

Dielectric Barrier Discharge Flow Control at NASA Langley

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RTO 27th Advanced Vehicle Technology Panel

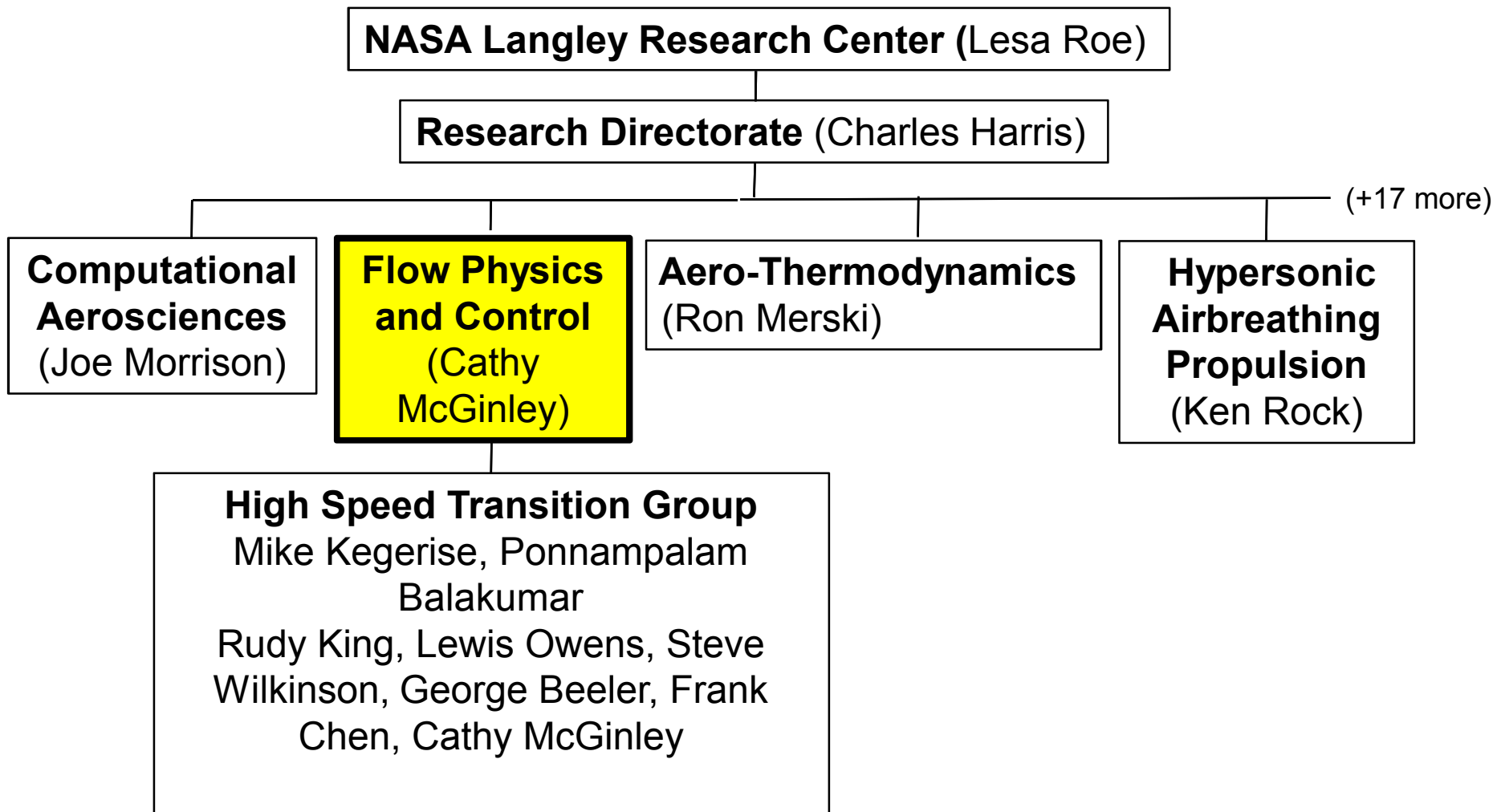
AVT-190 Task Group Meeting

Sofia, Bulgaria

May 16-20, 2011

NASA Langley Research Center Hampton, Virginia





Agenda

- Langley historical DBD studies
- Current DBD supersonic flow control
- Comments on AVT-190 DBD plans

Historical DBD Work

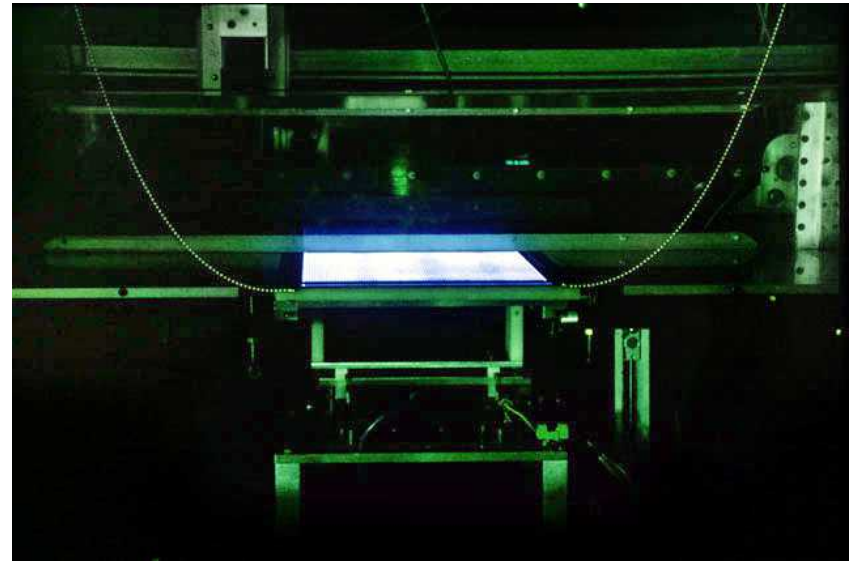
Background

- Initial studies in 1995 in cooperation with University of Tennessee/Knoxville (Roth)
 - Called OAUGDP (“One Atmosphere Uniform Glow Discharge”)
 - Measured direct, low speed drag on large electrode array panels
 - Depending on electrode orientation could get drag increase or reduction (thrust effect)
 - Flow visualization revealed local body force
 - Published in AIAA 1998-0328/AIAA J v38 n7 pp1166-1172 (2000)
 - US Patent 6200539 (UTK/NASA)
- Subsequent efforts to improve performance by phased, oscillating and AC/DC operation were unsuccessful
- NASA Langley last internally funded DBD work in 2003
- Work continued at NASA GRC for internal flows and on a few university grants and small business contracts.
- DBD work continues today mainly under Air Force and commercial sponsorship.

