M8
SOME COMMENTS ON SCALING
CFD FOR SOLVING MIXING PROBLEMS

GENERAL COMMENTS

- Nature of Mixing and Process Result
- Design mixer or choose operating conditions to achieve desired process result.
- Typically process result is a plateau
  - more mixing - speed and power does not improve the process
- Optimization is often not based on process result but rather on auxiliary conditions

DESIGN AND RATING

- DESIGN PROBLEMS
  - what equipment for a full scale facility
    - configuration
    - impeller type
    - impeller speed
    - power/motor
    - mechanical design

DESIGN AND RATING

- RATING PROBLEMS
  - Given this piece of equipment
  - will it do the desired job
    - required changes

TYPES OF ANSWERS

- PAPER
  - based on physical principles
  - physical properties
  - calculate from empirical theory based equations
  - long term goal
  - about 80 to 90 percent of cases
- Long Term Goal

TYPES OF ANSWERS

- SCALE UP
  - from small scale experiments predict large scale design and performance

SCALE UP VERSUS SCALE DOWN

- Scale up from arbitrary lab equipment to plant reactor which looks different
- Often full scale plant equipment is known or can be guessed with accuracy
- Mixing is very geometry dependent
  – HARD TO PREDICT
- Make lab equipment geometrically similar to plant. SCALE DOWN

SCALING

- Want all parameters on small scale to match large scale - IMPOSSIBLE
- Key parameters scale differently
  - solids suspension with tip speed
  - dispersion with power per unit volume
  - mix time with speed
- Must pick key variable for scaling
- Need to explore sped range on small scale
- Prefer data on two scales

SCALING

- Use geometric similarity
  - reduces scaling to speed
  - need to figure out which is key process result
  - then which fluid mechanic phenomena
- Key parameters
  - speed - position
  - tip speed - addition time
- Scale on that

SMALL SCALE EXPERIMENTS

- NOTE: Computational Fluid Mechanics is an experimental technique
- When?
  - Unusual configurations
  - Unusual process result
  - Unavailable basic data
  - Basic data changes during mixing

ANALYZING LAB EXPERIMENTS

- Philosophy
  - find out what controls
  - talk to chemists
  - define process results
  - run test on small scale to find out above
  - geometric similar equipment
  - vary speed - OBSERVE, OBSERVE
  - any effect - slope versus speed

ANALYZING LAB EXPERIMENTS

- Small scale
  - REAL FLUIDS
- Large Scale
  - Model fluids

SCALING

- Still somewhat of an art form
- Requires experience and knowledge of many fields
  - biochemistry
  - chemistry
  - reaction engineering
  - physical chemistry

ADVANCED TECHNIQUES

- Laser Doppler Anemometry (LDA)
- Computational Fluid Mechanics / Mixing

  CFD/CFM

WHAT WOULD WE LIKE TO KNOW?

- Velocity at very point
- Turbulence at every point

- In Principle could calculate
  - all forces
  - forces on second phase
  - map velocity fields
  - particles and their trajectories
  - concentration and paths

LASER DOPPLER ANEMOMETRY - LDA

- Experimental
  - one or two lasers
  - transparent tank
  - low concentration of tracker fine particles
  - measure vectors - fluctuations
- DPIV - laser sheet
- Digitized sequential pictures
  - lots of data
- Compress and present via computer graphics

COMPUTATIONAL FLUID MECHANICS

- Mathematical technique
- Mathematical modeling
- Assumptions
  - nature of turbulence
  - interphase forces
  - results only as good as assumptions
- Increasing but still limited applicability

COMPUTATIONAL FLUID MECHANICS

- Scale free modeling
- Needs confirmation
- LDA confirms CFD

COMPUTATIONAL FLUID MECHANICS

- Navier Stokes Equations
  - three dimensional partial differential equations
  - general
  - unsteady state
- Stress term
  - Laminar
  - constitutive equation

COMPUTATIONAL FLUID MECHANICS

- CONSTITUTIVE EQUATION
- relation between forces (stresses) and motion usually expressed as shear rate
- Rheological equations in 3D
- 27 element tensor
  - in simplest form - viscosity

COMPUTATIONAL FLUID MECHANICS

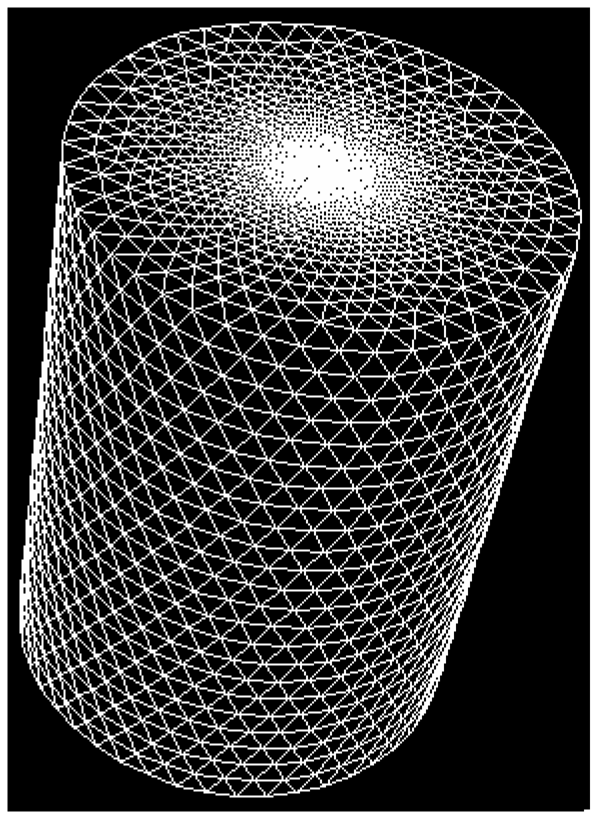
- TURBULENCE
- CONSITUTIVE EQUATIONS - many
- Concept of average and fluctuating velocities
    - V = Vave + V’
  - on averaging introduces extra stresses larger than laminar - turbulent stresssses (Reynolds)
  - Turbulent viscosity(diffusivity)* local shear rate

