Topological Aspects of the FAITH Experiment

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Background

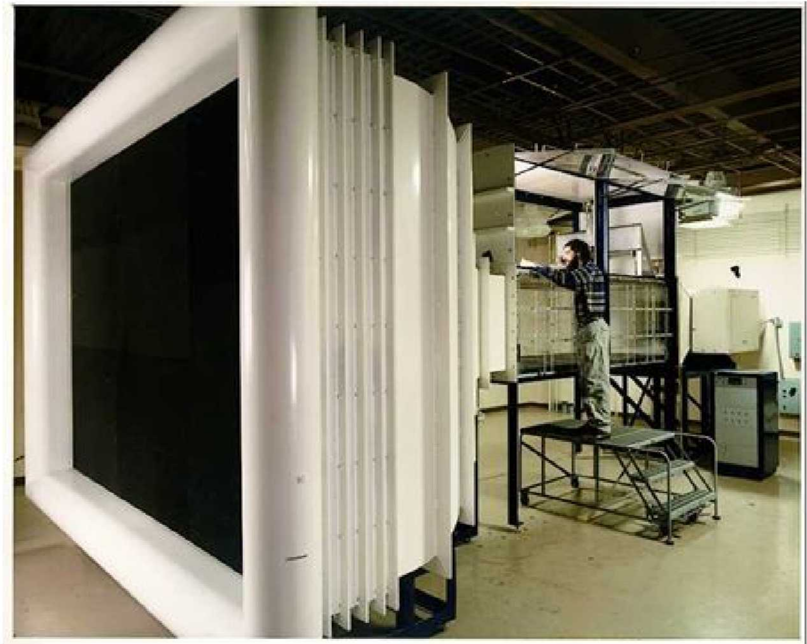
- Subsonic Flow Topology (Attached and Separated Flows)
  - What is relationship between surface pressure extrema and singular points?
    - Does every singular point in a pattern of skin friction lines occur at a surface pressure extremum? (and/or vice versa?)
  - Can this relationship be generalized to all geometries?
  - Previous Work
    - Legendre, Werlé, Coon, Tobak, et al
- FAITH Project
  - Sponsored by NASA fixed wing subsonic aero
  - Ongoing effort at NASA Ames Experimental AeroPhysics Branch
  - Multi-parameter wind tunnel investigation of flow around obstacle
  - Acquire data for CFD validation, optimization
- Relationship between FAITH and topology projects
  - Resulted in work described in this brief

Effort Scope

- Water Channel Experiments
  - FML Test Cell #3 (17” x 11”); 1 ips
  - 2” (height) hemisphere and FAITH models
    - Re $\#_{height}$ = 1250
    - $\delta/h \sim 0.2$
- Wind Tunnel Experiments
  - FML Test Cell #2 (48” x 32” indraft); 160 fps
  - 6” FAITH and 8” hemisphere (height) models
    - Re $\#_{height}$ = 500,000-750,000
    - $\delta/h \sim 0.2$
- Analytic Efforts
  - Make use of prior work
    - Legendre, Werlé, Coon, Tobak, et al

Experimental Facilities

- **FML Test Cell #2 Wind Tunnel**
  - **Oil/Smoke Flow, Cobra Probe, FISF, PSP, PIV**
  - **Indraft facility w/sonic throat**
  - **Test Section:**
    - 48” X 32”, 120” long
    - Polycarbonate sides, roof
    - Speed Range: 40 - 170 fps, 0.1% TI
  - **Instrumentation plenum above ceiling**



- **FML Test Cell #3 Water Channel**
  - **Dye Flow**
  - **Test Section:**
    - 17” X 11”, 96” long
    - Acrylic sides, floor
    - Speed Range: 1 – 4 in/s
  - **UV lamps and fluorescent dye**

