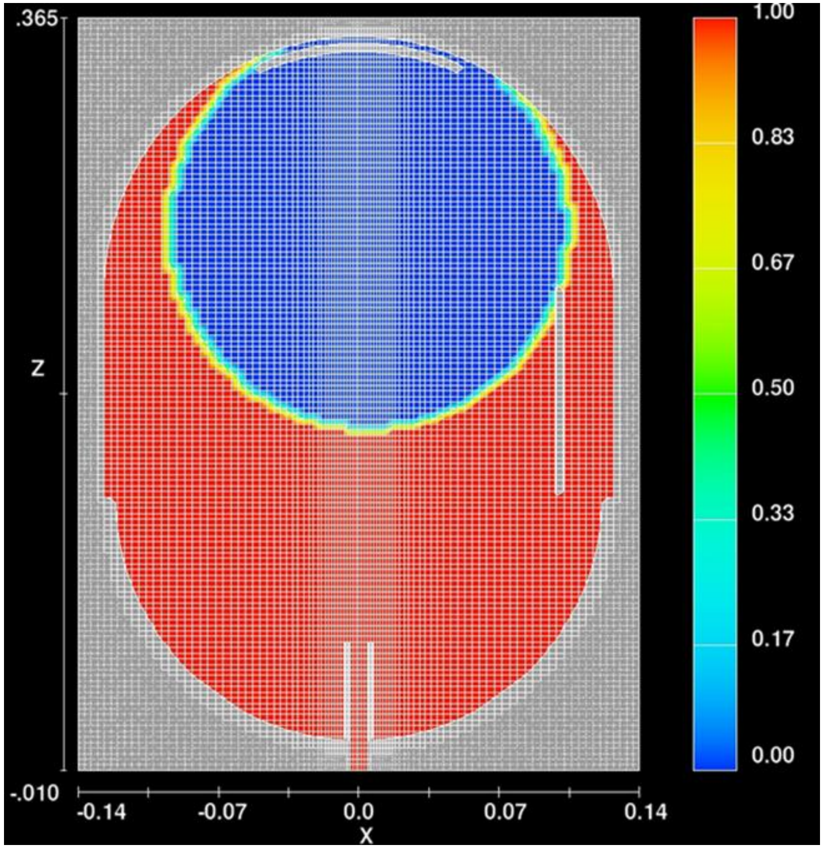
2^{nd} order advection

implicit surface tension

turbulence models (k-ϵ used)

5^{o} contact angle

thermophysical properties for Freon r113 from NIST

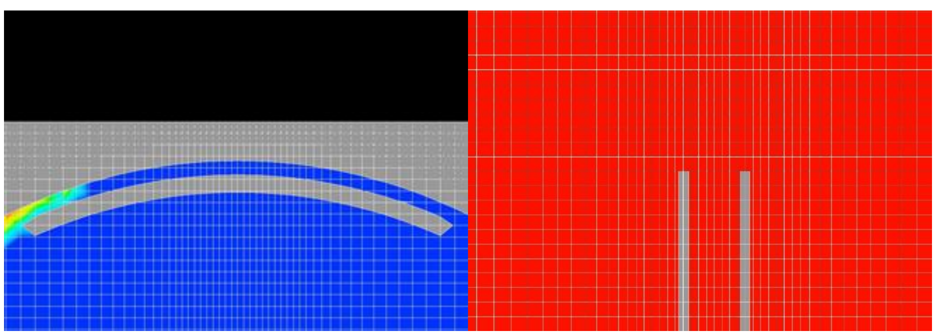


95 cells in the x and y directions

135 cells in the z direction (along jet axis)

