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

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Joint Propulsion Conference
Orlando, Florida
July 2015

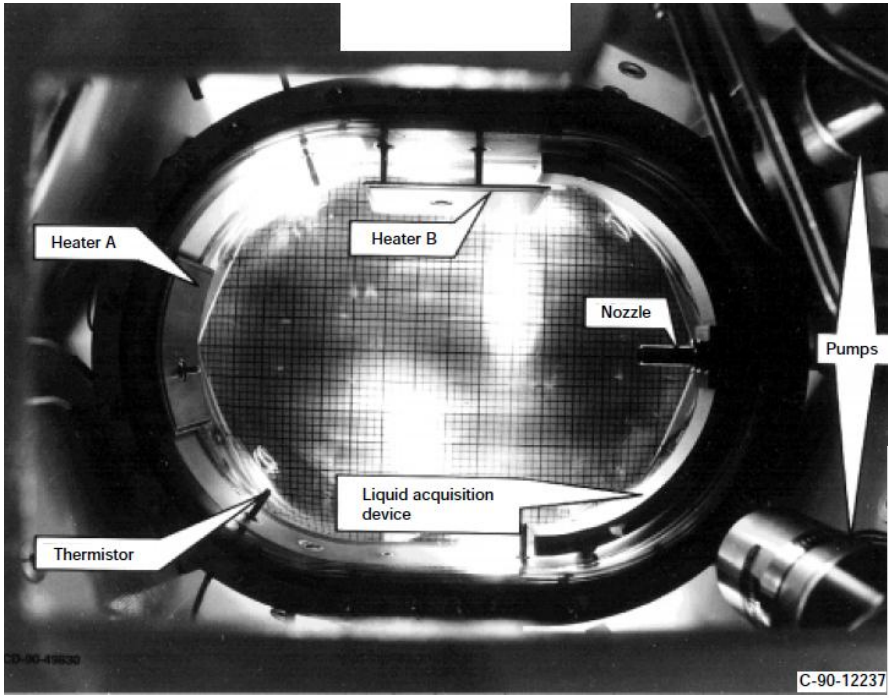
Tank Pressure Control Experiment (TPCE)

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

<u>Objectives</u>

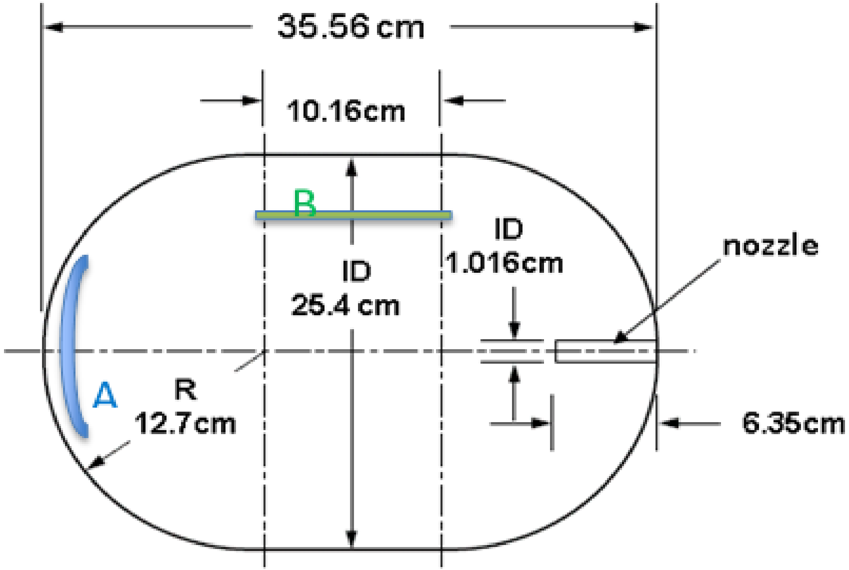
- characterize the dynamics of jet induced mixing processes in microgravity
- provide data to validate CFD models of jet mixing in microgravity