Models

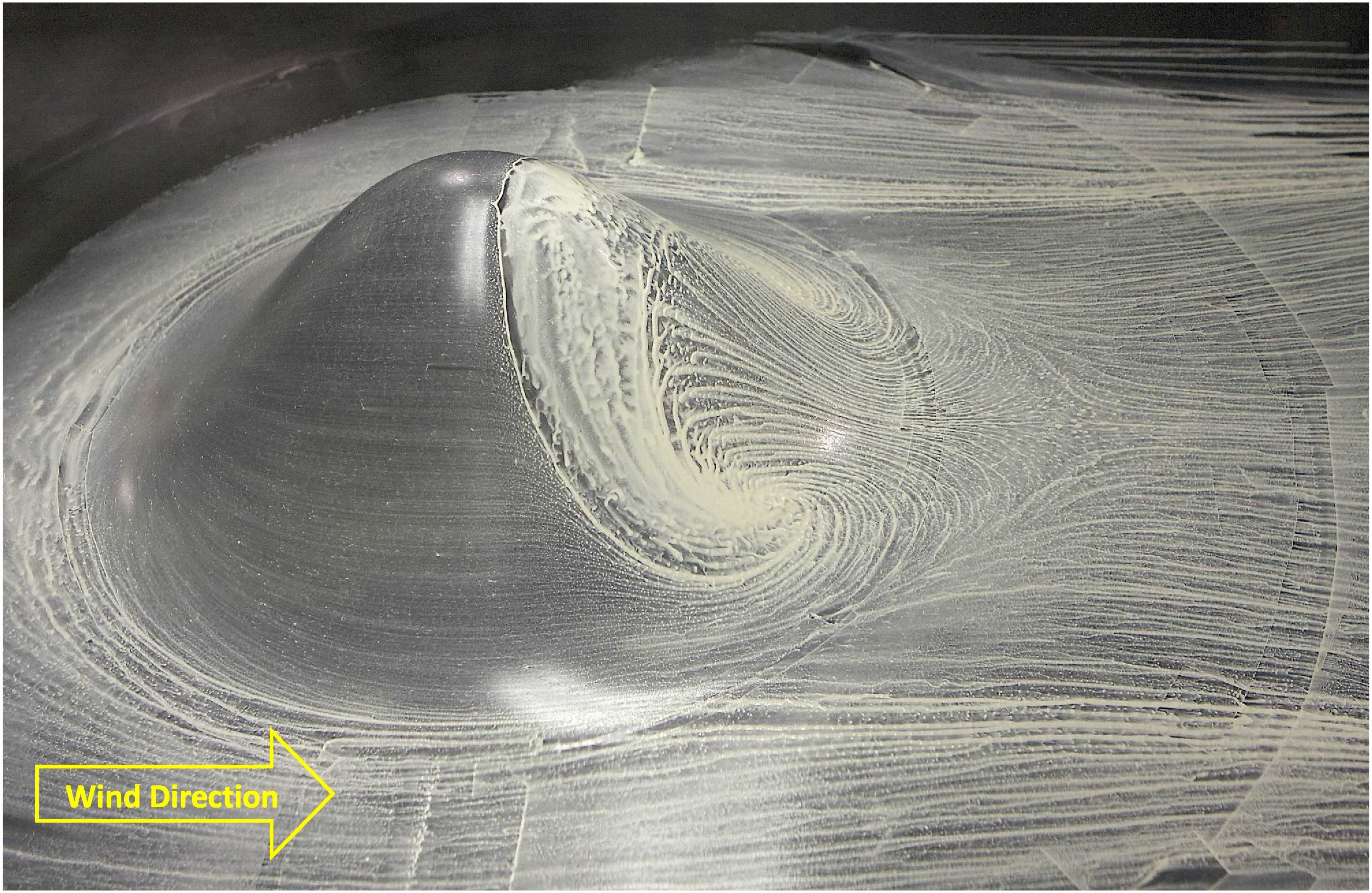
- **FAITH**
  - **Water Channel Experiments**
    - » SLS Sintered Nylon
    - » Max height = 2”
    - » Base diameter: 6”
  - **Wind Tunnel Experiments**
    - » Machined Aluminum
    - » Max height = 6”
    - » Base diameter: 17.95” (18”, sanded to eliminate razor edge)

$$h = 3 \cdot \cos\left(\frac{\pi}{9} r\right) + 3$$

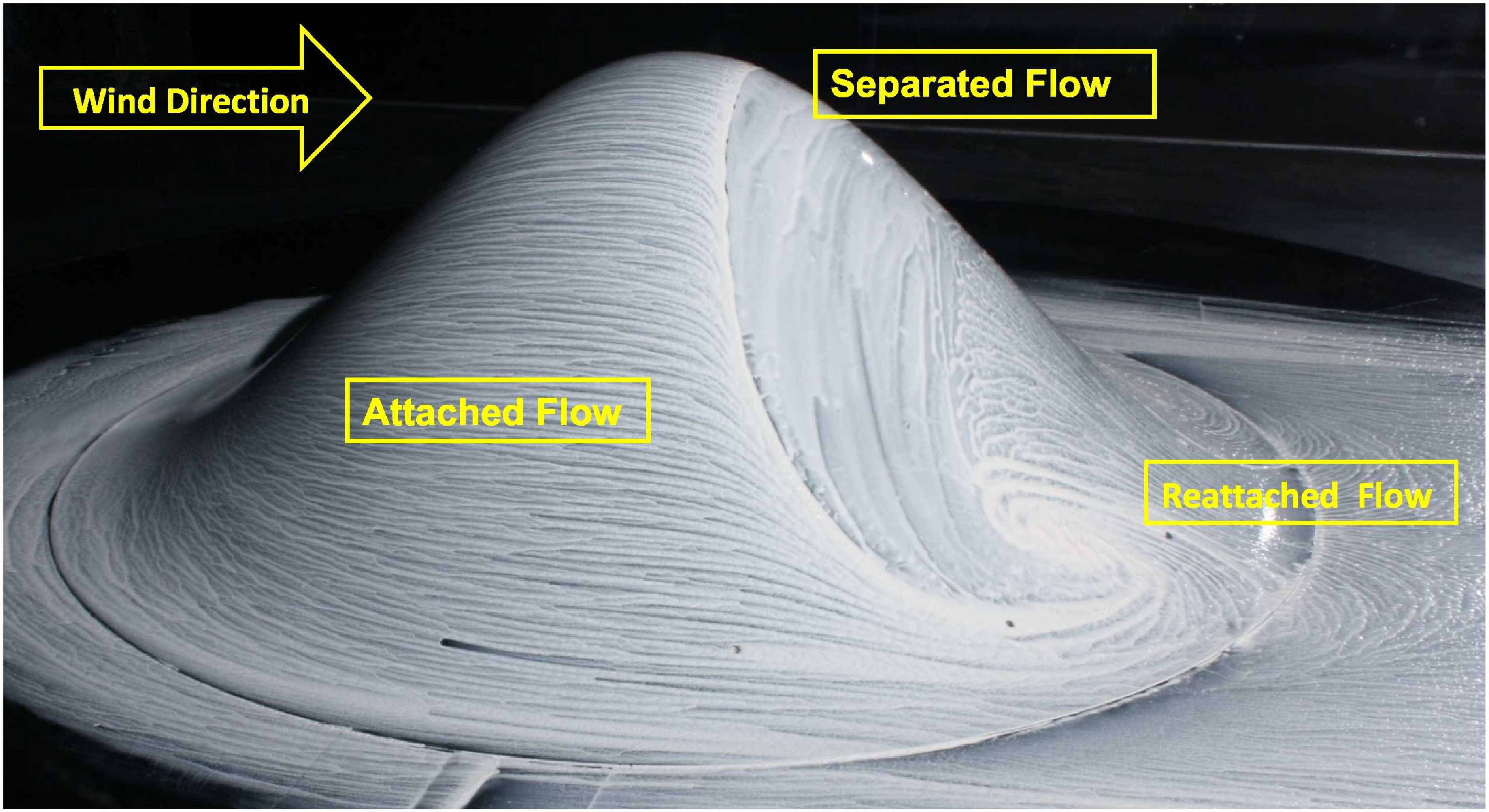
h = height above ground, in
r = radial distance from model center, in

