APEX Task II Overview

Neil Morley for the
APEX Task II Participants

APEX Semi-Annual Meeting
Scottsdale, AZ. November 7-9, 2001

Task II Overview

- Modeling
  - UCLA Codes
  - Hypercomp Phase II SBIR
  - Truchas with LANL
- Experiments
  - MTOR
  - FLIHY
- Other Work and Collaborations

Continued Modeling Work at UCLA

Complimentary 3D Formulations for Flow3D benchmarking and Task I analysis

A – Electric Potential Formulation

$$\nabla^2 \varphi = \nabla \cdot [U \times B] \qquad \vec{j} = \sigma[-\nabla\varphi + U \times B]$$

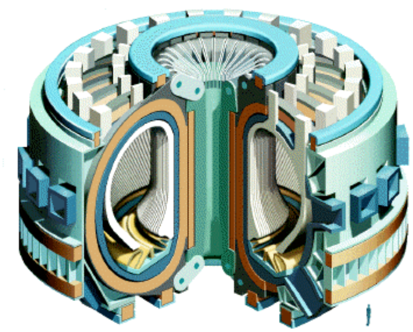
B – Induced Magnetic Fields Formulation

$$\frac{\partial B}{\partial t} = \frac{1}{\mu_0 \sigma} \nabla^2 B + (B \cdot \nabla) U - (U \cdot \nabla) B \qquad j = \frac{1}{\mu_0} (\nabla \times \vec{B}')$$

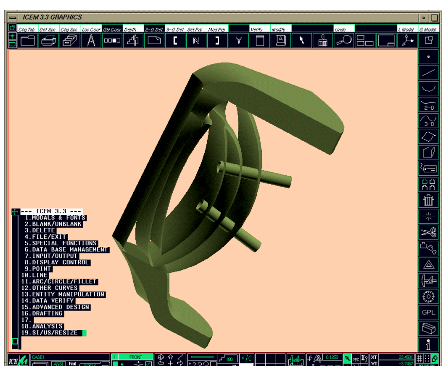
C – Parabolized 3D N-S with height function surface mapping (extension of successful 2.5D work)

HyPerComp Phase-II SBIR Research

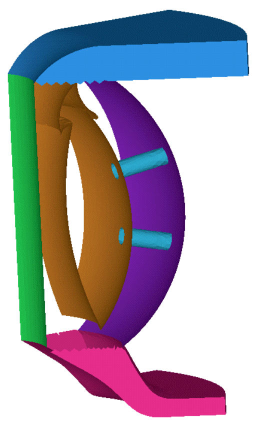
- To convert HyPerComp’s existing adaptive hybrid unstructured mesh environment to problems in liquid metal MHD with free surfaces.
- Modular code structure to the extent possible, for hierarchical MHD treatment
- Interaction with interested research groups *(LANL, LLNL, FZK, etc.)*
- Commercial applications to metallurgy *(MAG/GATE: Concept Engineering Group, PA)*



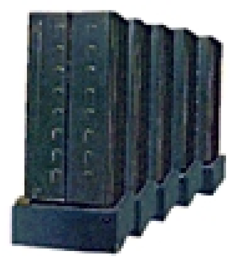
CAD/Grid generation

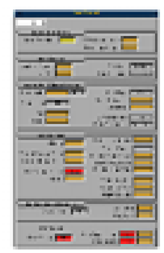


HIMAG : “*HyPerComp Incompressible MHD*
(HyPEX) *Adaptive Grid ”* suite of codes containing High Power Extraction code environment for nuclear fusion