Low Speed Drag Studies (1995-97)



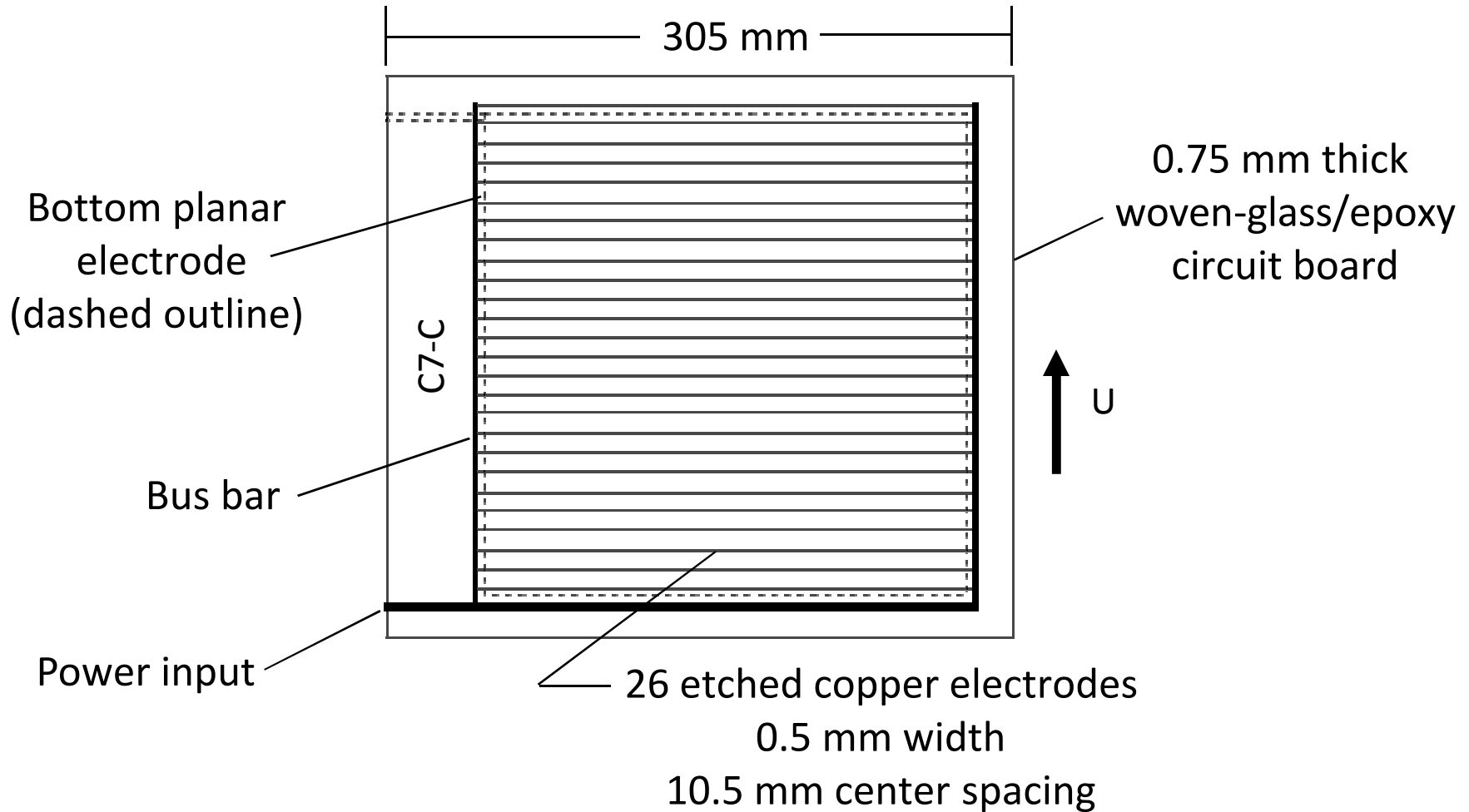
7x11 Inch Low Speed Tunnel (< 40 m/s)



DBD array on drag balance ($L \sim 0.3$ m)