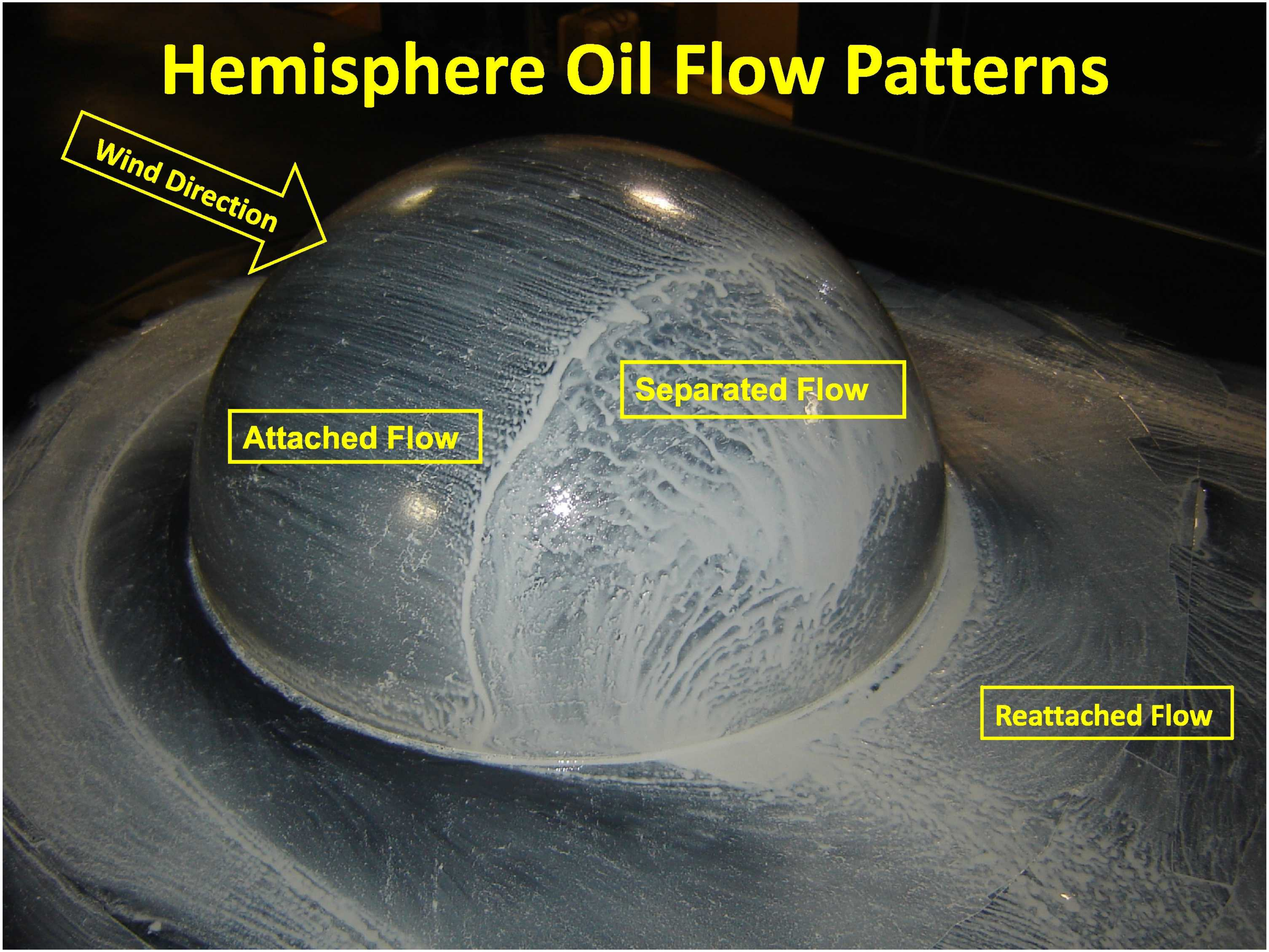
- **Hemisphere**
  - **Water Channel Experiments**
    - » SLS Sintered Nylon
    - » Max height = 2”
    - » Base diameter: 4”
  - **Wind Tunnel Experiments**
    - » Blown Acrylic
    - » Max height = 8”
    - » Base diameter: 18”