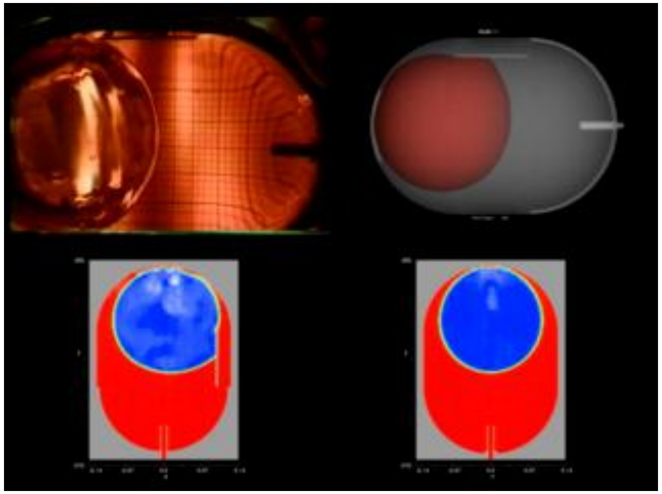
742,000 active cells

Clustered around the jet

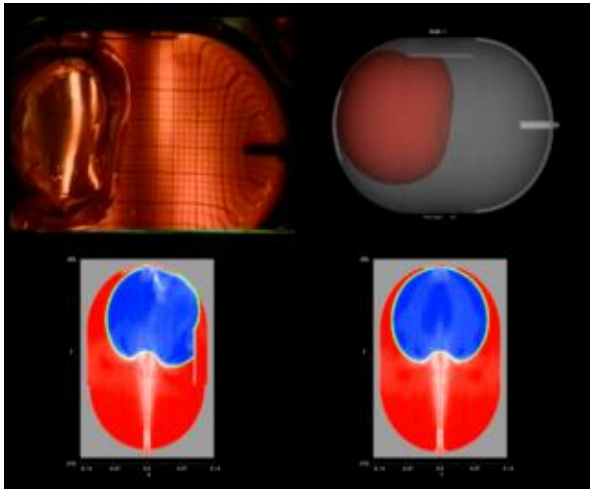


grid details above the top heater
and grid resolution of the jet (6 cells)

