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# DYNAMIC MODELING OF THE TURBULENT SHEDDING EFFECT ON A 30-METER GSMT PRIMARY MIRROR

Guanpeng Xu

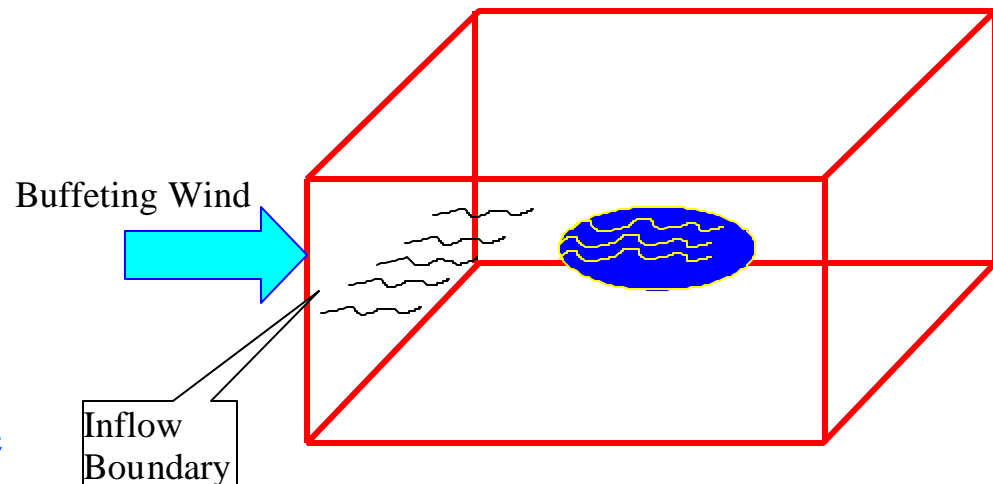
Mark Whorton

Yong X. Tao

Myung Cho

Center of Excellence

Tennessee State University,  
Nashville, TN 37203-3401



# RESEARCH ISSUES

- GSMT image quality is influenced by ambient wind in two ways:
  - Structural vibration due to dynamic wind loading; and,
  - Flushing of uneven temperature field (hot spots).
- Existing measurements on Gemini reveal the importance of dynamic wind loading.
- Dynamic wind loading is because of the wind buffeting and turbulence shed from the edges of enclosure opening and from the edge of telescope mirror.
- First-principles based CFD approaches can resolve these issues and assist the engineers in the development of better GSMT designs.
- CFD research focuses on:
  - Unsteady modeling for flow around the primary mirror;
  - Modeling the wind buffeting/turbulence from inflow

# MATHEMATICAL FORMULATION

Reynolds Averaged Navier-Stokes Equations in Finite Volume Representation:

$$\frac{\partial}{\partial t} \iiint q dV + \oiint [E\hat{i} + F\hat{j} + G\hat{k}] \cdot \vec{n} dS = \oiint [R\hat{i} + S\hat{j} + T\hat{k}] \cdot \vec{n} dS$$

where,

$q$  is the state vector.  $E$ ,  $F$ , and  $G$  are the inviscid fluxes, and  $R$ ,  $S$ , and  $T$  are the viscous fluxes.

A cell-vertex finite volume formulation using Roe's scheme is used.

The scheme is up to fifth order accurate in space and second order accurate in time.

## The k-ε Turbulence Model

- A two-equation turbulence model;
- Known capability to model separated flow.

$$\mathbf{m}_T = C_m \mathbf{r} \frac{k^2}{\mathbf{e}}$$

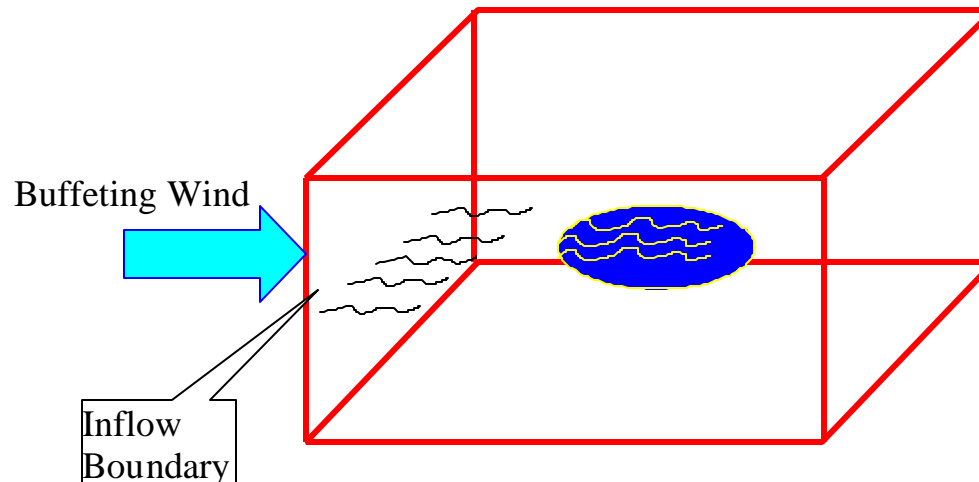
$$\mathbf{r} \frac{Dk}{Dt} = \frac{\partial}{\partial X_i} \left( \frac{\mathbf{m}_T}{\mathbf{s}_k} \right) \frac{\partial k}{\partial X_i} + P - \mathbf{r} \mathbf{e}$$

$$\mathbf{r} \frac{D\mathbf{e}}{Dt} = \frac{\partial}{\partial X_i} \left( \frac{\mathbf{m}_T}{\mathbf{s}_e} \right) \frac{\partial \mathbf{e}}{\partial X_i} + \frac{\mathbf{e}}{k} (C_1 P - C_2 \mathbf{r} \mathbf{e})$$