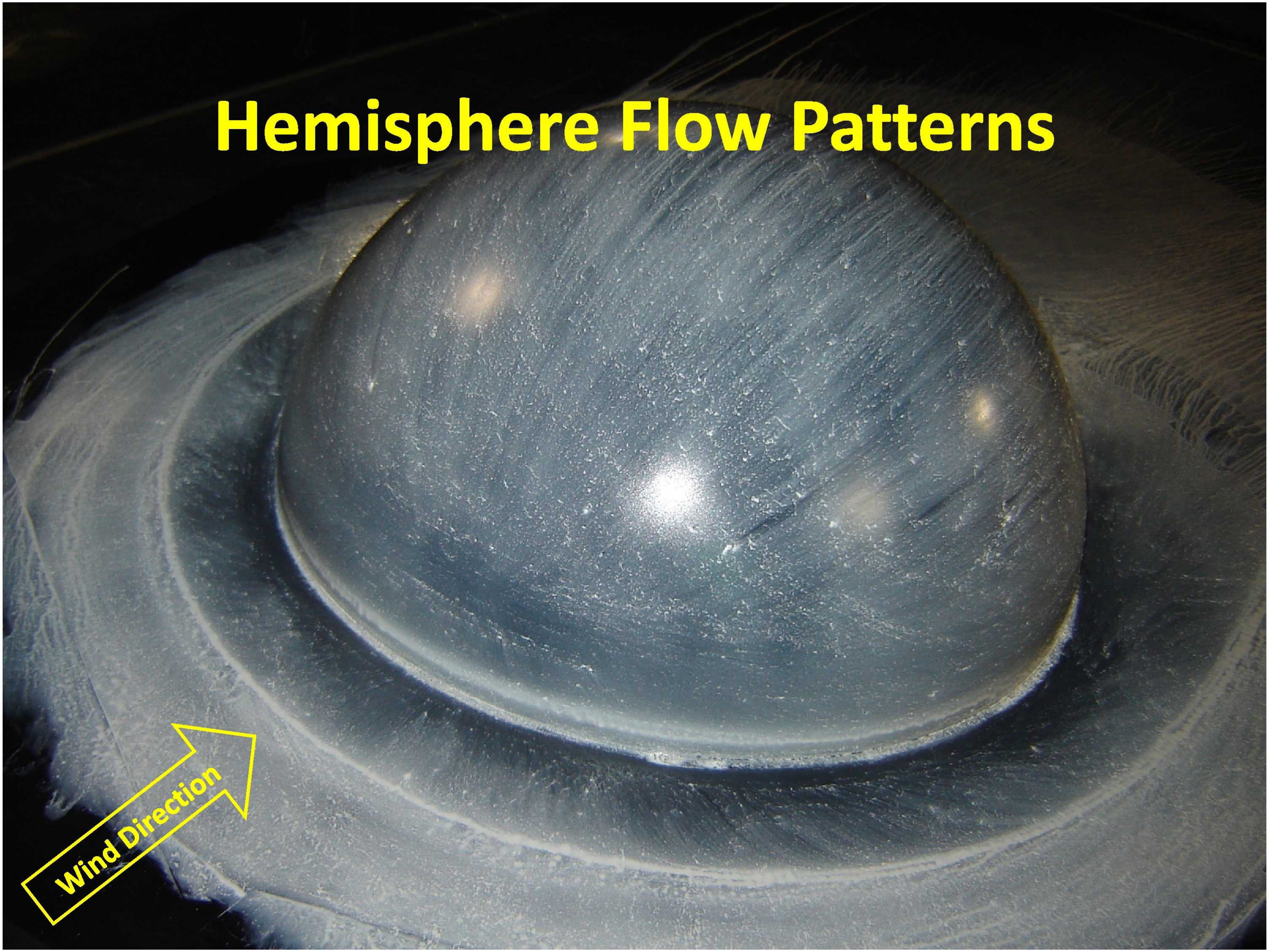
Oil Flow Visualization Experiments



Flow Identification: Left Side of Model




Hemisphere Oil Flow Patterns
Wind Direction
Separated Flow
Attached Flow
Reattached Flow