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


$3.1 < We_j < 4.8$


$4.8 < We_j < 6.3$

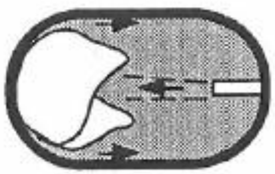

$14.5 < We_j < 22.6$

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)

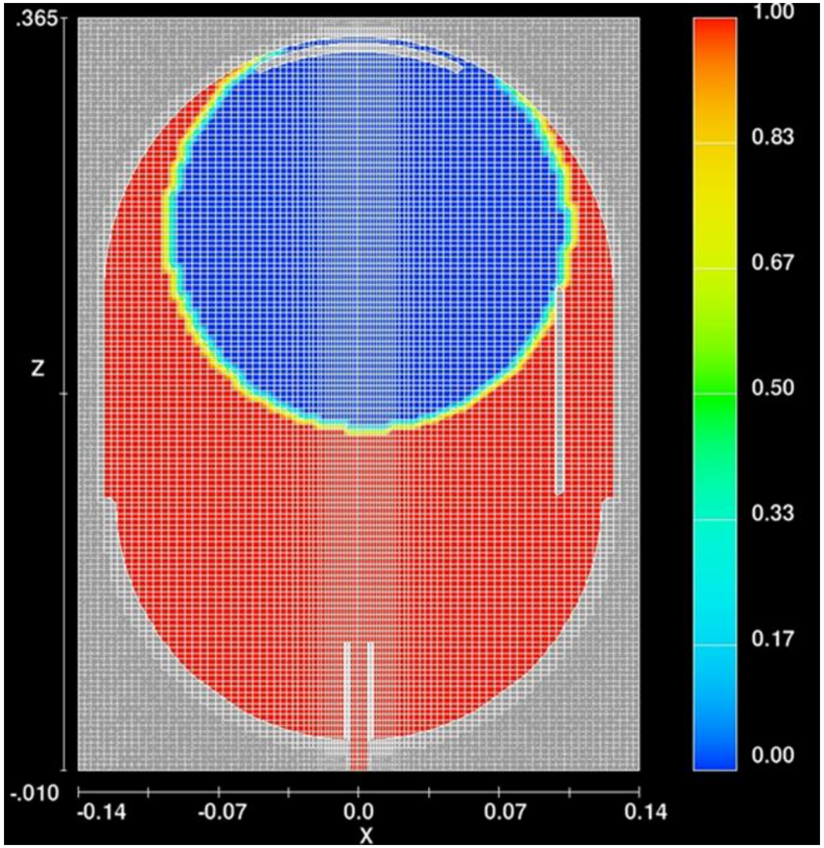
2^{nd} order advection

implicit surface tension

turbulence models (k-ϵ used)

5^{o} contact angle

thermophysical properties for Freon r113 from NIST

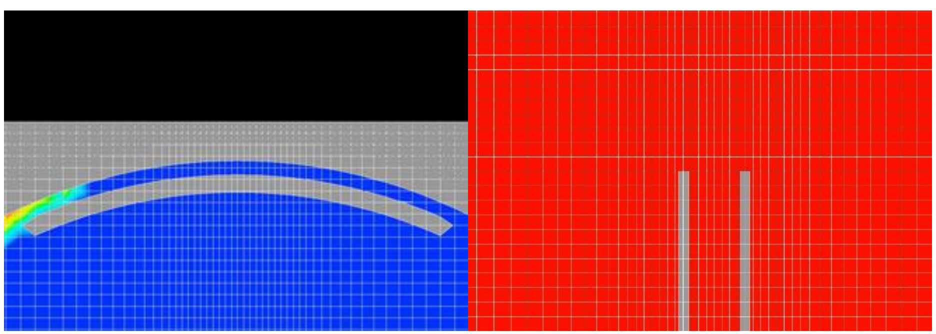


95 cells in the x and y directions

135 cells in the z direction (along jet axis)