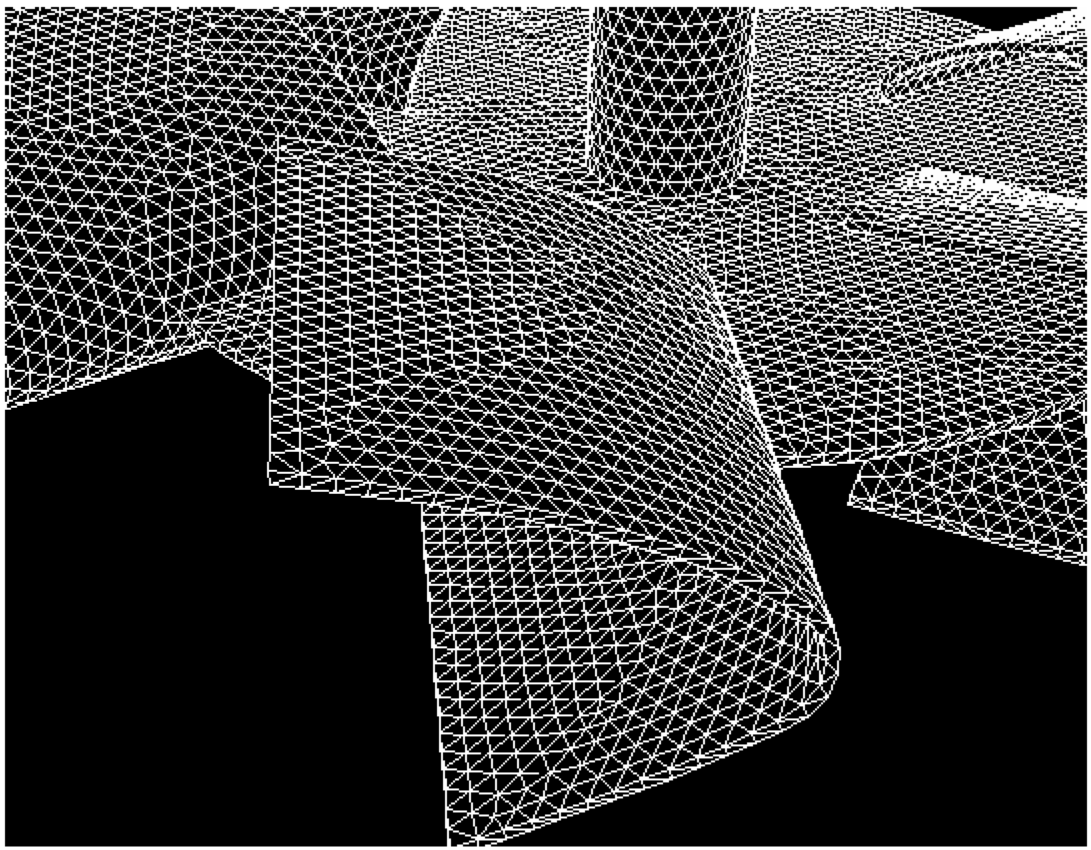
COMPUTATIONAL FLUID MECHANICS

- Methods of solving partial differential equations
  - finite volume
  - finite difference
  - finite element
  - boundary elements
  - body fitted coordinates - rectangular fits
  - mesh generation programs

COMPUTATIONAL FLUID MECHANICS

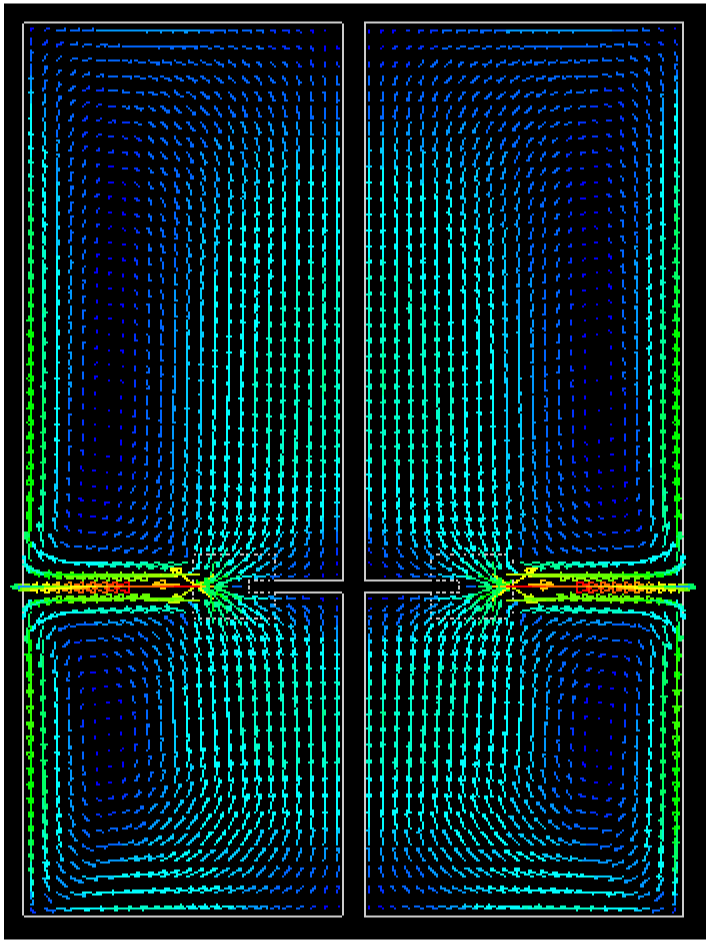
- Lots of mesh points at which variables are calculated (10,000 to 40,000)
- Lots of data
- Graphics display
  - same as for LDA
  - color required
- Particle tracking