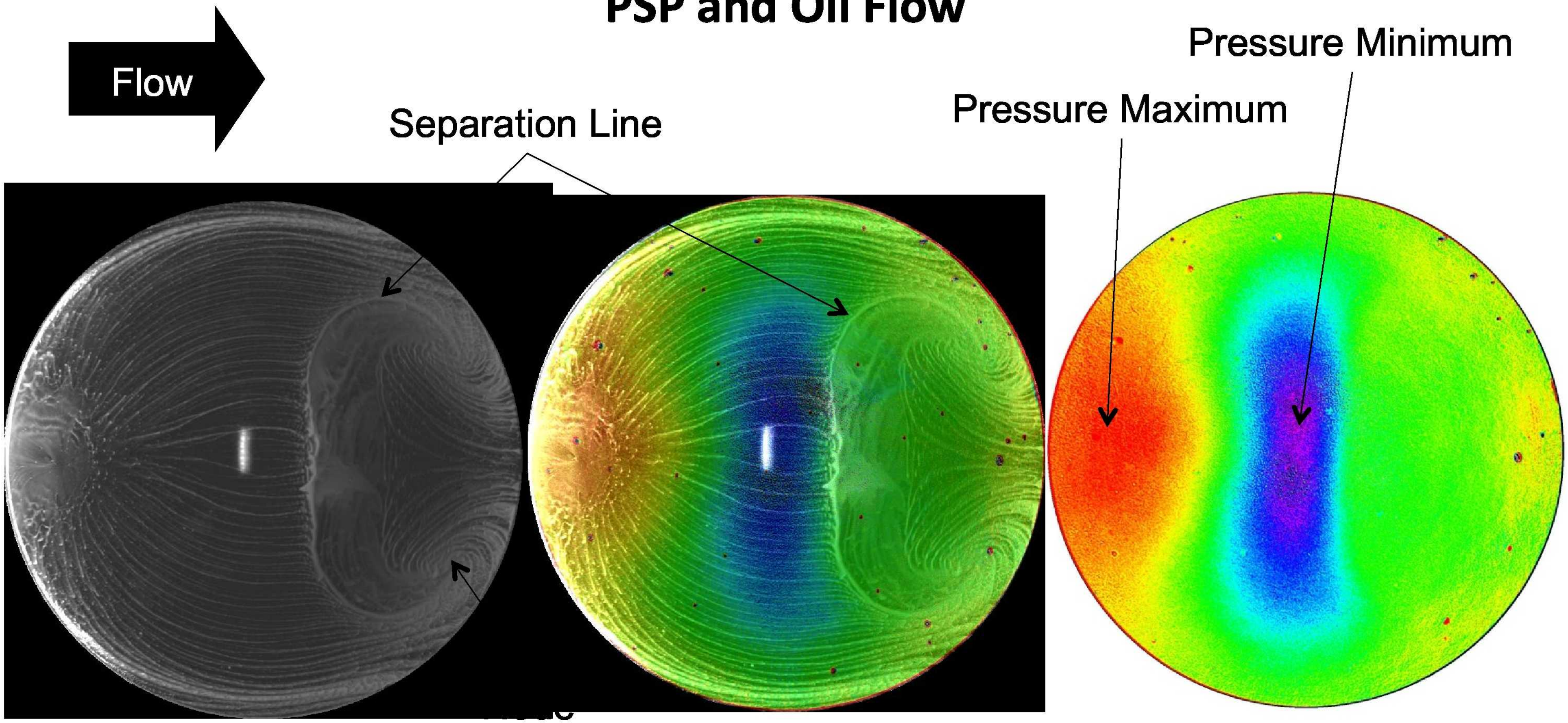

Hemisphere Flow Patterns
Wind Direction

Hemisphere Flow Patterns

Comparing Pressure and Oil Flow Patterns

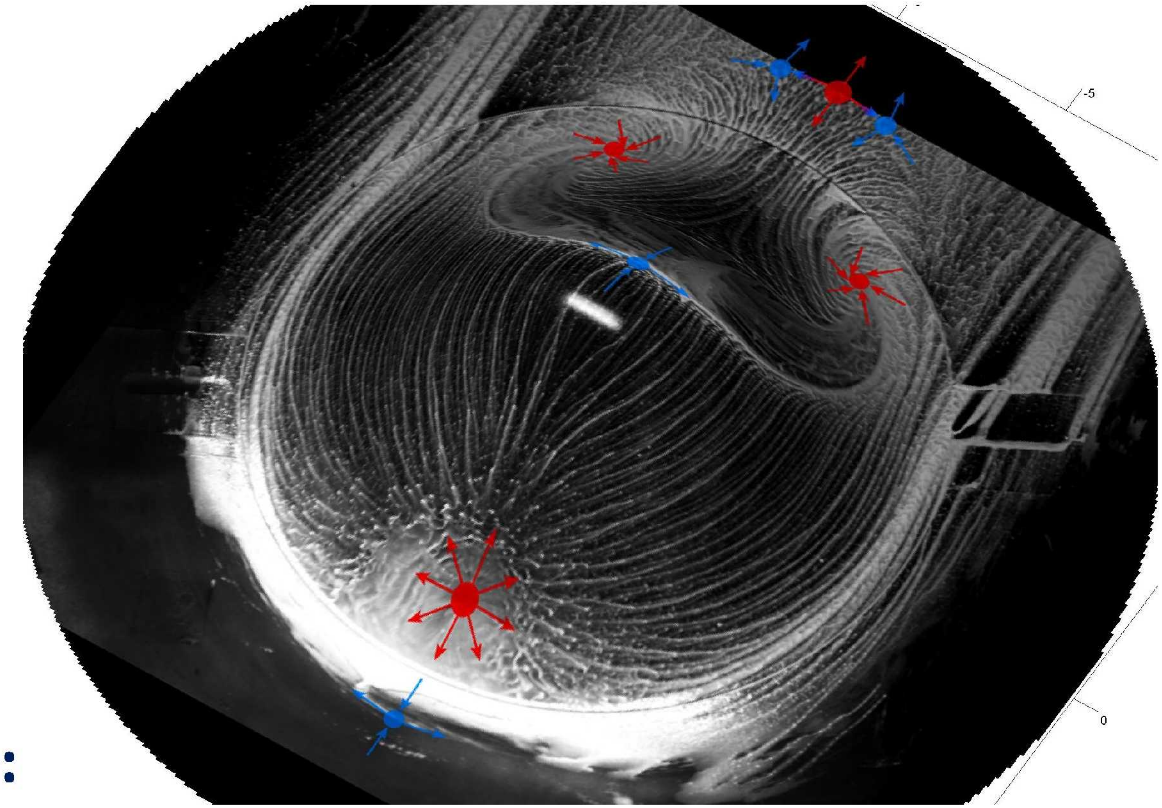
FAITH Model, 150 fps

PSP and Oil Flow



Oil Flow **Overlay of Oil Flow on top of PSP** **PSP**

Surface Flow Topology



- **Definitions**
  - **Saddle Point**
  - **Node**
  - **Focus**
- **General Topological Rule:**