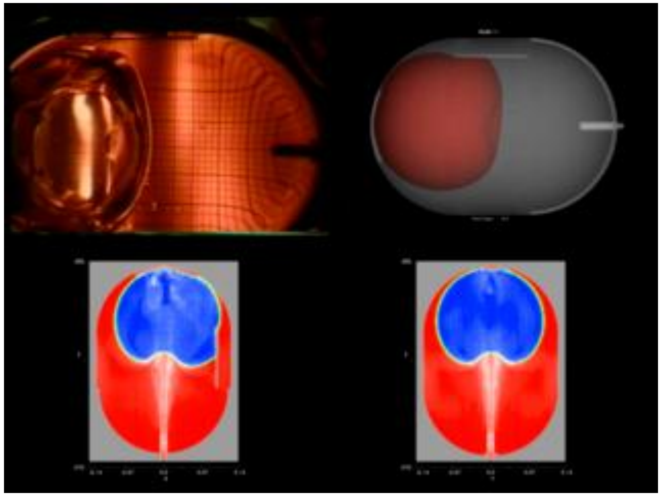
Run 11 We_j - .71 Non-penetrating



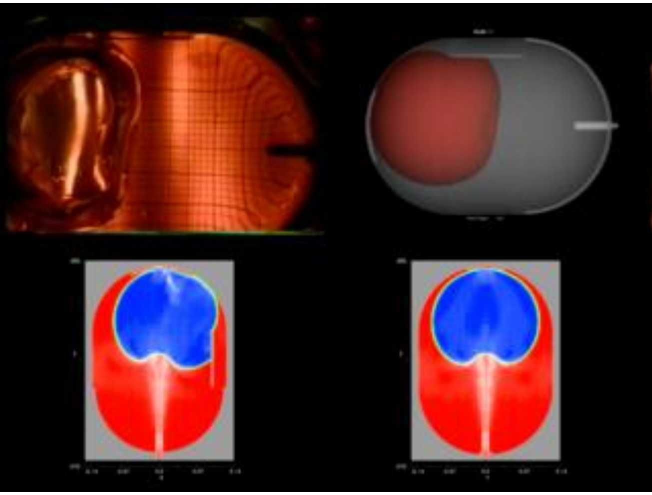
t= 20 s



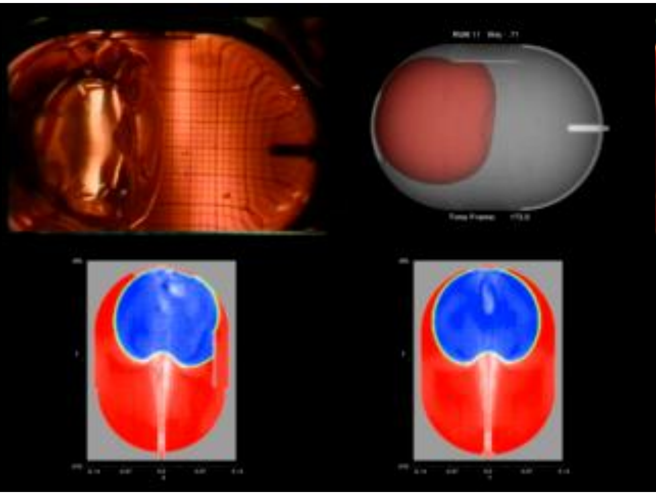
t= 55 s



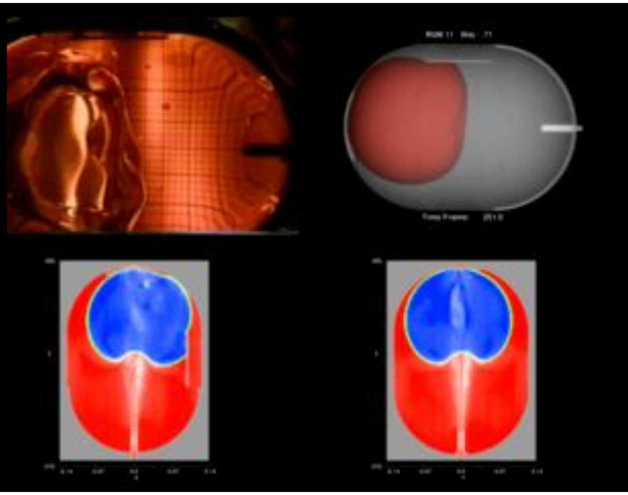
t= 90 s



t= 101 s