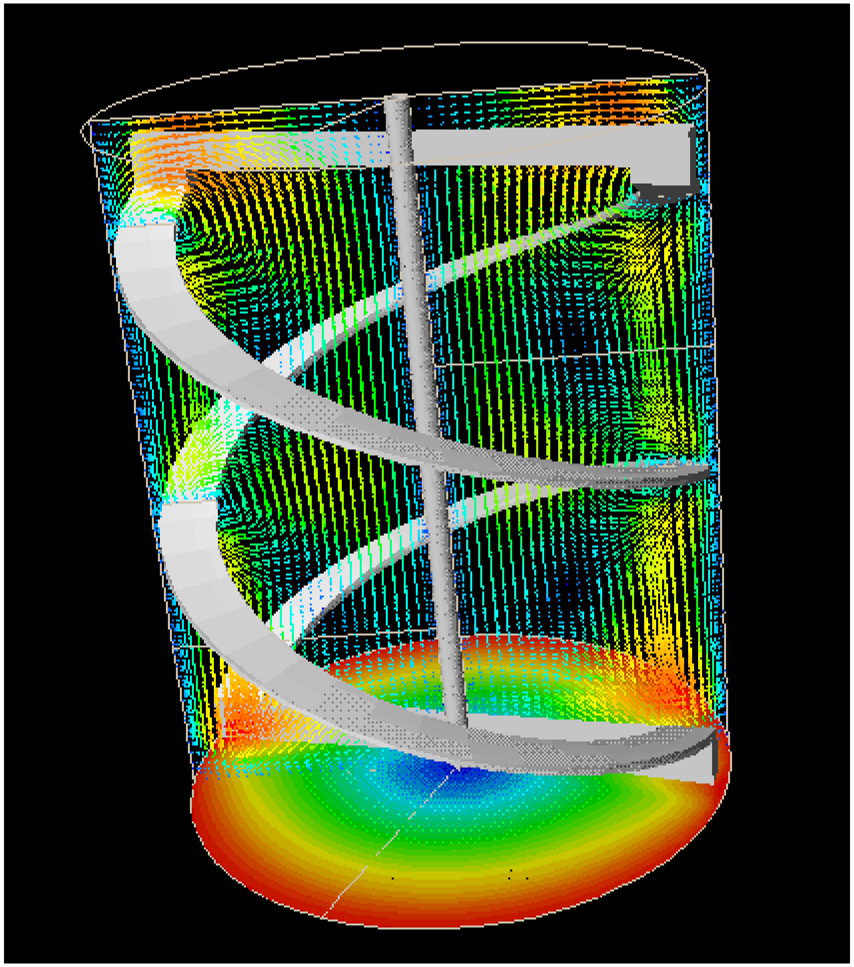




CFM FROM ANDRE BAKKER

http://www.bakker.org/cfm





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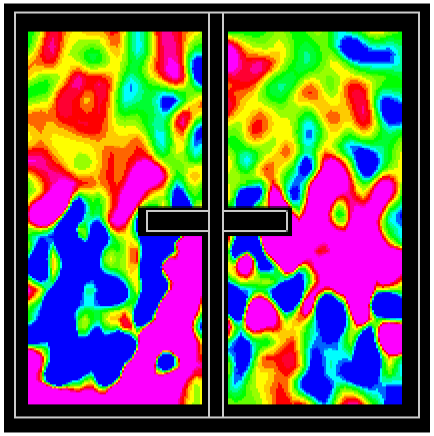
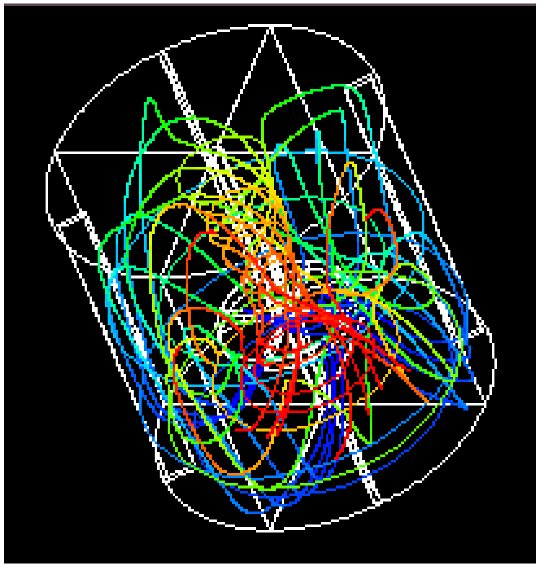
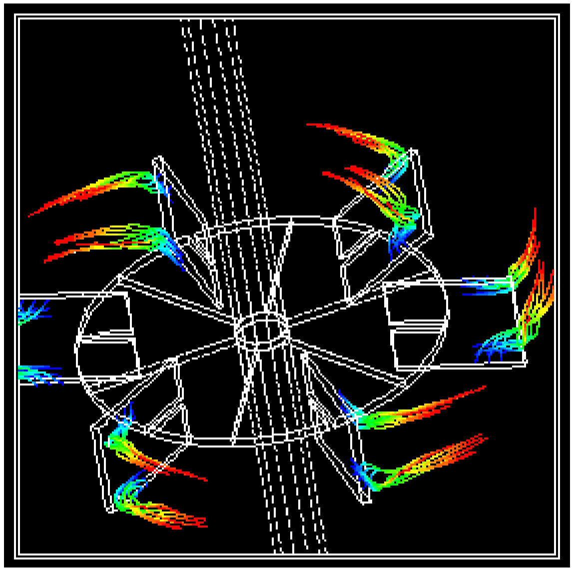