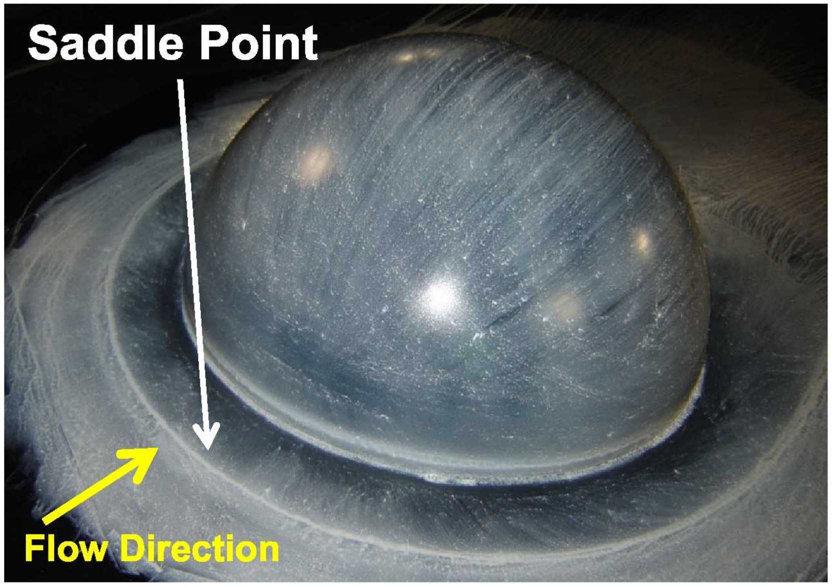
$$\Sigma N - \Sigma S = 0$$

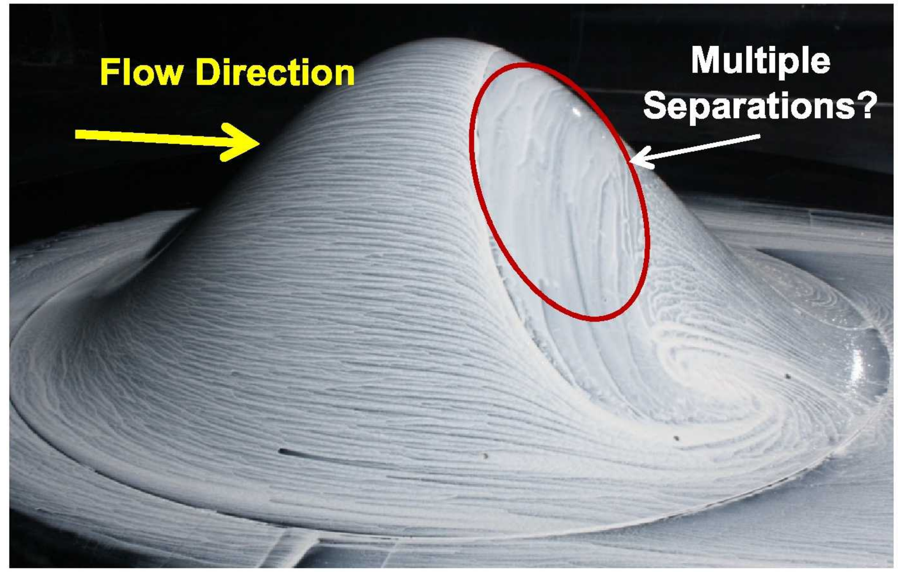
where

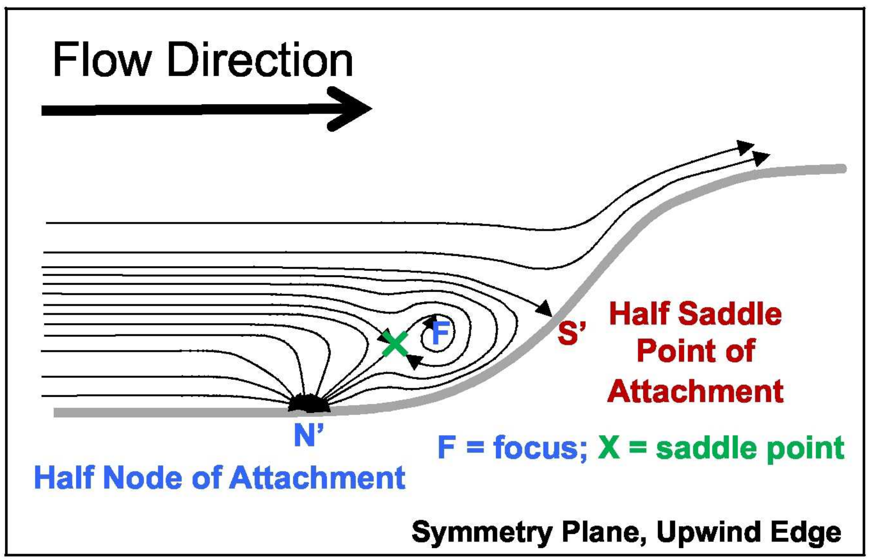
N =number of nodes
S = number of saddle points

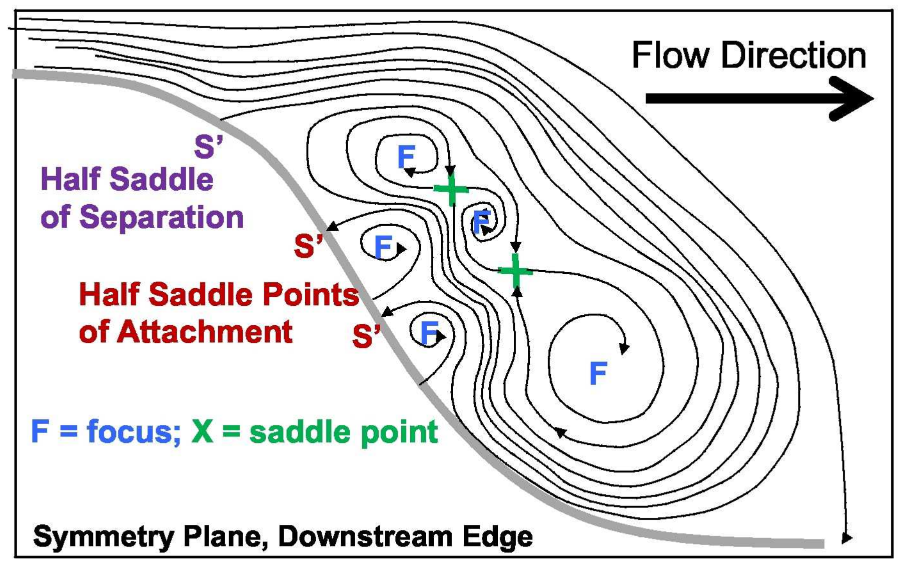
- **For FAITH and Hemisphere,**
  4 nodes and 4 saddle points

