

An Investigation of Bluff Body Corrections Using the NASA/ODU 6-inch MSBS

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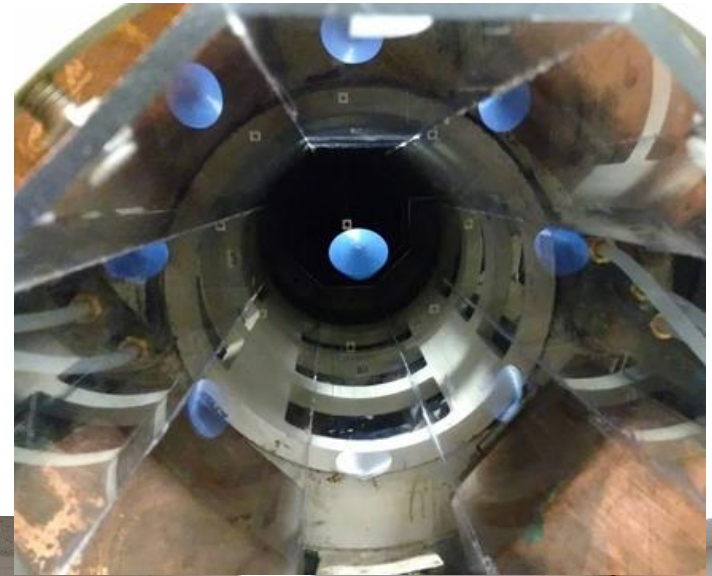
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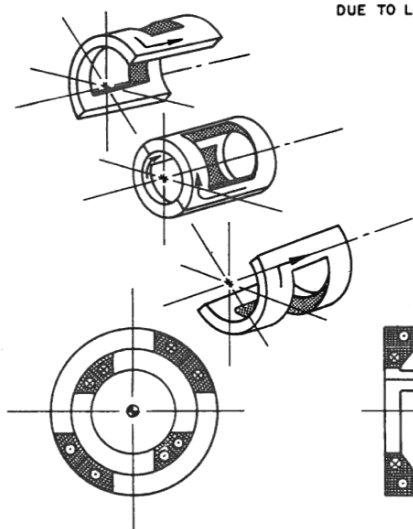
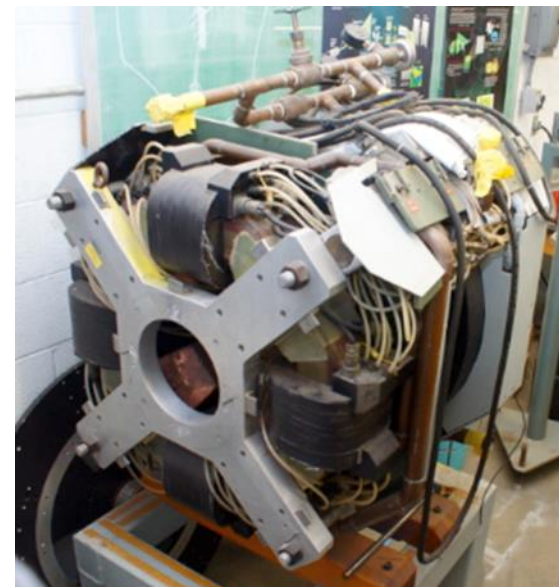
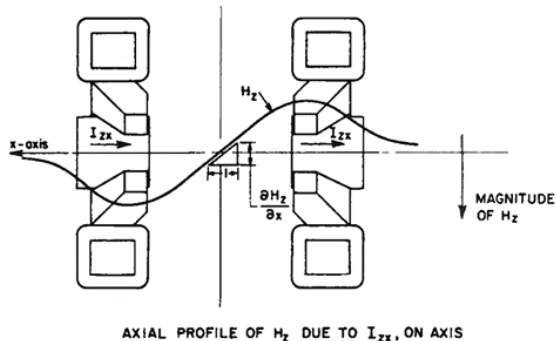
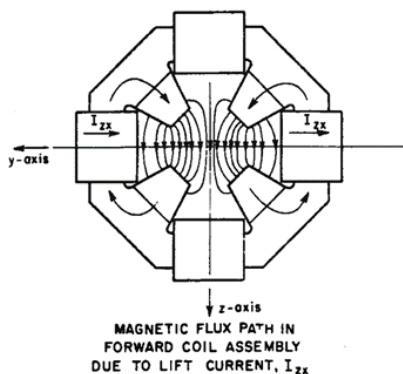


- Background
- Review of the NASA/ODU/MIT 6-inch MSBS
 - History and achievements
 - Technical description
 - Low-speed wind tunnel
- Reconfiguration to vertical magnetization
 - Motivation
 - Analysis and implementation
 - Evolution of control approach
- Sphere aerodynamics
 - Motivation
 - Drag measurements in MSBS
 - Dynamic behavior in MSBS
- Blockage corrections
 - Classical method (Maskell)
 - Wall pressure signatures
 - Wake profiles
- Summary & conclusions

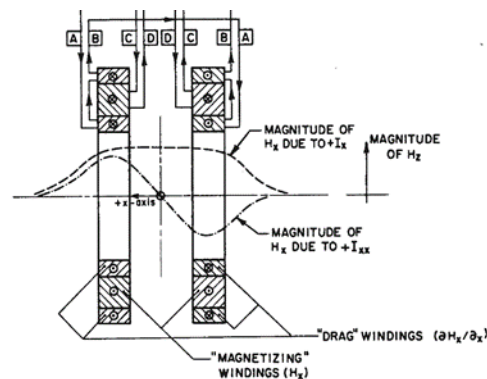
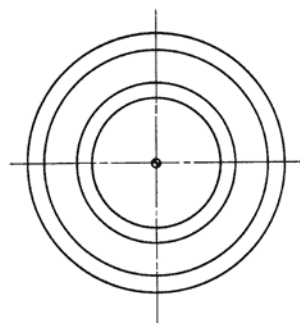


- Developed by Basmajian, Copeland, Stephens et.al. circa 1965/6
- Separate field and field gradients / degrees-of-freedom
- Electromagnetic Position Sensor (EPS)
- Recommissioned with wind tunnel at NASA LaRC