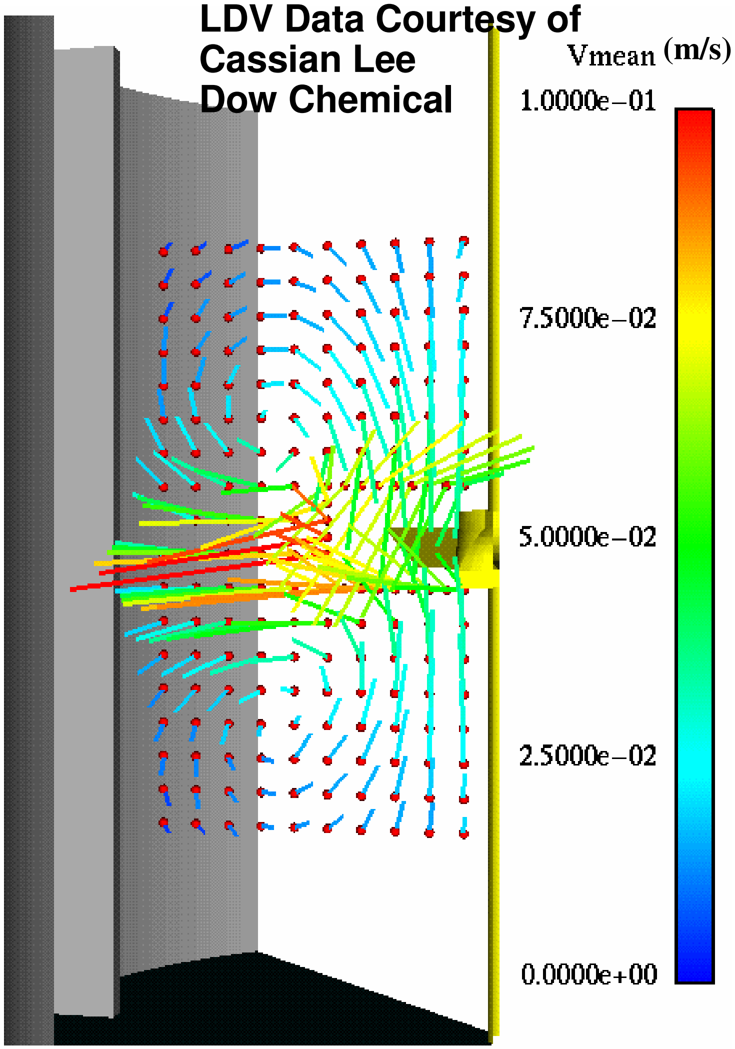


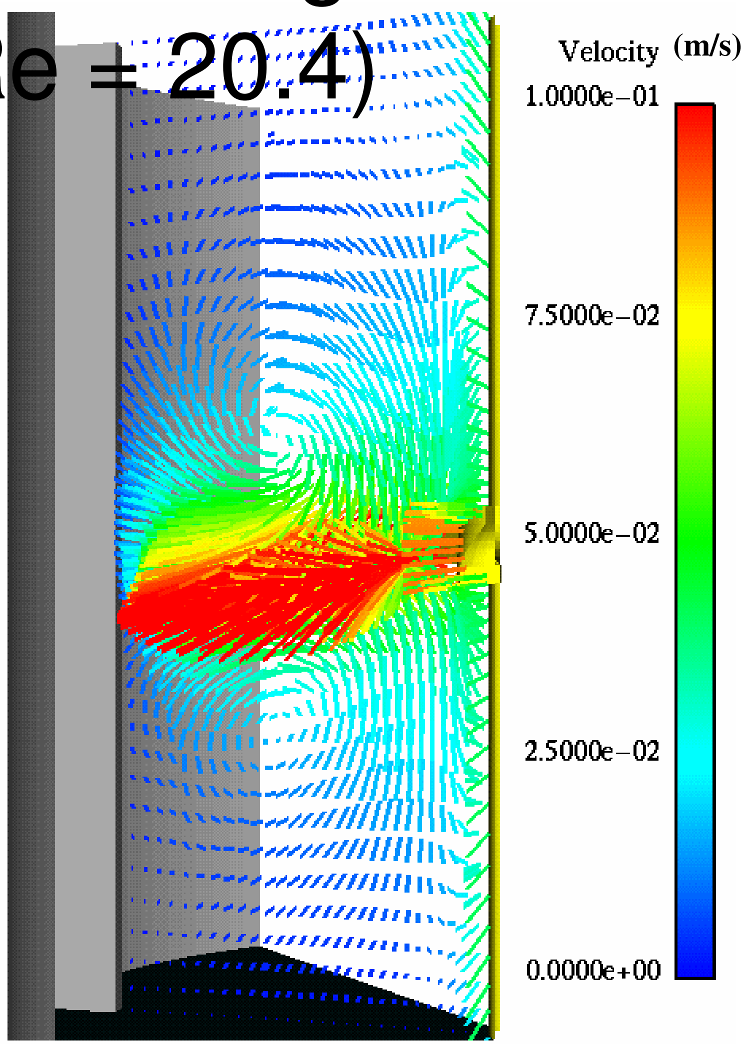
COMPUTATIONAL FLUID MECHANICS

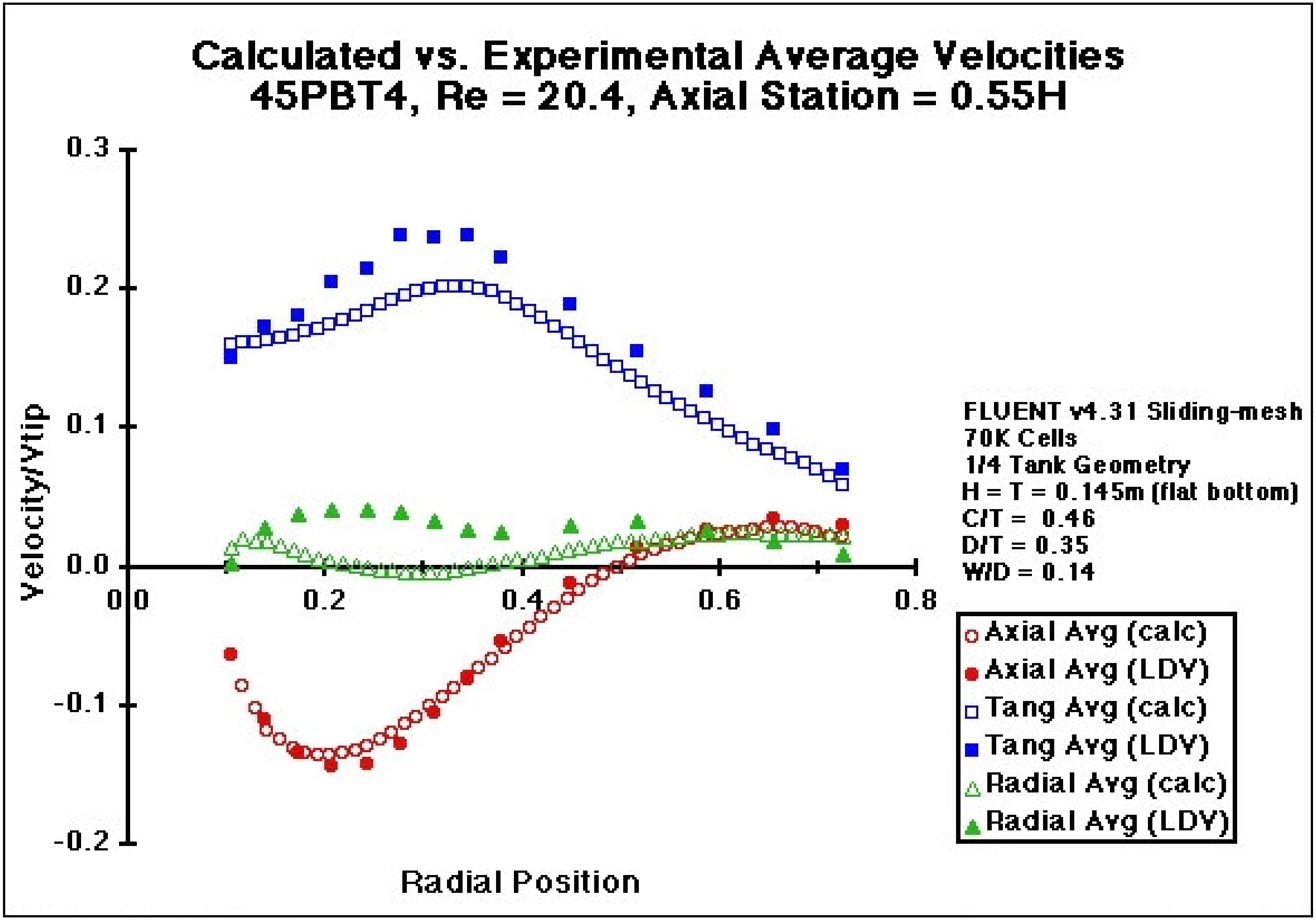
- MAJOR QUESTIONS
  - how to model turbulence
  - how to model impeller