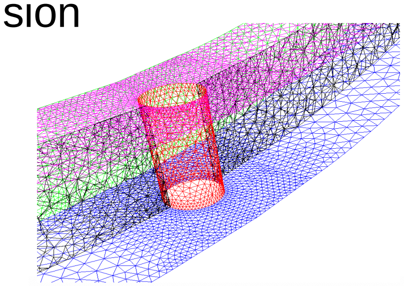


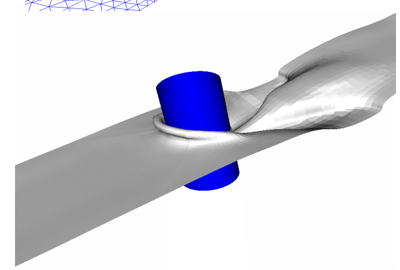
Domain decomposition



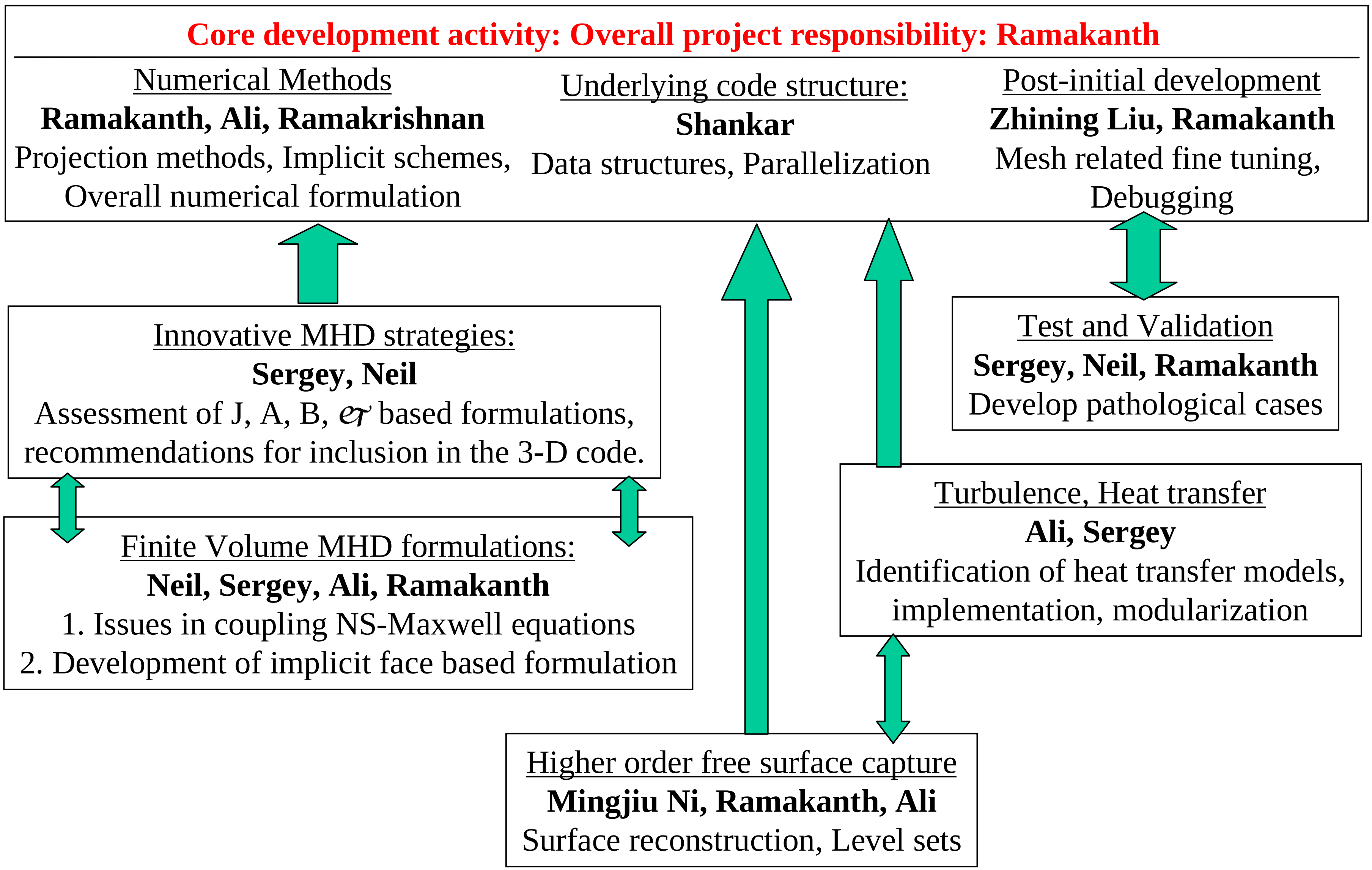


PC-cluster based parallel computing





Project Organization



Time-line

Mid-November : Target date for completion of preliminary incompressible solver.
Debugging and trial runs will commence.

Late-November: VOF testing will commence

Early December : Finalize our calculation procedure for EM-fields using eT, B (or J) formulations
Summary of trial runs on sample codes (Sergey, Neil)

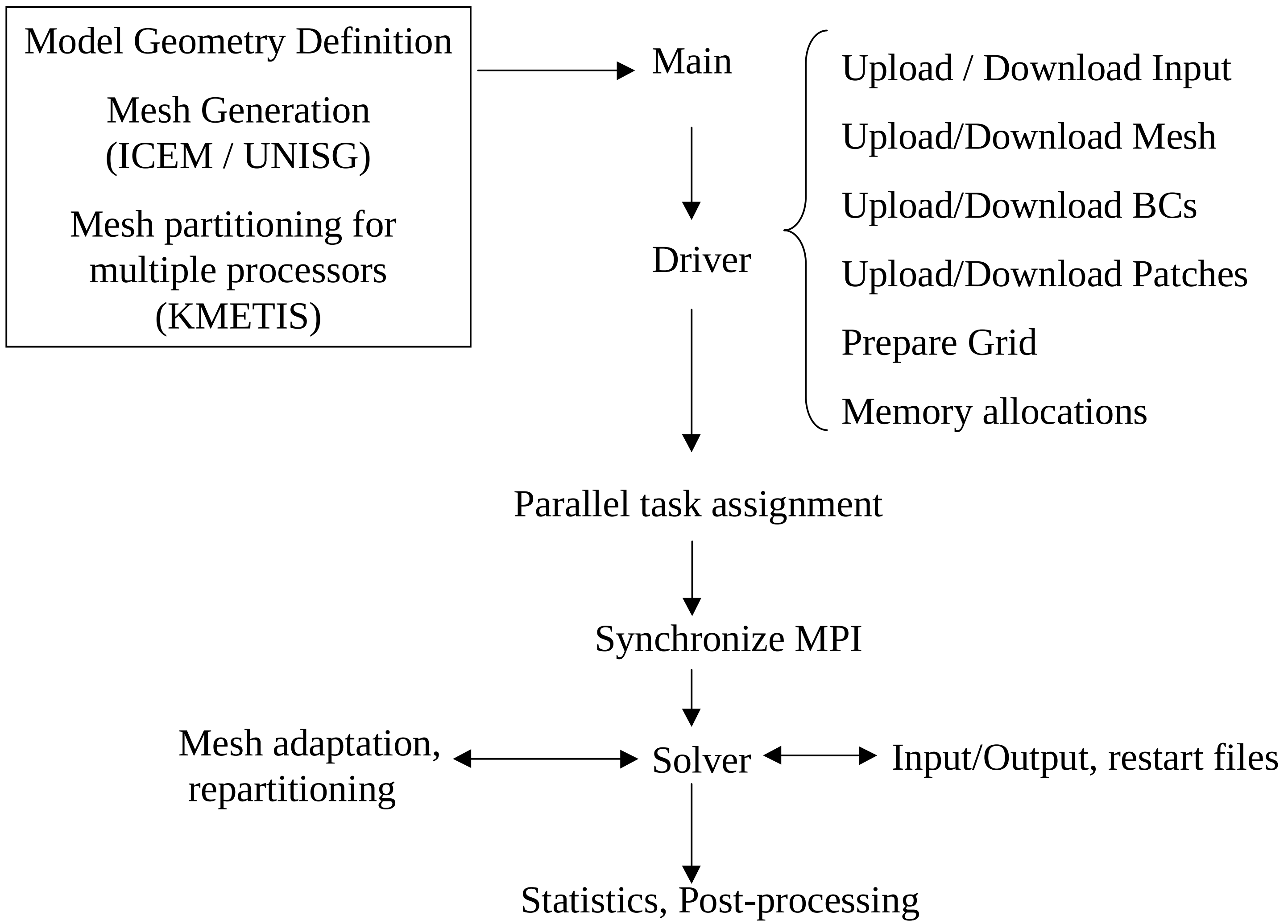
January - March : Induced field solver (B or J formulation)

