CFD ANALYSIS OF THE 24-INCH JIRAD HYBRID ROCKET MOTOR

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ABSTRACT

A series of multispecies, multiphase CFD analyses of the 24-inch diameter joint government/industry IR&D (JIRAD) hybrid rocket motor is described. The 24-inch JIRAD hybrid motor operates by injection of liquid oxygen (LOX) into a vaporization plenum chamber upstream of ports in the hydroxyl-terminated polybutadiene (HTPB) solid fuel. Injector spray pattern had a strong influence on combustion stability of the JIRAD motor so a CFD study was initiated to define the injector-end flow field under different oxidizer spray patterns and operating conditions. By using CFD to gain a clear picture of the flow field and temperature distribution within the JIRAD motor, it is hoped that the fundamental mechanisms of hybrid combustion instability may be identified and then suppressed by simple alterations to the oxidizer injection parameters such as injection angle and velocity.

The simulations in this study were carried out using the GALACSY (General ALgorithm for Analysis of Combustion SYstems) multiphase combustion codes. GALACSY consists of a comprehensive set of droplet dynamic submodels (atomization, evaporation, etc.) and a computationally efficient hydrocarbon chemistry package built around a robust Navier-Stokes solver optimized for low Mach number flows. Lagrangian tracking of dispersed particles describes a closely coupled spray phase.

The CFD cases described in this paper represent various levels of simplification of the problem. They include: (A) gaseous oxygen with noncombusting fuel vapor blowing off the walls at various oxidizer injection angles and velocities, (B) gaseous oxygen with combusting fuel vapor blowing off the walls, and (C) liquid oxygen with combusting fuel vapor blowing off the walls. The study used an axisymmetric model and the results indicate that the injector design significantly effects the flow field in the injector-end of the motor. Markedly different recirculation patterns are observed in the vaporization chamber as oxygen velocity and/or spray pattern is varied. The ability of these recirculation patterns to stabilize the diffusion flame above the surface of the solid fuel gives a plausible explanation for the experimentally determined combustion stability characteristics of the JIRAD motor, and suggests how combustion stability can be assured by modifications to the injector design. Planned future activities to the submodels which allow for additional degree of realism will be discussed.

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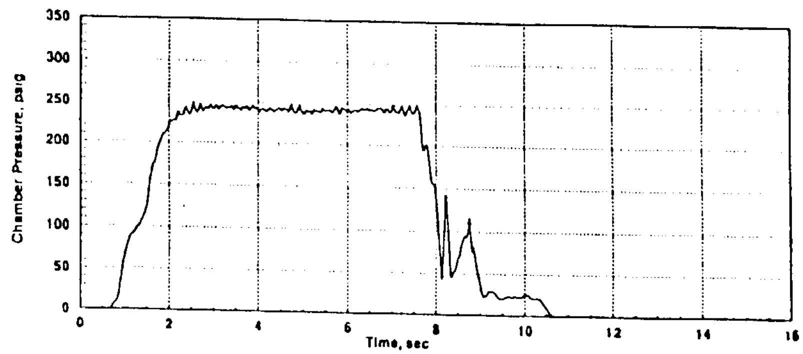
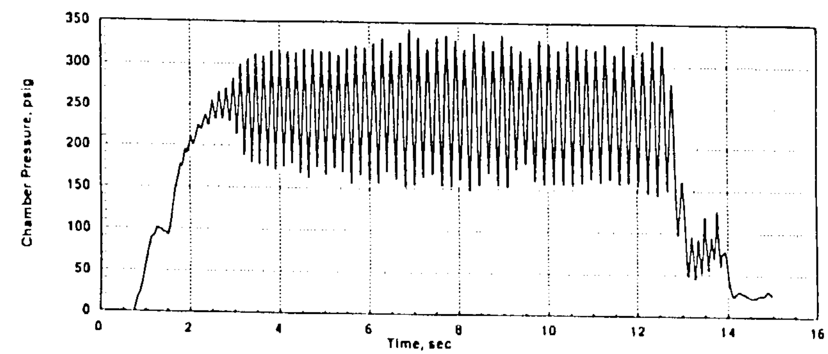
OVERVIEW