“Lift” and
“Sideforce”
coils – 2 sets
per iron yoke

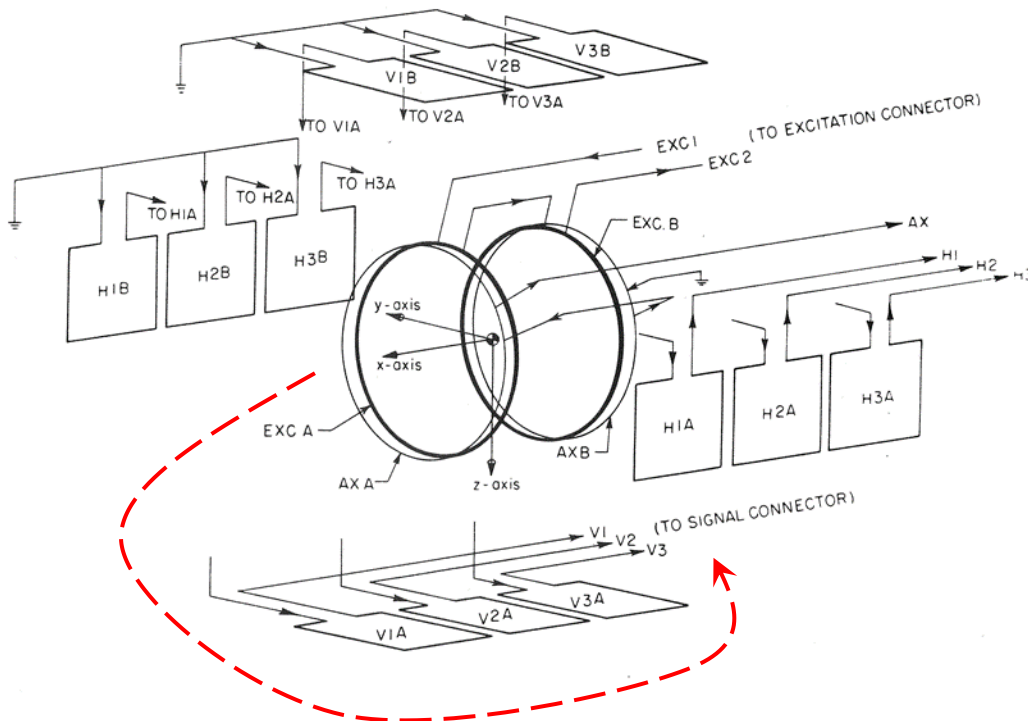


“Saddle” coils
for pitch/yaw

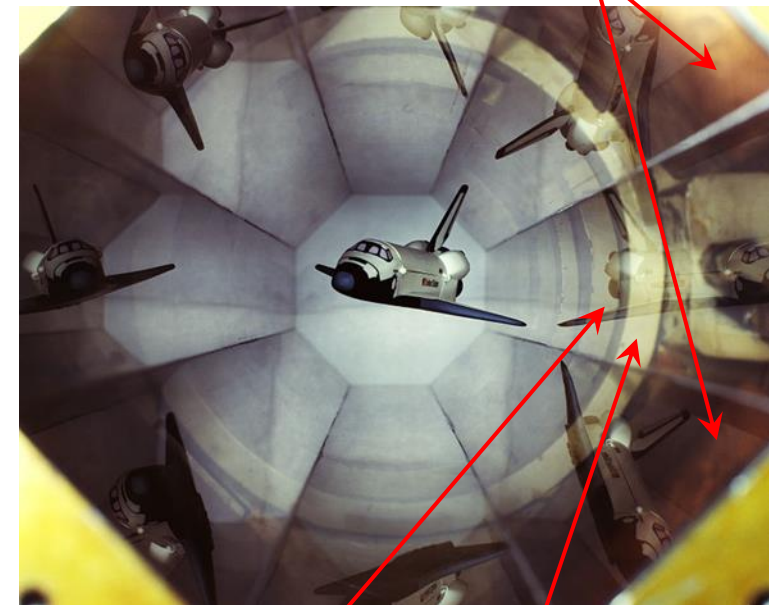


“Helmholtz”
pair for
magnetizing
field and drag

- The EPS system is unique to the NASA/ODU/MIT MSBS
 - Two other groups experimented with EPSs, but without success for various reasons
 - *University of Virginia and ONERA*
- NASA is now accumulating operational experience and investigating upgrades
- Drift of the null points is a constant issue – requires routine adjustments
 - Thought to be due to “external” coupling - temperature dependent!



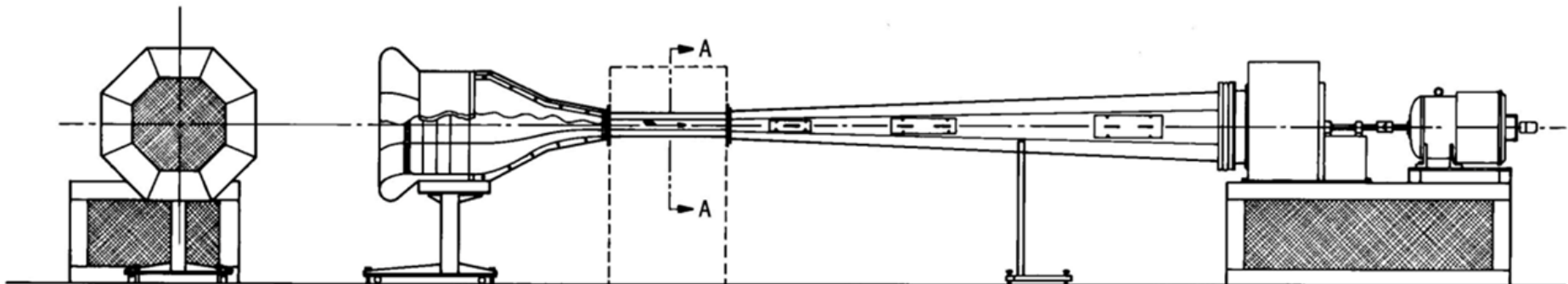
Copper pole covers (example)