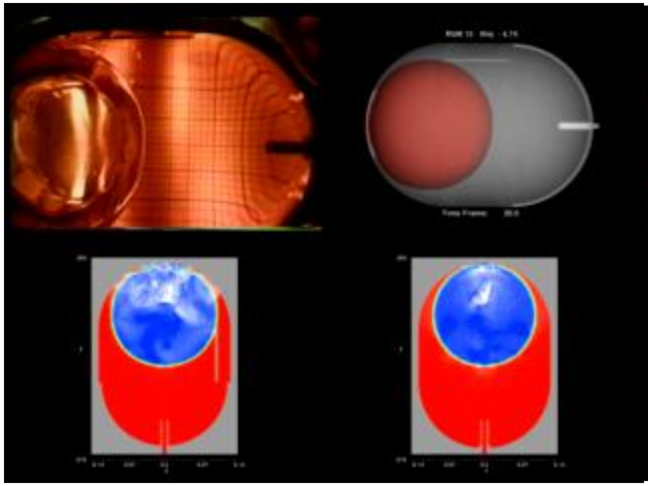


t= 180 s

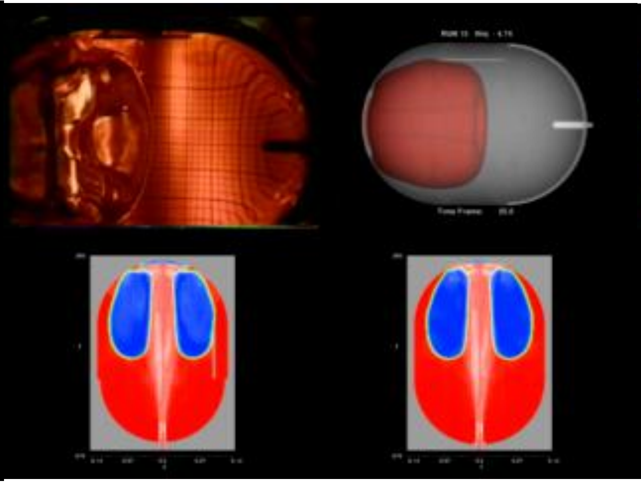


t= 261 s

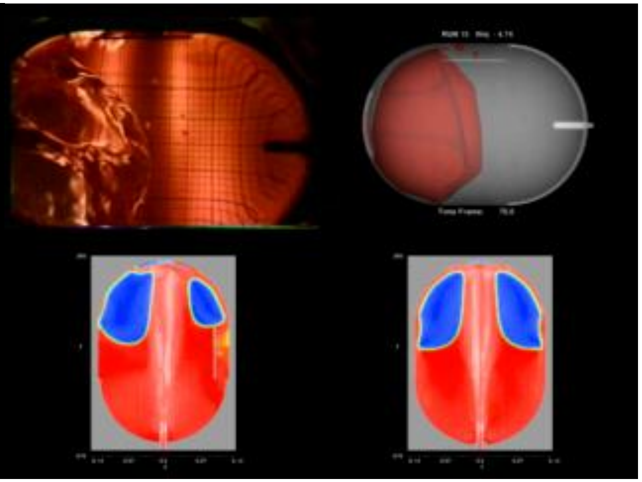
Run 15 We_j – 4.74 Asymmetric



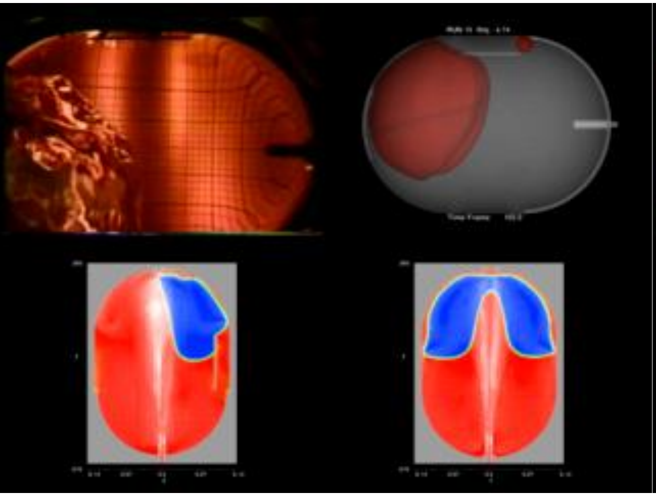
t= 20 s



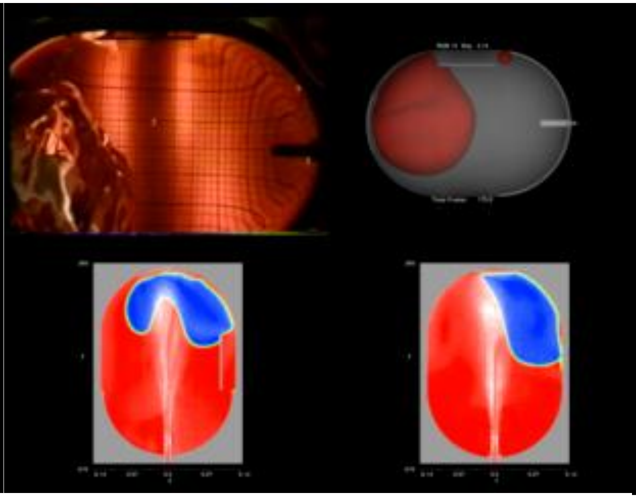