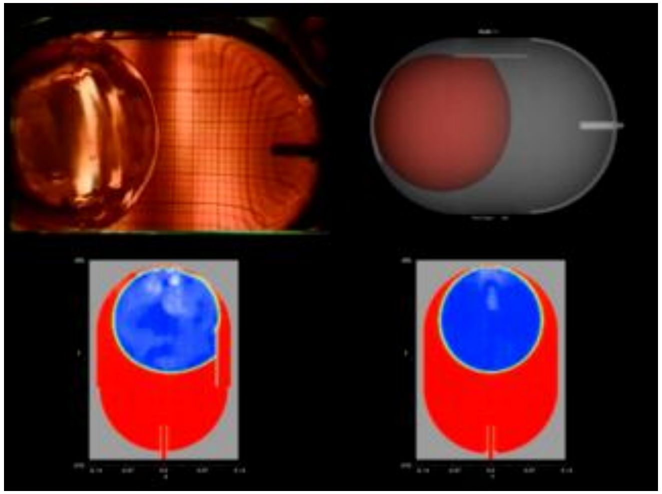
742,000 active cells

Clustered around the jet

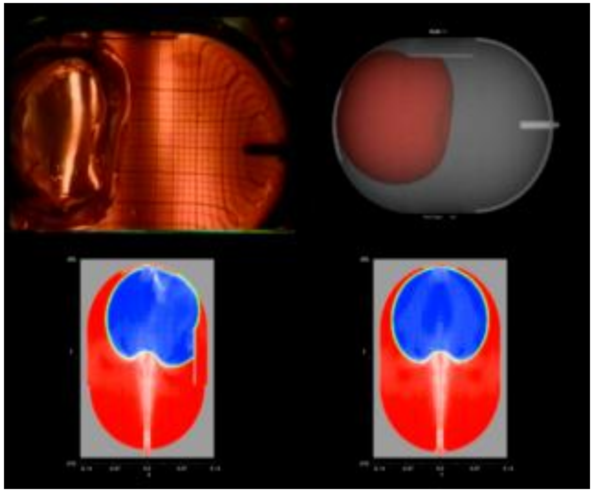


grid details above the top heater
and grid resolution of the jet (6 cells)