  - how to handle multiphase
    - coupling equations
    - effect of dispersed phase on continuous

CFM FROM DICK LAROCHE
http://www.cpcfd.org/laroche/

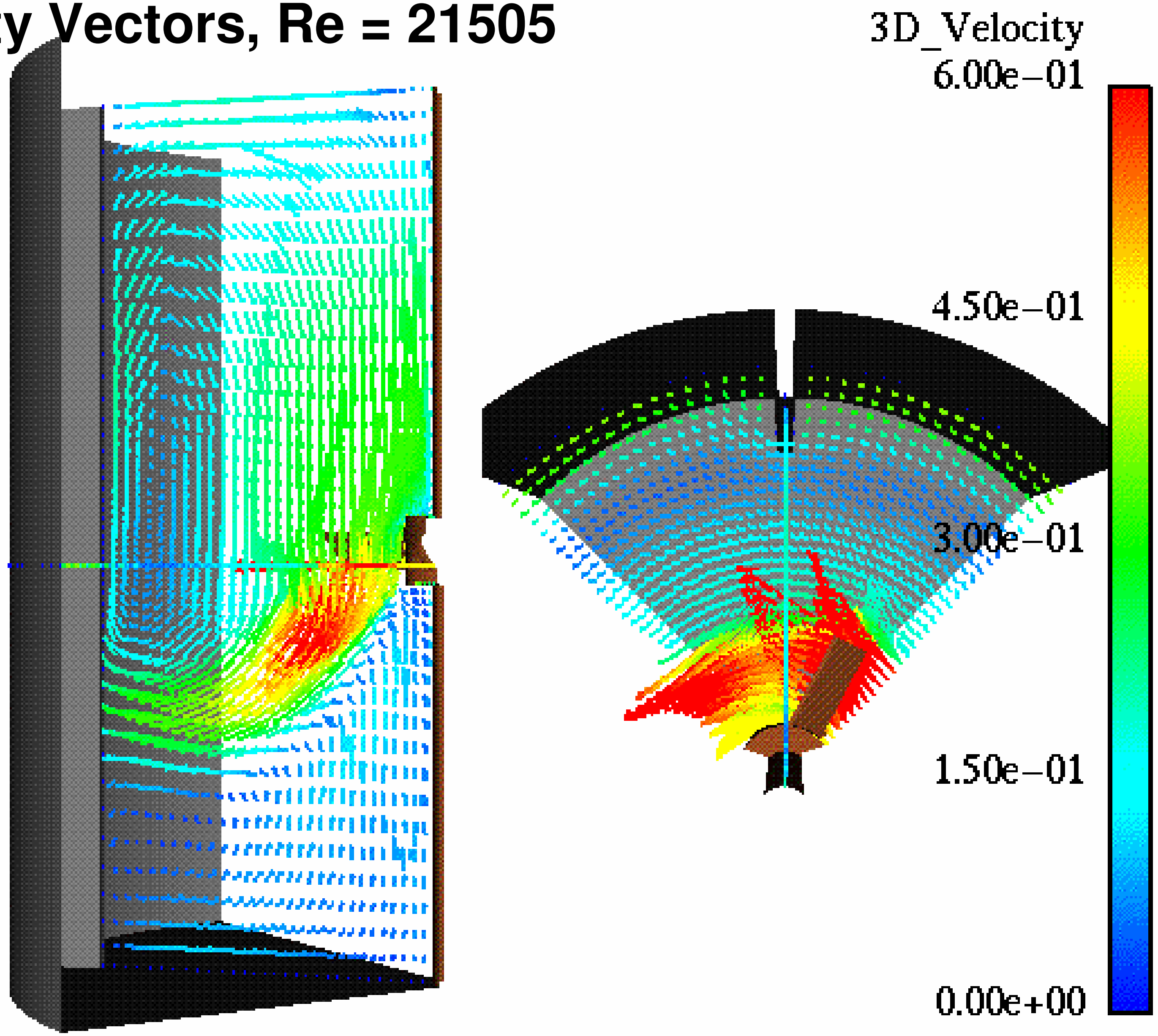
Experimental vs. FLUENT Sliding-Mesh (Re = 20.4)