t= 25 s



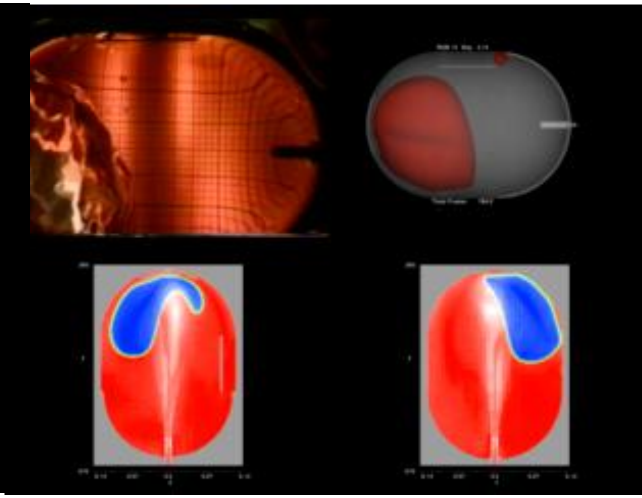
t= 71 s



t= 104 s

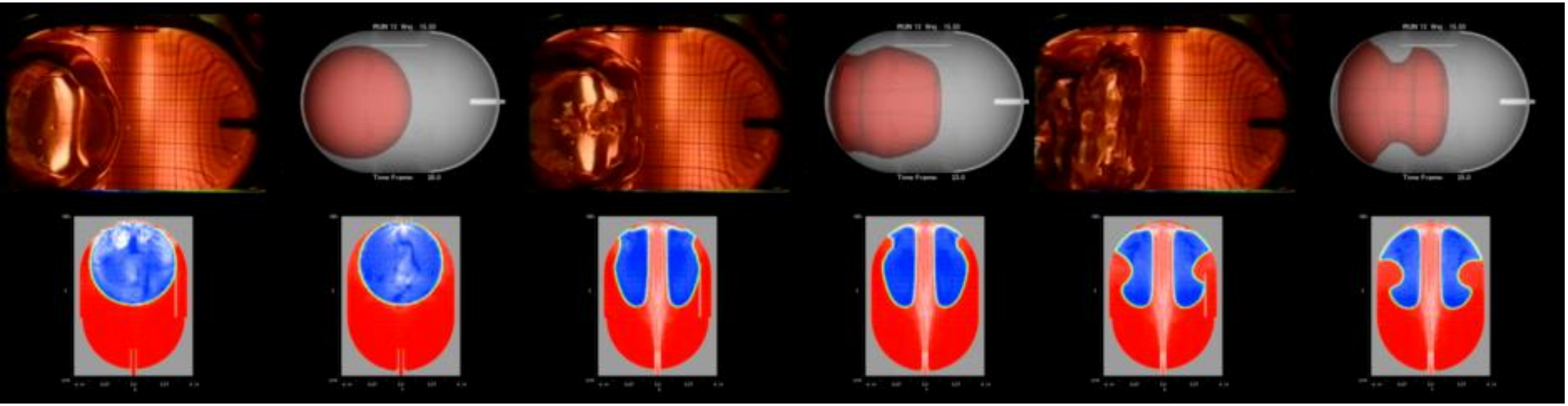


t= 173 s

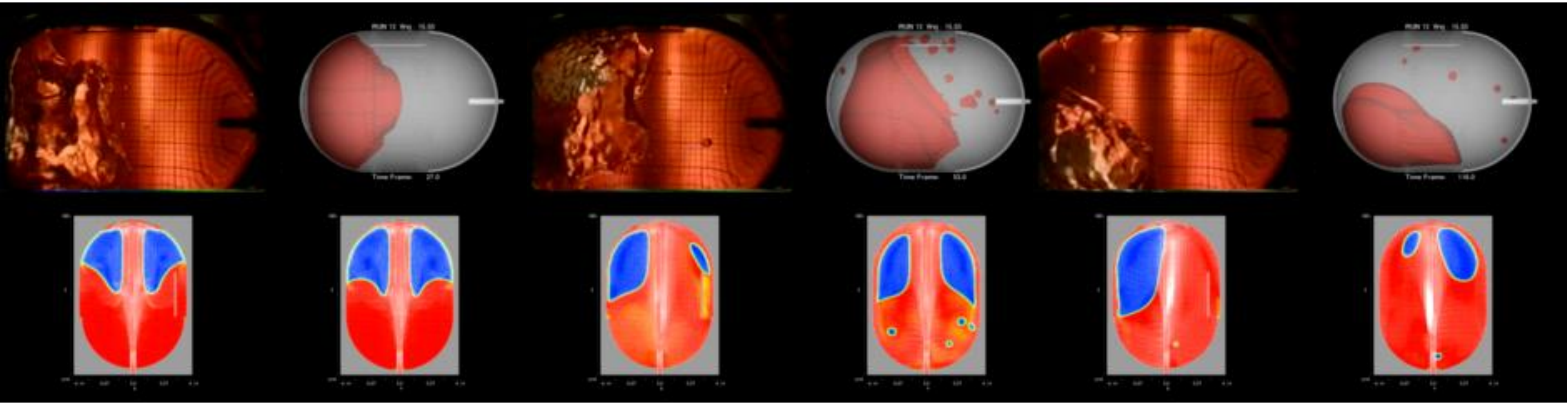


t= 203 s

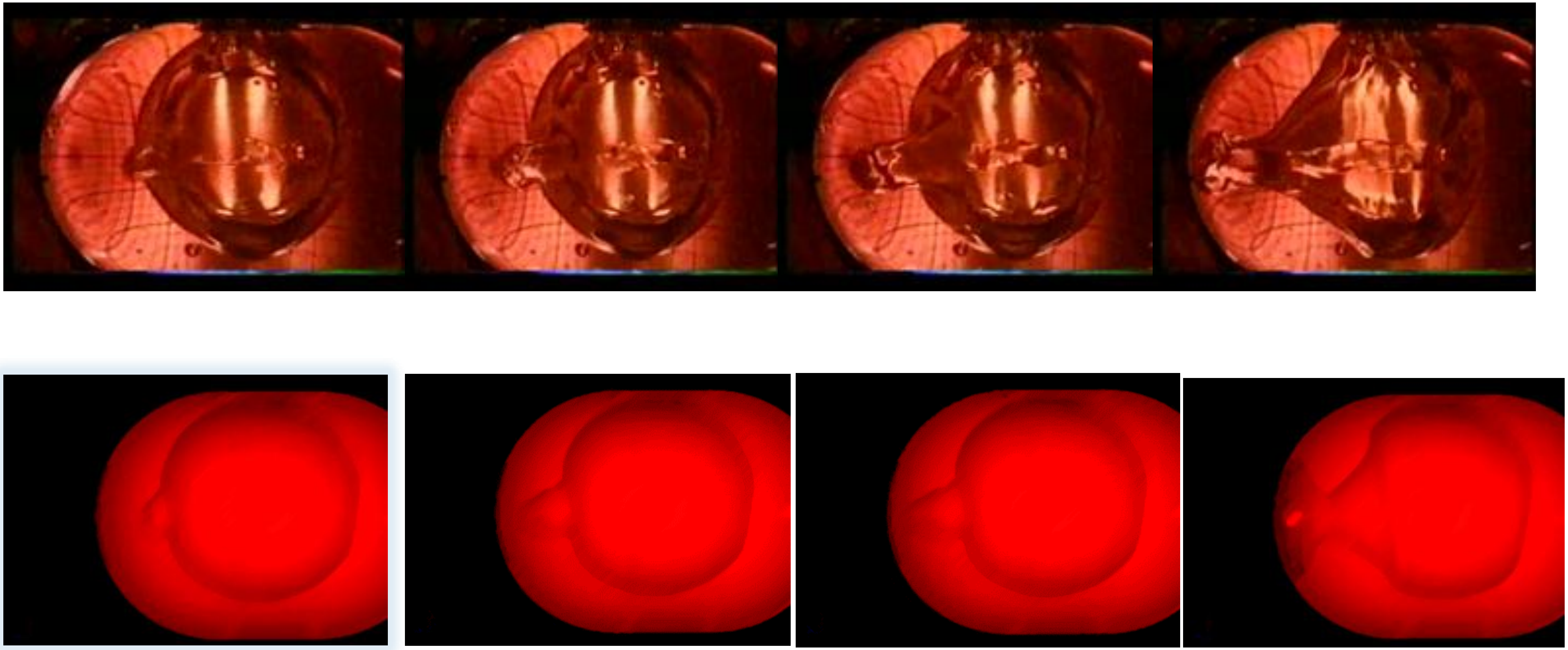
Run 13 We_j – 15.5 Penetrating



