COMPUTATIONAL PREDICTION OF PROPELLANT REORIENTATION

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WORK SUPPORTED BY NASA LeRC
THROUGH GRANT NAG3–578

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COMPUTATIONAL TECHNOLOGY
- SOLA FAMILY
- UNIQUE FEATURES OF NASA–VOF2D

PROPELLANT REORIENTATION
- MOTIVATION
- COMPUTATIONAL DETAILS
- CODE VERIFICATION
- PRELIMINARY RESULTS

NASA–VOF2D

DEVELOPED FOR LeRC BY THE LOS ALAMOS SCIENTIFIC LABORATORY (LASL) AS PART OF AN ONGOING INTERAGENCY AGREEMENT.

GENERAL CAPABILITIES:

- TWO DIMENSIONAL (CARTESIAN OF CYLINDRICAL)
- VARIABLE MESH (ROWS & COLUMNS)
- EULERIAN FORMULATION
- STAGGERED GRID OF PRIMITIVE VARIABLES
- TRANSIENT LAMINAR HYDRODYNAMICS WITH A FREE SURFACE

UNIQUE FEATURES

SOLA: SOLUTION ALGORITHM

VOF: VOLUME-OF-FLUID METHOD

SURFACE TENSION MODEL

PARTIAL CELL BLOCKAGE

PROPELLANT REORIENTATION

MOTIVATION

DESIRE TO PREDICT PROPELLANT MOTION DURING IMPULSIVE SETTLING.

POTENTIAL APPLICATIONS

- CONSERVATION OF PROPELLANT IN NEW DESIGNS
- MATCH EXISTING EQUIPMENT TO NEW APPLICATIONS
- INVESTIGATE NOVEL APPROACHES

CODE VERIFICATION

COMPARE COMPUTATIONAL PREDICTIONS TO EXPERIMENTAL DATA FOR SMALL SCALE TANKS.

6 CASES SELECTED FROM:

SUMNER, I.E.; LIQUID PROPELLANT REORIENTATION IN A LOW–GRAVITY ENVIRONMENT. NASA TM–78969, 1978

- DATA IS FROM LeRC ZERO–GRAVITY FACILITY
- CASES INCLUDE A RANGE OF TEST FLUIDS, ACCELERATION LEVELS, GEYSER HEIGHTS, AND TANK SHAPES
- A CORRELATION IS PROPOSED FOR PREDICTING REORIENTATION PERFORMANCE.

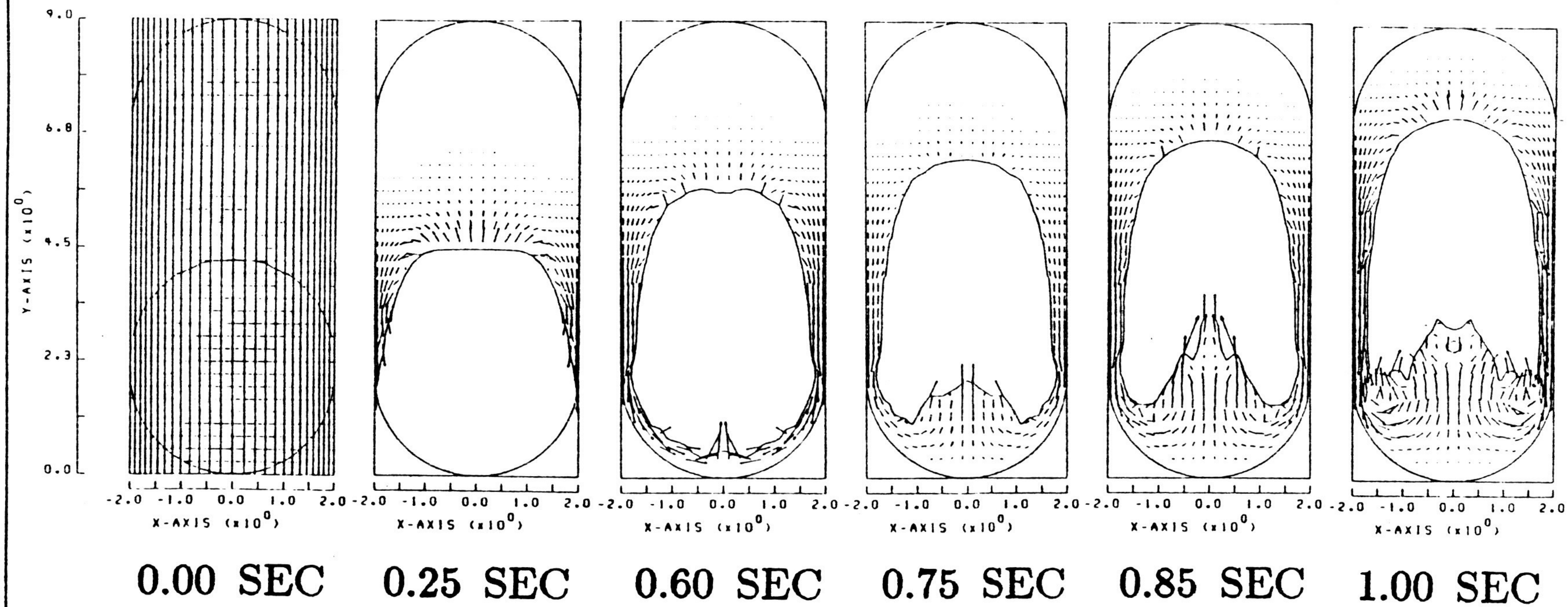
SUMMARY OF TEST CONDITIONS

TEST	TR	FR	FLUID	FL	AT	BO	GEYSER
5	2.0	2.25	ETHANOL	62	29.4	4.2	SMALL
1	1.65	4.0	TCTFE	71	16.7	3.9	SMALL
12	3.22	2.14	ETHANOL	71	10.8	4.0	NONE
6	2.0	2.25	ETHANOL	29	29.4	4.2	LARGE
7	2.0	2.25	METHANOL	51	29.4	4.1	MODERATE
8	2.0	2.25	METHANOL	33	29.4	4.1	LARGE

TR = TANK RADIUS (CM)
FR = FINENESS RATIO
FL = FILL LEVEL (%)
AT = TANK ACCELERATION (CM/SEC**2)
BO = BOND NUMBER
TCTFE = TRICHLOROTRIFLUOROETHANE