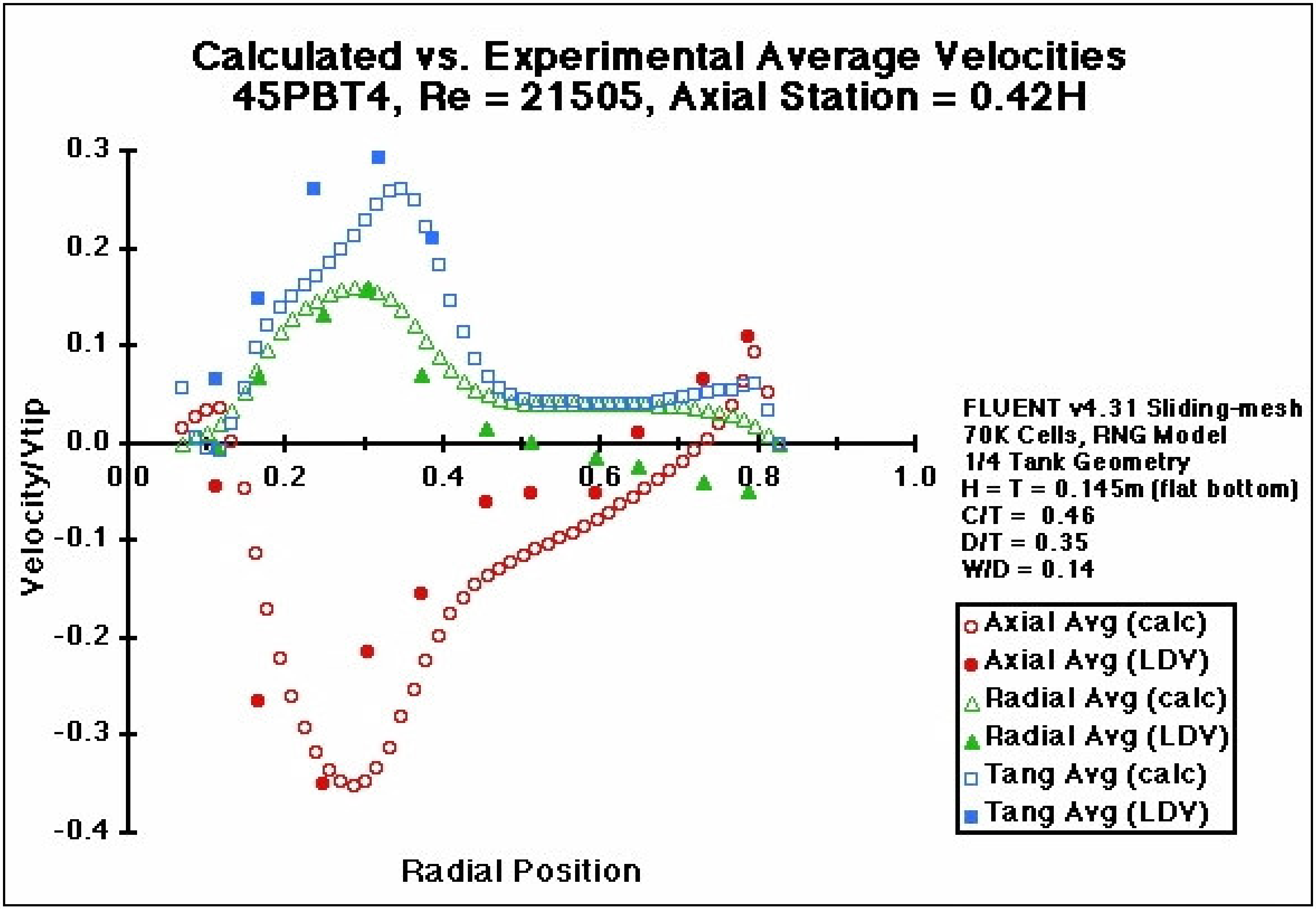





Calculated vs. Experimental Average Velocities
45PBT4, Re = 20.4, Axial Station = 0.55H
0.3
0.2
0.1
0.0
-0.1
-0.2
Velocity/Vtip
0.0
0.2
0.4
0.6
0.8
Radial Position
FLUENT v4.31 Sliding-mesh
70K Cells
1/4 Tank Geometry
H = T = 0.145m (flat bottom)
C/T = 0.46
D/T = 0.35
W/D = 0.14
Axial Avg (calc)
Axial Avg (LDV)
Tang Avg (calc)
Tang Avg (LDV)
Radial Avg (calc)
Radial Avg (LDV)