April - June : Validation, Debugging, test cases, code optimization
Setting up and sample runs of NSTX geometry

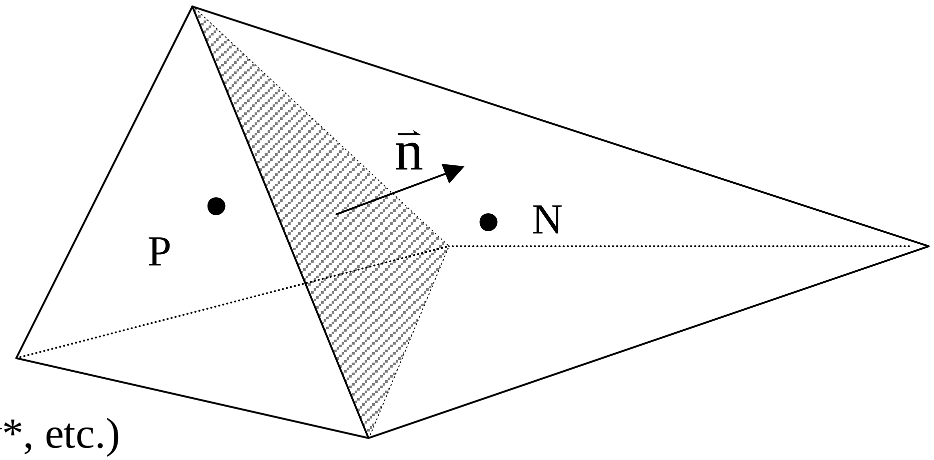
Year - 2:

Complex geometry cases
Higher order schemes
Complex boundary condition procedures
Parallel large scale simulations
Commercialization

Structure of the HIMAG Solver



Schematic of Flow Solver



Initialize: u, v, w, p, eT at cell centers

Time Loop $t = t_0$ to t_{max}

Compute allowable dt
Initialize mass flux at cell faces
Initialize intermediate velocities (u*,v*,w*, etc.)

Sub-iterations between t and t + dt

Repeat until t + dt quantities are converged (including BC values)

- For each interior cell face:
  - Compute VOF and momentum flux-terms
  - Compute Pressure Poisson flux-terms
  - Add/subtract from adjacent cell centers
- For each boundary cell:
  - Impose appropriate boundary flux
  - Add/subtract from adjacent cell center
- Form updated intermediate states (repeat if predictor-corrector)

Update state vector q = (u,v,w,p,eT) at each cell center

Incompressible Flow Solvers

Time advancement from n to n+1 (detailed solution description in report-1)

1. A simple implicit fractional step method

   Here, u,v,w,p,*eT* are stored at cell centers and a face normal velocity U is stored at cell faces.

   (i) Solve Crank-Nicholson discretized momentum equations for an intermediate state u*,v*,w*

   (ii) Compute interpolated value U*

   (iii) Solve pressure Poisson equation using U* to obtain p(n+1)

   (iv) Obtain u,v,w, *eT* at n+1

2. PISO Scheme

   This is a non-iterative predictor-corrector scheme. Operations on pressure and velocity and pressure are decoupled. However, in a point-implicit technique as in our current work, we would need to perform sub-iterations to converge the predictor and corrector steps.

   (i) Solve for first intermediate state u*,v*,w* using the pressure p at time level n

   (ii) Solve for updated pressure p* using u*,v*,w* in pressure Poisson equation

   (iii) Using p*, solve for u**,v**,w**

   (iv) Obtain p** from u**,v**,w**

   (v) Using p**, obtain u***,v***,w*** - the final solution.

Free Surface: Algorithmic aspects

- The purpose of the free surface module is to advance and reconstruct a scalar function φ from t to t + dt
- This will be accomplished by summing a face-based flux of the advected quantity given a local velocity field, with appropriate higher order corrections.
- Apart from the mesh data structure, also available is the cell centered velocity field and a face-based mass flux
- This routine may be called several times during the sub-iterations, with intermediate flow quantities.