# Methodology for Inflow Turbulence and Wind Buffeting

- Inflow wind turbulence is represented by turbulence kinetic energy (TKE) at the inflow boundary.
- Wind buffeting effect is studied directly:

$$u_b(t) = U_b \sin(\omega t + \mathbf{f})$$



# Water Tunnel Setup

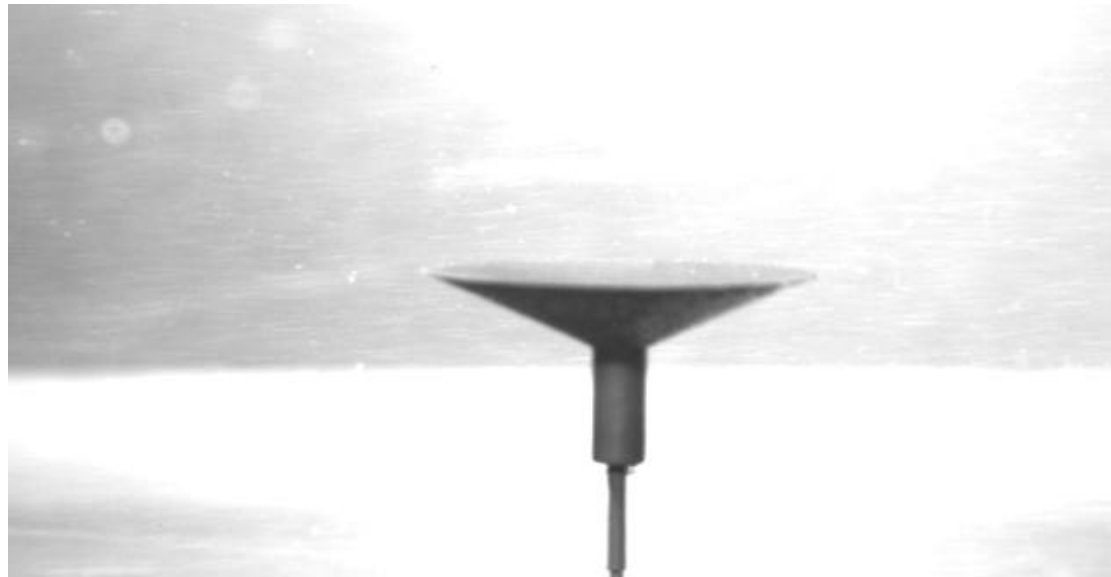
Re: 3,000

Size: 1:833

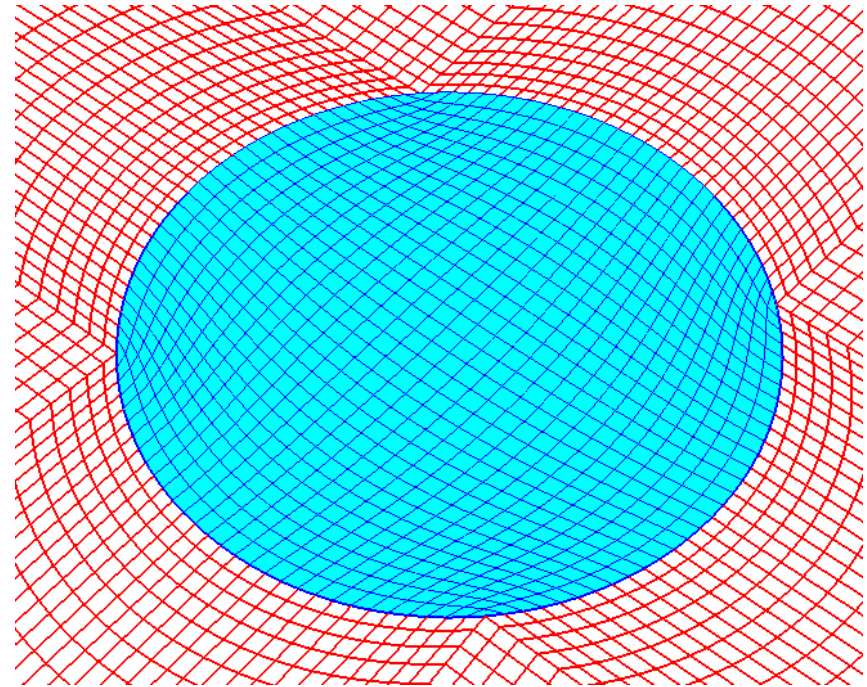
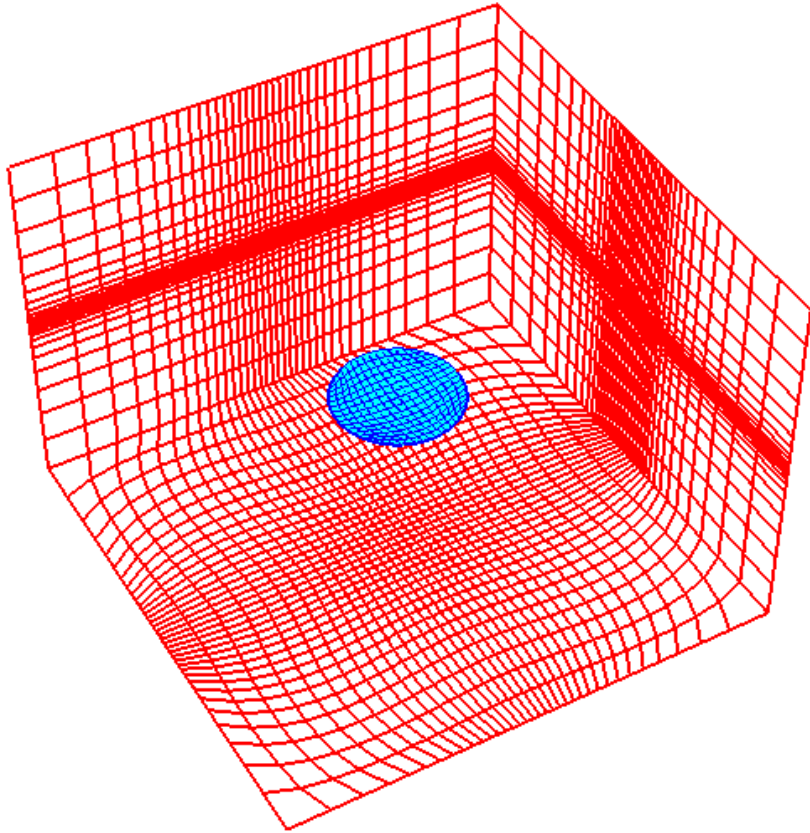
Test Section:

0.156m×0.131m

Particle Imaging  
Velocimetry for  
flow field  
measurements  
and visualization

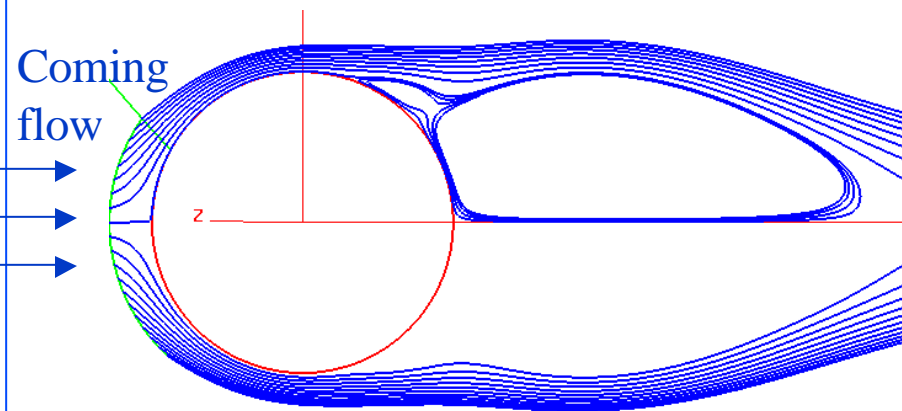
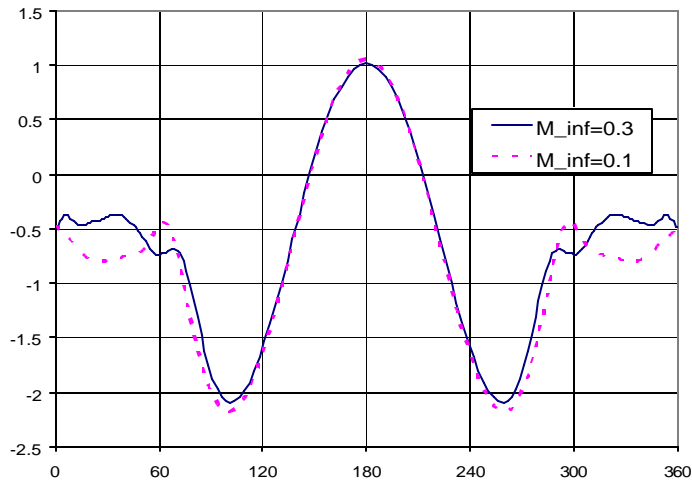


# GRID FOR GSMT MIRROR



Sample H-H grid for  $f/D = 1$   
grid dimension is  $(71 \times 71 \times 70) \sim 353,000$