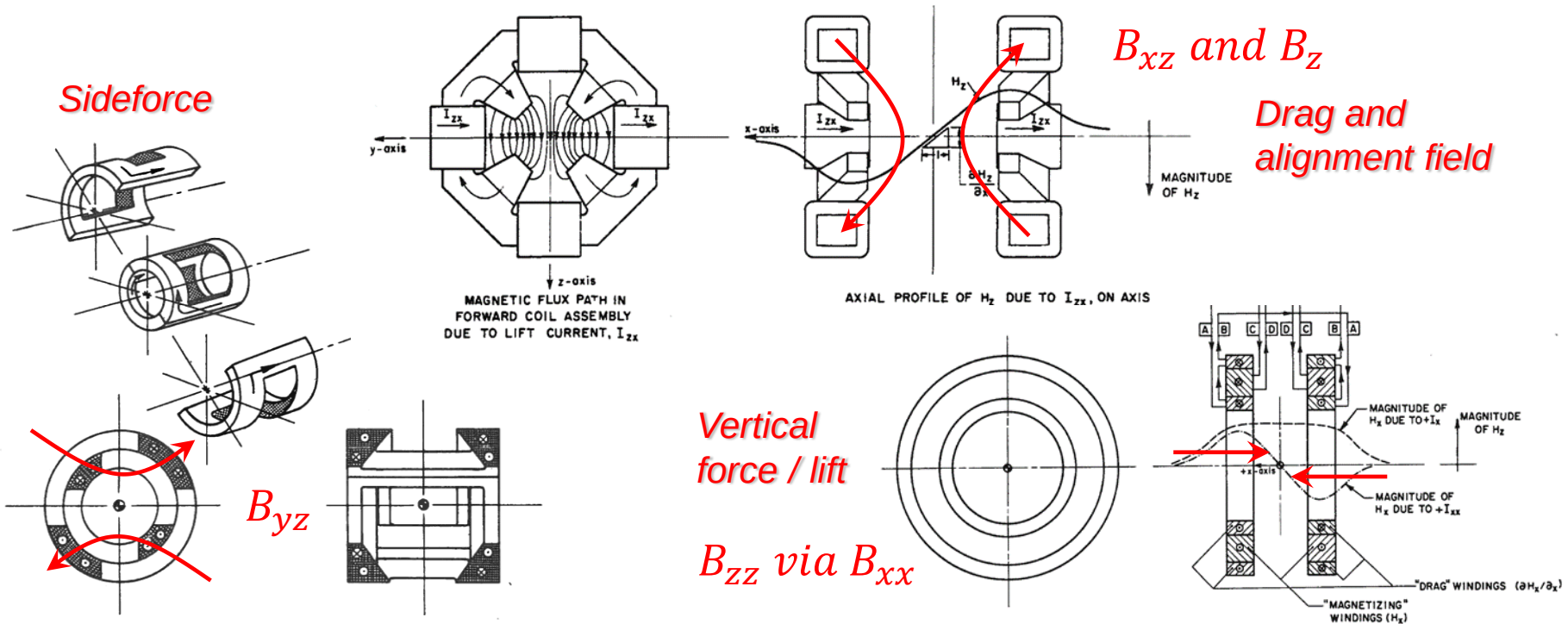
Excitation coils

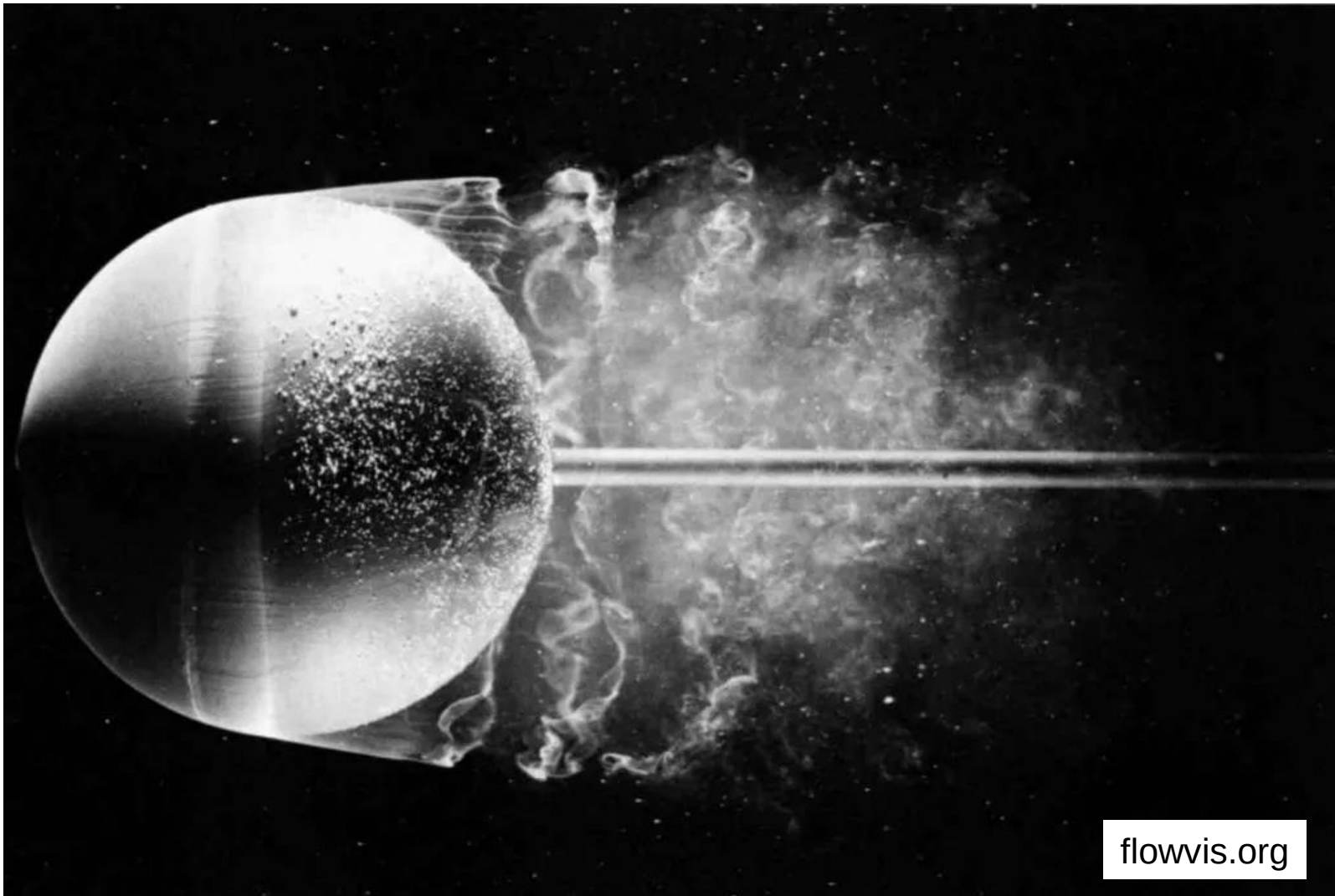
H1A coils

- Designed/constructed by MIT in the 1960's (Vlajinac, et.al.)
- Used for many years at MIT, then NASA, then at ODU (without MSBS)
 - Constructed mostly of wood, with Plexiglas test section
 - Maximum Mach number is just above 0.5
 - Similar dynamic pressure to proposed supersonic applications (>10 kPa)
 - Three 46% solidity screens (original honeycomb removed), 20:1 contraction ratio
 - Octagonal cross-section, 5° diffuser with 3 access ports and model catch net
 - Squirrel-cage fan, 20 HP motor (original DC replaced by AC variable-frequency drive)
- Original calibration showed 0.1-0.3% turbulence intensity