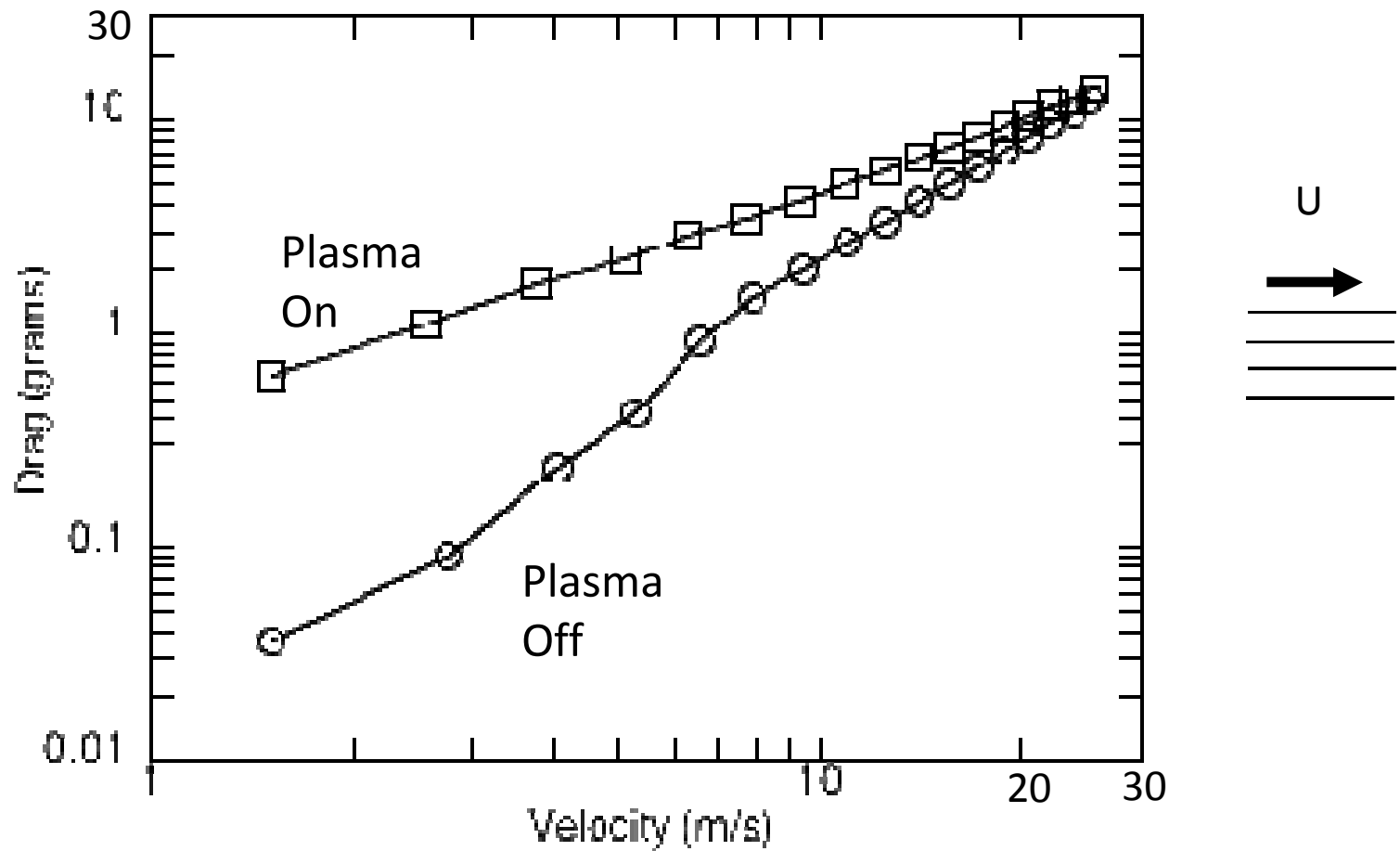
Typical OAUGDP Panel

Spanwise, Symmetric Electrodes (C7-C)



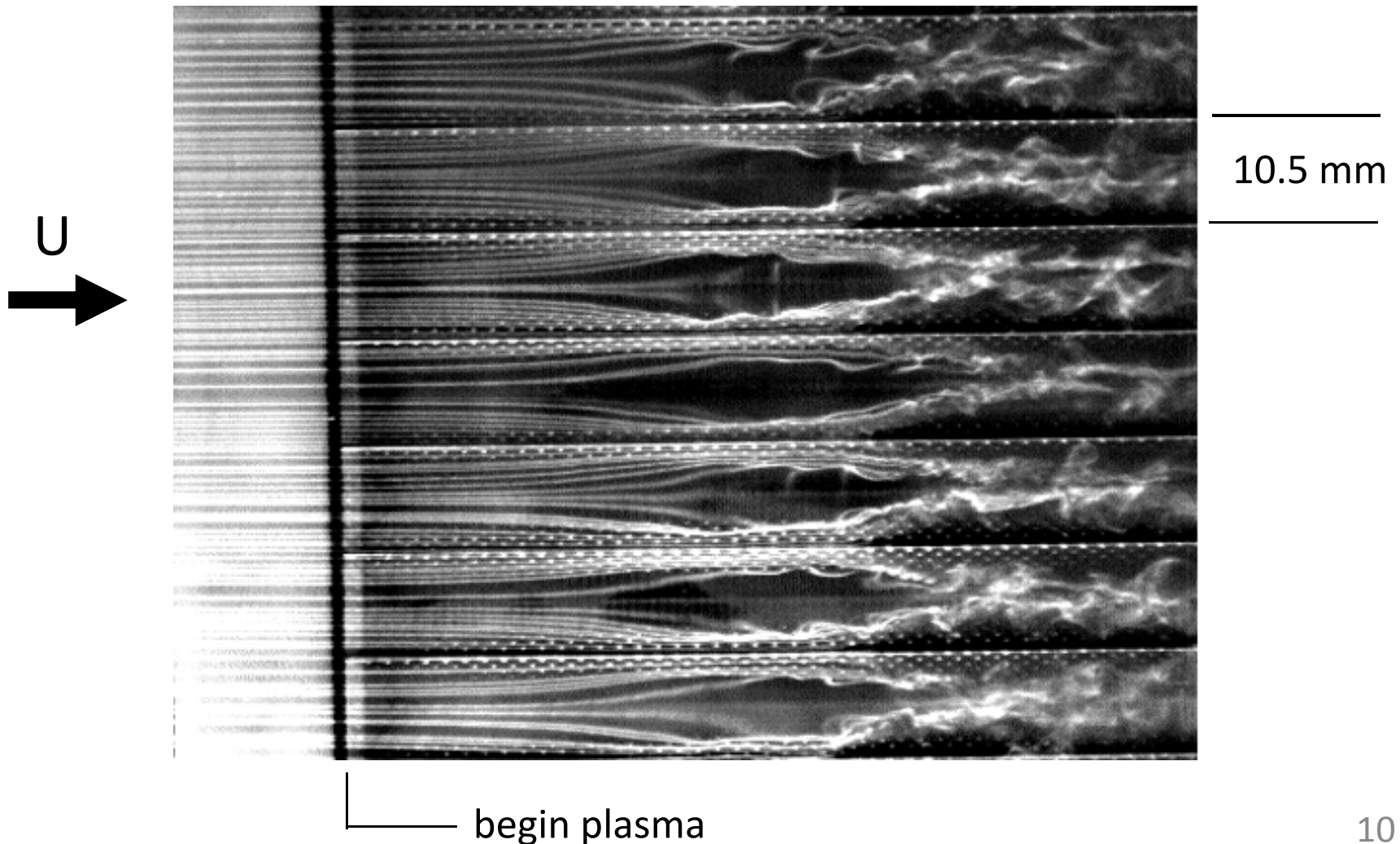
Panel C7-A - Streamwise, Symmetric Electrodes