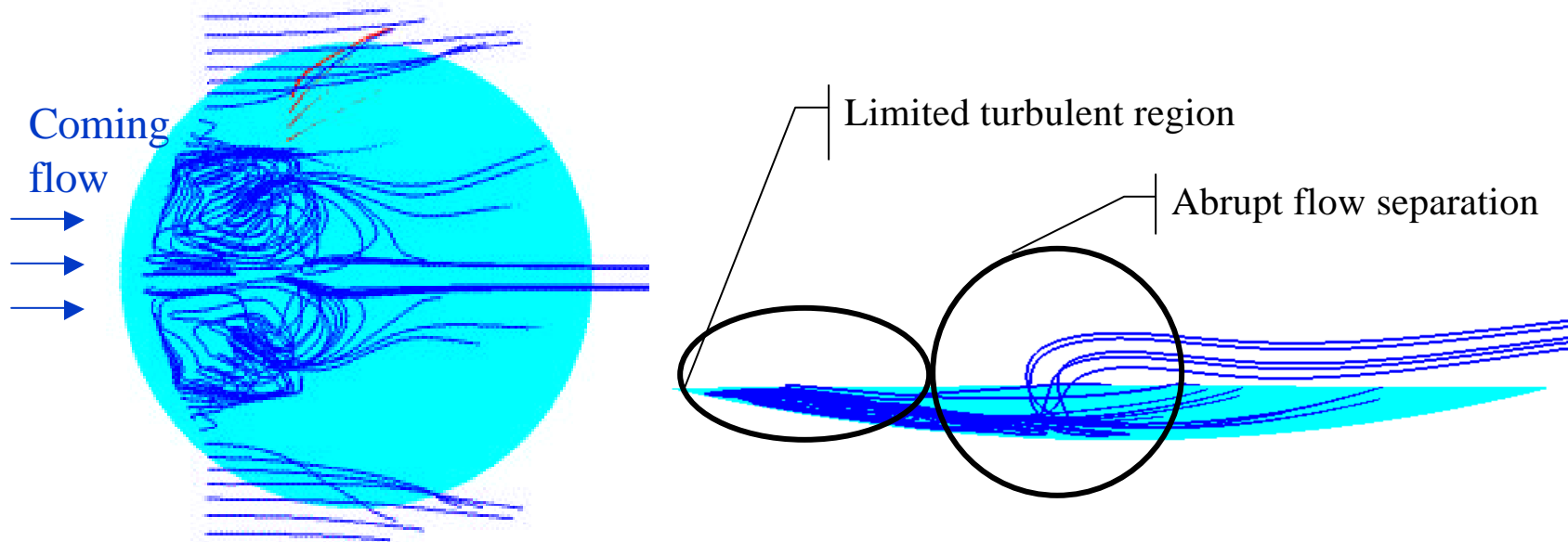
# Validation of Methodology



- A Cylinder/Circle configuration is used;
- Identical results obtained for  $M_\infty=0.1$  and  $0.3$  for attached flow region;
- Difference was observed at separated region

# Round Edge Mirror Configuration

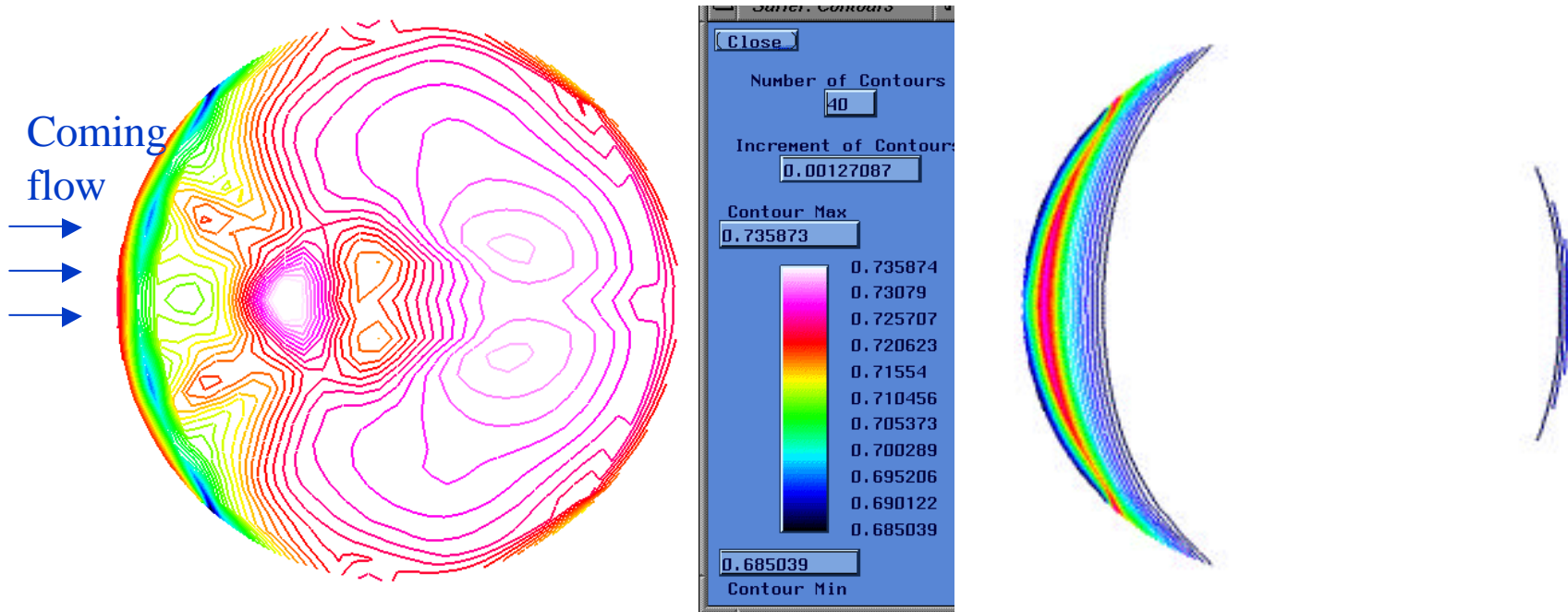
- 8m/s wind;  $0^\circ$  impinging angle;
- Strong vortex after mirror leading edge