- ISSUE: SIGNIFICANT INCREASES IN PRESSURE OSCILLATION RECORDED DURING TESTING OF ANGLED AND STRAIGHT LOX INJECTORS

STRAIGHT

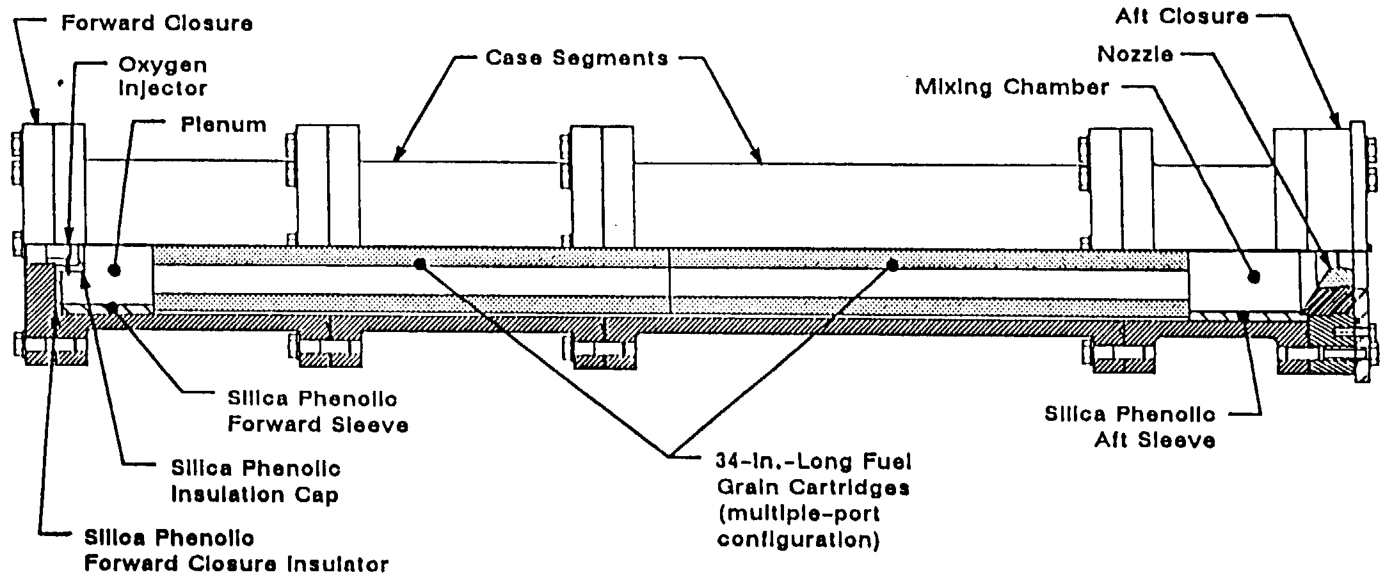


ANGLED



- GOAL: TO GAIN AN UNDERSTANDING OF THE PHYSICAL MECHANISMS OF HYBRID ROCKET MOTOR COMBUSTION AND THE CONDITIONS LEADING TO COMBUSTION OSCILLATIONS

HYBRID ROCKET MOTOR



- LIQUID / GAS OXIDIZER INJECTED INTO VAPORIZATION CHAMBER
- SOLID FUEL SUBLIMATES WHICH THEN REACTS WITH OXIDIZER
- INJECTOR-END RECIRCULATION PATTERN DEEMED CRITICAL TO COMBUSTION STABILITY AND FLAME HOLDING MECHANISMS

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PLAN

APPROACH:

- USE GALACSY CFD COMBUSTION CODE FOR CFD ANALYSIS
- CONDUCT SERIES OF ANALYSES AT SEVERAL LEVELS OF SOPHISTICATION TO IDENTIFY BASIC FLUID DYNAMIC MECHANISMS