- Unusually long test section ($\approx 6:1$ L/D) causes some concern over boundary layer growth, particularly at lower speeds



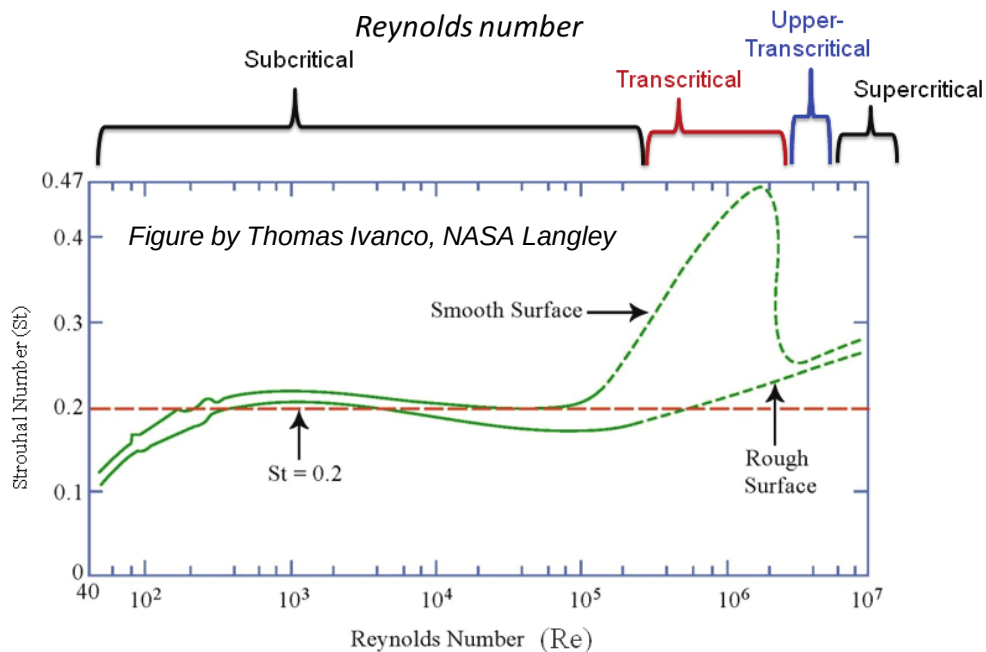
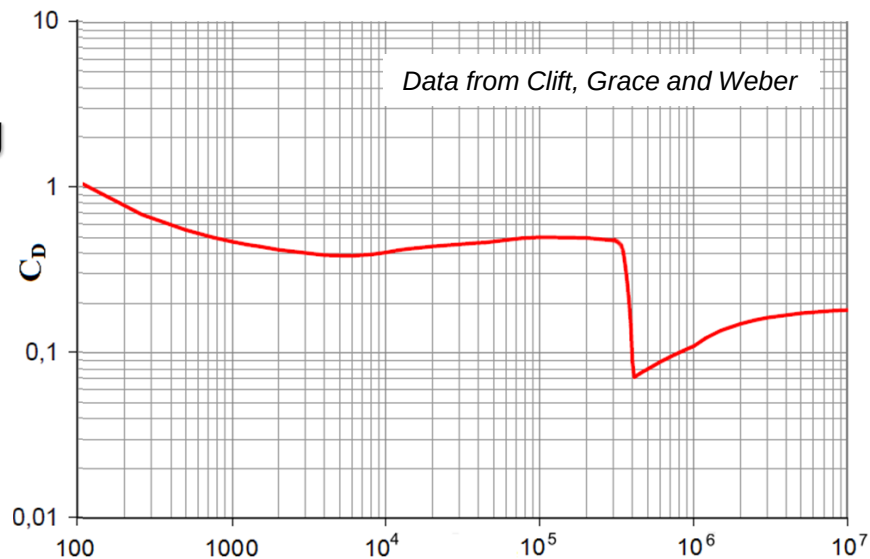
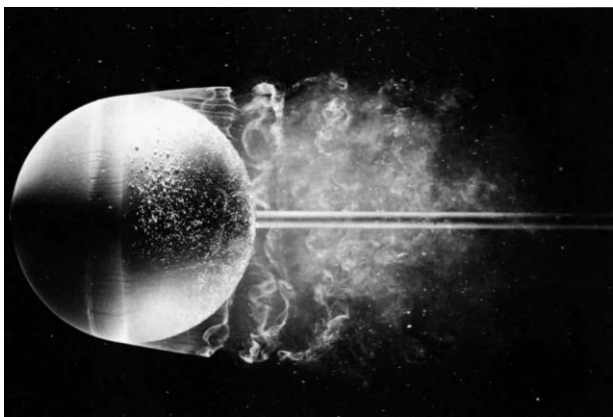
- The coil usage has been changed to implement a “free-to-yaw” configuration
 - Vertical magnetization axis
 - Only 3 translations (x, y, z) controlled
 - 2 rotations (roll and pitch) passively stabilized by a steady alignment field (B_z)
- Side force derived from the original “saddle” coils with reversed relative polarity
- Vertical force derived from original “drag” coils
- Axial (drag) force and alignment field from original “lift” coils operated as front/rear