Visualization of Fluid Particle Traces on Top Mirror

# Round Edge Mirror Configuration

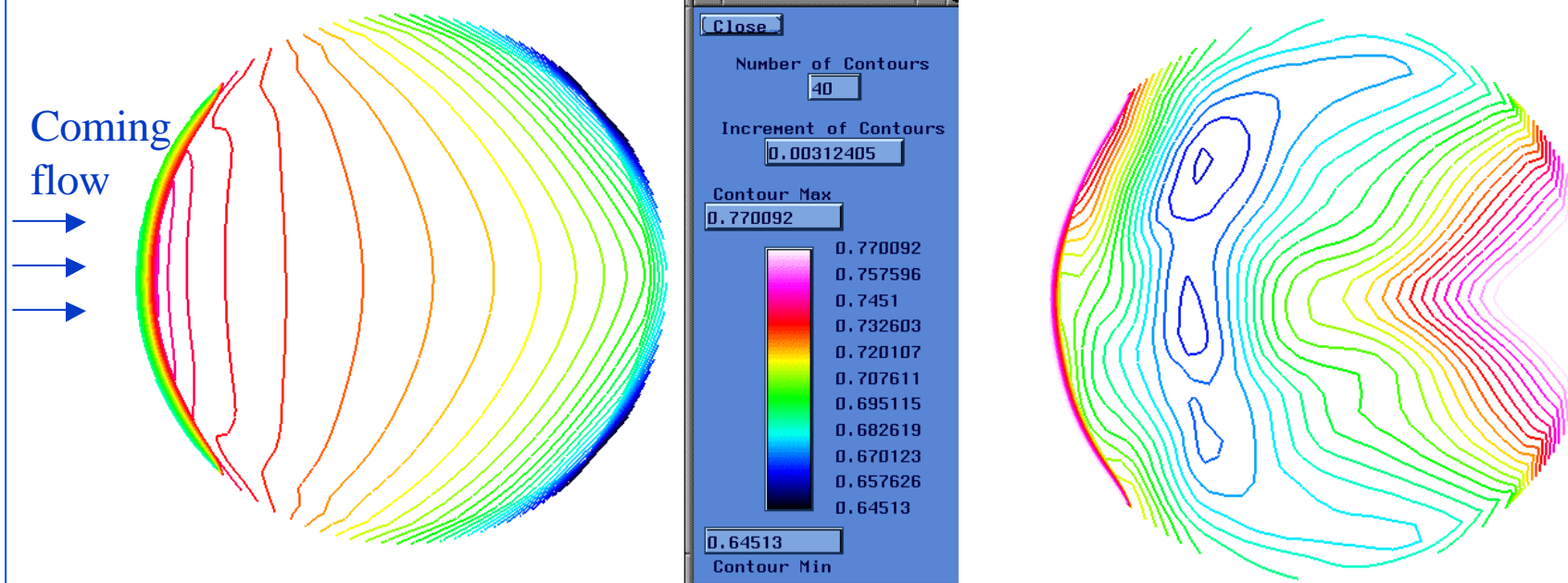
- 8m/s wind;
- 0° impinging angle



Pressure Contour on Upper and Lower Mirror Surface

# Round Edge Mirror Configuration

- 8m/s wind;
- 35° impinging angle

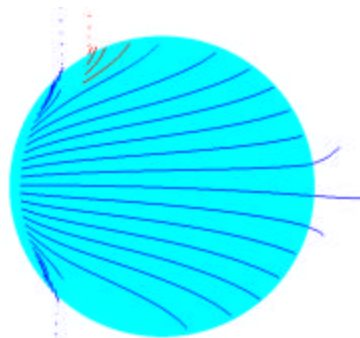


Upper Surface

Lower Surface

Pressure Contour on Upper and Lower Mirror Surface

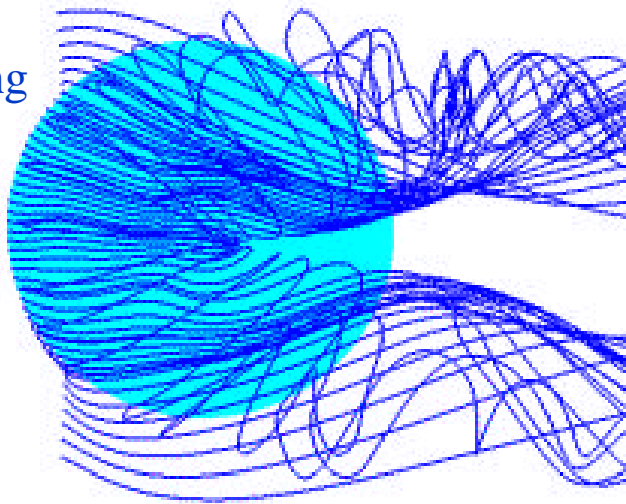
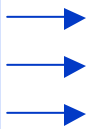
# Round Edge Mirror Configuration



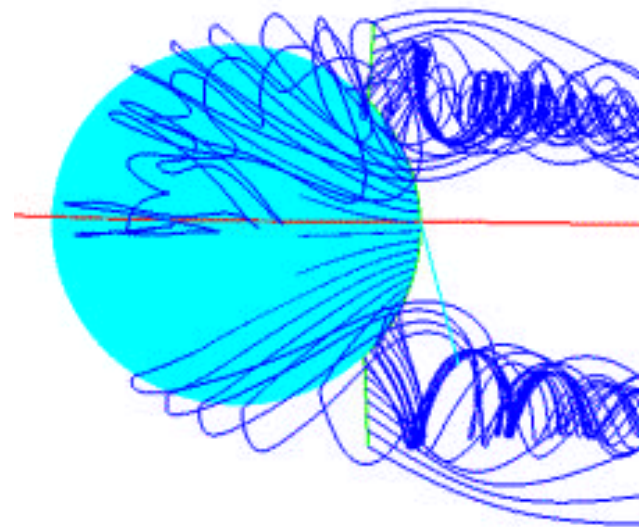
Top View

- 8m/s wind;
- 35° impinging angle.