• MODEL

- TWO ZONE, AXISYMMETRIC (STEPS 1,2, & 3)
- WALL BLOWING FUEL REPRESENTING SUBLIMATION PROCESS
- O_2/RP-1 CHEMISTRY

• PLAN:

- STEP 1 - THREE NON REACTING GOX FLOW CALCULATIONS WITH DIFFERENT INLET CONDITIONS (COMPLETED)
- STEP 2 - ANGLED AND STRAIGHT REACTING GOX CASES (COMPLETED)
- STEP 3 - LOX STREAM REPRESENTED AS FULLY ATOMIZED DROPS; STRAIGHT AND ANGLED FLOW (IN PROGRESS)
- STEP 4 - MULTI-PORT COMBUSTOR, STRAIGHT AND ANGLED FLOW

GALACSY CODE

- **PRESSURE-BASED, EXTENDED SIMPLE-S SEQUENTIAL SOLVER METHODOLOGY (REACT PLATFORM)**
- **LAGRANGIAN DROPLET TRACKING, "ONION SKIN" EVAPORATION MODEL**
- **EXPLICIT INTER-ZONAL COUPLING FOR MULTIZONE PROBLEMS**
- **GLOBAL FINITE RATE REACTION FOR HYDROCARBON FUEL PLUS H/O EQUILIBRIUM CHEMISTRY (VALIDATED FOR CH4)**
  - RP1 (REPRESENTED AS $C_{12.449}H_{24.47}$) CHEMISTRY REQUIRES 10 SPECIES

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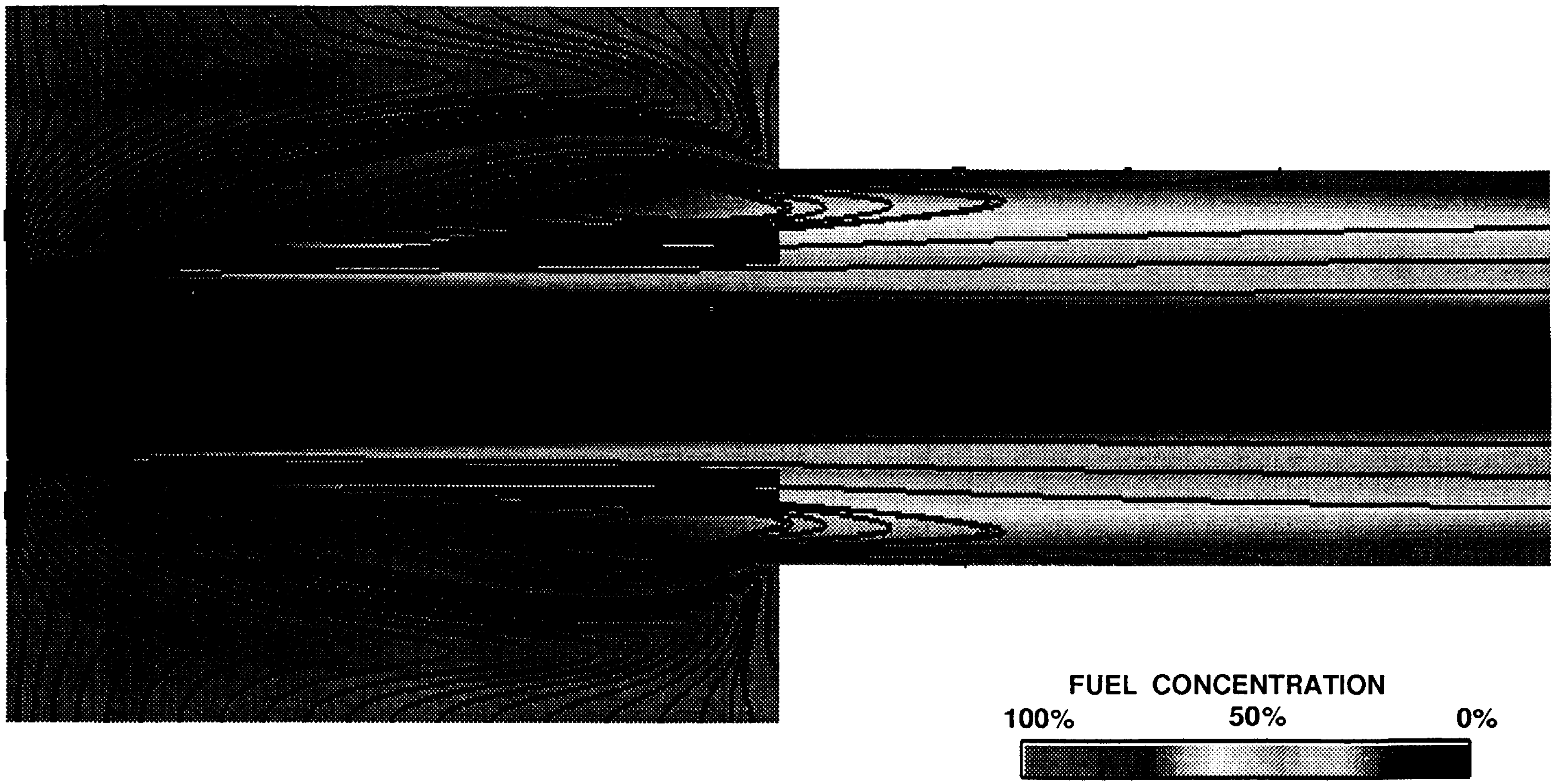
STEP 1 – NON REACTING RESULTS