CODE VERIFICATION

TEST 5



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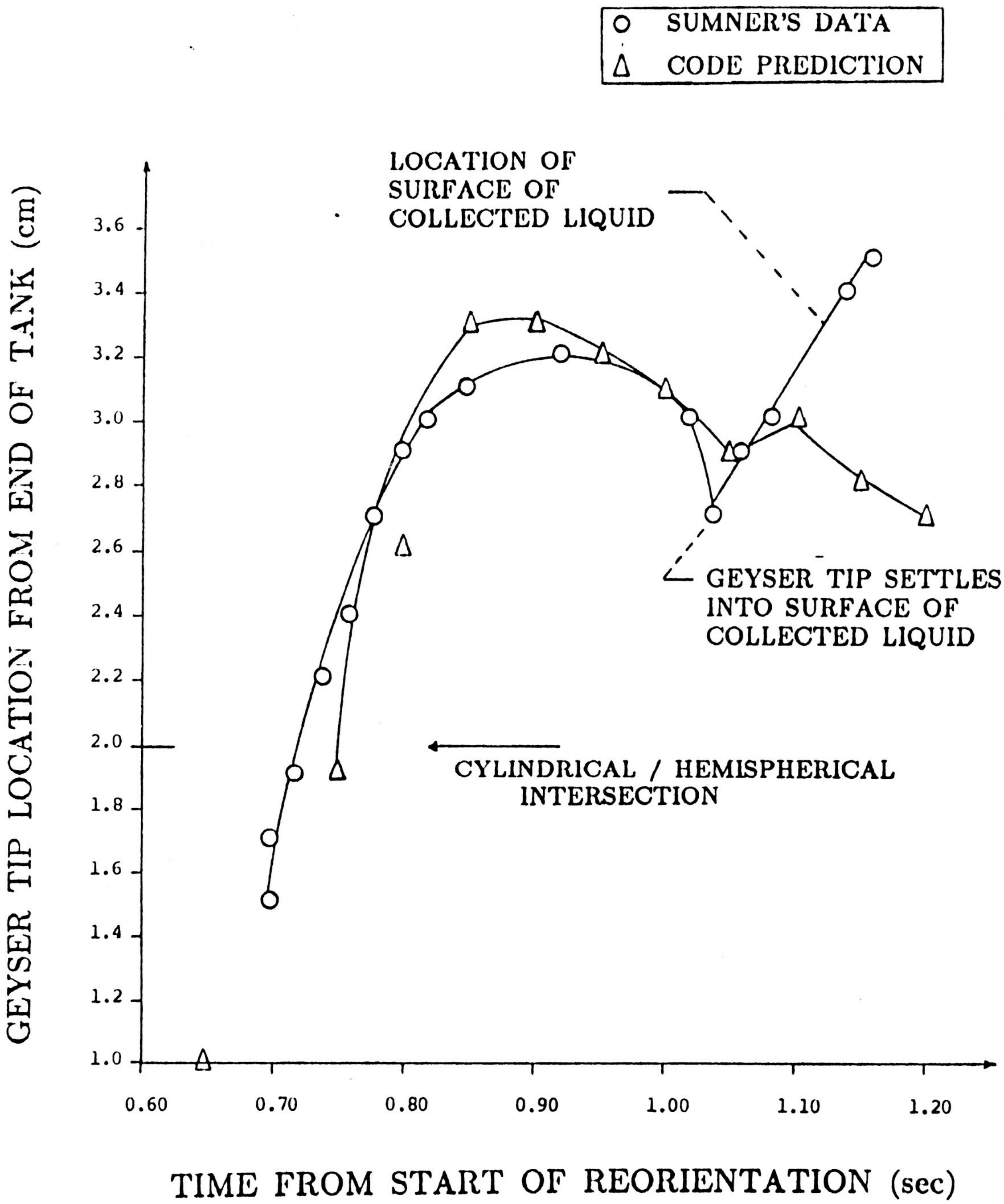
TEST 5: GEYSER TIP LOCATION



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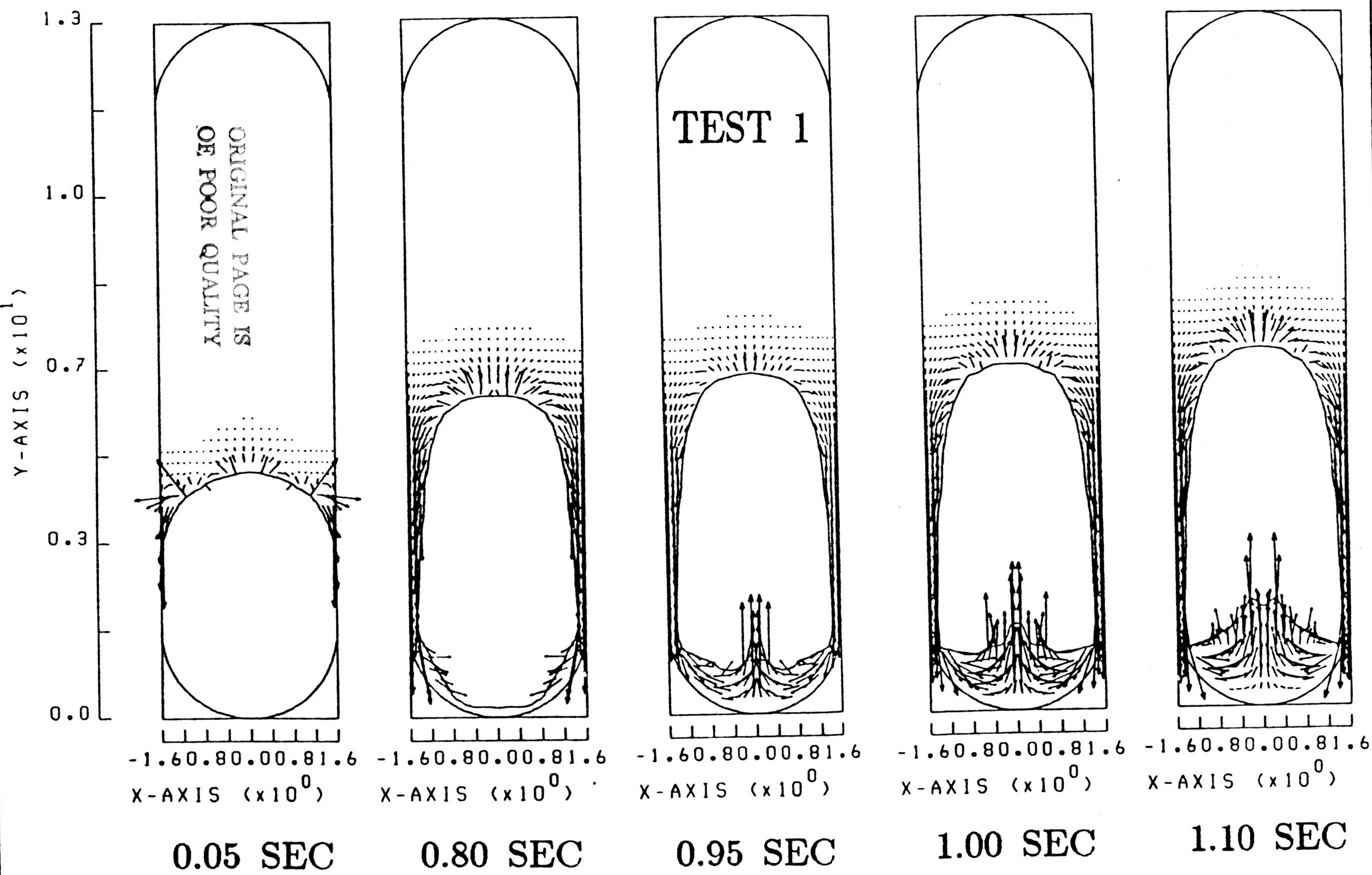

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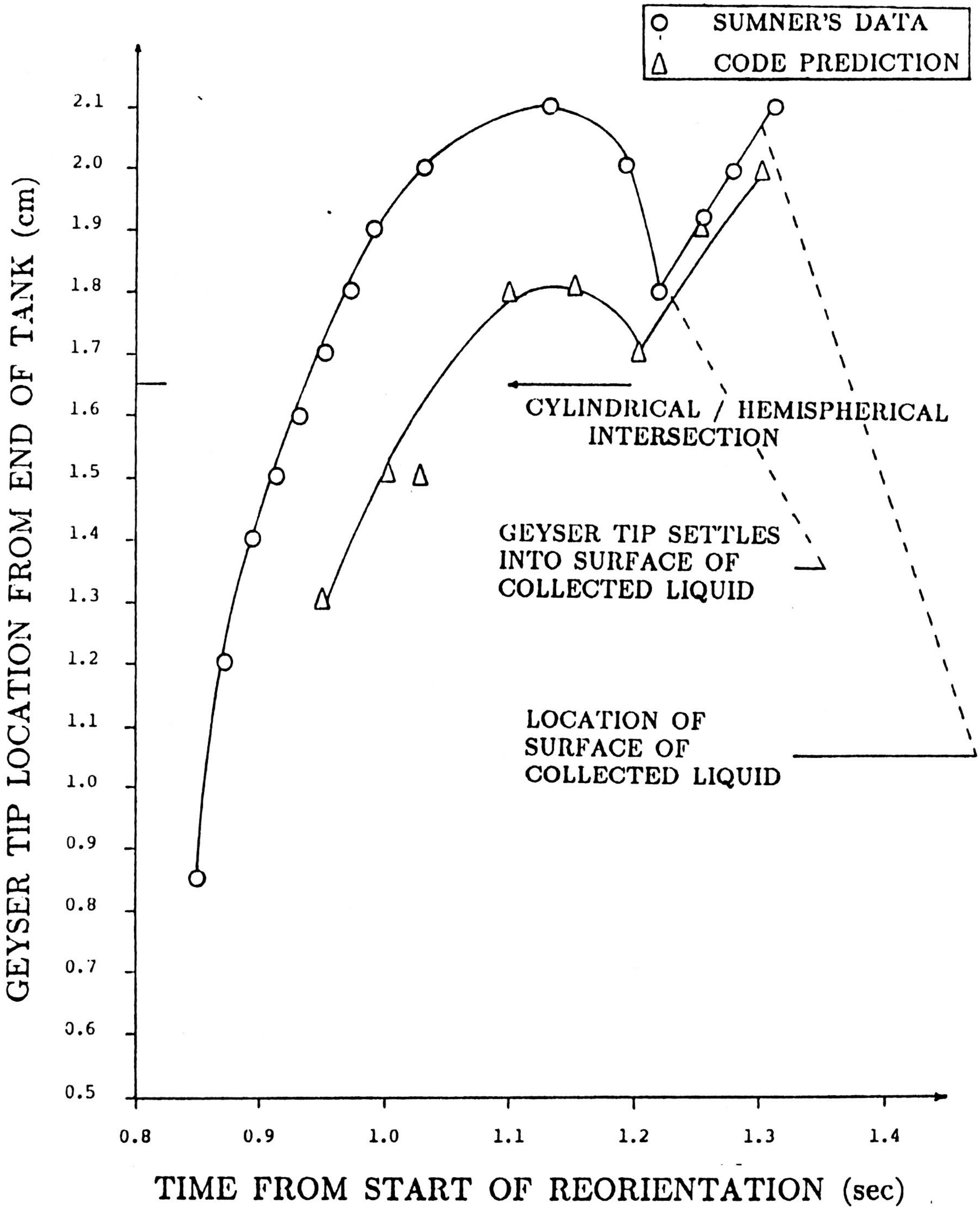
TEST 1: GEYSER TIP LOCATION