Coming  
flow



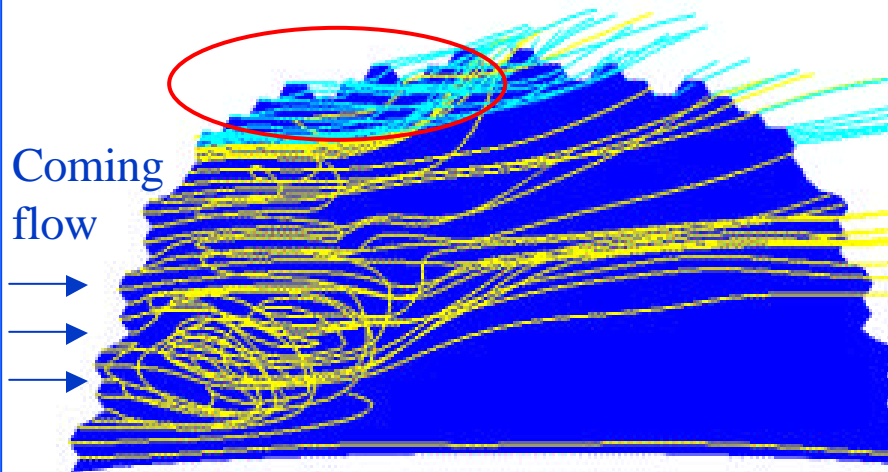
Particles from Leading Edge



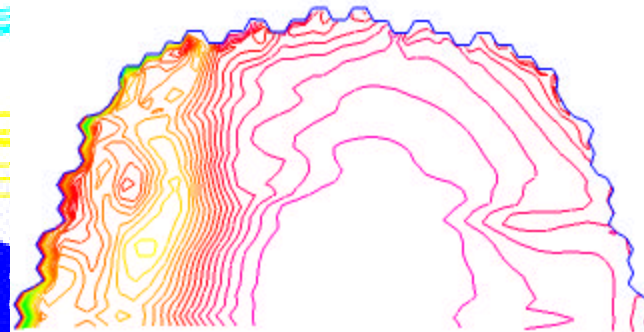
Particles from Trailing Edge

# Effect of Serrated Edge

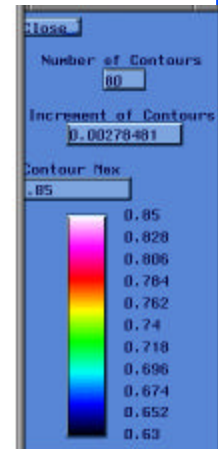
- 8m/s wind; 0° impinging angle;
- Serrated edge enhances turbulent mixture, reduce the oscillation of mirror loading.



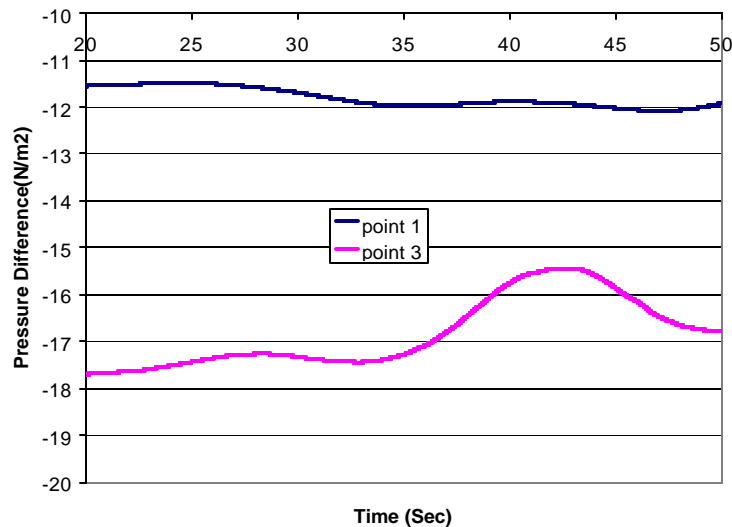
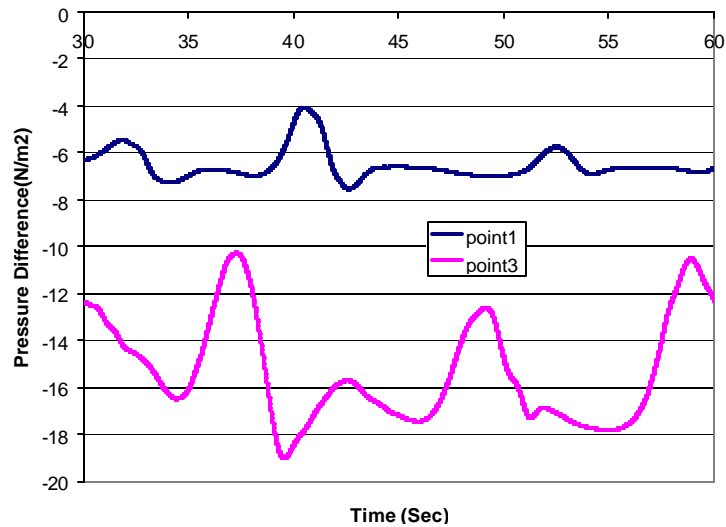
Particle Traces on Top



Pressure Contour on Top

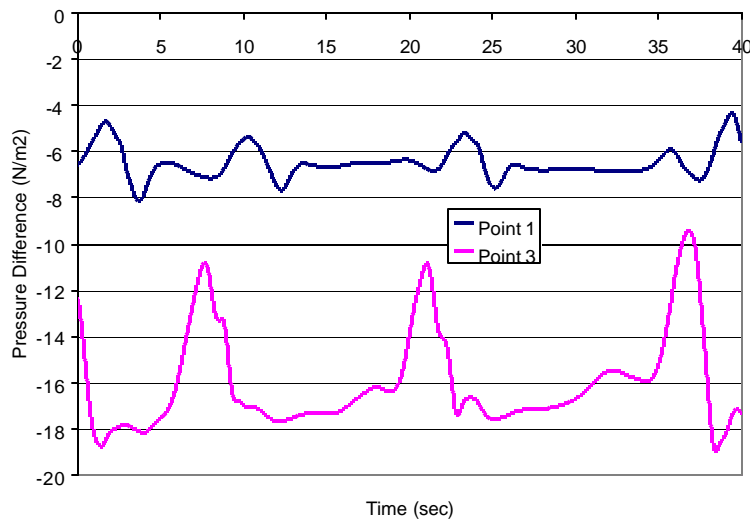
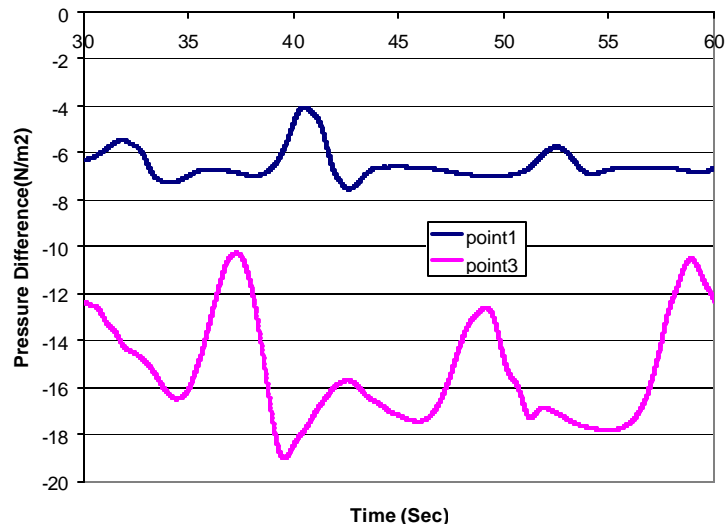