CASE 1 RESULTS*



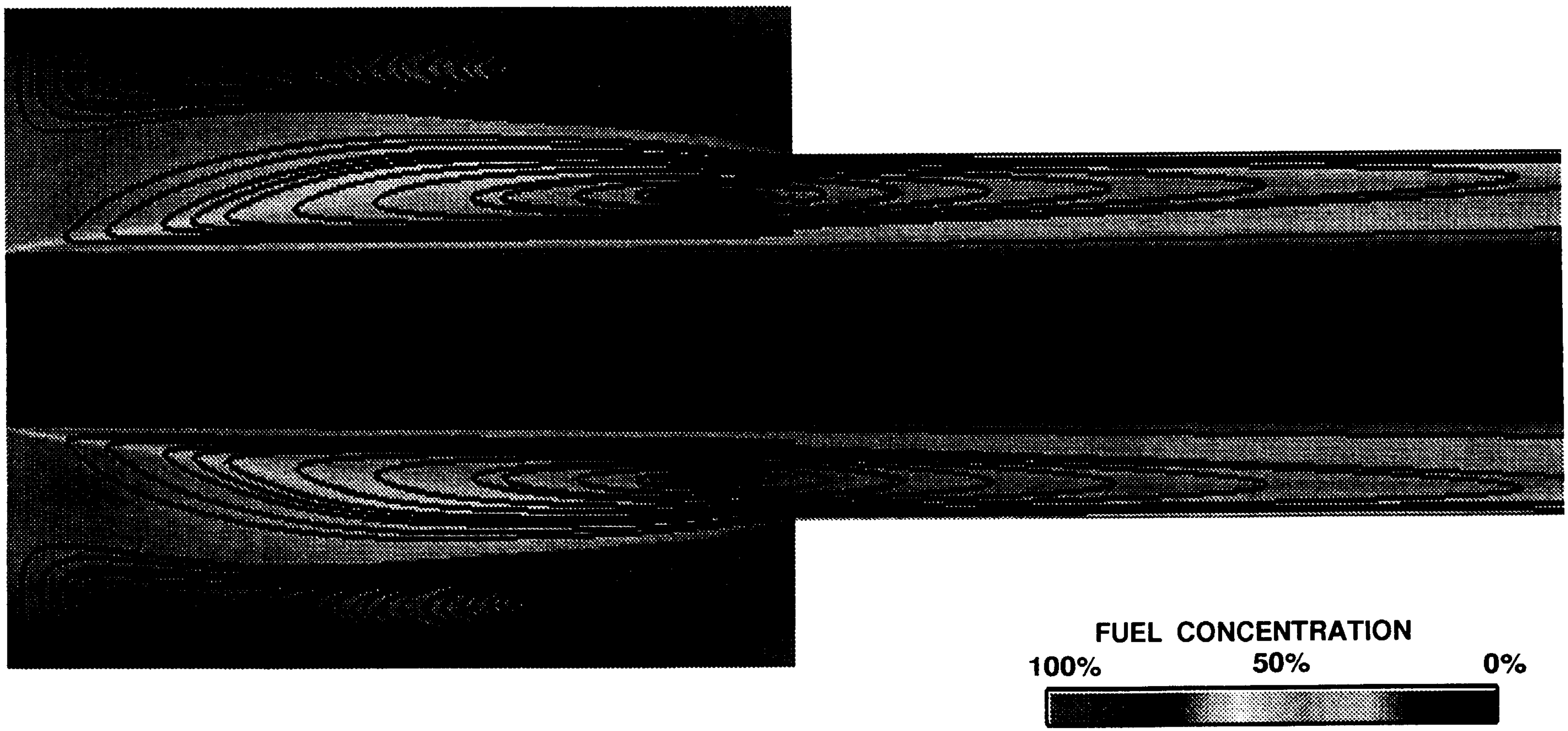
CONDITIONS: TWO ZONE: 90x40, 100x16

GOX, Tin=293^{O} K, Uin=47 m/s

* IMAGE TRUNCATES COMPUTATIONAL DOMAIN AND PARTICLE TRACES DO NOT MOVE BETWEEN ZONES

STEP 1 – NON REACTING RESULTS

CASE 2 RESULTS*



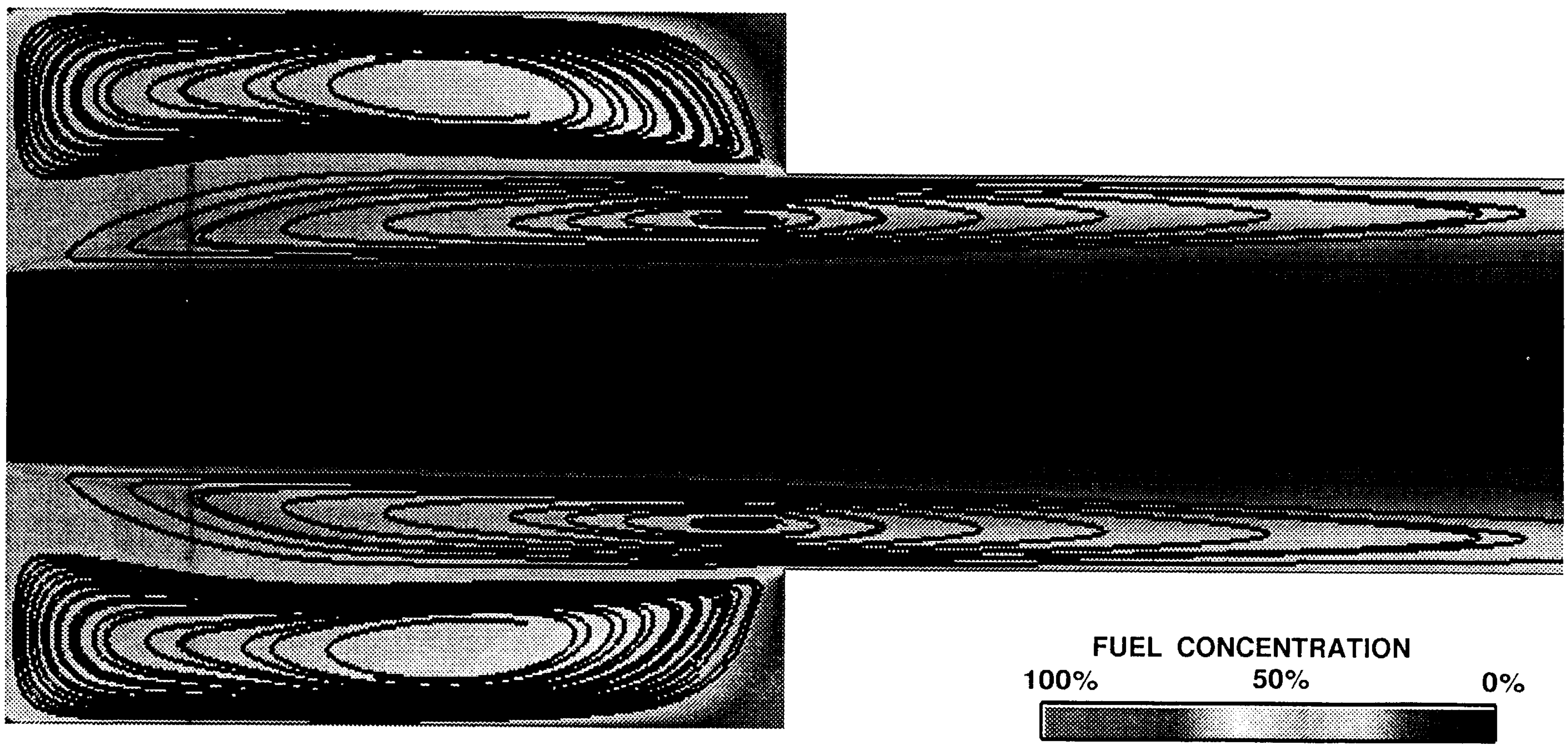
CONDITIONS: TWO ZONE: 90x40, 100x16