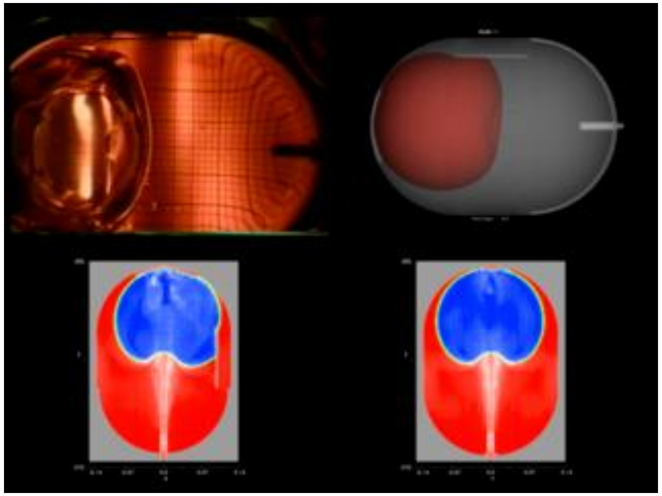
Run 11 We_j - .71 Non-penetrating



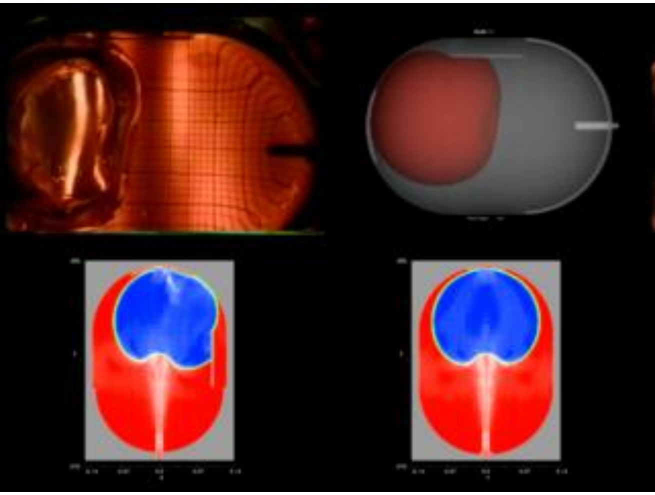
t= 20 s



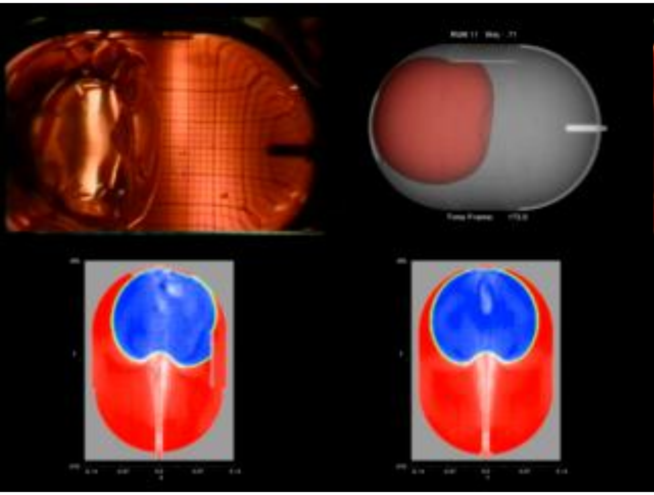
t= 55 s