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- Simple geometry with minimal aerodynamic/magnetic/inertial coupling
- Drag coefficient and unsteady wake structure well understood
 - Primary Strouhal number around 0.2
 - Higher-frequency secondary mode
- Traditional area of interest for MSBSs – support interference-free
- Three 3D-printed models
 - 44.45, 50.8, 57.15mm diameter
- Same magnetic core
 - 25.4mm length & diameter cylinder



- A spare Plexiglas test section was pressure-tapped on 2 opposing walls
- An all-plastic rake was constructed to avoid interaction with the EPS
- A slender plastic pitot tube supported by an existing downstream retractable strut
- Pressures measured via two 16-channel Scanivalve DSA3217 pressure scanners

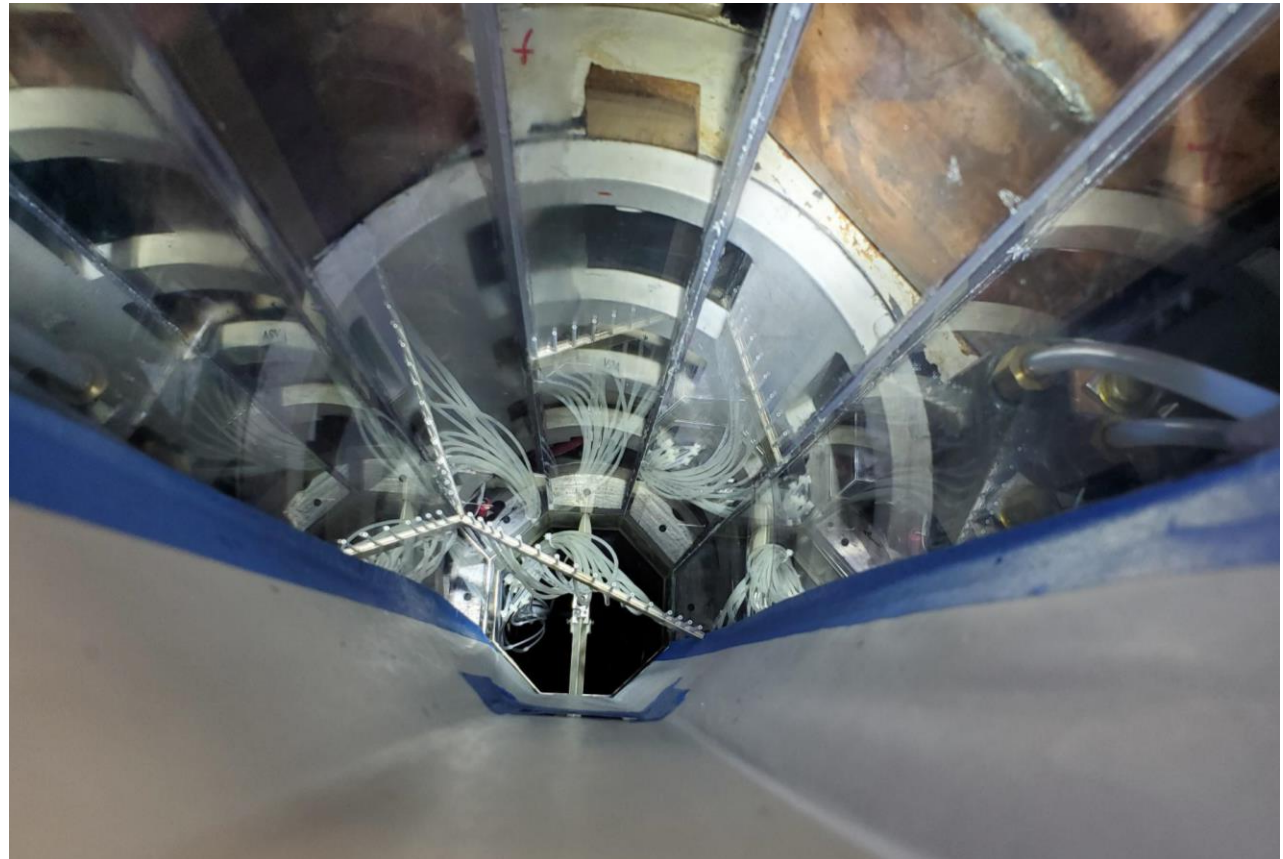
View of rake from upstream