Saddle Points of Attachment and Separation





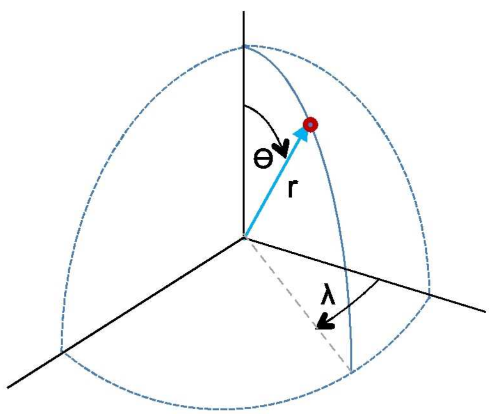




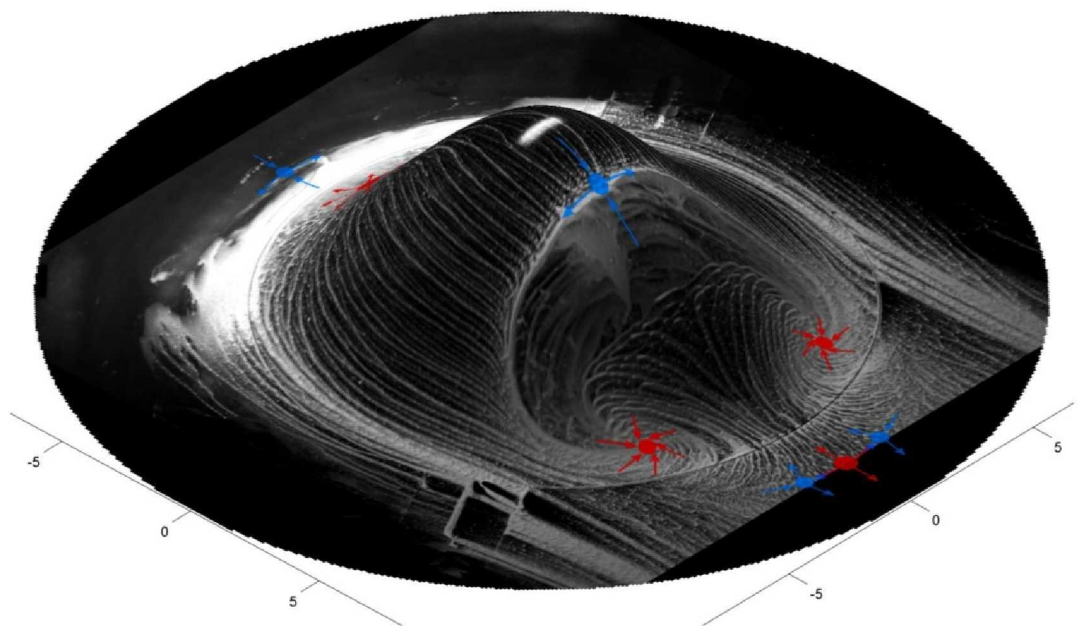
Similar to flow patterns noted in Coon and Tobak, "Experimental Study of Saddle Point of Attachment in Laminar Juncture Flow"