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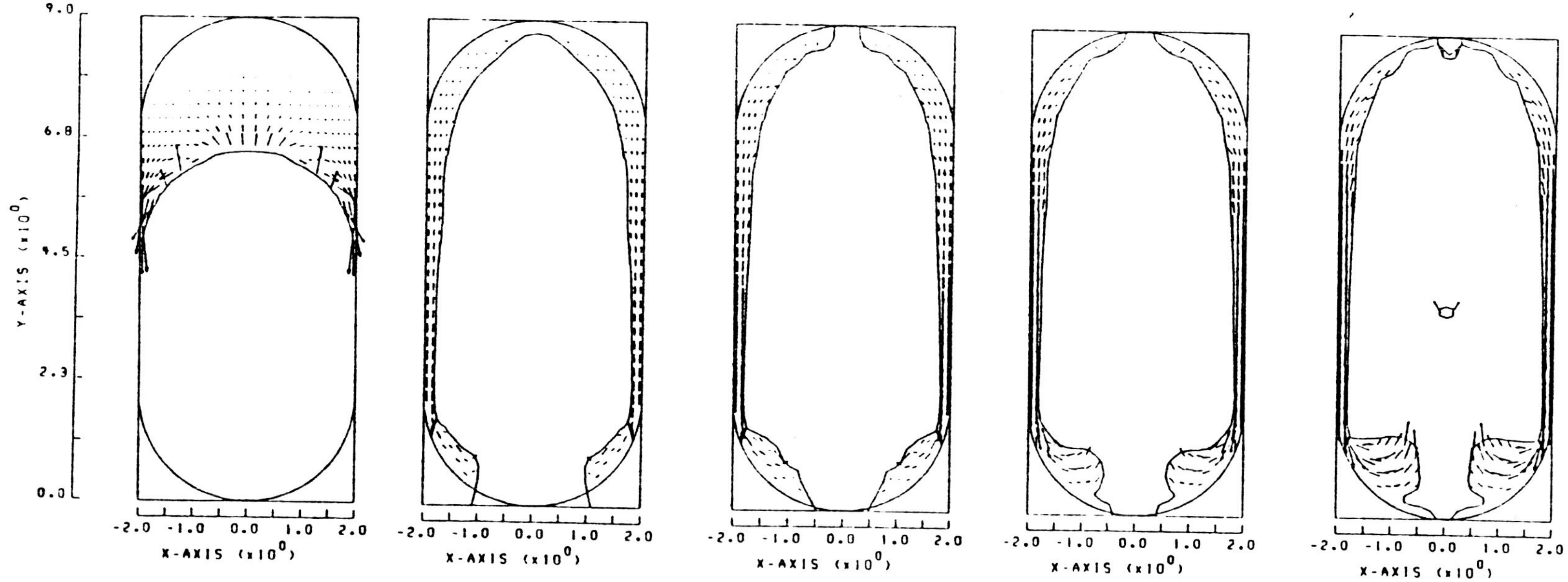
TEST 8



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CONCLUSIONS ABOUT CODE PERFORMANCE

- AGREEMENT BETWEEN EXPERIMENTAL DATA AND COMPUTATIONAL PREDICTIONS RANGES FROM EXCELLENT TO FAIR.

- DIFFICULTY WITH SURFACE FOAMING APPEARS IN SOME ANALYSES, REQUIRES FURTHER EVALUATION AND POSSIBLY ALGORITHM MODIFICATION.

PULSED SETTLING

CONCEPT

REPLACE A CONSTANT THRUST (ACCELERATION) LEVEL WITH INTERMITTENT PULSED ACCELERATIONS TO IMPROVE EFFICIENCY AS MEASURED BY PROPELLANT CONSUMPTION.

SPECIFIC CASE STUDY

CFMFE: PRIOR TO TANK–TO–TANK LIQUID TRANSFER, THE LIQUID IN THE SUPPLY TANK MUST BE POSITIONED OVER THE OUTLET.

PROBLEM: ACCELERATION IMPARTED BY FIRING SHUTTLE RCS THRUSTERS FAR EXCEEDS OPTIMAL LEVEL

SOLUTION: PULSED OPERATION?

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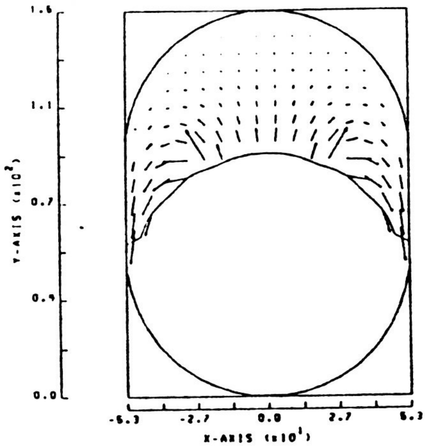
PREDICTIONS FOR 1/4 SCALE CFMFE TANK



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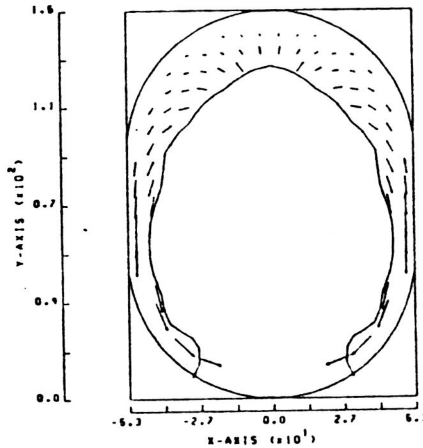

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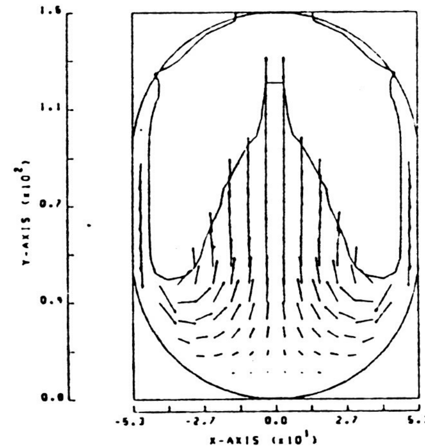

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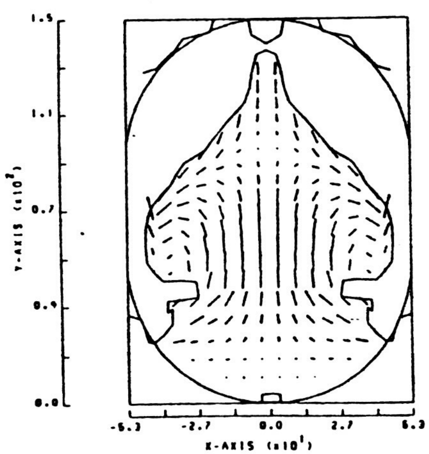