Sample computation (using Crank-Nicholson discretization):

$$\varphi_t + \vec{\nabla} \cdot \left(\vec{V}\varphi\right) = 0 \quad \Rightarrow \quad \left(\varphi_P^{t+\delta t} - \varphi_P^t\right)\Omega_P = -\sum_{faces} \frac{1}{2}\left(\varphi_f^{t+\delta t} - \varphi_f^t\right) F_f \,\delta t$$

where $F_f \approx \vec{V} \cdot \vec{A}$

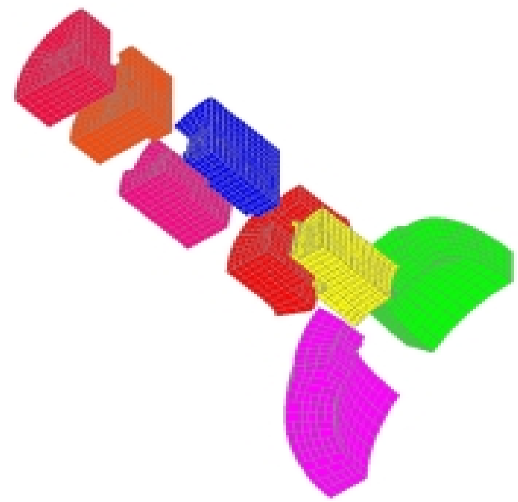
eventually, we get:

$$\varphi_P^{t+\delta t} = \frac{\sum_{faces} a_f \varphi_{nb}^{t+\delta t} + \sum_{faces} b_f \varphi_{nb}^t + \varphi_P^t \dfrac{\Omega_P}{\delta t}}{\sum_{faces} c_f}$$

Based upon an appropriate evaluation of the face-based values of φ, the routine will return the coefficients a,b,c for each face when consulted

Collaboration with LANL on Truchas Code (Telluride)

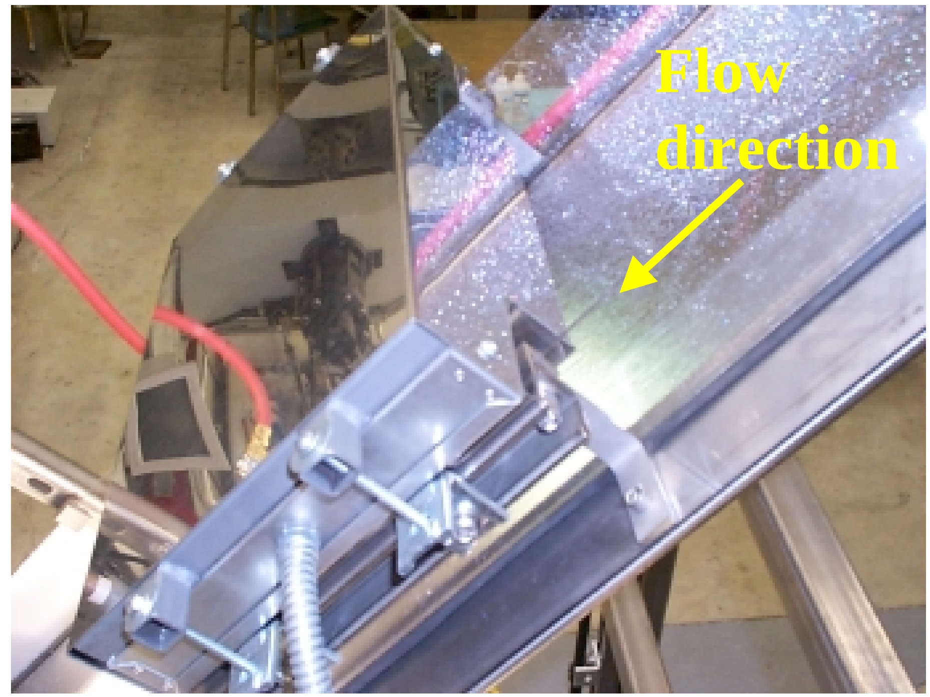
- Large Scale Parallelism
  - 1000+ CPUs
  - via domain decomposition
  - innovative solution algorithms
- Will use initially for:
  - studying circulation in droplets
  - test unstructured MHD models (LANL has a person working on this with us)
  - compare with FLOW3D