16 tubes spanning opposing apex points of octagonal test section

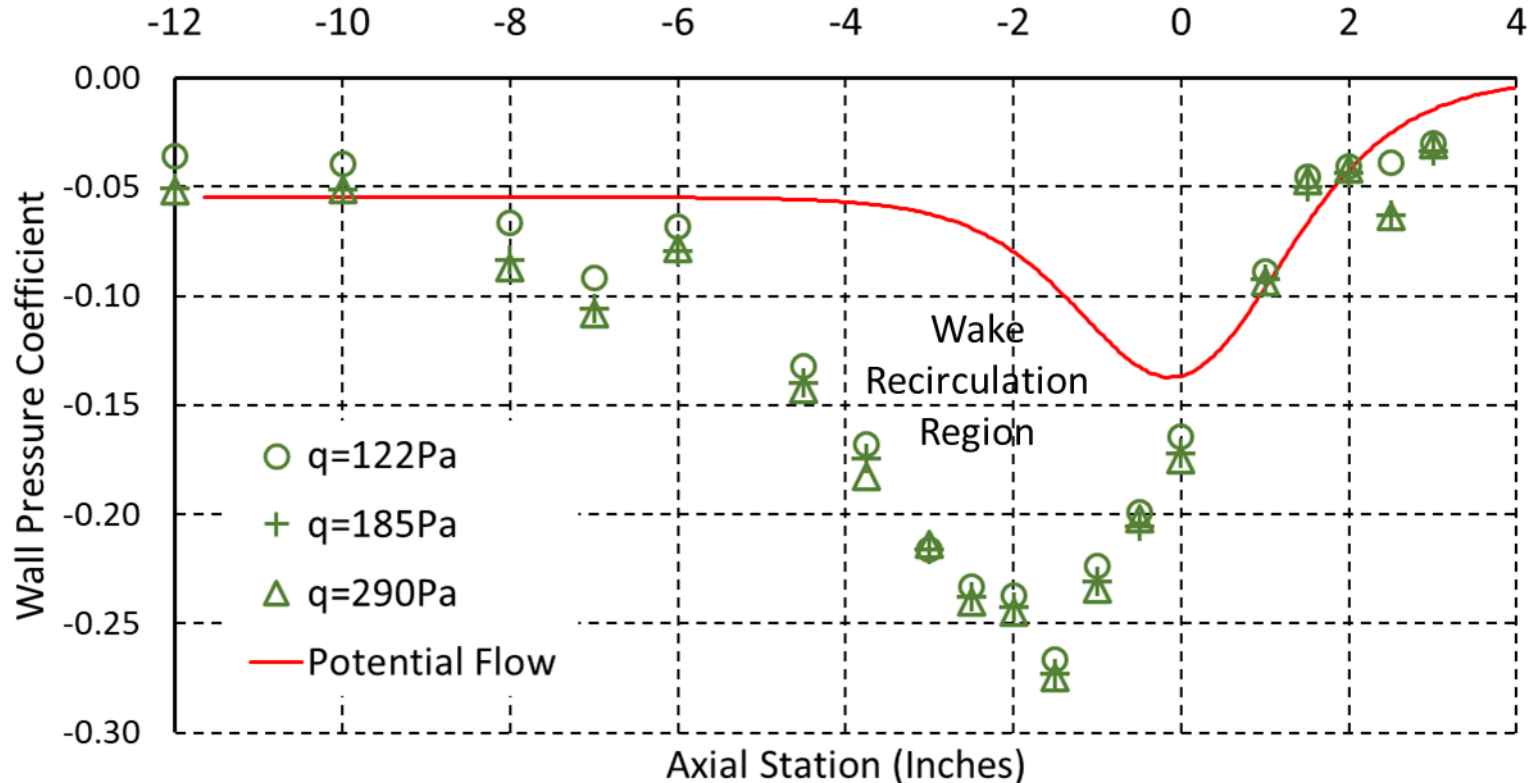
Mounted 150 mm downstream of centroid

Sidewall taps in alternative test section (not shown)

Pitot probe mounted on downstream strut (retractable)



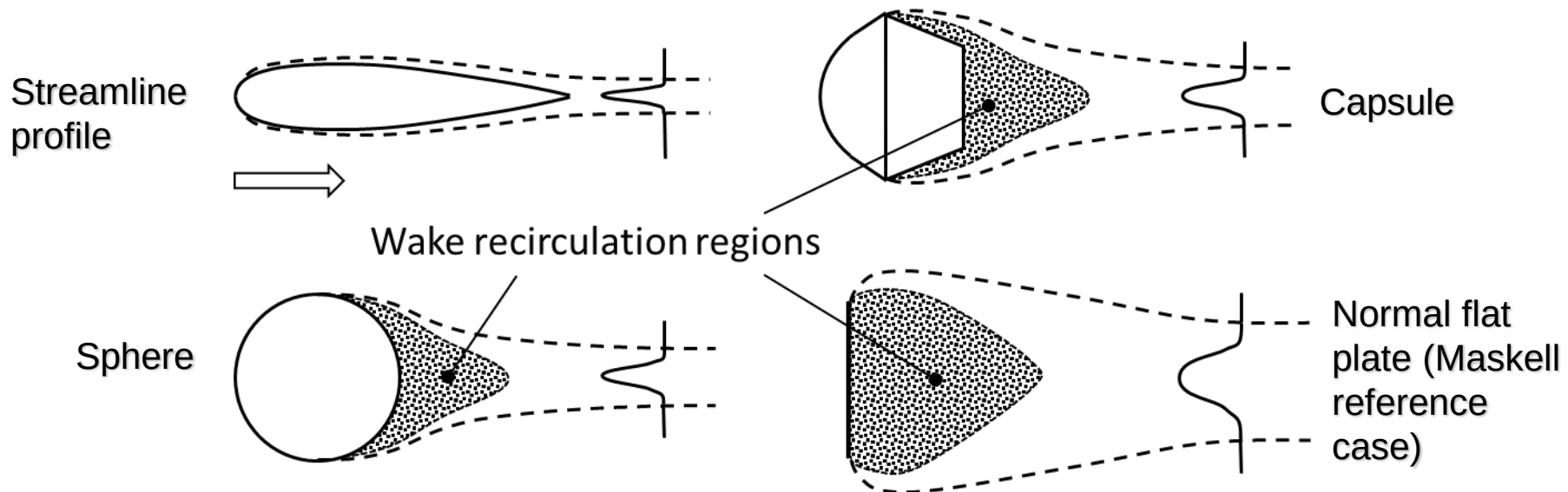
- Wall pressure signatures broadly correspond to expected behavior
- Baseline model diameter shown (50.8 mm diameter, blockage ratio 8.1%)
- Wake recirculation region is tricky to model
- Some evidence of flow breakdown with largest model (57.15 mm; 13,4% blockage)



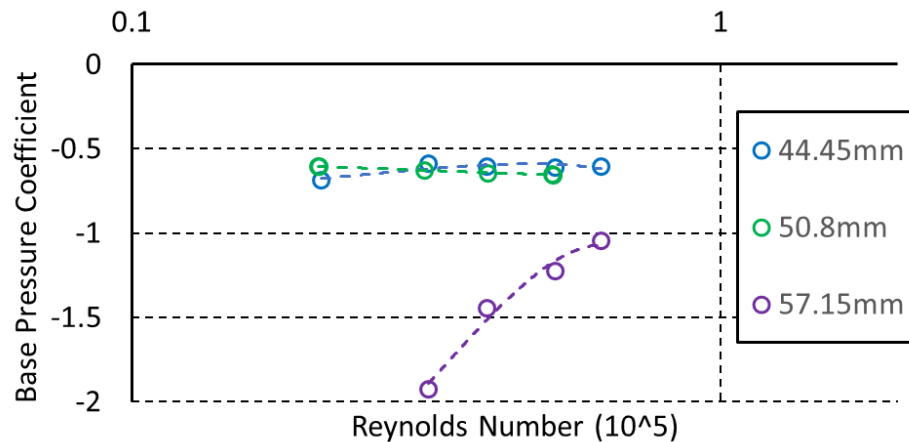
- Classical method for bluff bodies due to Maskell
- Originally developed for flat plates normal to the air stream
- Generalized for bluff bodies

$$k^2 = 1 - C_{p_b} \qquad (k_c^2)_n = k^2 / \left[1 + \frac{1}{(k_c^2)_{n-1} - 1} \frac{C_{D1} S}{C} \right]$$