3 kHz 4 kVrms

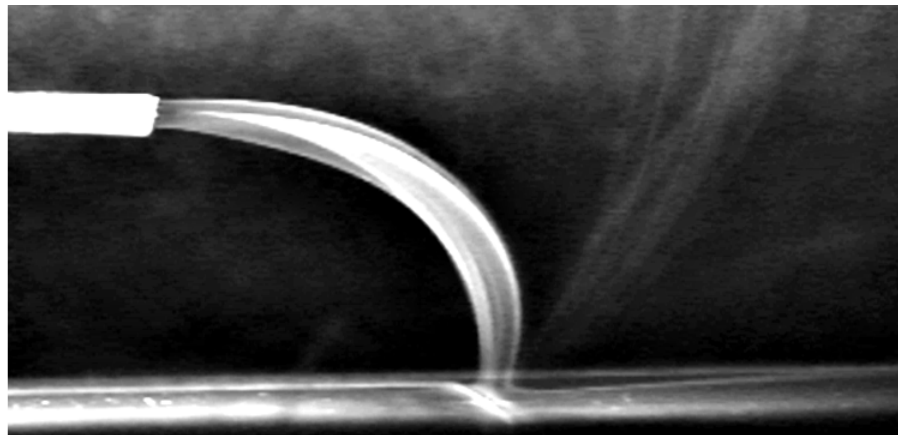
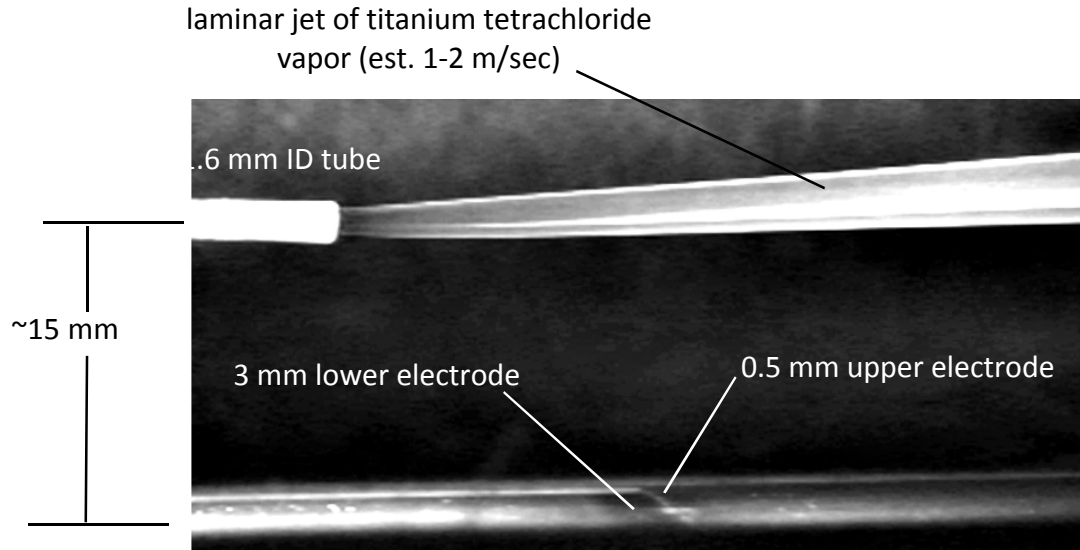


Smoke Wire Flow Visualization for Panel C7-A

$E=3$ kV rms $F=3$ kHz
 $Y/\delta \sim 0.33$ $U = 4$ m/s



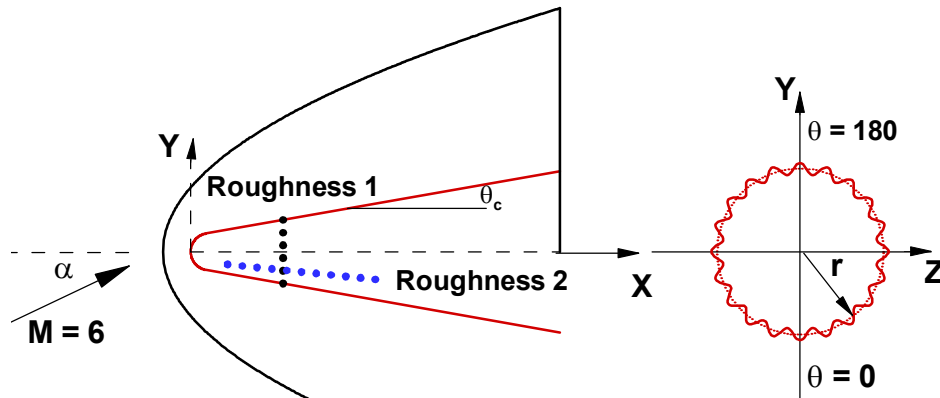
Demonstration of OAUGDP Paraelectric Force Due to a Single Asymmetric Electrode Pair



Current Supersonic DBD Flow Control

Cross Flow Instability Simulation

7-Degree Cone Mach6



$$M_{\infty} = 6$$

$$Re = 10.4 \cdot 10^6 / m$$

$$\text{Stagnation Pressure} = 965.26 \text{ kPa (140 psi)}$$

$$\text{Stagnation Temp.} = 430 \text{ }^{\circ} \text{K}$$

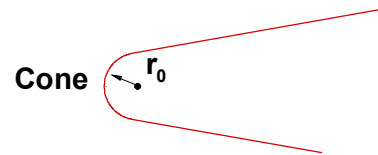
$$T_{\infty} = 52.43 \text{ }^{\circ} \text{K}$$

$$T_{\text{wall}} = 300.0 \text{ }^{\circ} \text{K}$$

$$\text{Leading edge radius } r_0 = 0.050 \text{ mm (0.002 in.)}$$

$$\text{Cone half-angle} = 7 \text{ degrees.}$$

$$\text{Angle of attack} = 6 \text{ degrees.}$$



Roughness 1

$$y_c(x, \theta) = h e^{-\sigma_x \left(\frac{x-x_r}{l} \right)^2} \cos m\theta$$