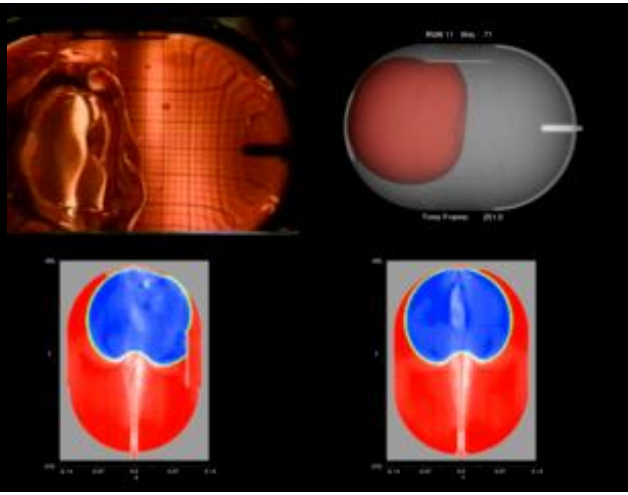
t= 90 s



t= 101 s

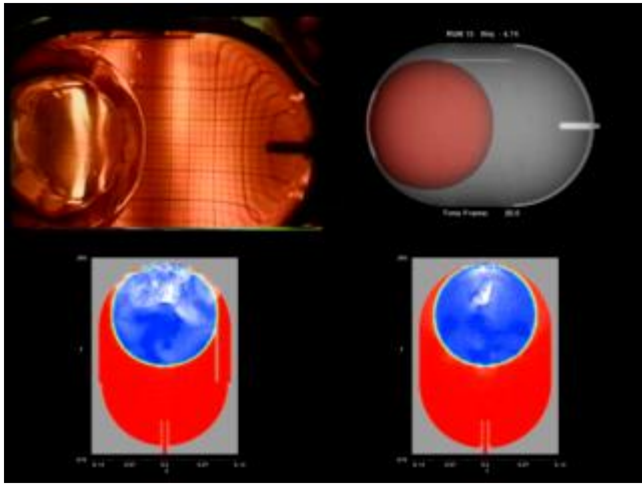


t= 180 s

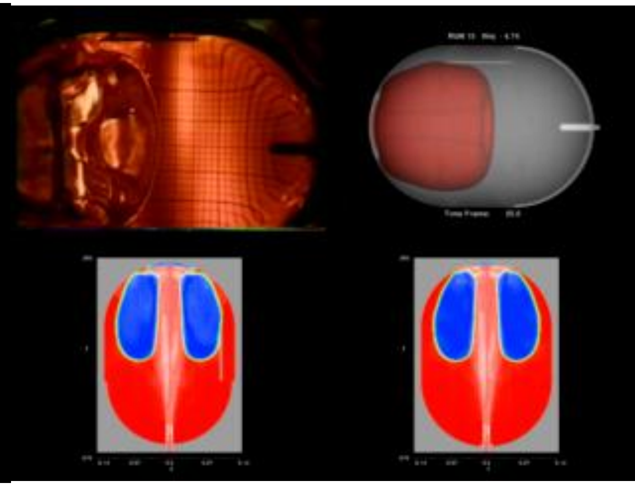


t= 261 s

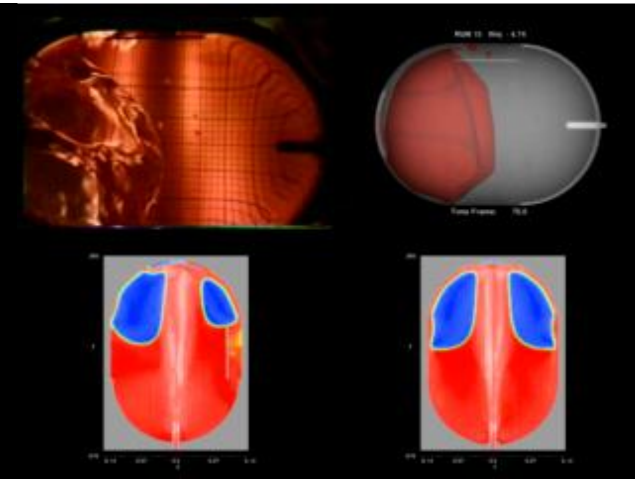