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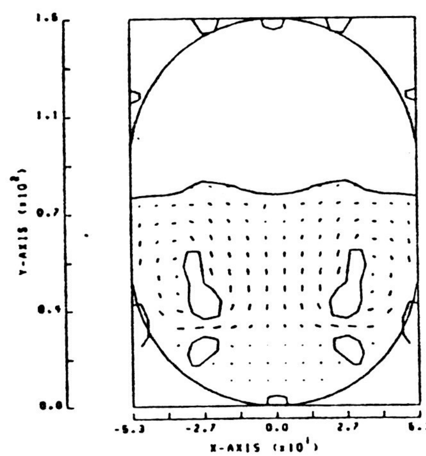

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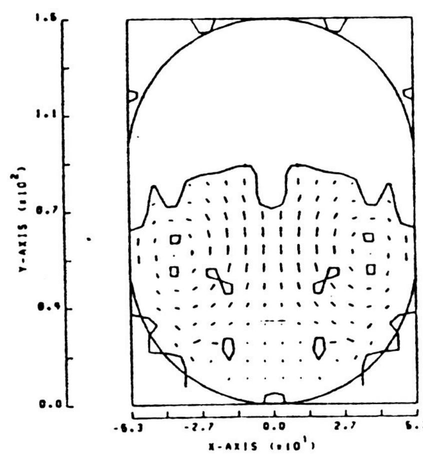

20.0 SEC

A = 0.008g's

REORIENTATION

PARAMETERS WHICH GOVERN OR DESCRIBE PULSED SETTLING PERFORMANCE.

- –SETTLING TIME
- –PULSE FREQUENCY
- –PULSE MAGNITUDE
- –PULSE DURATION
- –PROPELLANT CONSUMPTION

SUMNER'S CORRELATION WAS USED TO PREDICT AN OPTIMAL STEADY ACCELERATION FOR REORIENTING THE LIQUID IN THE CFMFE.

ACCELERATION = 0.036 CM/SEC = 0.000037 g's

SETTLING TIME = 63 SECONDS

VEHICLE DELTA V = 2.3 CM/SEC

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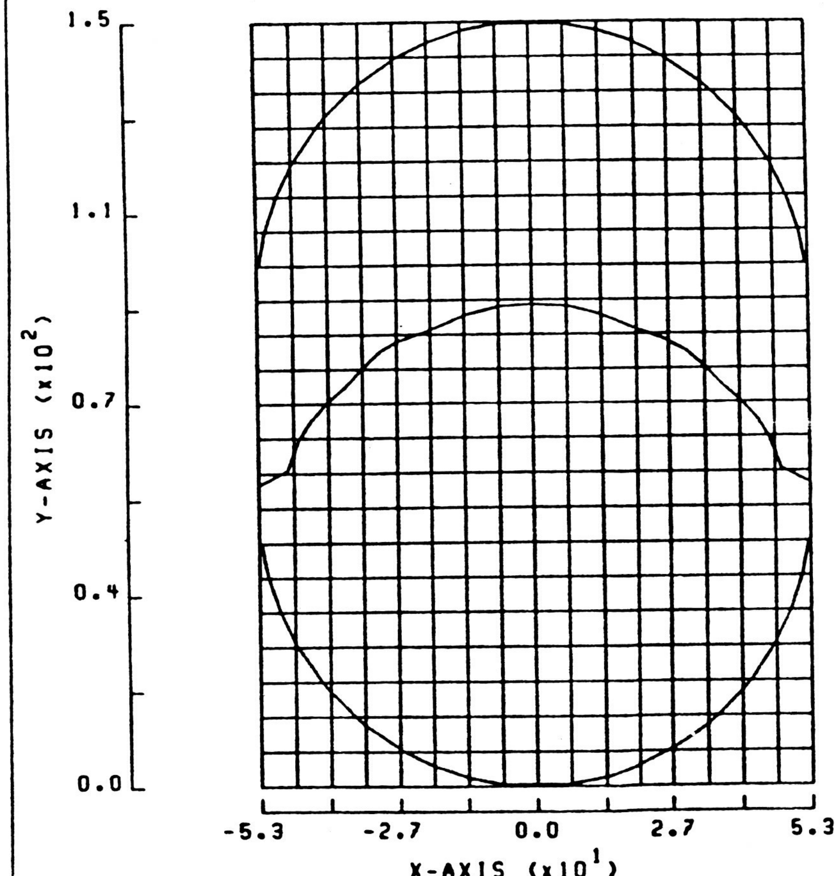
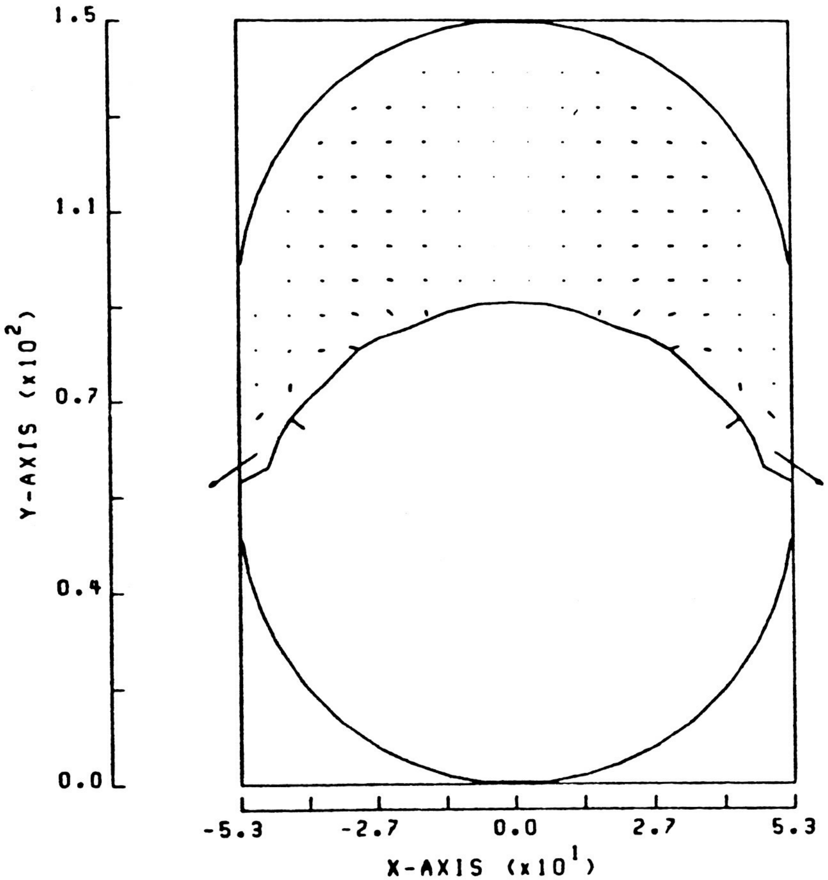
PREDICTIONS FOR 1/4 SCALE CFMFE TANK

OPTIMAL STEADY ACCELERATION (SUMNER)