x_r (mm)	h (mm)	h/δ
50	0.01	1/20 ~ 1/40

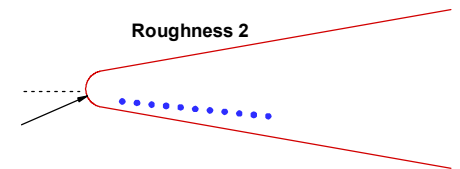
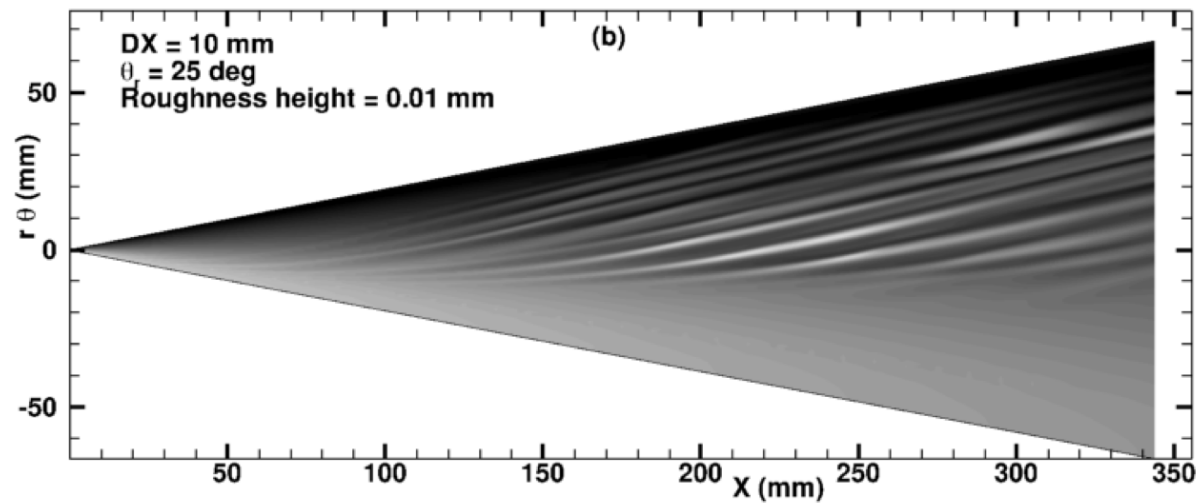
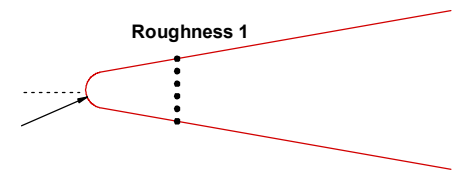
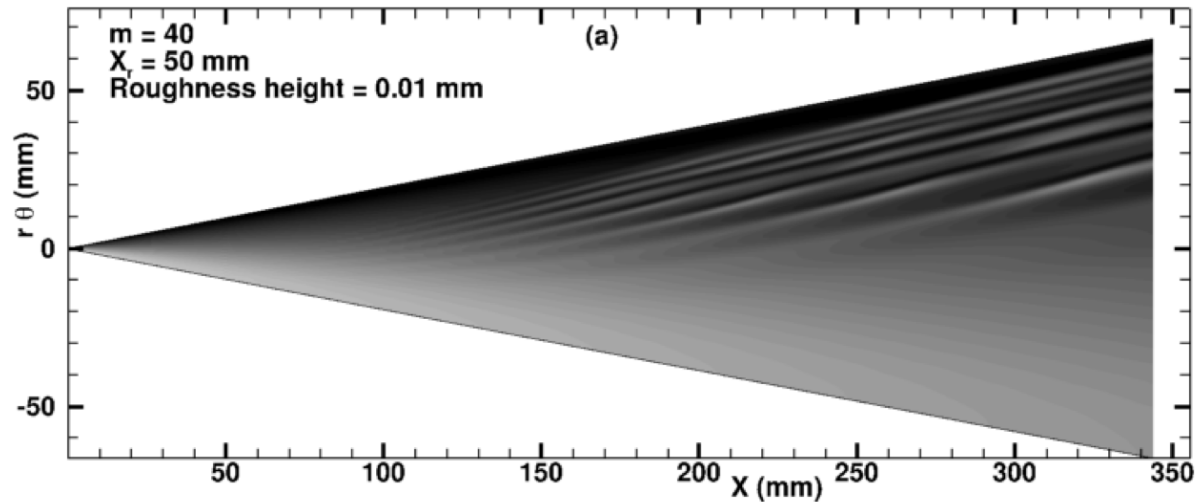
Roughness 2

$$y_c(x, \theta) = h e^{-\sigma_{\theta} \left(\frac{\theta - \theta_r}{\Delta\theta} \right)^2} \sum_{n=1}^N e^{-\sigma_x \left(\frac{x-x_n}{l} \right)^2}$$