# Effect of Serrated Edge



- Unsteady wind loading at two typical locations; Point 1 is next to leading edge, point 2 is near the mirror center.
- Upper left for round mirror; Lower left for serrated mirror;
- Serrated edge mirror reduces the oscillation of mirror loading.

# Effect of Wind Buffeting

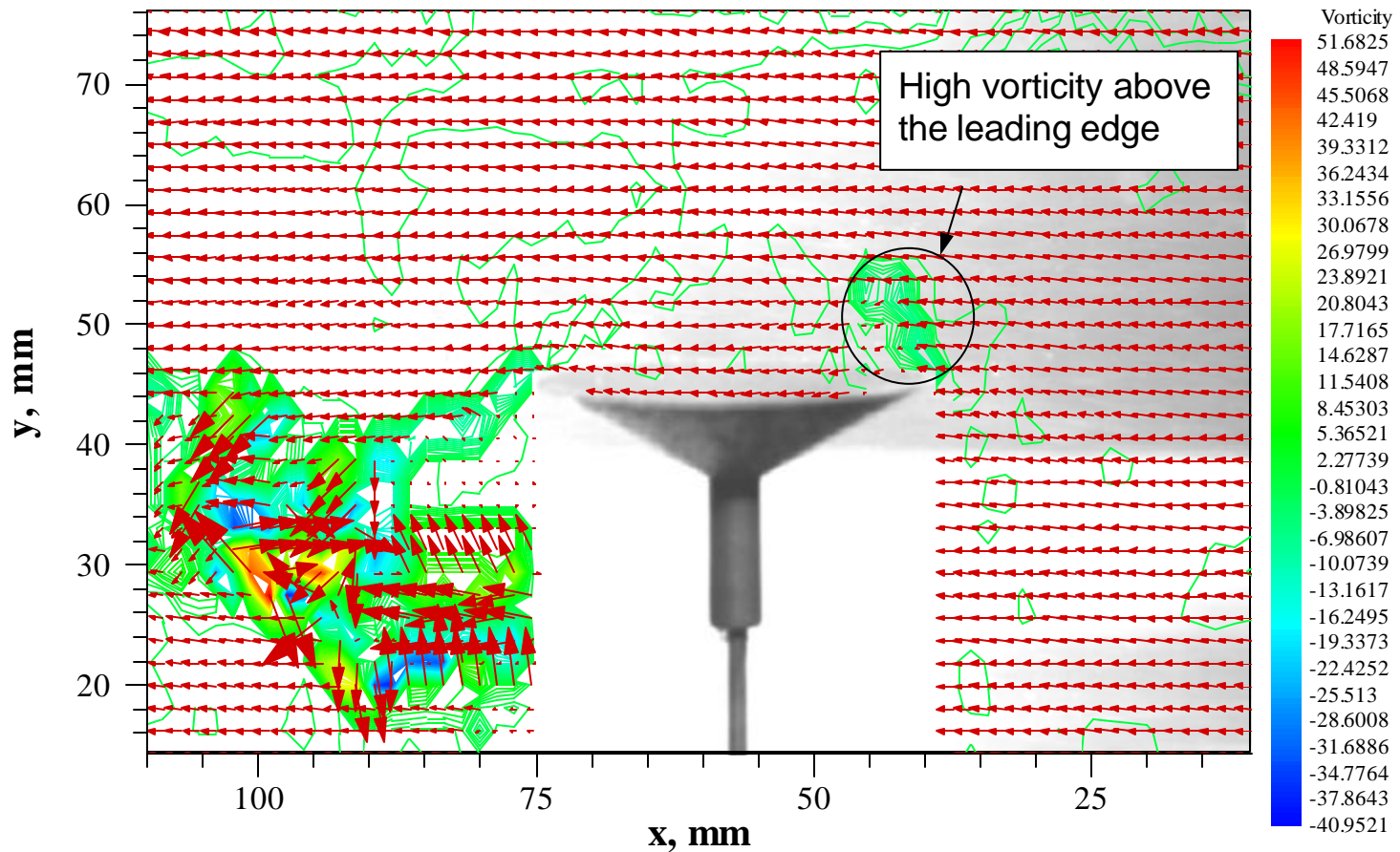


- 2m/s, 0.5Hz wind buffeting upon 8m/s mean wind;
- Upper left is for steady wind, lower left is for buffeting wind;
- Little difference on dynamic wind loading;
- Vortexes shed from mirror leading edge dominant the dynamic wind loading;
- More cases to be studied.