Run 15 We_j – 4.74 Asymmetric



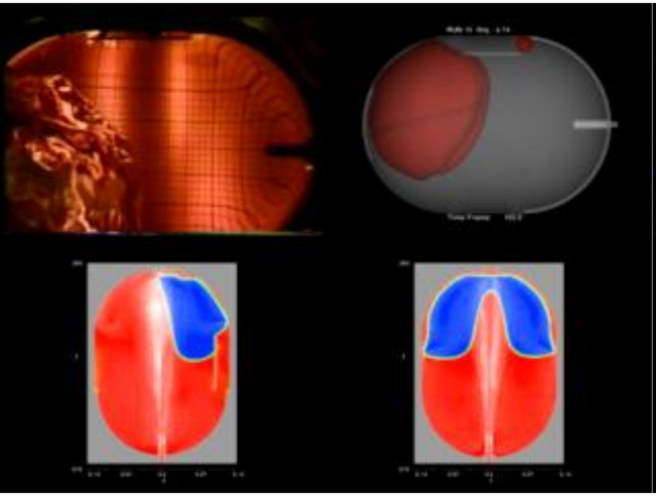
t= 20 s



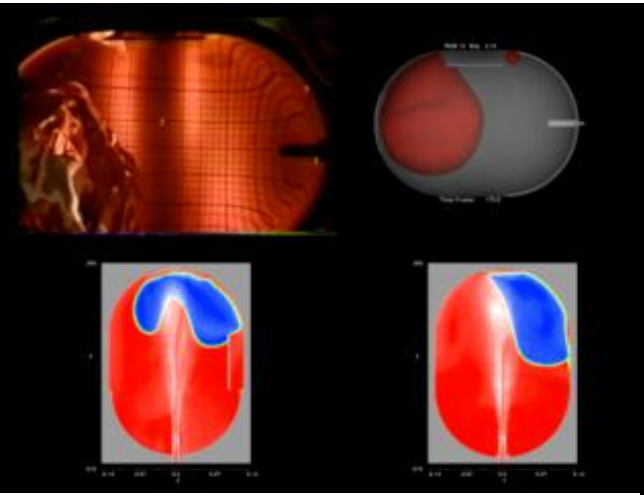
t= 25 s



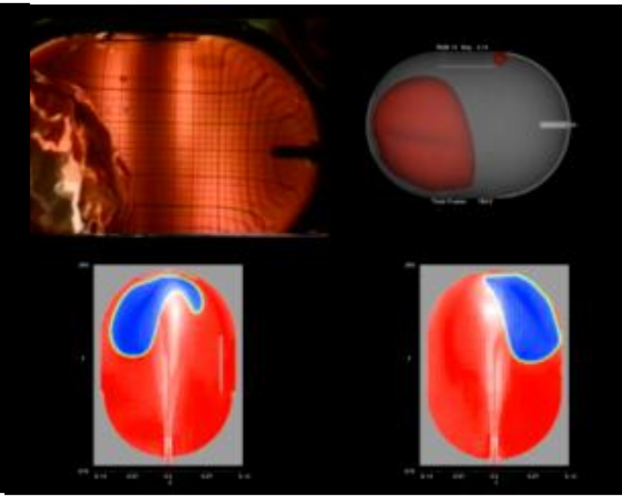