COMPUTATIONAL MESH



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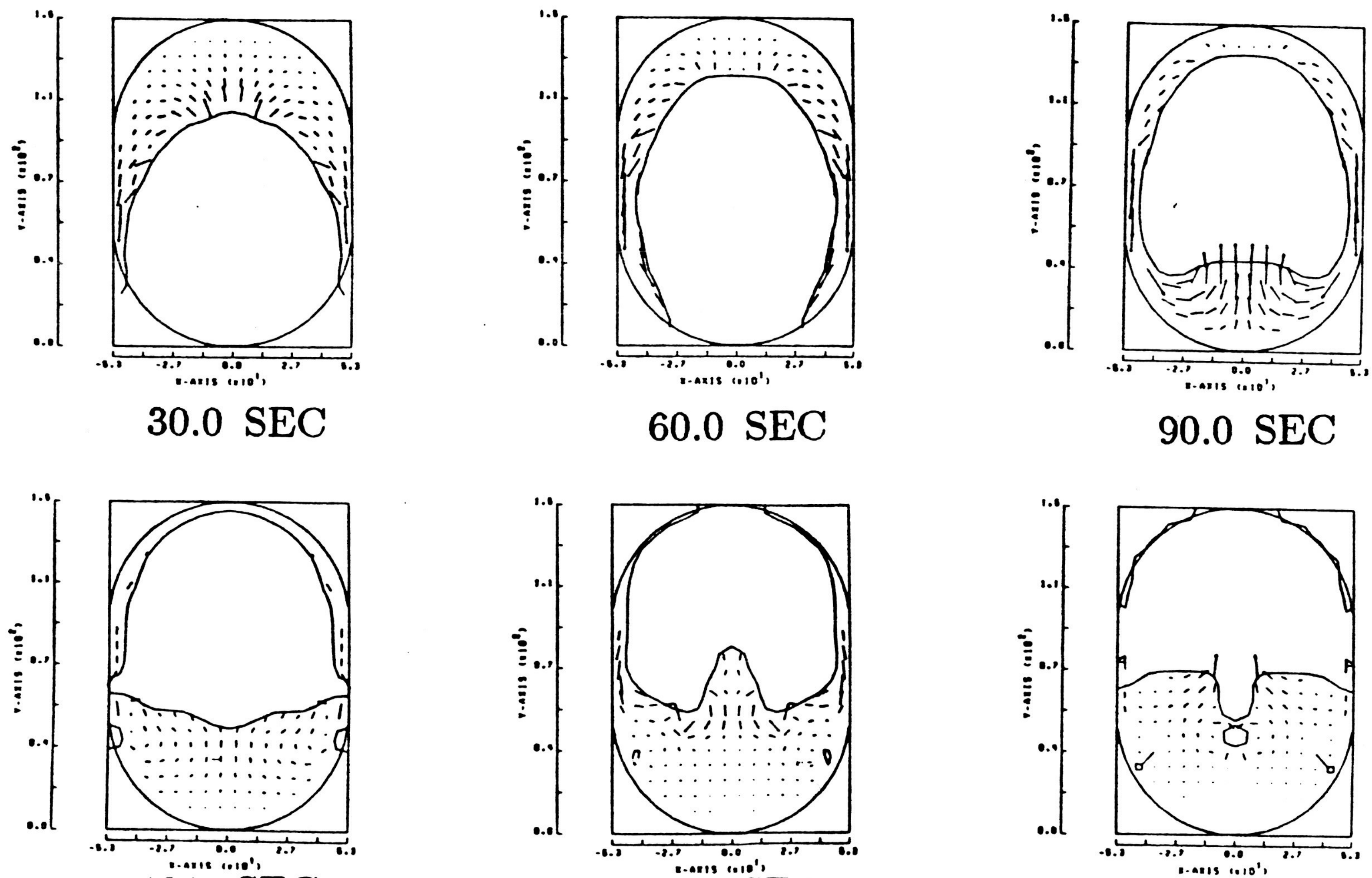
PREDICTIONS FOR 1/4 SCALE CFMFE TANK



OPTIMAL STEADY ACCELERATION (SUMNER)

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PULSED SETTLING

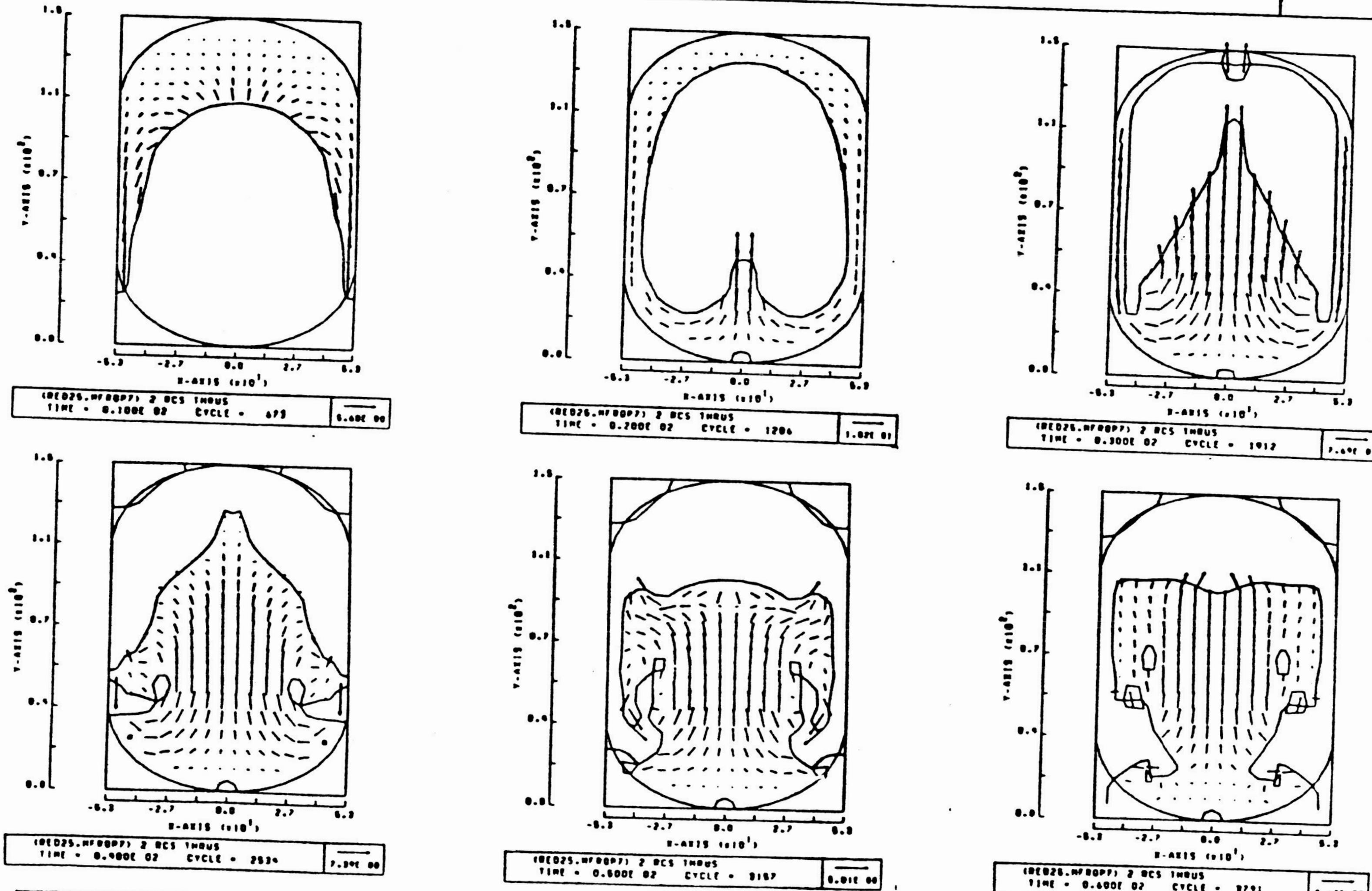
PARAMETER VALUES USED IN PRELIMINARY STUDY

TANK	CFMFE 25%
FILL	50% FULL
BACKGROUND ACCEL	ZERO
FLUID	LIQUID HYDROGEN
PULSE MAGNITUDE	0.008g's (2 RCS)
PULSE FREQUENCY	0.1 – 1.5 Hz
PULSE DURATION	0.1 & 0.2 SEC

PROPELLANT IS CONSIDERED SETTLED WHEN THE DISTANCE BETWEEN THE FREE SURFACE AT THE TANK CENTERLINE AND THE OUTLET EXCEEDS 20% OF THE TOTAL TANK LENGTH.