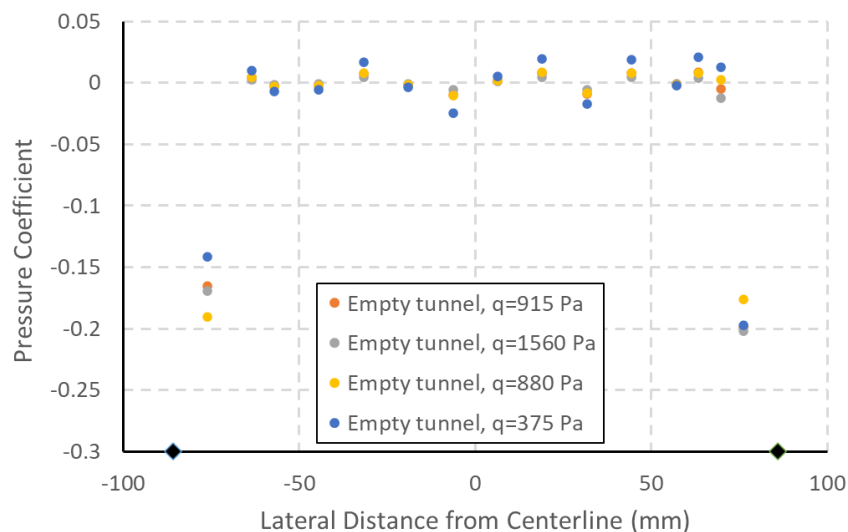
$$\frac{q_c}{q} = \left[1 + C_{D0} \frac{S}{2C} - \frac{1}{(C_{p_b})_c} \frac{S}{C} \right]$$



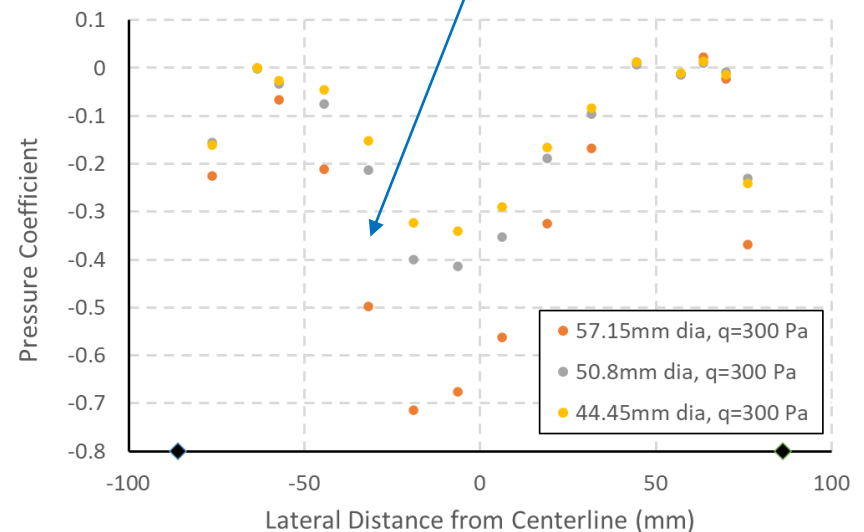
- Base pressures reasonably consistent for smaller sphere sizes; ≈ -0.6
- Anomaly for largest sphere – considerably lower C_{pb} values
 - Suggests flow breakdown or merging of sphere wake with tunnel boundary layers