# Water Tunnel Measurements (I)

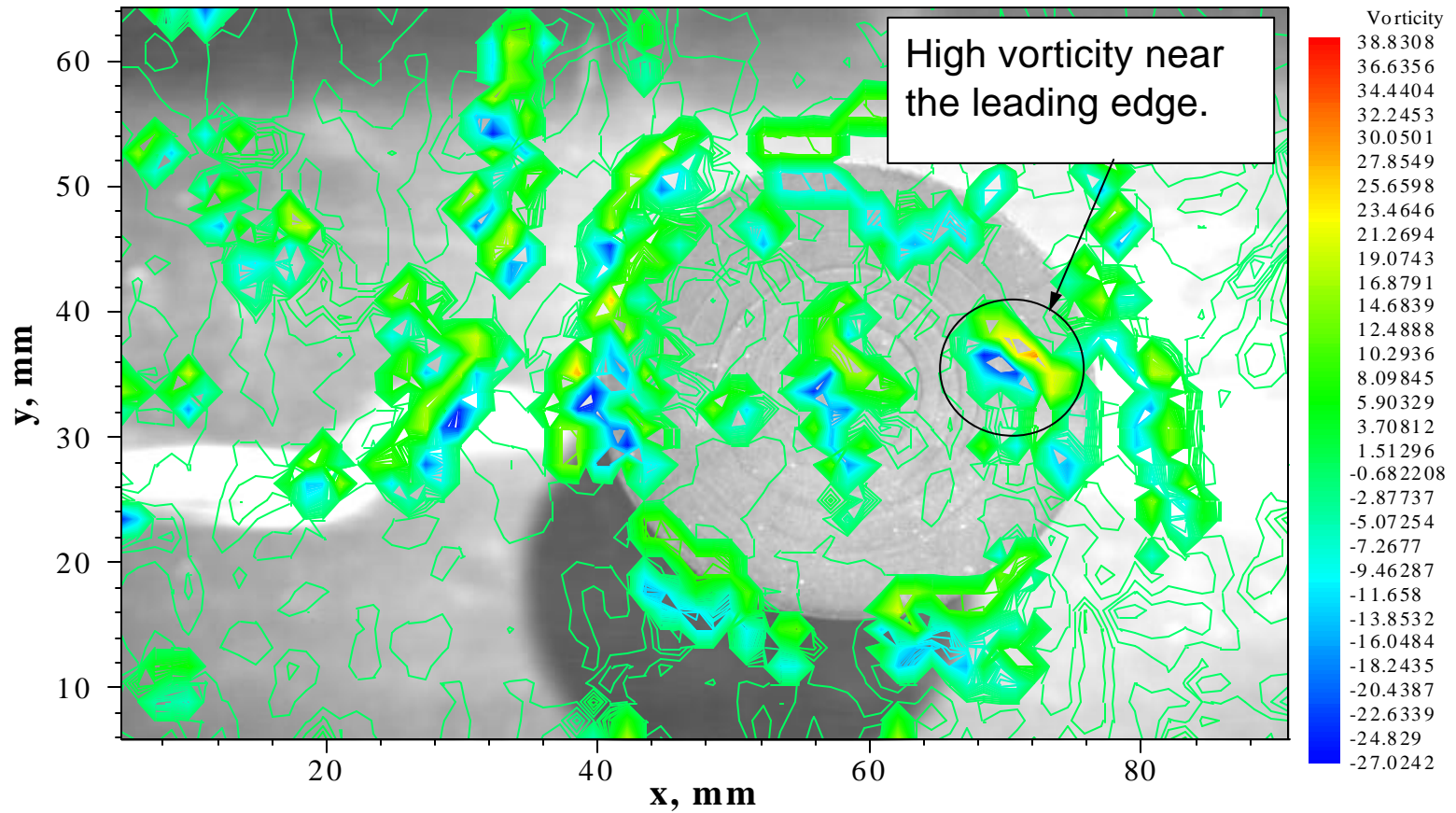
Mainstream WaterFlow:  $T_{\infty} = 25.02 \text{ }^{\circ}\text{C}$ ,  $V_{\infty} = 0.1085 \text{ m/s}$

← Flow direction



# Water Tunnel Measurements(II)

Mainstream Water Flow:  $T_\infty = 25.02 \text{ }^\circ\text{C}$ ,  $V_\infty = 0.1085 \text{ m/s}$  ← Flow direction



## CONCLUSION (I)

- The methodology for modeling the dynamic wind loading on the 30 meter GSMT primary mirror configuration has been established;
- Reynolds averaged Navier-Stokes equations are solved with a two-equation turbulence model;
- Numerical procedures for wind turbulence and buffeting effects were established;

## CONCLUSION (II)

- The frequency of the turbulence captured by the present methodology is between 0.2 to 0.5 Hz. Finer grid has to be used for unsteadily modeling turbulence in higher frequency;
- Serrated edges reduce dynamic wind loading;
- A limited positive impinging angle from top mirror will result in perfect flushing on the upper surface, while the moderate turbulence under the mirror is inevitable due to the complex structure there for actual GSMT mirror configurations.
- The turbulence shed from mirror leading edge dominants the dynamic wind loading for the case studied: 2m/s, 0.5Hz wind buffeting on 8m/s mean wind, which was qualitatively verified by the limited data on flow field measurements around a scaled-down mirror model.

## WORK TO BE DONE DURING REMAINING PERIOD

- More Calculations:
  - Wind turbulence and buffeting;
  - Refined grid.
- Correlation with measurements at 8m Gemini telescope