Decomposition of part for parallel computation

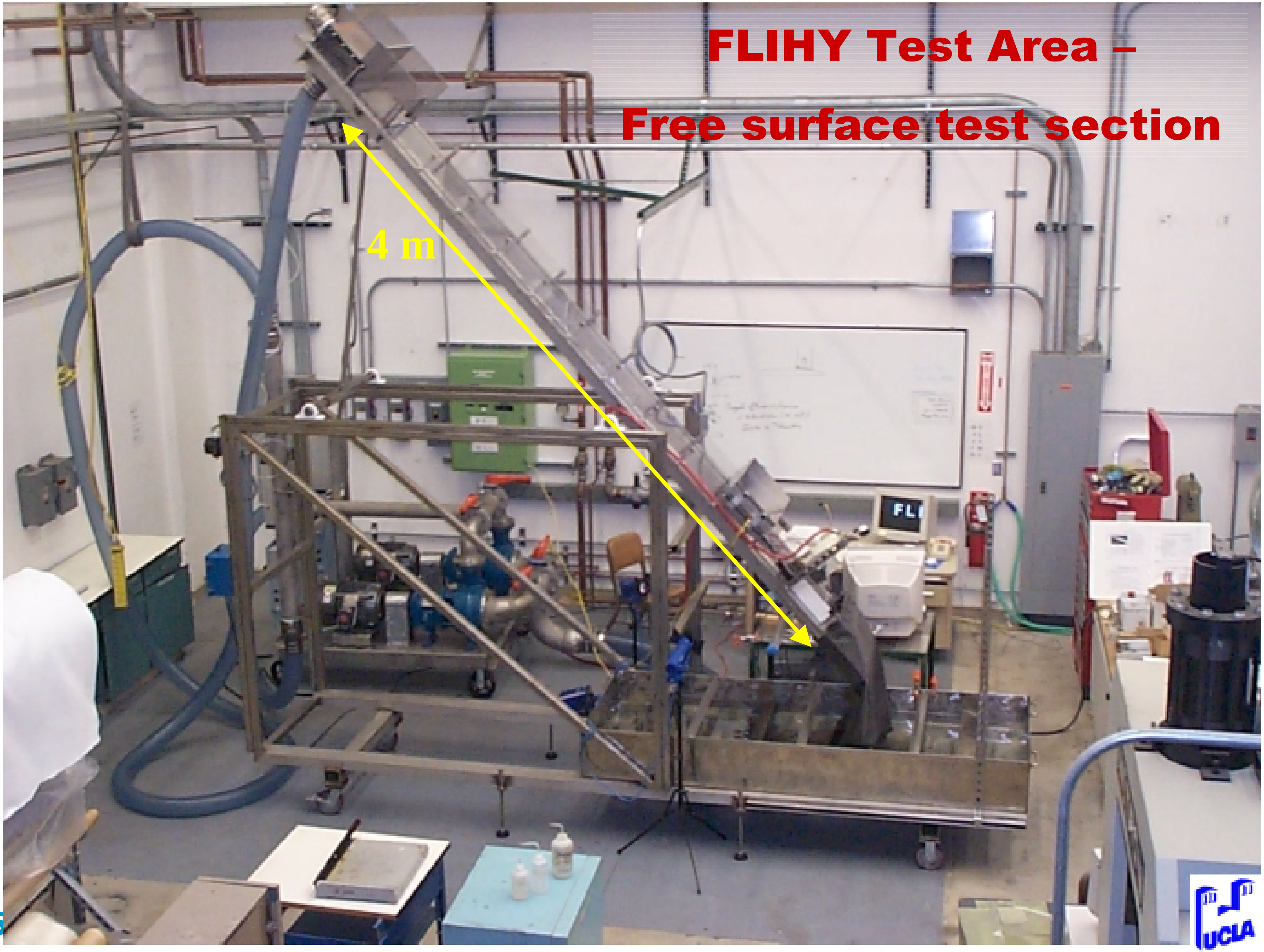
Current Status FLIHY Facility Systems

- Pumping station, flow meter and 4 m straight test section installed and operating
- IR heater system installed and operating (40 kW/m^2)
- Ultrasound and IR camera diagnostics working, techniques continue to be evolved
- Dye injection system working



Water Film flowing under IR heater

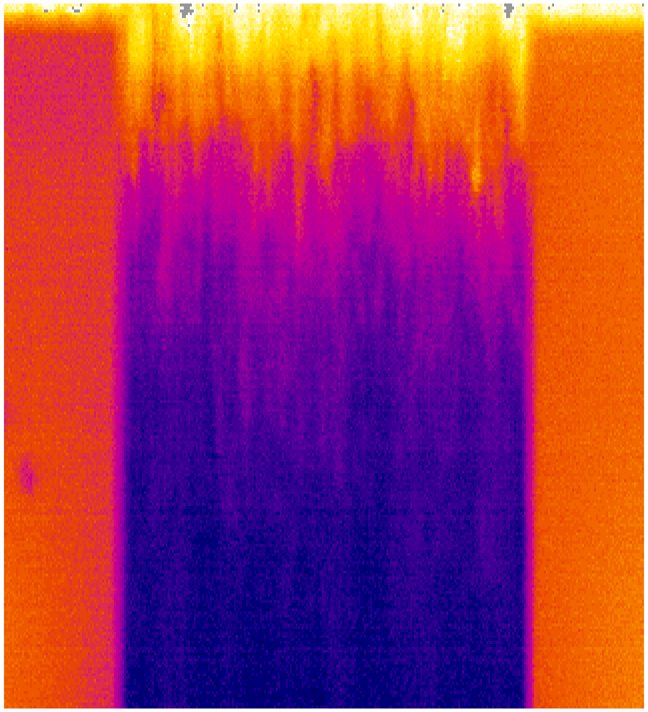
FLIHY Test Area – Free surface test section



First Experiments on Free Surface Turbulent Heat Transfer Underway

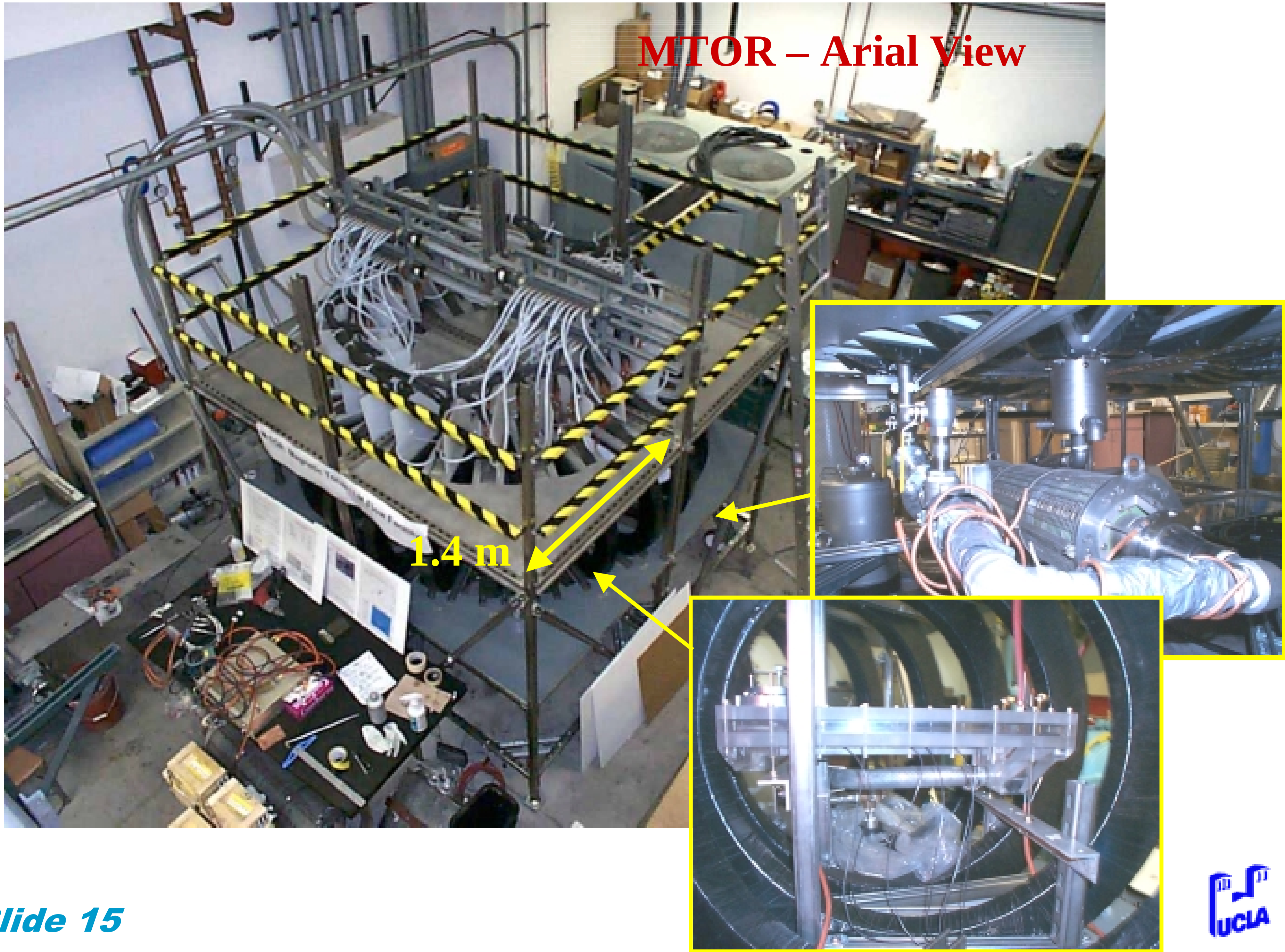
IR study of surface cooling as a function of flow height, velocity and inclination