$$x_n = x_1 + (n-1) * \lambda$$

Θ_r (deg)	h (mm)	h/δ
25	0.01	1/12

Crossflow Vortices Originating from Roughness 1 and 2

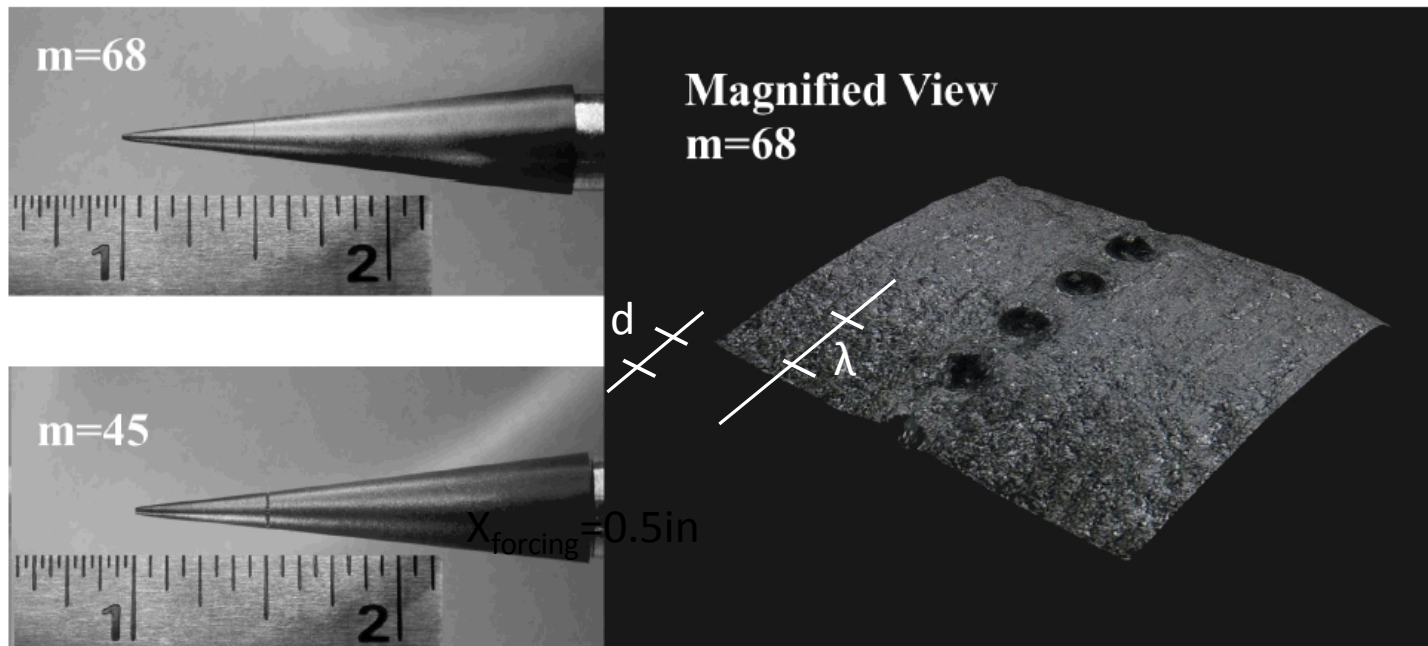


Notre Dame/NASA Cross Flow Instability Control by Distributed Roughness

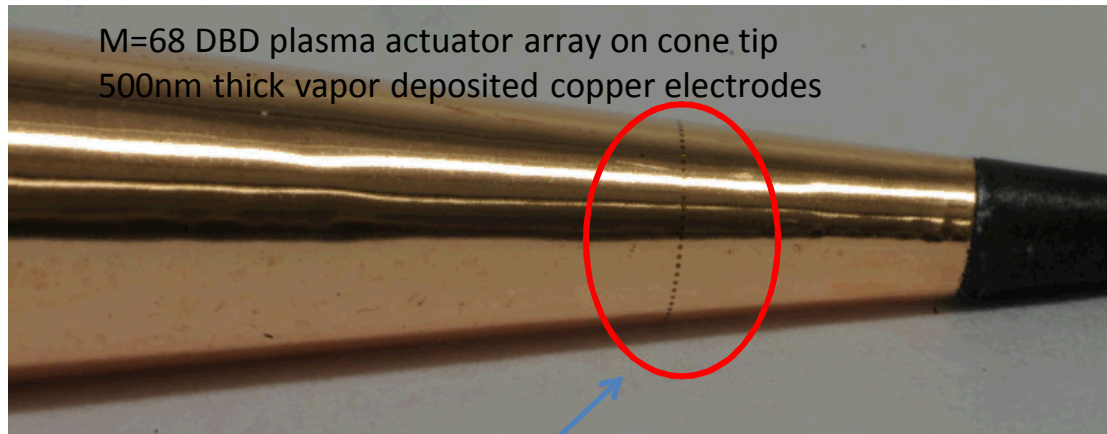
$m=0$ Plain tip, natural roughness

$m=45$ Most Amplified Wavenumber (critical)

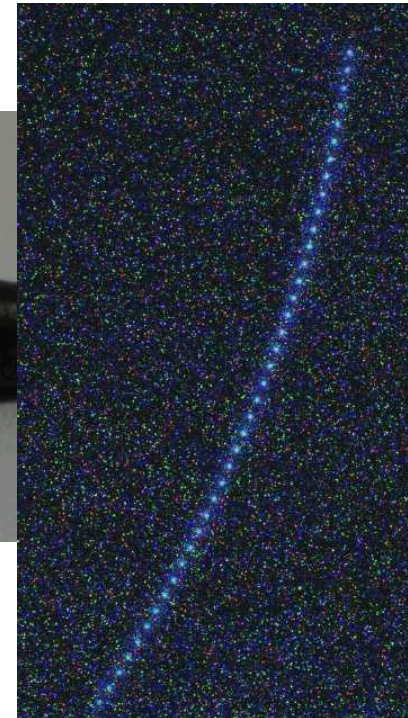
$m=68$ $3/2 \times$ Most Amplified Wavenumber (subcritical)



DBD Plasma “Bumps” Replace Physical Roughness



Plasma-Dots (ø75 μm)



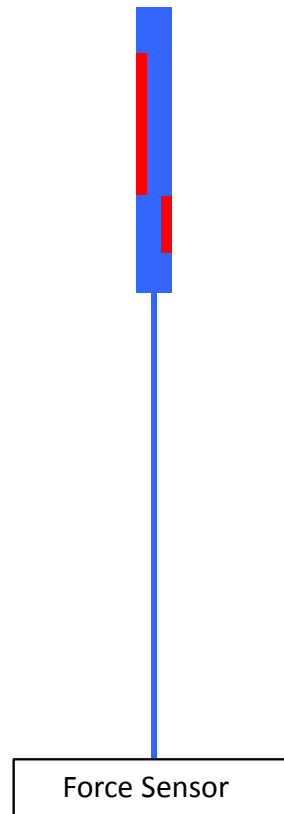
m=68 DBD
plasma array at
3.5kVpp in a
vacuum vessel,
dielectric:
0.5mil thick
kapton