PULSED SETTLING

20/27



DURATION = 0.1 sec FREQUENCY = 0.7 Hz

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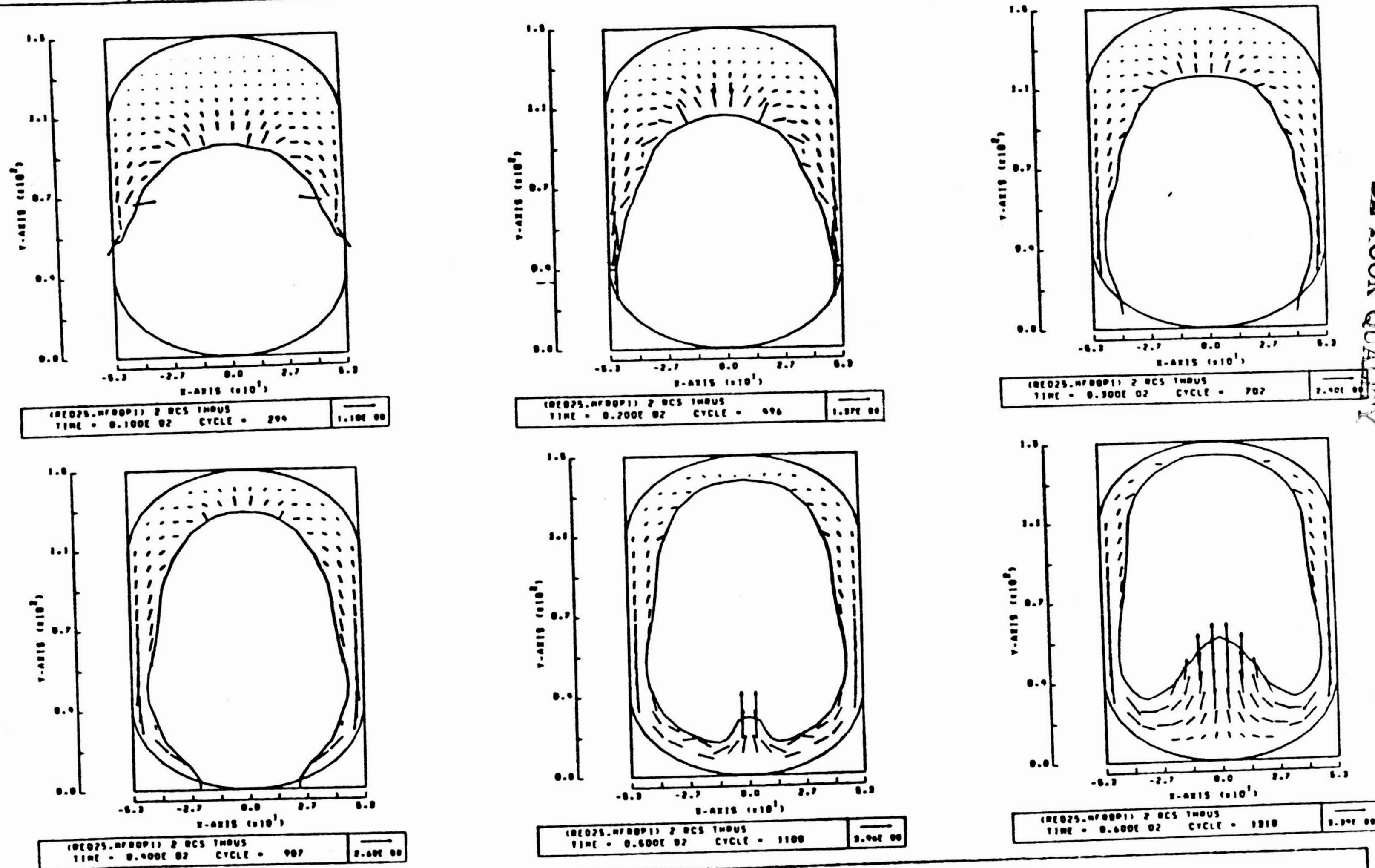
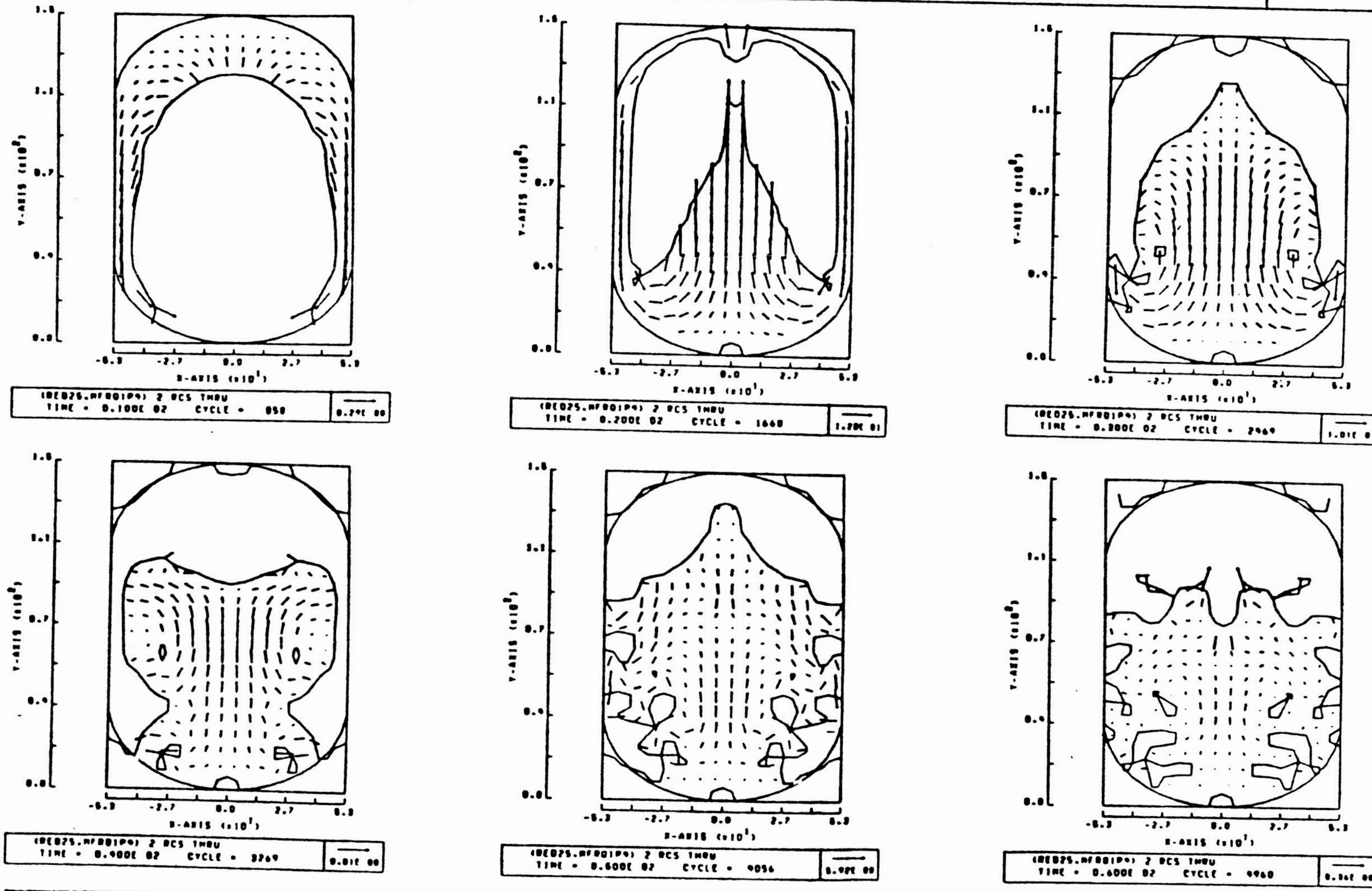