Will be summarized by Sergey Smolentsev



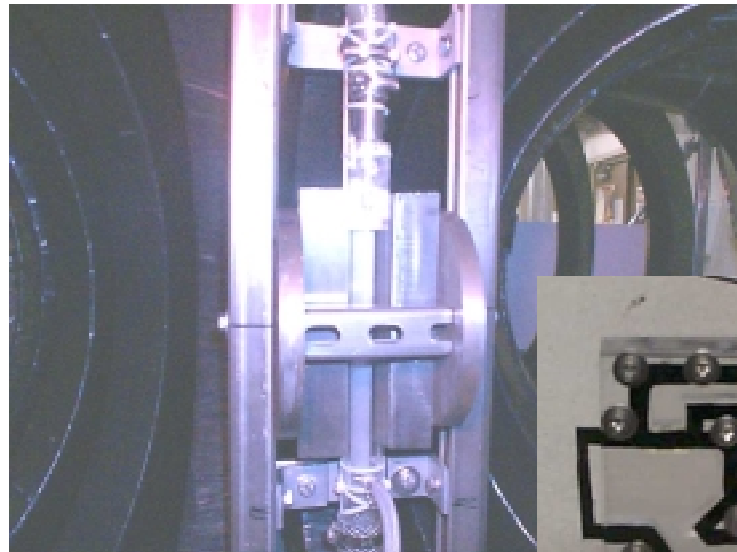
IR image of water surface emerging from IR heater section

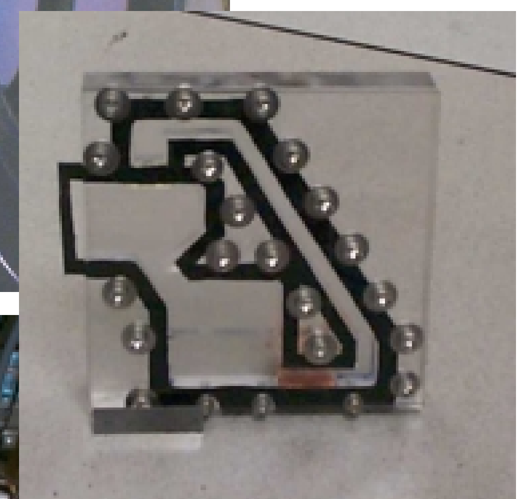
MTOR – Arial View

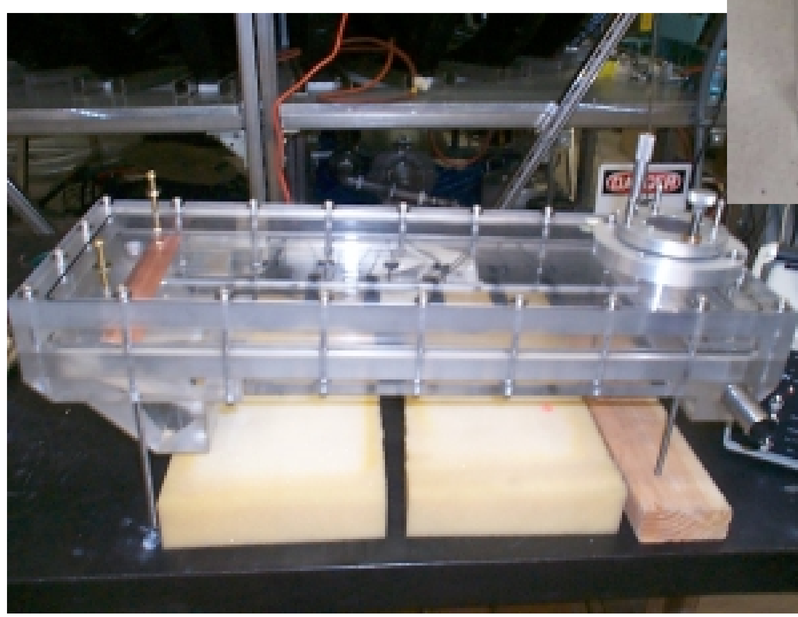


Initial Experiments in MTOR

- Inclined plane with magnetic propulsion
- Self-contained recirculating cell
- Magnetic flux concentrators
- Free jets and soaker hose in uniform fields and field gradients