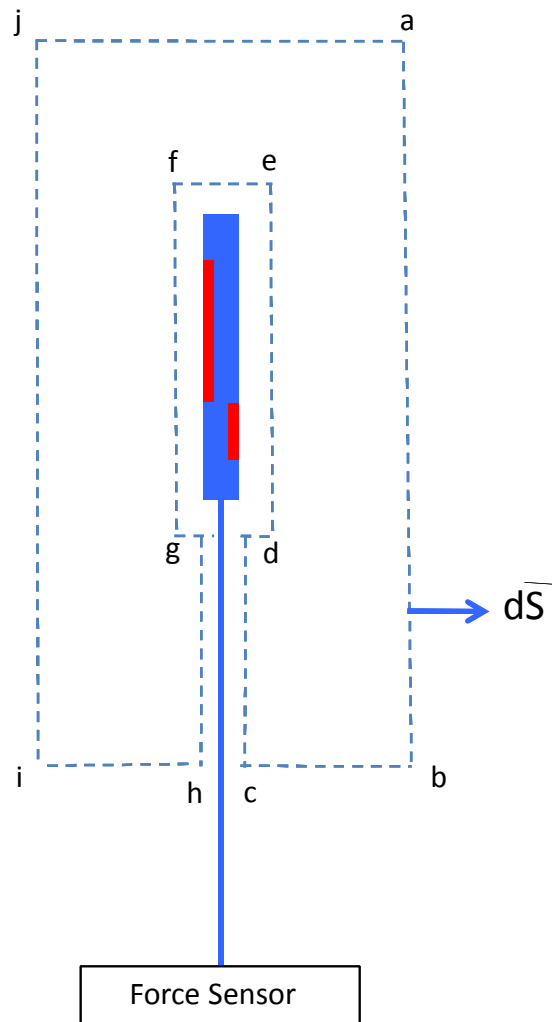
Current AVT190 DBD Work

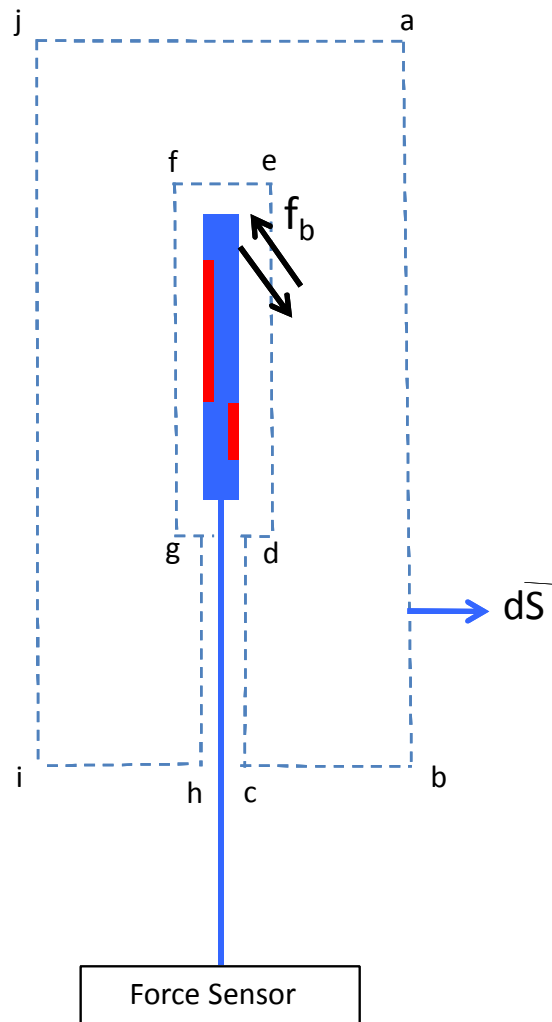
Original DBD Force Balance at USAFA

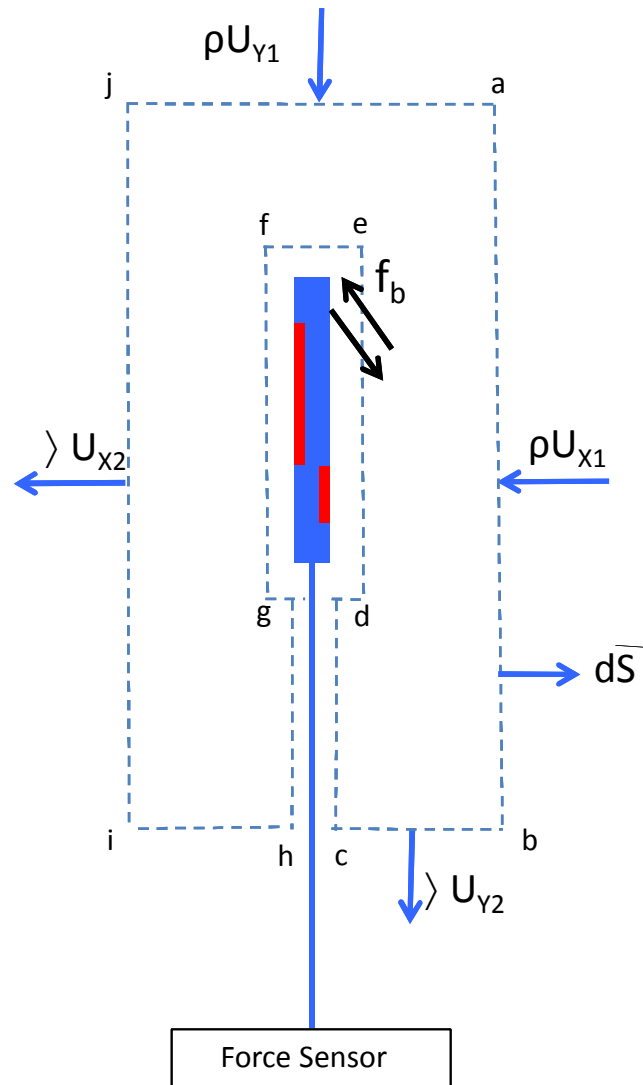


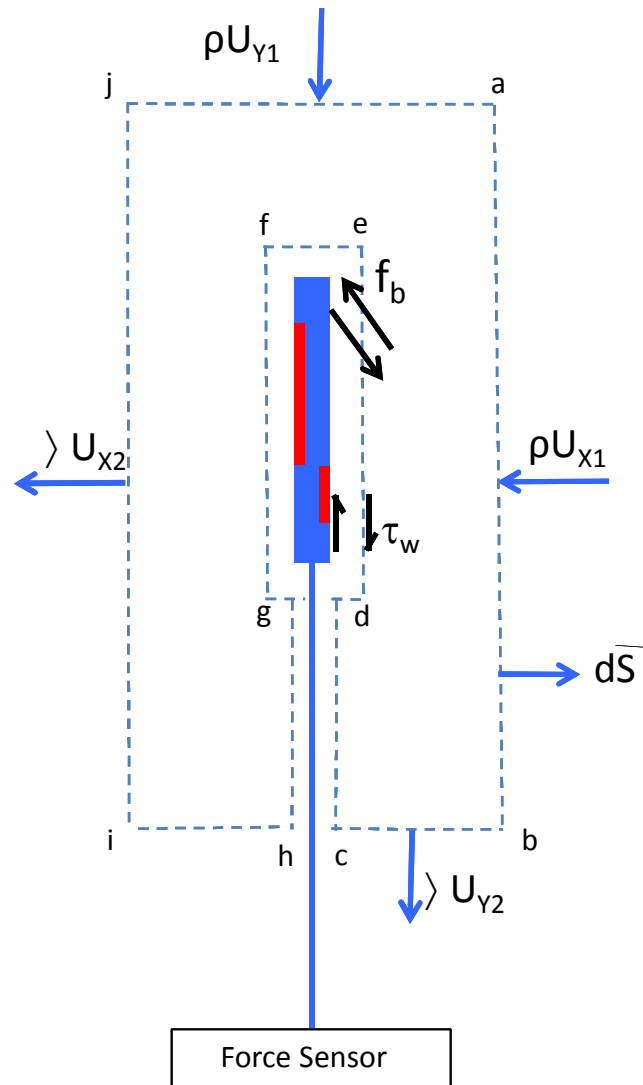
Development of a Canonical Force Balance