DURATION = 0.1 sec   FREQUENCY = 0.1 Hz

PULSED SETTLING



DURATION = 0.1 sec   FREQUENCY = 1.4 Hz

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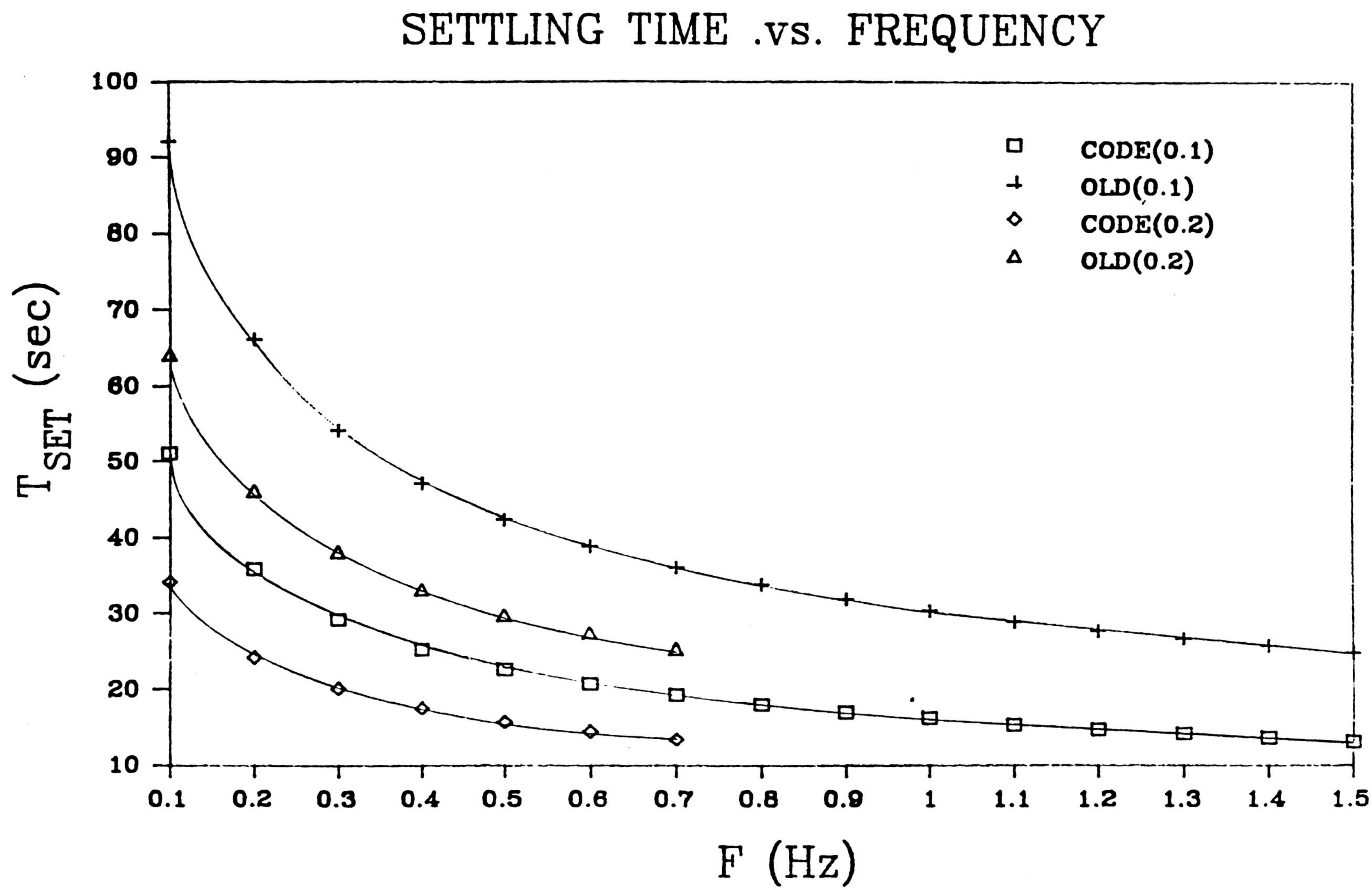
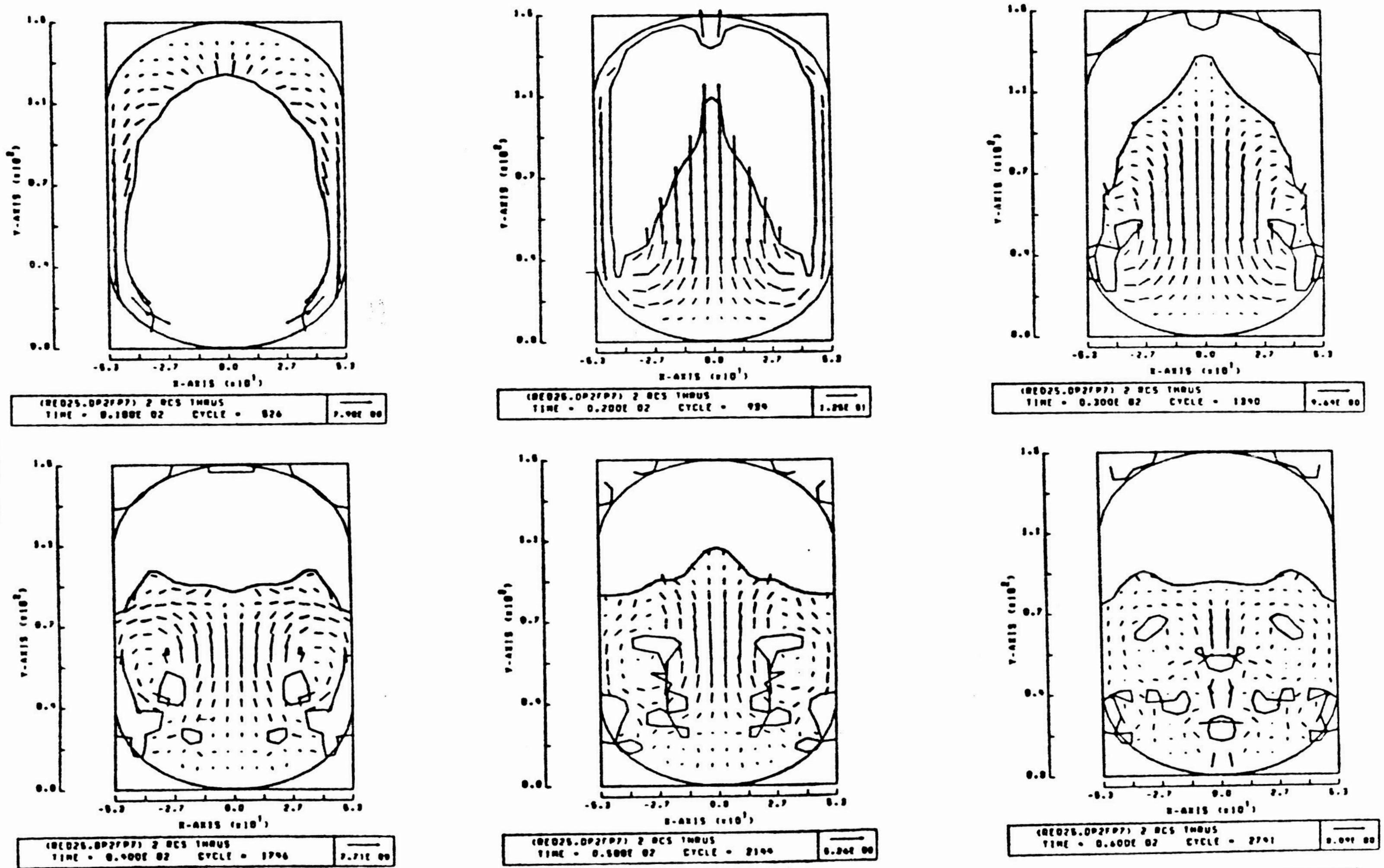
PRELIMINARY RESULTS