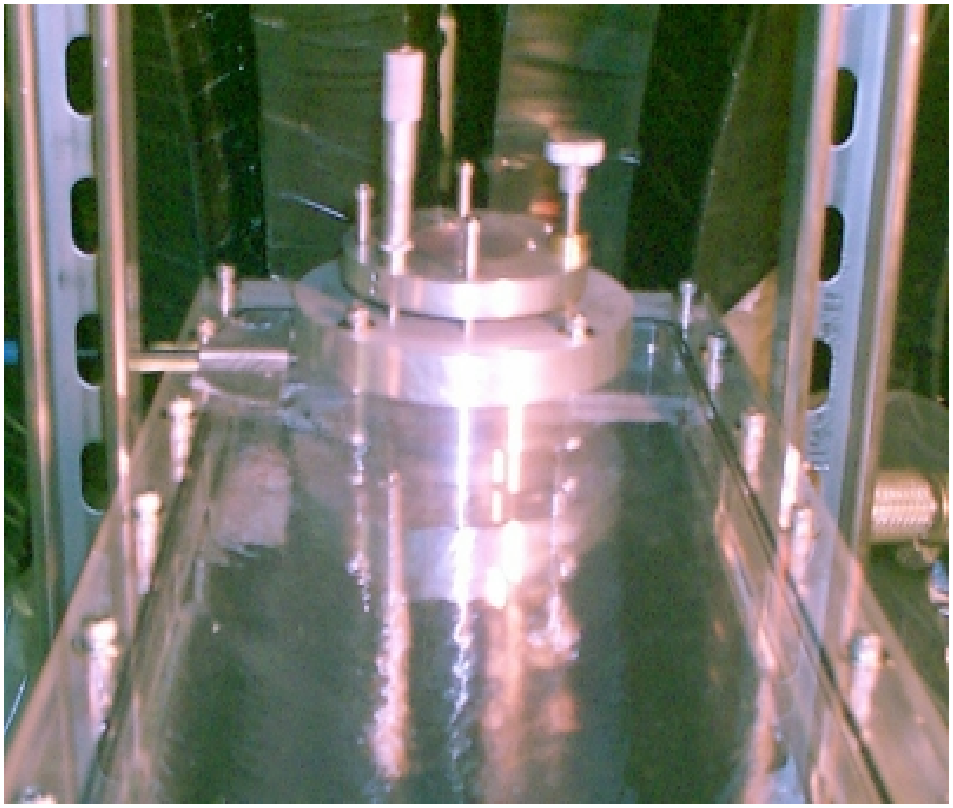






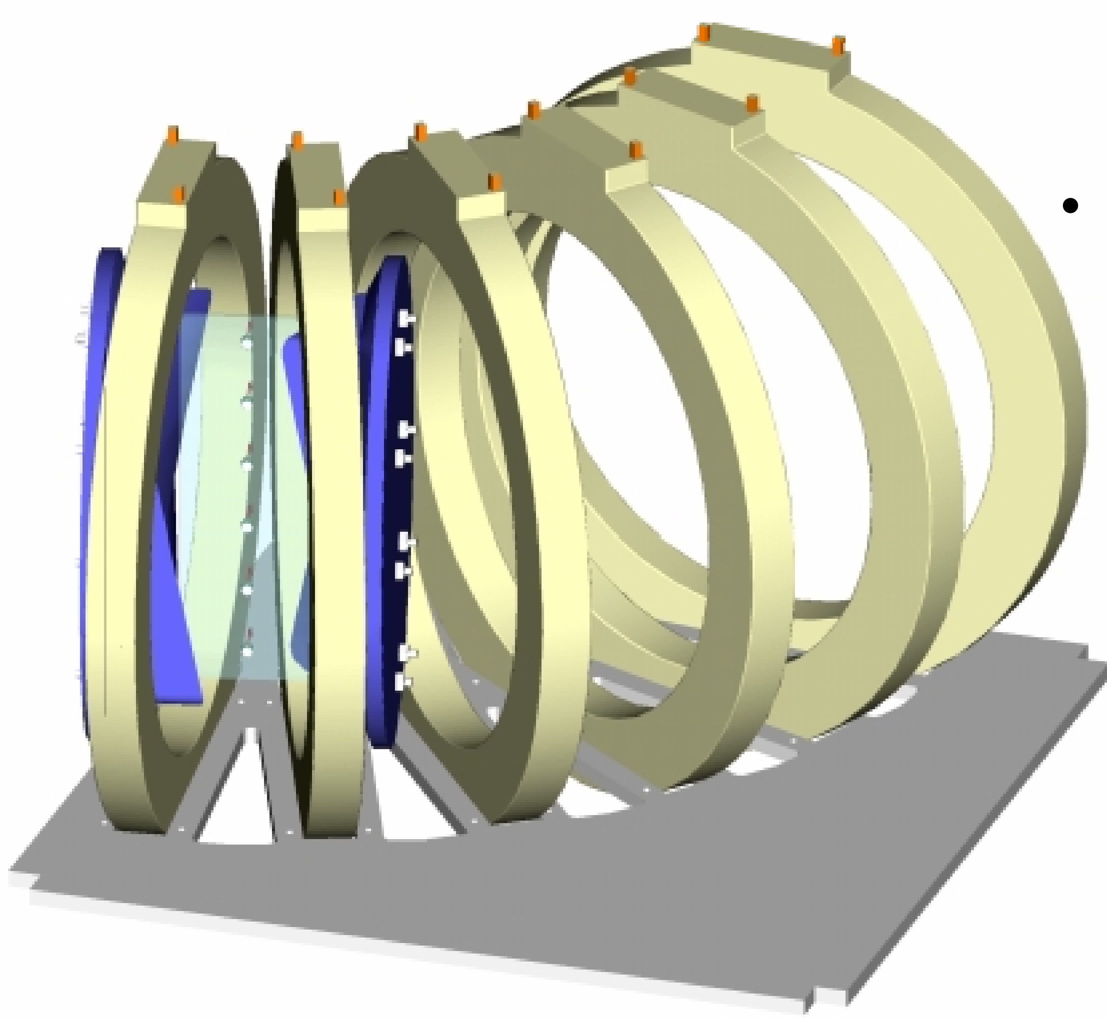
Current Status M-TOR Systems

- PPPL DC power supply and 24 coil torus operating up to 2650 A (B = 0.45 T). Trouble shooting underway to reach full 3600 A.
- Water coolant loop and over temperature sensing systems operational
- Pumped, 16 L, Ga-In-Sn flow loop operational
- Inclined plane, flux concentrator, and small jet experiments installed and data currently being acquired.

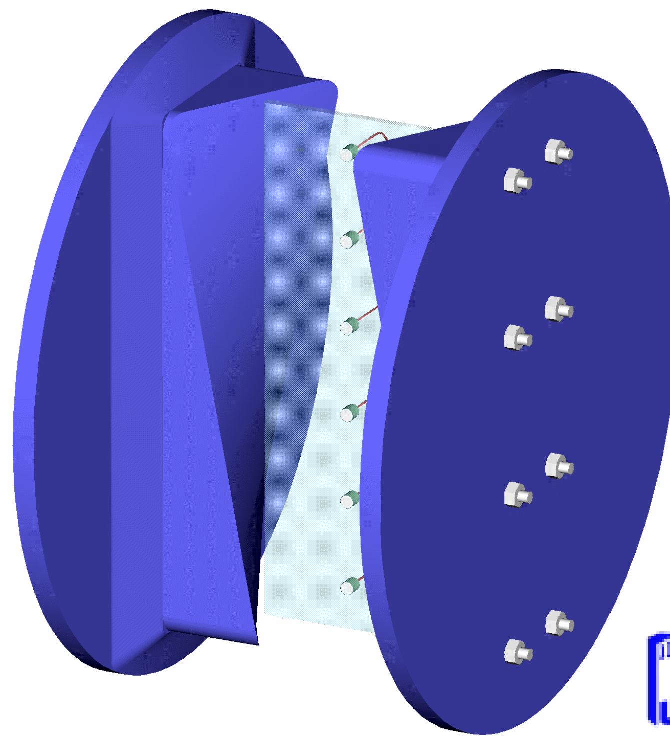


Ga-In-Sn flowing in 20 cm wide, open channel

MHD Tests in NSTX conditions

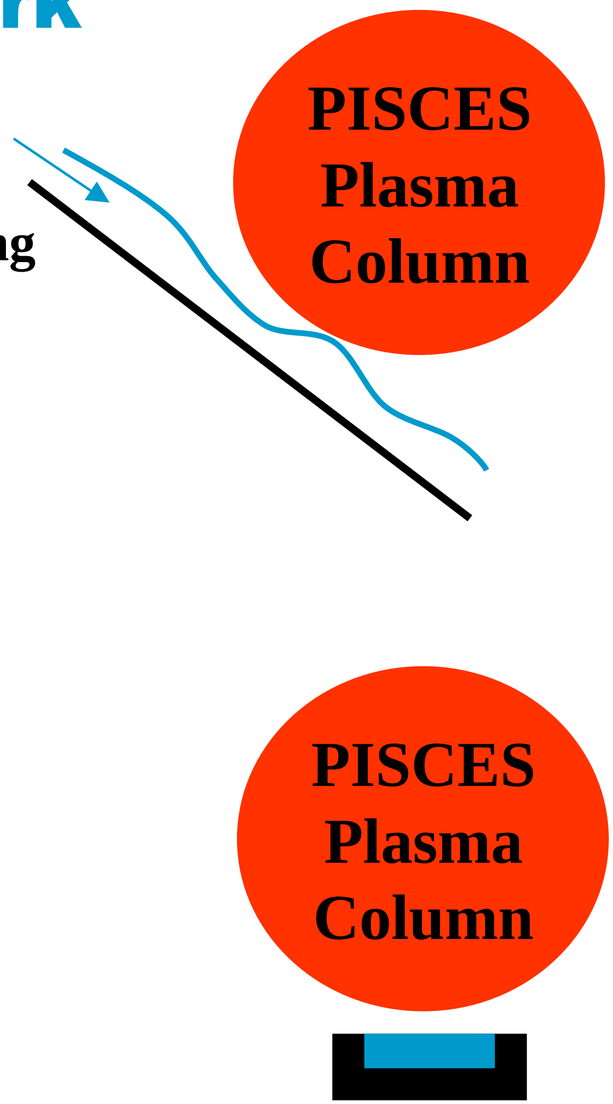


- Flux horns for field concentration (B=0.8 T) and directional variation
- Good match for Ha, Re, and Fr to NSTX outboard conditions



Other Task-II related work

- Liquid Walls in spheromak studies
- Integrated plasma eq/ LW motion modeling (PPPL)
- Plasma wind tests in PISCES - Collaboration with G. Antar and R. Doerner (UCSD)
- Modeling of DIII-D lithium sample movement – Collaboration with D. White and C. Wong (GA)
- FLIHY closed channel flow influence of MHD –
  Jupiter II collaboration with Japan
- LIMITs and FLIRE lithium flow facilities at SNL and UIUC



Flowing film and stagnant boat tests in PISCES