GOX, Tin=811° K, Uin=132 m/s

* IMAGE TRUNCATES COMPUTATIONAL DOMAIN AND PARTICLE TRACES DO NOT MOVE BETWEEN

STEP 1 – NON REACTING RESULTS

CASE 3 RESULTS*



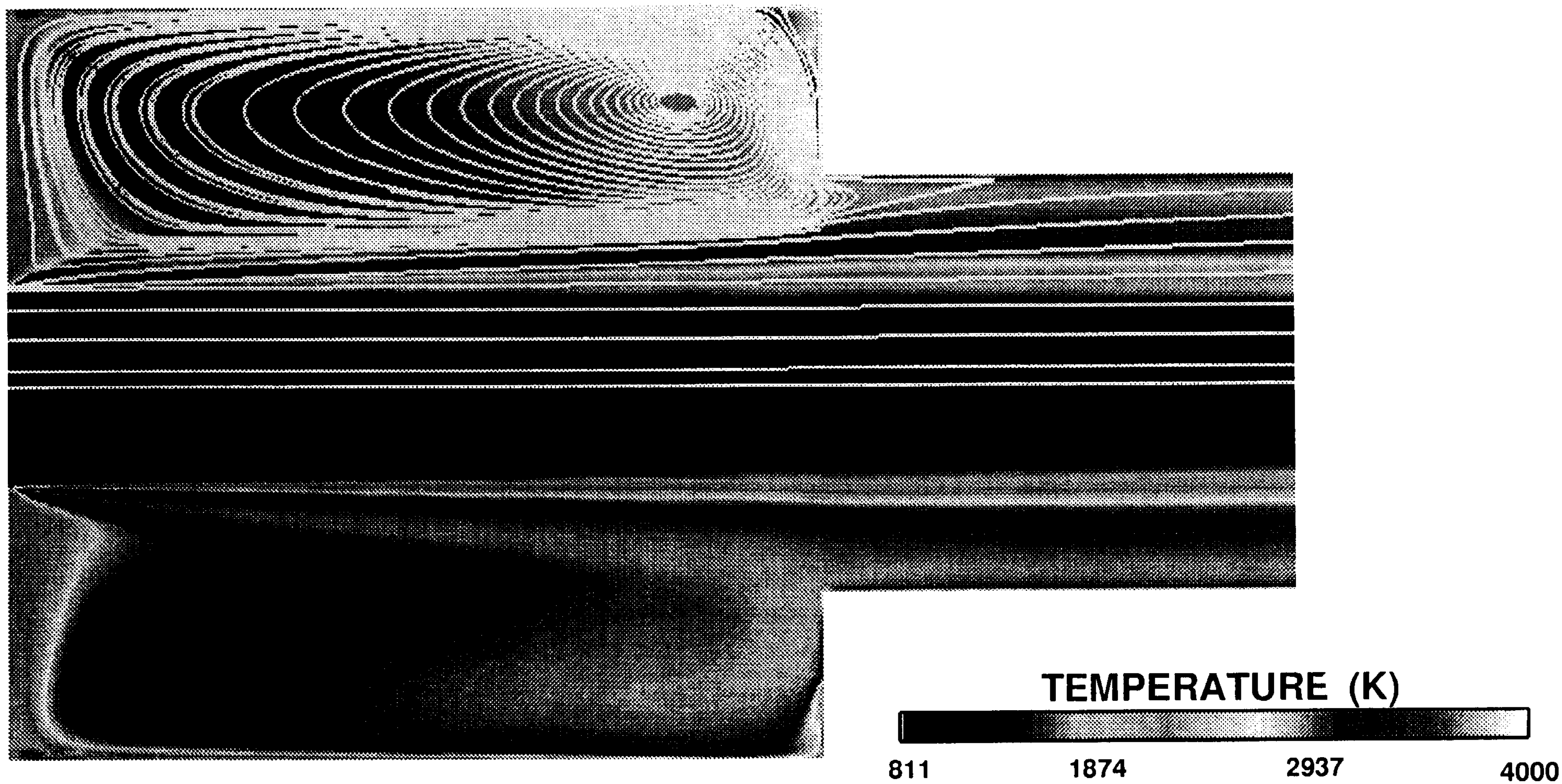
CONDITIONS: TWO ZONE: 90x40, 100x16

GOX, Tin=1810^{O} K, Uin=296 m/s

* IMAGE TRUNCATES COMPUTATIONAL DOMAIN AND PARTICLE TRACES DO NOT MOVE BETWEEN ZONES