PULSED SETTLING



DURATION = 0.2 sec FREQUENCY = 0.7

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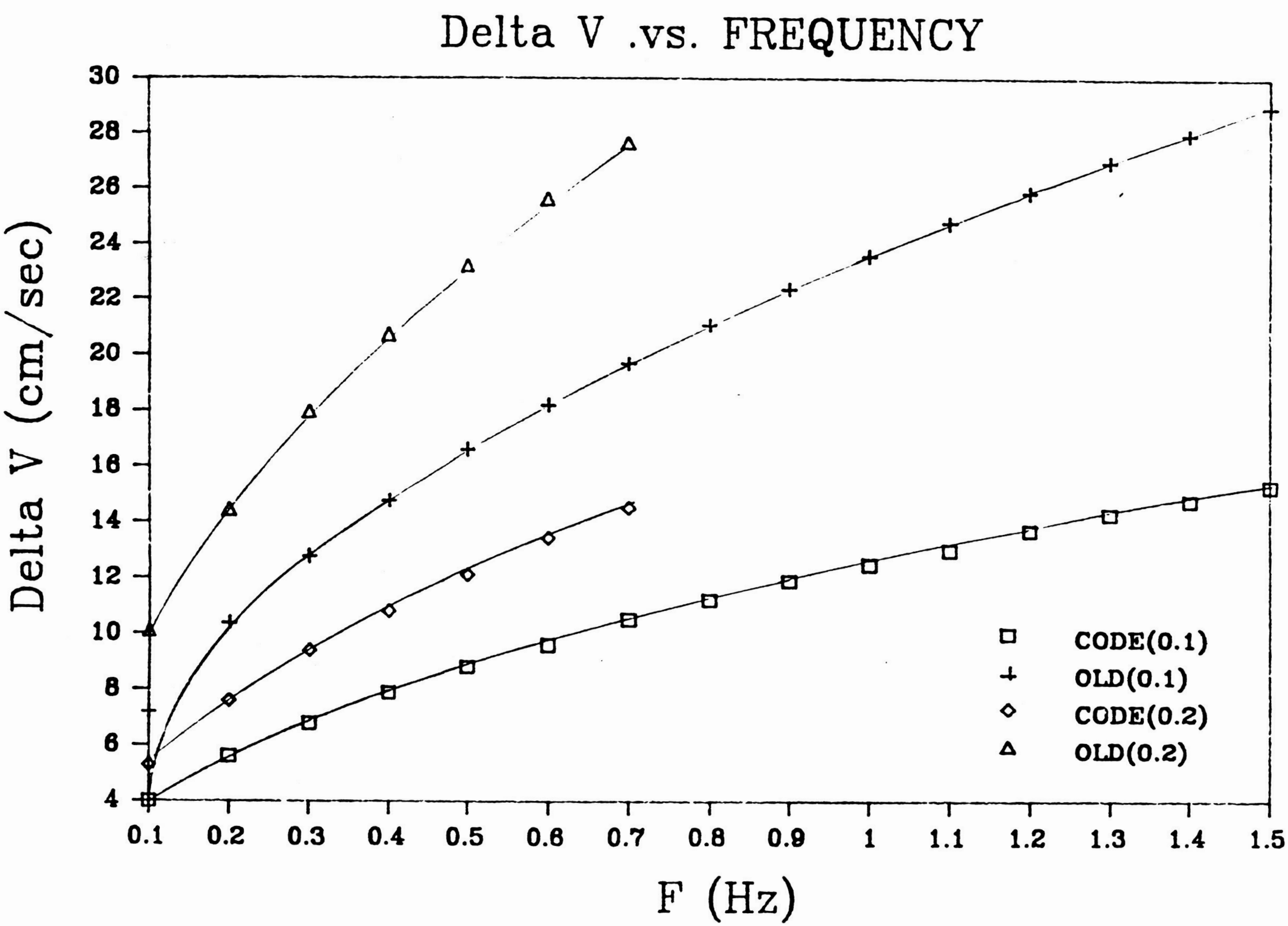
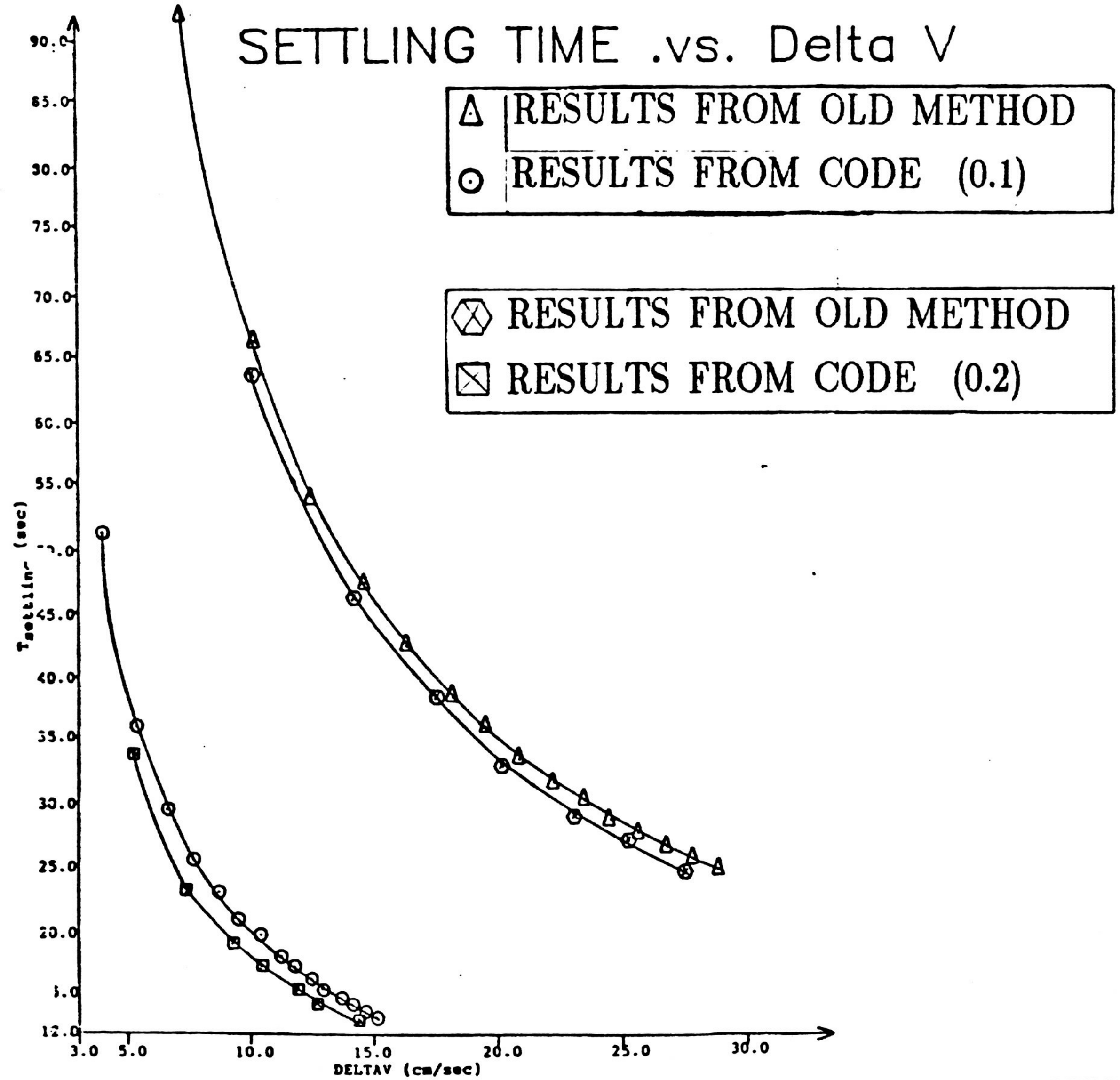
PRELIMINARY RESULTS



PRELIMINARY RESULTS

SETTLING TIME .vs. Delta V



PLANED EFFORTS

- STUDY SURFACE FOAMING PROBLEM UNCOVERED DURING VERIFICATION PHASE. MODIFY ALGORITHM IF NECESSARY.

- EXPAND PRELIMINARY STUDY INTO A FULL RANGE PARAMETER STUDY OF PULSED SETTLING IN A TYPICAL ORBIT TRANSFER VEHICLE PROPELLANT TANK.

SPEAKER: JOHN I. HOCHSTEIN/WASHINGTON UNIVERSITY

James J. Der/Aerospace Corporation:

Did you compare your result with results from the FLOW-3D or HYDR-3D codes, particulary on the foaming problem?

Hochstein:

No we haven't. As you know, the three dimensional codes are more complex, so you get considerably more computational expenses to do that. One of the differences between that code and what we are working with is that the free surface, both the free surface algorithm which works the VOF function, which moves the volume of fluid around, is a little more sophisticated in this code and the surface tension model is considerably more detailed. In FLOW-3D, there would be a substantial computational expense in three dimensions to compute that. What I will say is that when we worked with an earlier version of SOLA-VOF, the mixing problem I alluded to did not have surface foaming in it. That is another reason why we are reasonably convinced it is a computational problem which we haven't identified yet.

Robert S. Rudlin/Martin Marietta Denver Aerospace:

The problem I think you are trying to model is one where you've settled the liquid and then you either drain the liquid out the bottom or you take the gas out the top. This means you could very easily have a boiling situation or you could have bubbles entrained in the outflow, which is a three dimensional problem. Are you planning on doing work in that area in the future so you could understand the draining problem without getting gas in the liquid or the venting problem without getting boiling and liquid going out your vents?

Hochstein:

That is certainly the direction we would like to head. Some of the ongoing work that Lewis is sponsoring is doing things like developing heat transfer and thermodynamic capabilities for this code. As far as the 3-D versus the 2-D effects, I think we can do some good work with the 2-D code before we move on to a 3-D code if we just keep the vents and outlets on the axis. That is work that we intend to do.