Velocity Vectors, Re = 21505



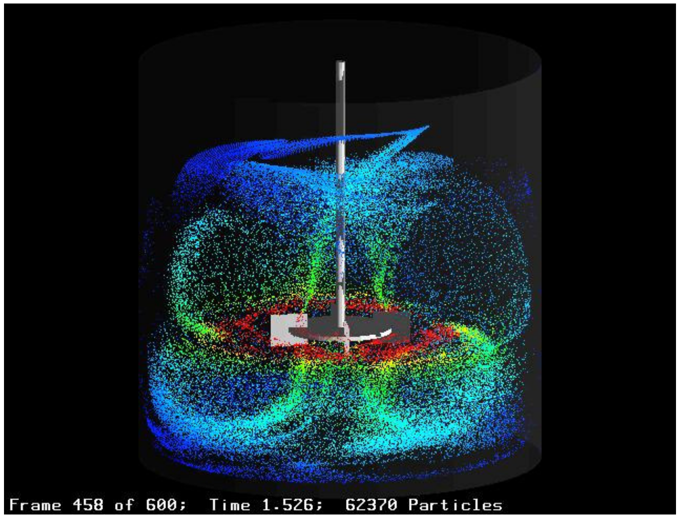


Calculated vs. Experimental Average Velocities
45PBT4, Re = 21505, Axial Station = 0.42H
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
Velocity/Vtip
0.0
0.2
0.4
0.6
0.8
1.0
Radial Position
FLUENT v4.31 Sliding-mesh
70K Cells, RNG Model
1/4 Tank Geometry
H = T = 0.145m (flat bottom)
C/T = 0.46
D/T = 0.35
W/D = 0.14
Axial Avg (calc)
Axial Avg (LDV)
Radial Avg (calc)
Radial Avg (LDV)
Tang Avg (calc)
Tang Avg (LDV)

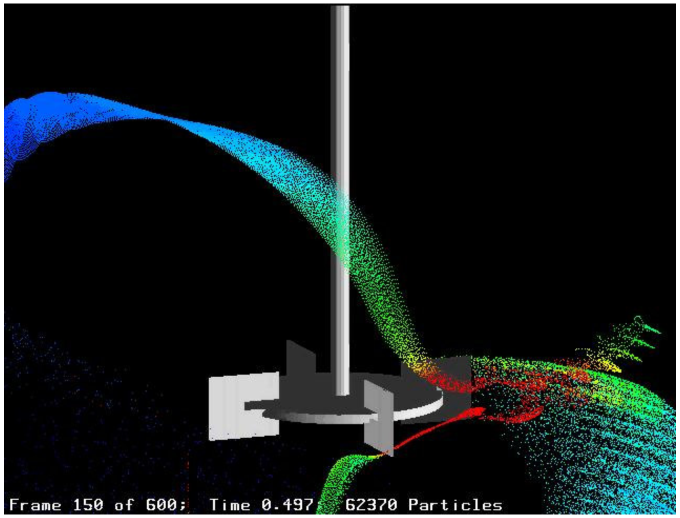
Lagrangian Particle Tracking for Laminar Flows

$$\frac{\mathrm{D}\boldsymbol{x}}{\mathrm{D}t} = \boldsymbol{u}$$

x is the massless particle position
u is the fluid velocity vector

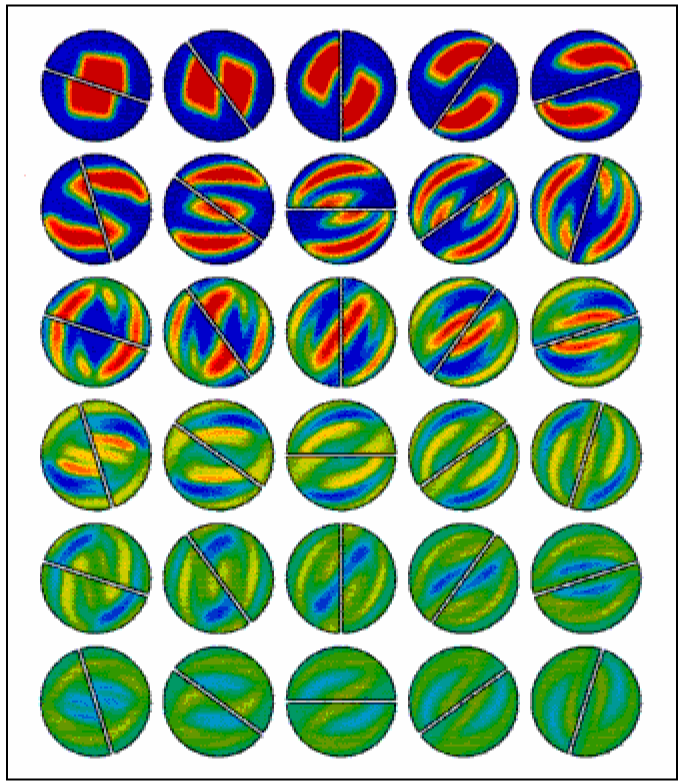


- Tracking 10K to 1000K "massless"particles
- Reveals flow structures
- Statistics for process dynamics



COMPUTATIONAL FLUID MECHANICS

- SOME SUCCESSFUL USES
    - stagnation in laminar flows - Tanguy
    - caverns around impellers
    - jet mixing - Forney
    - Draft tubes - Strand
- TOUGHER PROBLEMS
    - Free surfaces
    - high swirl
    - high non symmetry
    - multi phase