t= 20s t= 23s t= 25s

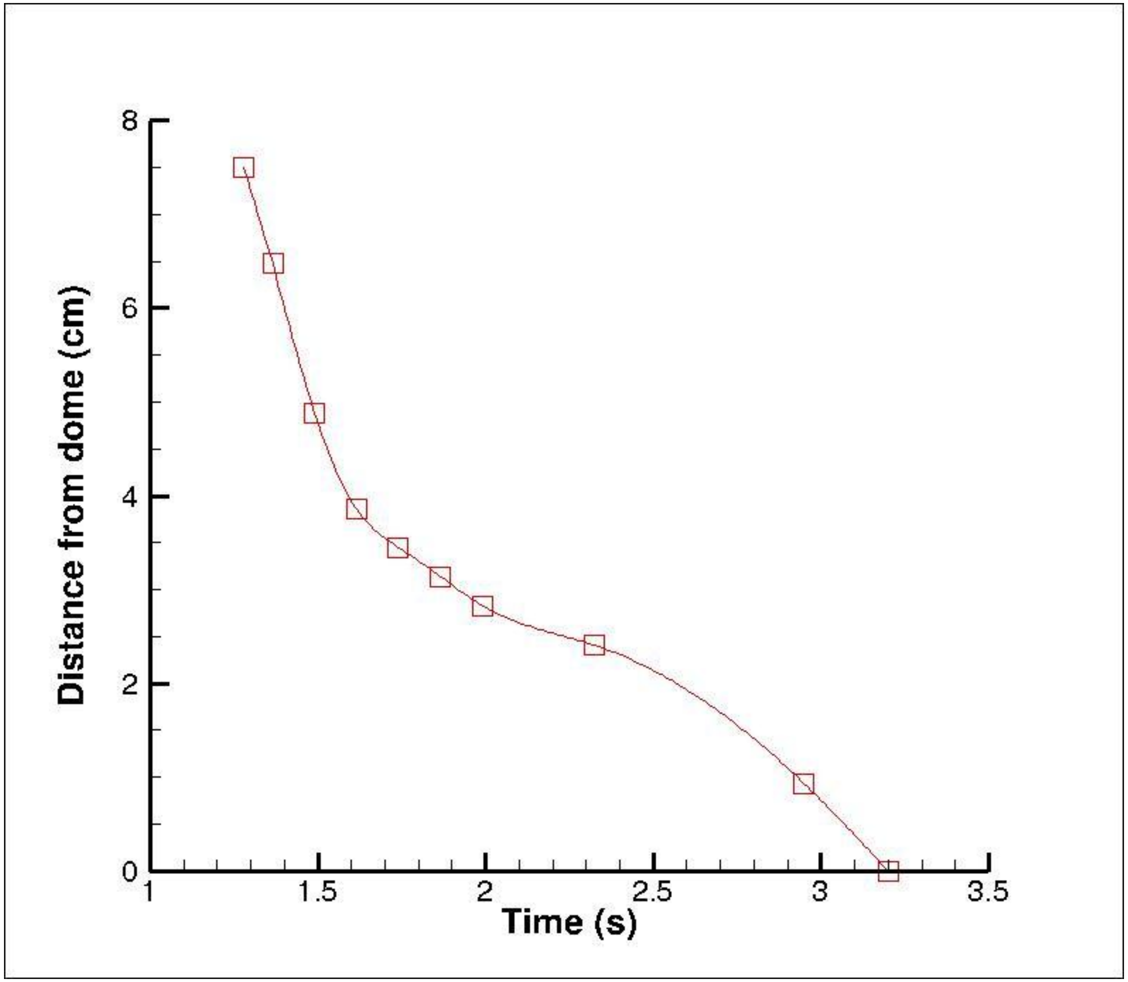


t= 27 s t= 53 s t= 116 s



t=1.25 s t=1.45s t=1.55s t=2.6s

Run 4 – Comparison of simulation to experimental ullage protuberance.



Transit of ullage protuberance digitized from video images

Qualitatively able to capture ullage dynamics for a range of jet Weber numbers

- quantitative comparisons remain an issue (ray tracing?)

Future work

include heating portion of test

use multiblock capability to refine jet

add acceeration(s) to simulations