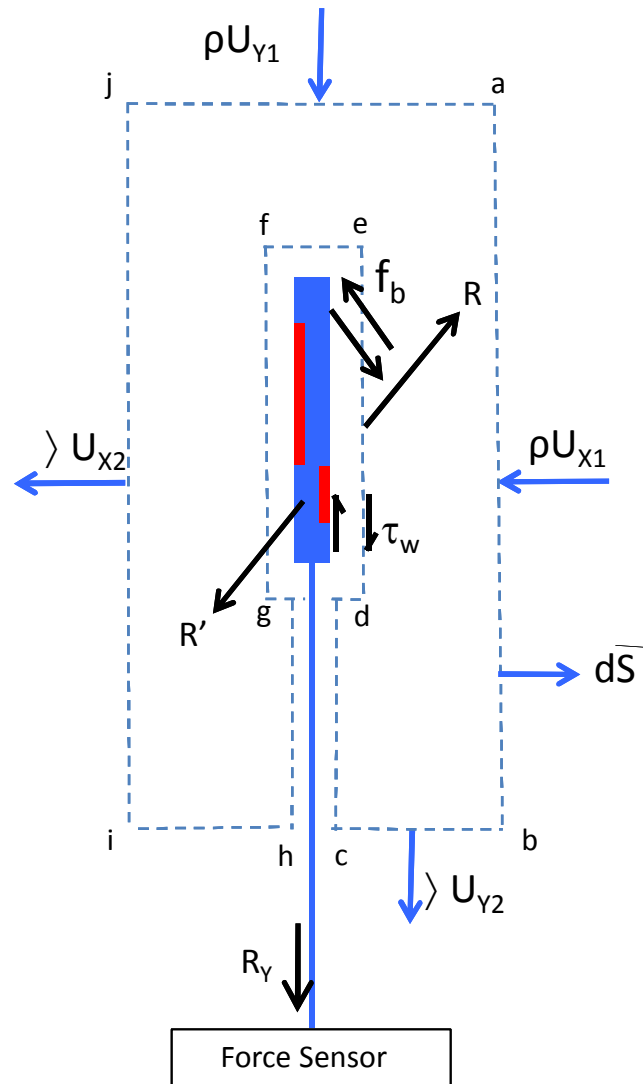


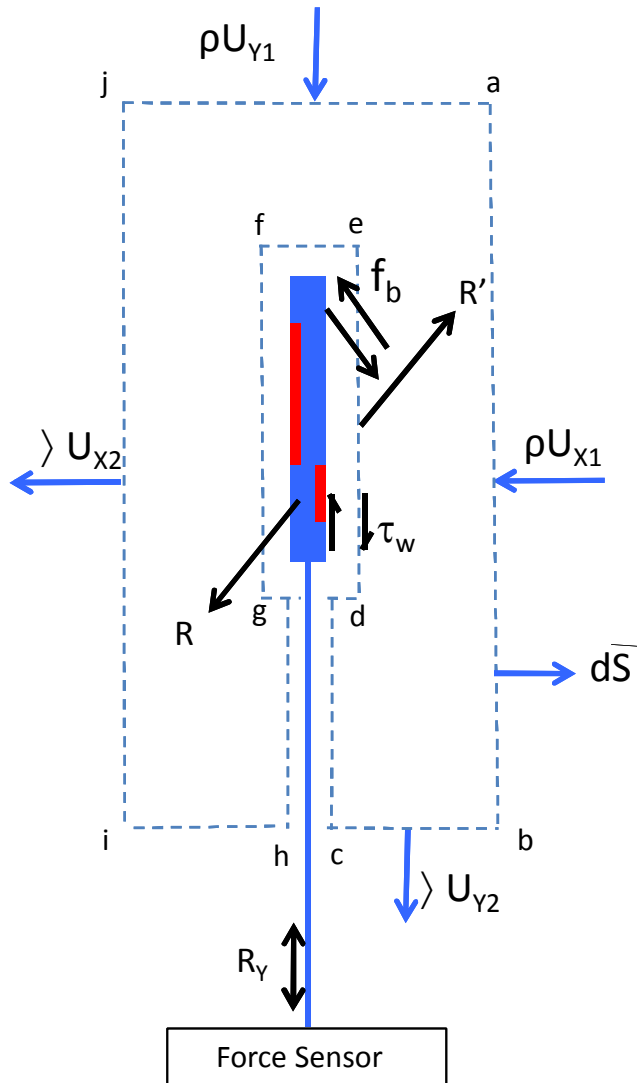












Steady, integral momentum equation for an arbitrary control volume:

$$\oint_S (\rho \mathbf{U} \mathbf{g} d\mathbf{S}) \mathbf{U} = - \oint_S p d\mathbf{S} + \oint_S \mathbf{\tau}_w d\mathbf{S} + \int_V \rho \mathbf{f}_b dV \quad (1)$$

By Newton's 3rd law, if R is the total combined force on the model from all sources, an equal and opposite force, -R', acts on the control volume

$$\oint_S p d\mathbf{S} + \oint_S \mathbf{\tau}_w d\mathbf{S} + \int_V \rho \mathbf{f}_b dV = R = -R' \quad (2)$$

Applying the momentum equation to CV in figure:

$$\oint_S (\rho \mathbf{U} \mathbf{g} d\mathbf{S}) \mathbf{U} = R \quad (3)$$

Assuming constant pressure, the pressure integral vanishes. The vertical component of R is:

$$R_y = \int_{hb} \rho U_{Y2}^2 dX - \int_{ia} \rho U_{Y1}^2 dX \quad (4)$$

If $U_{Y2} \gg U_{Y1}$, the axial thrust, R_y , is given by:

$$R_y ; \int_{hb} \rho U_{Y2}^2 dX \quad (5)$$

Summary

- Any force balance for a DBD actuator will measure the net effect integrated skin friction, pressure, and induced momentum flux
- The body force can only be determined by subtracting viscous and pressure contributions.
- Does a better DBD geometrical arrangement of the DBD exist that minimizes viscous and pressure contributions?
- Should the effort be expanded to include velocity profile measurement?

END