STEP 2 – REACTING RESULTS

CASE 1 STRAIGHT FLOW*



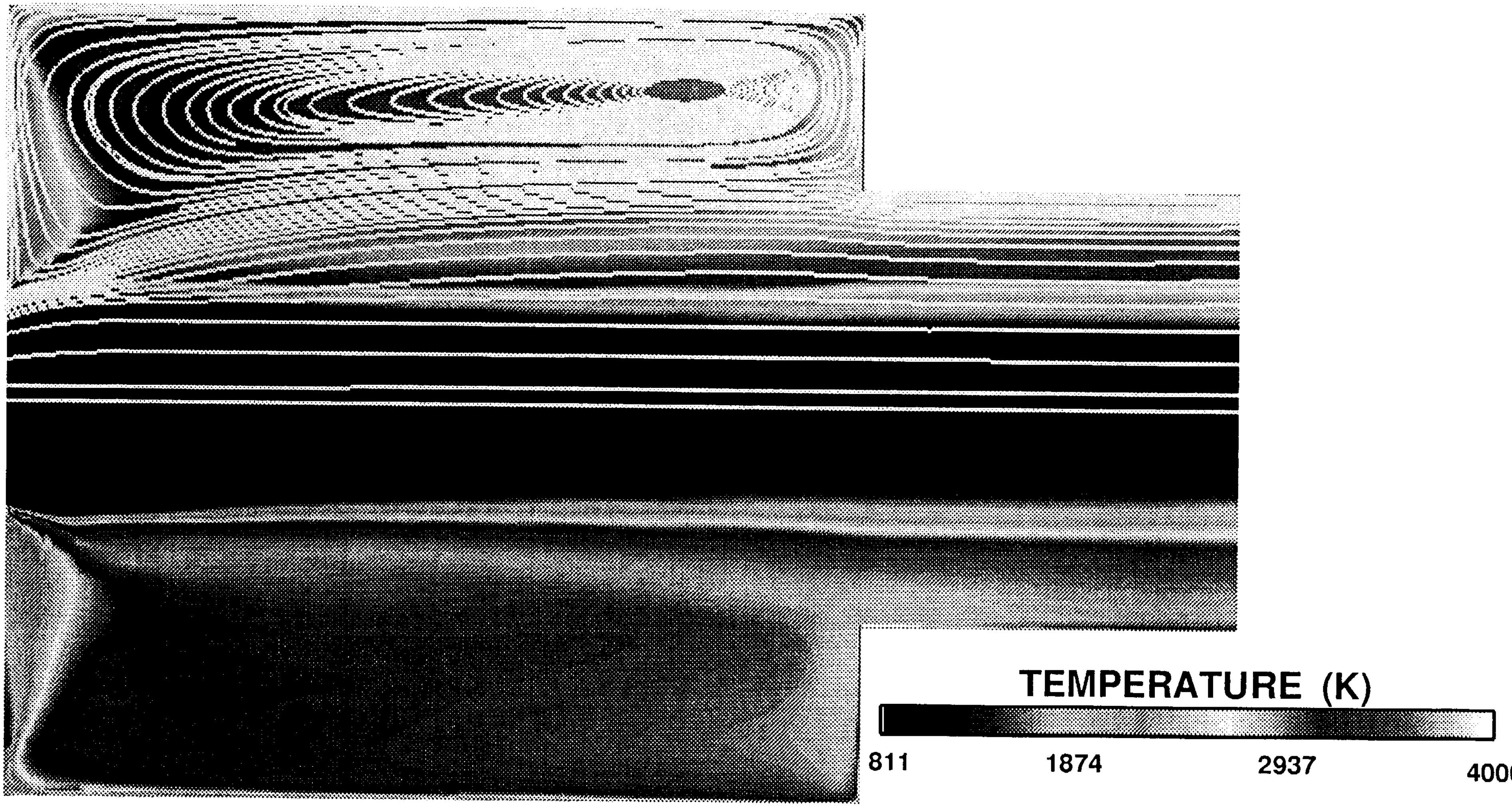
CONDITIONS: TWO ZONE: 90x40, 100x16

GOX, Tin=811° K, Uin=132 m/s

* IMAGE TRUNCATES COMPUTATIONAL DOMAIN AND PARTICLE TRACES DO NOT MOVE BETWEEN

STEP 2 - REACTING RESULTS

CASE 2 ANGLED FLOW*



CONDITIONS: TWO ZONE: 90x40, 100x16

GOX, Tin=811^{O} K, Uin=132 m/s

* IMAGE TRUNCATES COMPUTATIONAL DOMAIN AND PARTICLE TRACES DO NOT MOVE BETWEEN ZONES

CONCLUSIONS

- **COMPLETED CASES CONSISTENT WITH SINGLE POINT TEST DATA**
- **RECIRCULATION PATTERN CAN CHANGE COMPLETELY DUE TO DIFFERENCES IN INJECTOR PATTERN**
- **CHEMISTRY PACKAGE NEED ADDITIONAL VALIDATION**
- **NEW CALCULATIONS (STEP 3) INDICATE PERFORMANCE DECREASE OF NUMERICAL SCHEME DUE TO DROPLET COUPLING AND INTERZONAL BOUNDARIES**
  - NEED ALGORITHMIC REFINEMENT TO INCREASE PERFORMANCE
  - POSSIBLE OPTION: REASSEMBLY OF MULTIZONE MATRICES BACK INTO SINGLE ZONE MATRIX BEFORE CALLING MATRIX SOLVER

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