Empty tunnel calibration



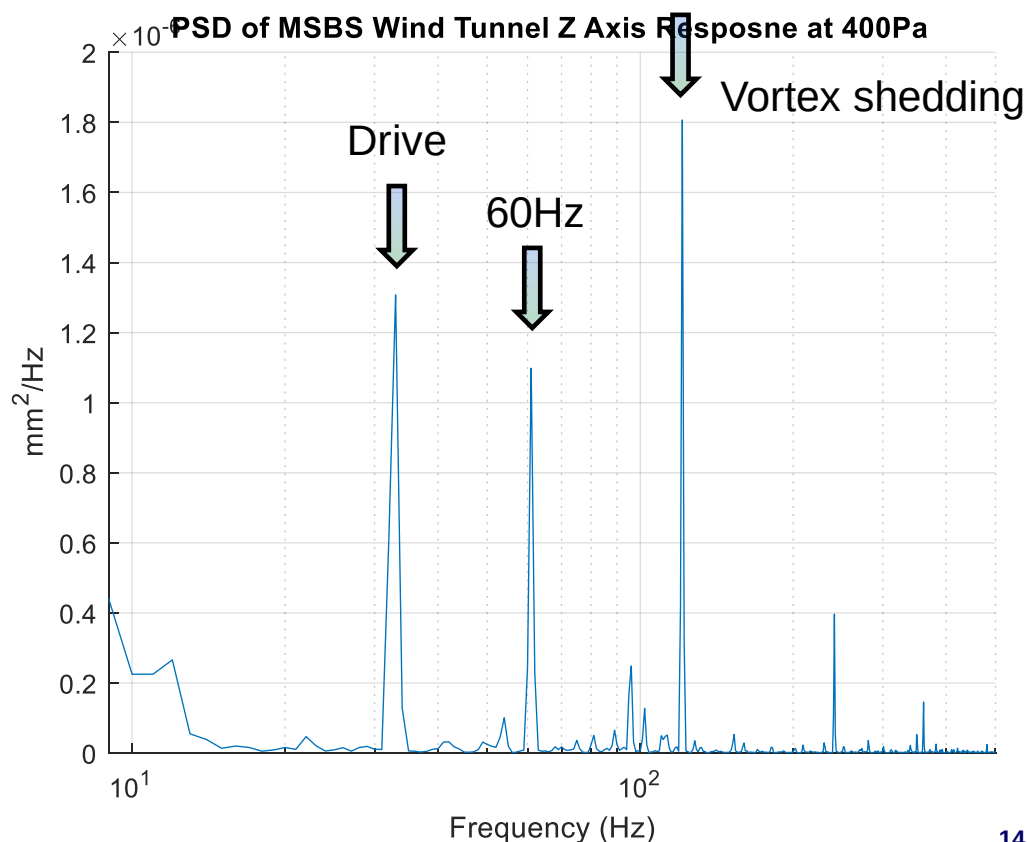
Sphere wakes



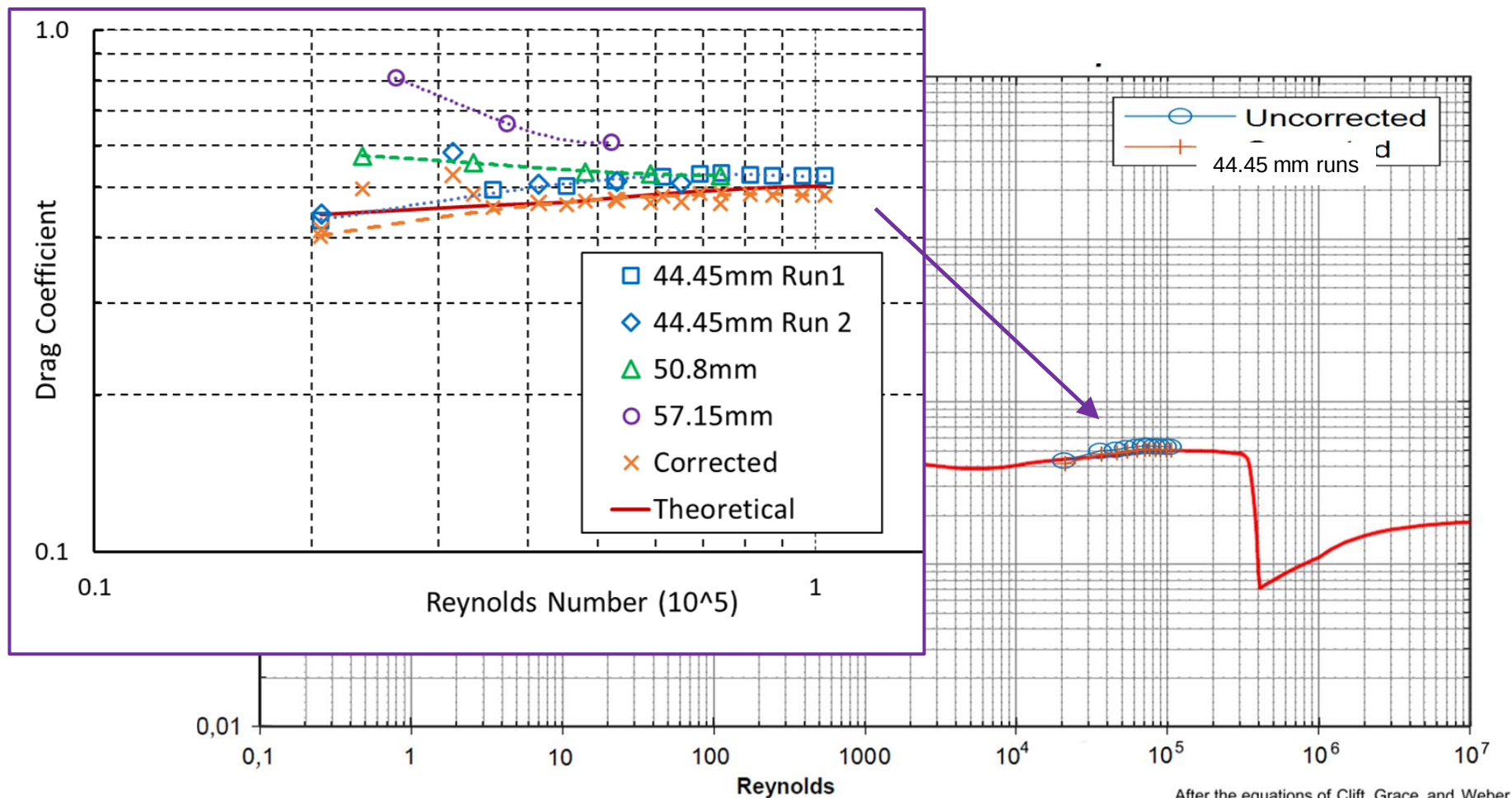
- Spheres “buffet” with wind tunnel on – significant amplitudes, increasing with Q
- Presumed forcing from wake vortex shedding
 - Also, some evidence of drive system noise (*approximately $180 \times \%maxRPM$*)
 - Picked up by EPS; currently working to suppress

$$St \approx 0.2 = \frac{fD}{V}$$

- *Sphere diameter 44.55 mm*
- *Nominal velocity 25.5 m/s*
- *$f \approx 115$ Hz*
- *Drive noise @ 32-33 Hz?*



- C_D for smaller spheres match fairly well to reference data
- Blockage corrections are of appropriate sign and magnitude
- Insufficient precision (so far) to draw conclusions about correction method





Summary & Conclusions

6-inch MSBS

- The NASA/ODU MSBS has been reconfigured to operate with a vertically magnetized permanent magnet core
- A “free-to-yaw” configuration; 3-dof control; passive alignment in roll/pitch
- Performance is steadily improving as system models are refined
- Recently modified to increase coil current capacity (parallel PCI amplifiers)

Sphere Aerodynamics

- Drag coefficients match reference data with moderate uncertainty
- Motion of model at higher dynamic pressures is larger than desired
- Forcing due to vortex shedding; some drive system noise pickup on EPS

Blockage Corrections

- Wall pressures, wake momentum deficit and drag measured for 3 sphere sizes
- Insufficient small sphere data so far to address accuracy of Maskell's method
- Evidence of flow breakdown in tunnel with largest sphere size
- Further research required



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