t= 71 s



t= 104 s

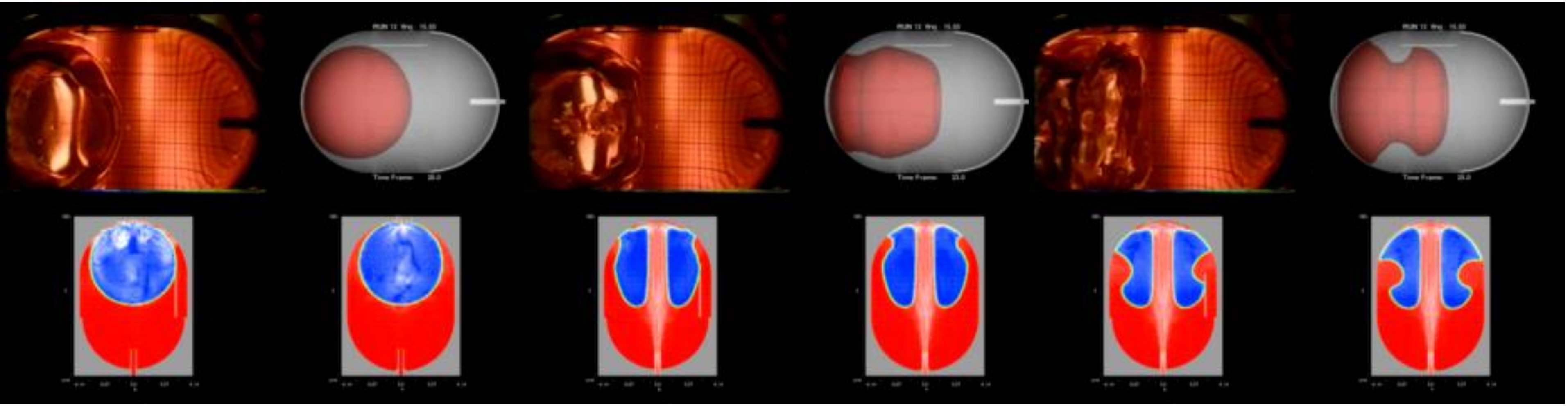


t= 173 s

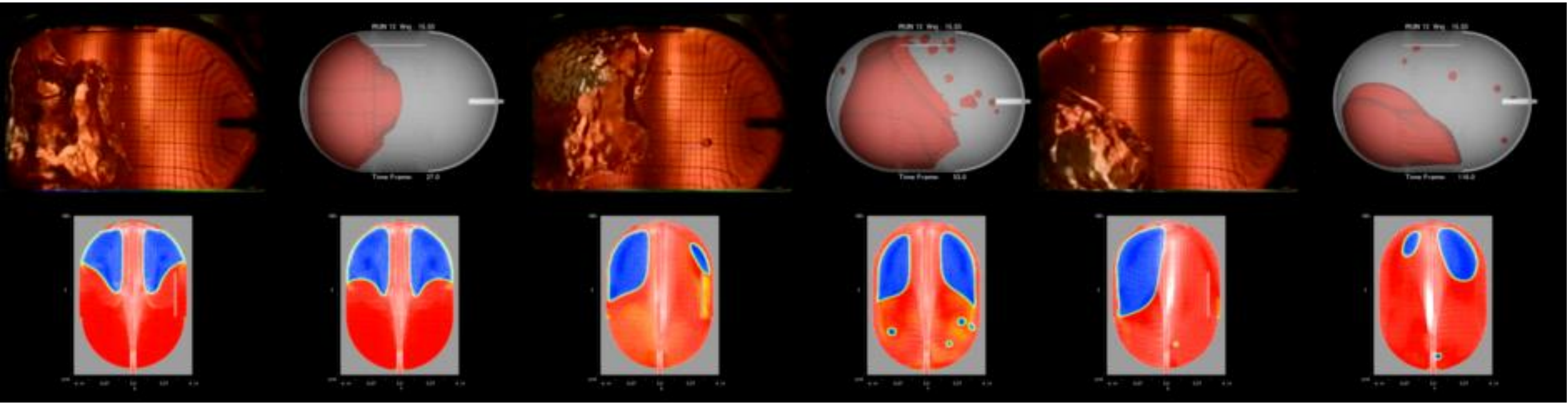


t= 203 s

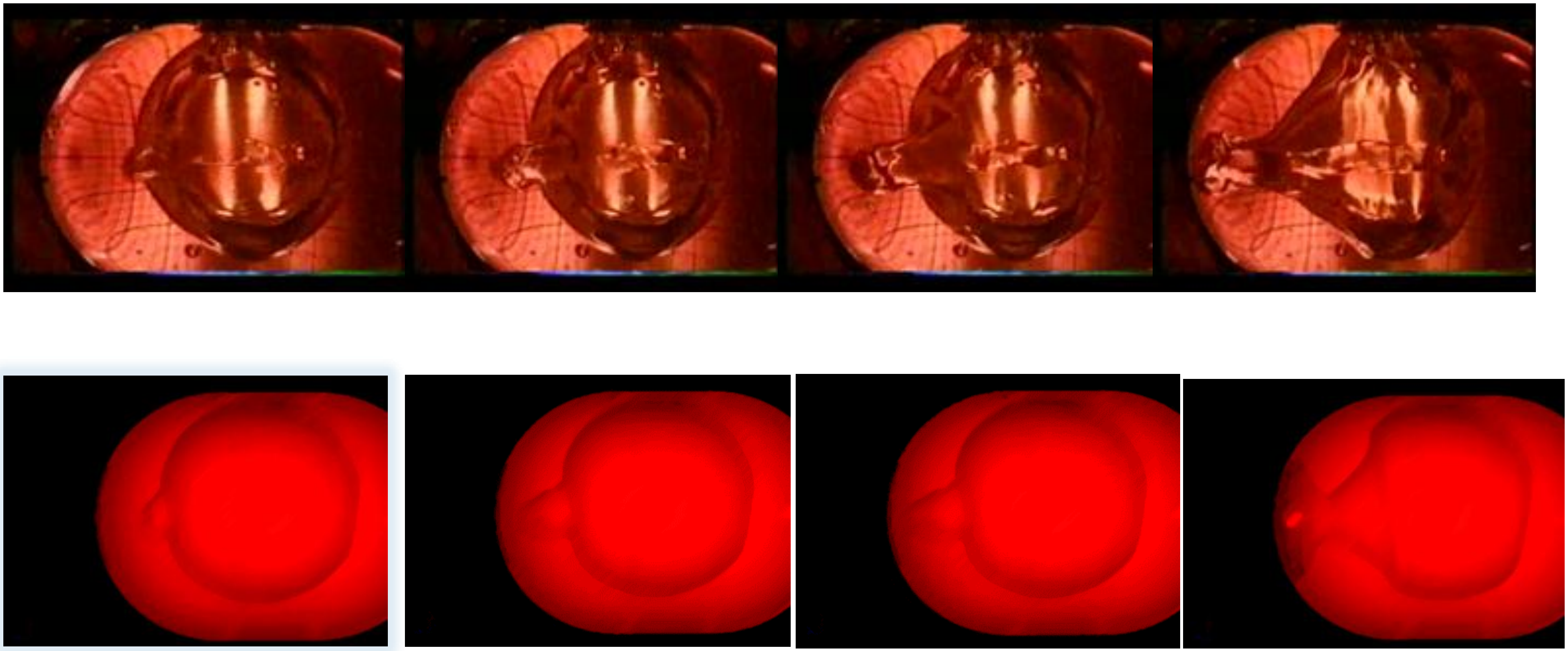
Run 13 We_j – 15.5 Penetrating



