Wind Loading of Large Telescopes

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Wind is a key factor in large telescope design

Driving factors:
- Larger telescope size, larger wind-induced deflections
- Telescope frequencies closer to peaks of wind spectra

Seeing and buffeting
- Wind helps to mitigate thermally-induced local seeing
- Wind buffeting affects pointing and tracking and causes localized deformations of mirrors

Wind Test (pressure and velocity)
- Wind test on Gemini South Telescope, May 2000
Wind Test and Procedures

• **Why**: to identify source of pressure variations
  – Wind attack angles
  – Telescope pointing angle (Zenith angle)
  – Wind vent gate positions

• **How**: to setup various test configurations
  – 116 different combinations of wind test

• **What**: to measure wind pressure/velocities
  – 24/32 pressure; 6 anemometers
  – Pressure/velocities at 10 samples/second (no delay)
Gemini South Wind Tests
(May 2000) Sensor locations

Ultrasonic anemometer
Pressure sensors

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SPIE Kona Conference (4837-40) #4
Overview of the L16, L9 Analyses

statistical approach - standard design of experiments (DOE)

- Largest effect is from vent gate position.
- Elevation angle is NOT statistically significant.
Simultaneous Animations

c0003000

Wind Pressure (N/m²)  Mirror Deformation (microns)

Wind Speed at 5 Locations (m/sec)

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Structure function

Correlation length, $L_p$

Are the pressures on the mirror correlated? If so, what is the limiting distance?

Solution: Structure function

$$D(\rho) = \langle |P(r+\rho) - P(r)|^2 \rangle$$

<table>
<thead>
<tr>
<th>wind direction</th>
<th>wind direction</th>
<th>wind direction</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td>$0^\circ$</td>
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<td>$90^\circ$</td>
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</table>

- $L_p$ data set
- $L_p$ data set
- $L_p$ data set

1.95 meter c00030oo 1.33 meter c04530oo 0.83 meter c09030oo
1.80 meter t00030oo 1.71 meter t04530oo
1.78 meter c00060oo 1.38 meter c04560oo 0.90 meter c09060oo
1.88 meter d00060oo
1.90 meter d09060oo
1.90 meter d09060oo

Correlation length is less than 2 meters for most wind cases

Strong dependence on wind direction
Is it possible to characterize wind pressure as a time varying average pressure pattern?

- If so, average temporal pressure can be representable to wind pressure.
- Average pressure can be predictable from Computational Fluid Dynamics (CFD) models.
- Then, characteristics of wind pressure and velocity from CFD models can be an input wind loading as PSD in FE analyses.
Best Fit to Average Pressure

\[ P_i(t) = C(t) P_{ai} + P_{ri}(t) \]

- \( P_i(t) \): raw data at time \( t \) at \( i^{th} \) sensor
- \( C(t) \): coefficient of fit at time \( t \)
- \( P_{ai} \): temporal average pressure at \( i^{th} \) sensor
- \( P_{ri}(t) \): fit residual at time \( t \) at \( i^{th} \) sensor

\[ <P_i(t)^2> = <C(t) P_{ai}^2> + <P_{ri}(t)^2> + 2 <P_{ri}(t) * C(t) P_{ai}> \]
Coefficient of Fit $C(t)$

$$\langle P_i(t)^2 \rangle = \langle C(t) \ P_{ai} \rangle^2 + \langle P_{ri}(t)^2 \rangle + 2 \langle P_{ri}(t) \times C(t) \ P_{ai} \rangle$$

Temporal average of RESIDUAL: $\langle Pr(t)^2 \rangle$ (c09060oo)

Average pressure is representable to wind pressure
Does $C(t)$ contain velocity effects?

$C(t)$ with wind velocity at M1

Kolmogorov:

$$\Phi_v(f) = C_v f^{-5/3}$$

Prms vs $C(t)$ PSD fit (open-open) ($f^n$)

$C(t)$ shows Kolmogorov velocity PSD $f^{-5/3}$ rule
Comparison of Predicted and Measured Pressure Patterns

Facing into wind, Zenith angle = 30°

Pressure pattern using a simple disk predicted by CFD (DeYoung)

Measured pressure patterns

c0003000

t0003000
Alternate CFD Model

For further investigation, Oleg Likhatchev (University of Arizona) set up simple CFD models with a disk of D x H (8m x 2m).

- CFD code FLUENT; Quasi-steady assumption; Zenith angle = 30

Stepped CFD model shows similar effect to measured data

Accurate CFD modeling is essential; NIO/TSU collaboration

“CFD modeling of turbulent shedding effects on 30m GSMT”
Poster paper by Xu (4840-43)
Goals in segment wind modeling
- To specify segment support stiffness
- To identify segment control bandwidth
- Subscale model to GSMT integrate model
- Enables to build analytical tools for GSMT

Segment configuration
- Dimension = 1.33 m point to point
- Support stiffness = 10 N/microns
- 36 segments for a 8 m primary mirror
Sample wind at $t=0.1$ sec. ($t0000000o$)

Wind pressure distribution

Segment displacement pattern (microns)

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Spot size for Diffraction limit
(single segment)

0.1 arcseconds

0.5 arcseconds

nominal seeing

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GISM Sample animation (t00000000)

Segment displacement pattern (microns) Spot diagram (arc-seconds)

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SPIE Kona Conference (4837-40) #18
Simultaneous Animation (t00000000)

Active optics and control architecture for GSMT
presented by Angeli (4840-22)
GISM wind effects (t0000000)

90% energy encircled at 0.173 arcsec radius (for 5 minute integration)

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### Effect of vent gate positions

<table>
<thead>
<tr>
<th></th>
<th>Pressure</th>
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<td>Surface P-V = 0.80 um</td>
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<tr>
<td>closed</td>
<td>Surface RMS = 0.03 microns</td>
<td>Surface P-V = 0.07 um</td>
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</table>
Summary and Conclusions

- Correlation length is less than 2 meters in most cases
- Average wind pressure: Low in “leading”; High in “trailing”
- CFD should reflect physical geometries, turbulent flow conditions
- Average pressure pattern contains most energy (small fit residuals)
- Wind pressure is favorably expressed by time varying $P_{avg}$
- PSD of $C(t)$ fits with frequency in $f^n$, $n \sim (-1.4 \text{ to } -2.4)$
- On average $C(t)$ fits show Kolmogrov velocity PSD $f^{-5/3}$ rule
- M1 wind deformations: astigmatisms; Segment in high frequencies
- Developed analytical/design tools for GSMT
Future Plan

- Wind loading simulation
  - Wind loading characteristics (Lo, Lp, PSD,…)
  - Gemini Segmented Mirror Testbed simulation
- CFD analyses
  - Establish CFD models for GSMT
  - Identify and quantify key design parameters
- More wind tests
  - Longer time at higher rate in denser samples
  - Share expertise and collaborations
The Gemini South wind test results are available on the AURA New Initiatives Office Web site at:

www.aura-nio.noao.edu