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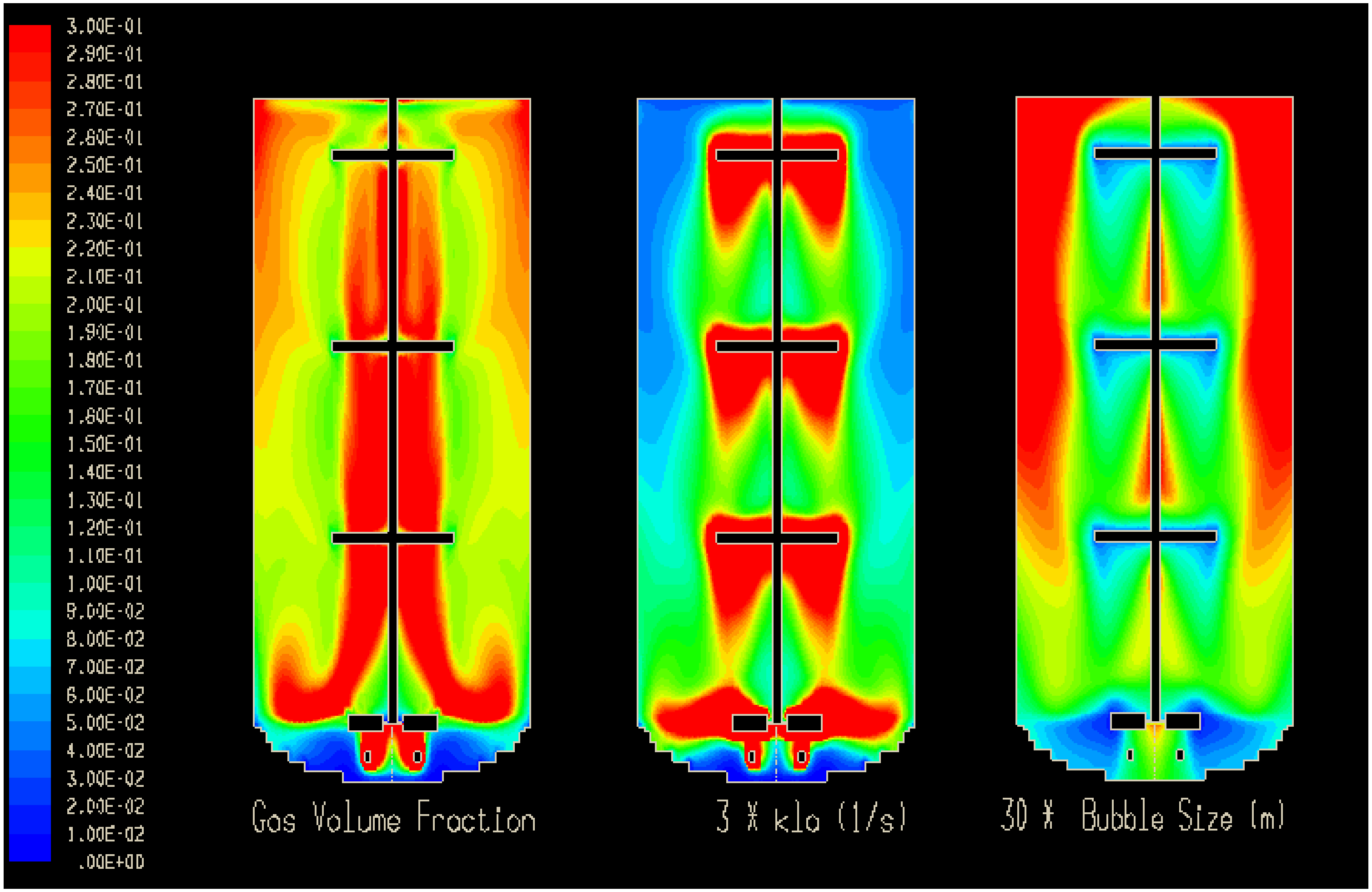

SOLID SUSPENSION AND CFD

- Must use approximations
- Two fluid phase models
- Can not describe discrete phase
- Couple through drag laws
- May not handle turbulent effects of particles well
- Very useful qualitative.

SOLIDS SUSPENSION AND DISTRIBUTION

- Can not duplicate turbulence mechanism for solids re-suspension
- Can qualitatively and perhaps quantitatively describe distribution above Njs – see work of Bechtel SF on WTP
  - Some assumptions to handle conditions
  - GO TO ATTACHED PDF FOR EXAMPLES

ORGANIZATIONS

- NORTH AMERICAN MIXING FORUM NAMF
  - Industrialists and academics interested in mixing
  - self election
  - newsletter with announcements
  - conferences
    - leave a business card with Etchells
- Web site - www.Mixing.net/namf

ORGANIZATIONS

- BRITISH HYDROMECHANCIAL RESEARCH GROUP (BHRG)
- Research consortium
- about $30,000 per year per group
- Fluid Mixing Processes - FMP
- Tank and pipeline
- Contract Research
- David Brown - www.BHRGroup.co.uk

ORGANIZATIONS

- University of Maryland Rotor-Stator Consortium
- Prof. Rich Calabrese

CONFERENCES

- UK WORKING PARTY – Fluid Mixing 8 April 10-12 2006 King's College London www.fluidmixing8.org/
- AMERICAN INSITITUE OF CHEMICAL ENGINEERS - Nov. each year-
  - 2008 Philadelphia
  - NAMF sponsors about six sessions (9 mixing sessions)
- 13th EUROPEAN MIXING CONFERENCE
  - 2009 London
- NAMF BIANNUAL CONFERENCE
  - 2010 Victoria BC Canada
  - no proceedings –
  - Contact – http://mixing.net/namf/conferences/
- ISMIP – Industrial Mixing – Canada June 2008

NEW BOOK

- Handbook of Industrial Mixing
  - editors: Ed Paul, Suzanne Kresta, Victor Atiemo-Obeng
  - Wiley June 2003
  - with an all star cast