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

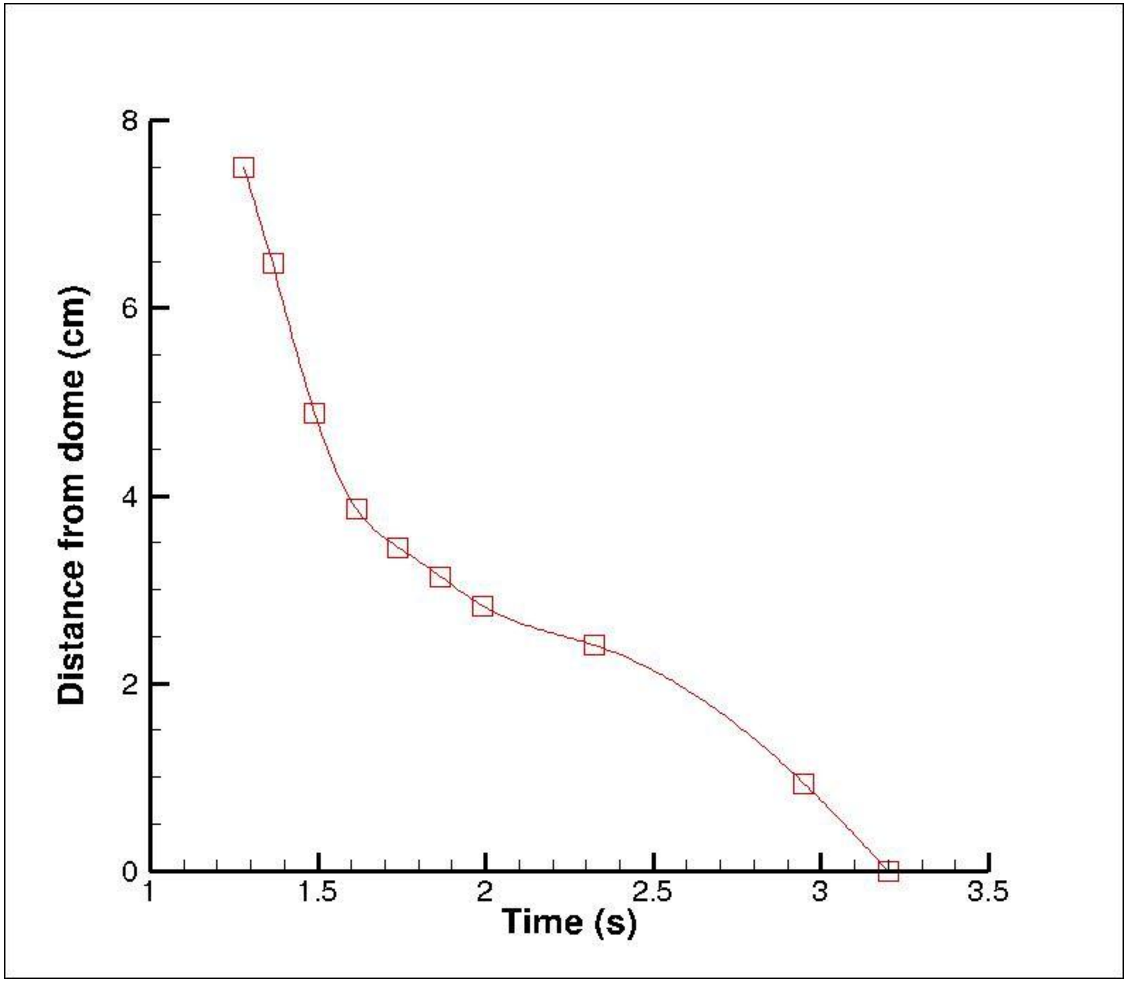


t= 27 s t= 53 s t= 116 s



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