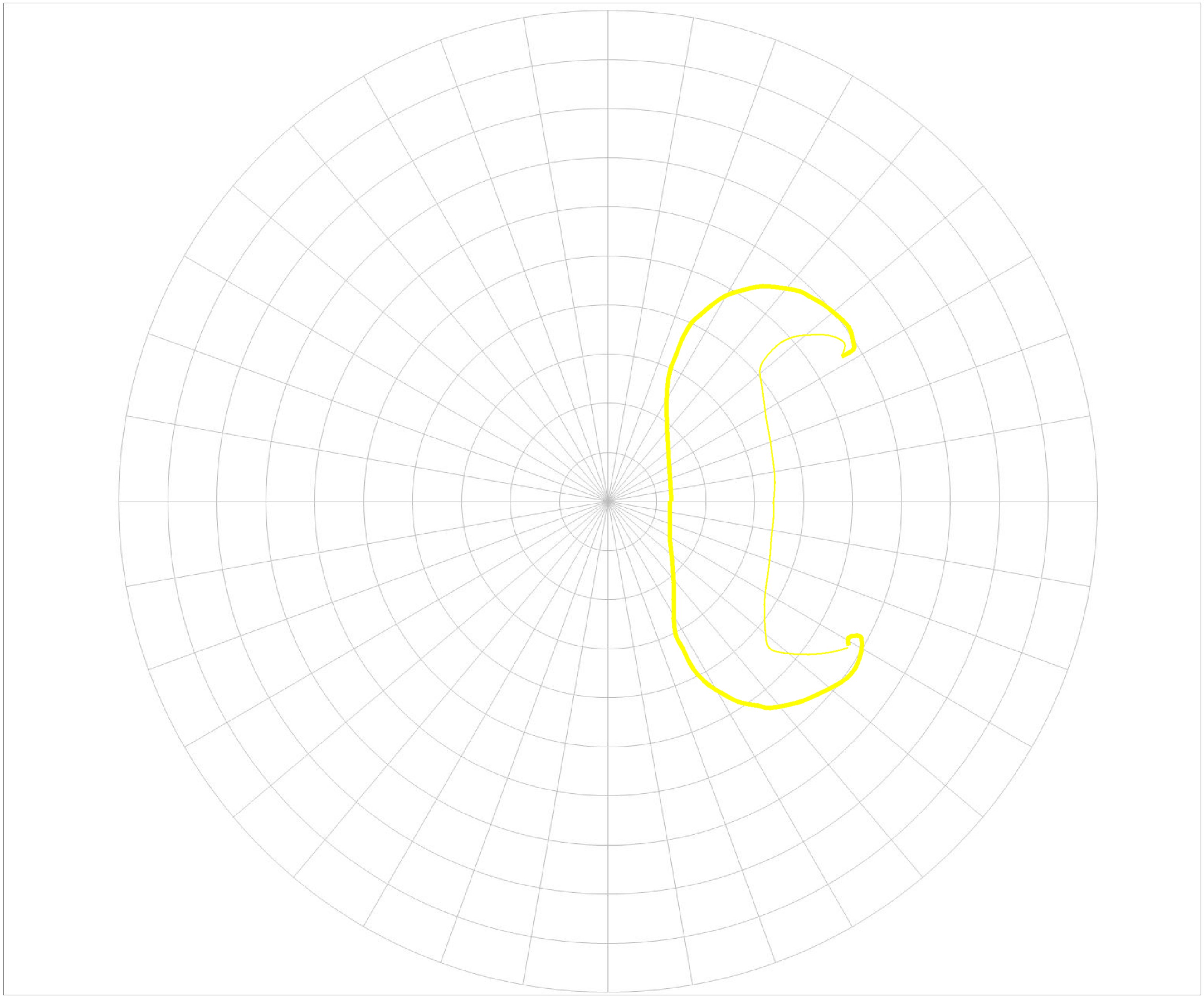
Analysis of Surface Flow Topology

Need to employ generalized coordinate system (r, ϴ, λ)

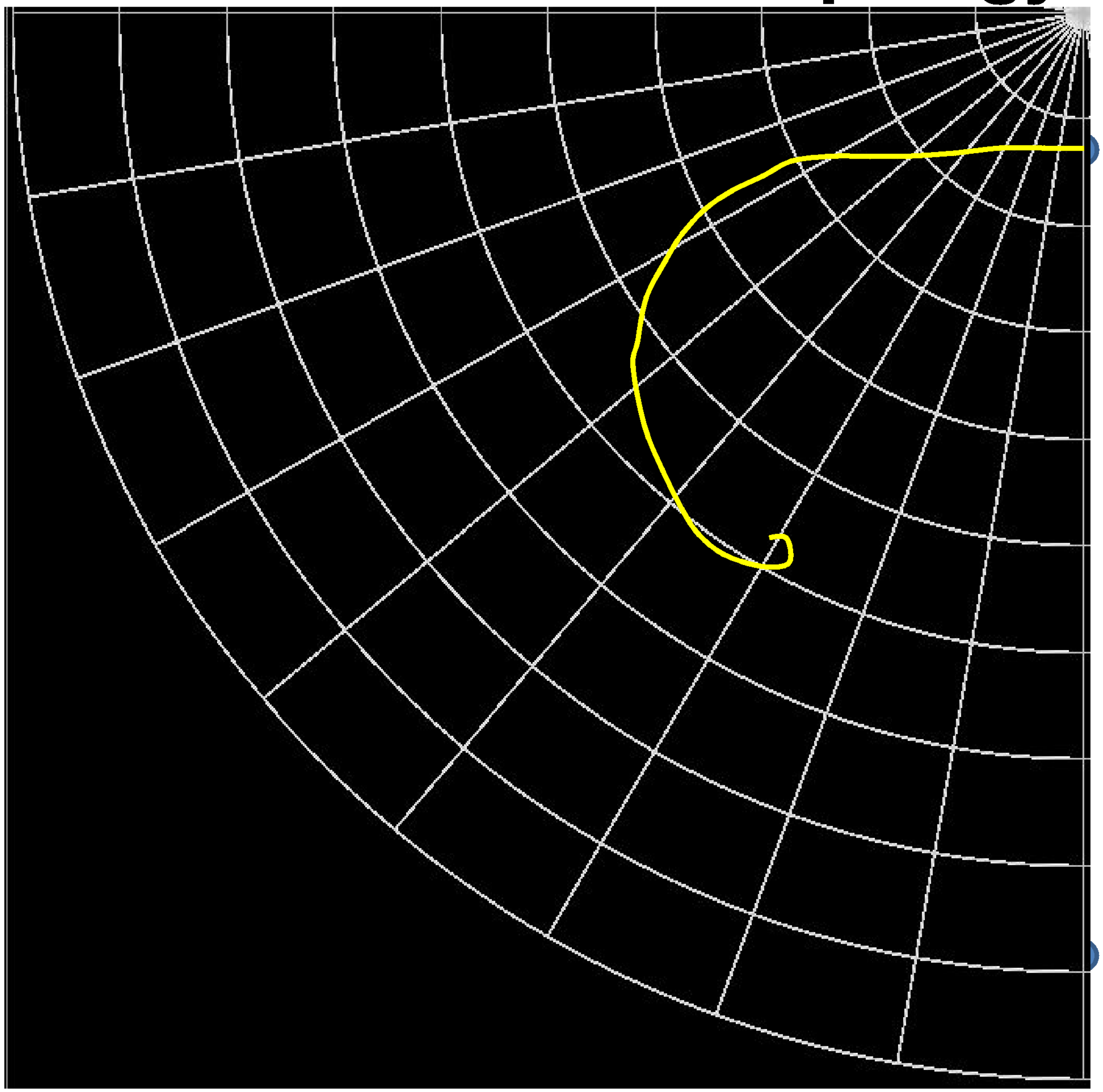


Generalized Coordinate System

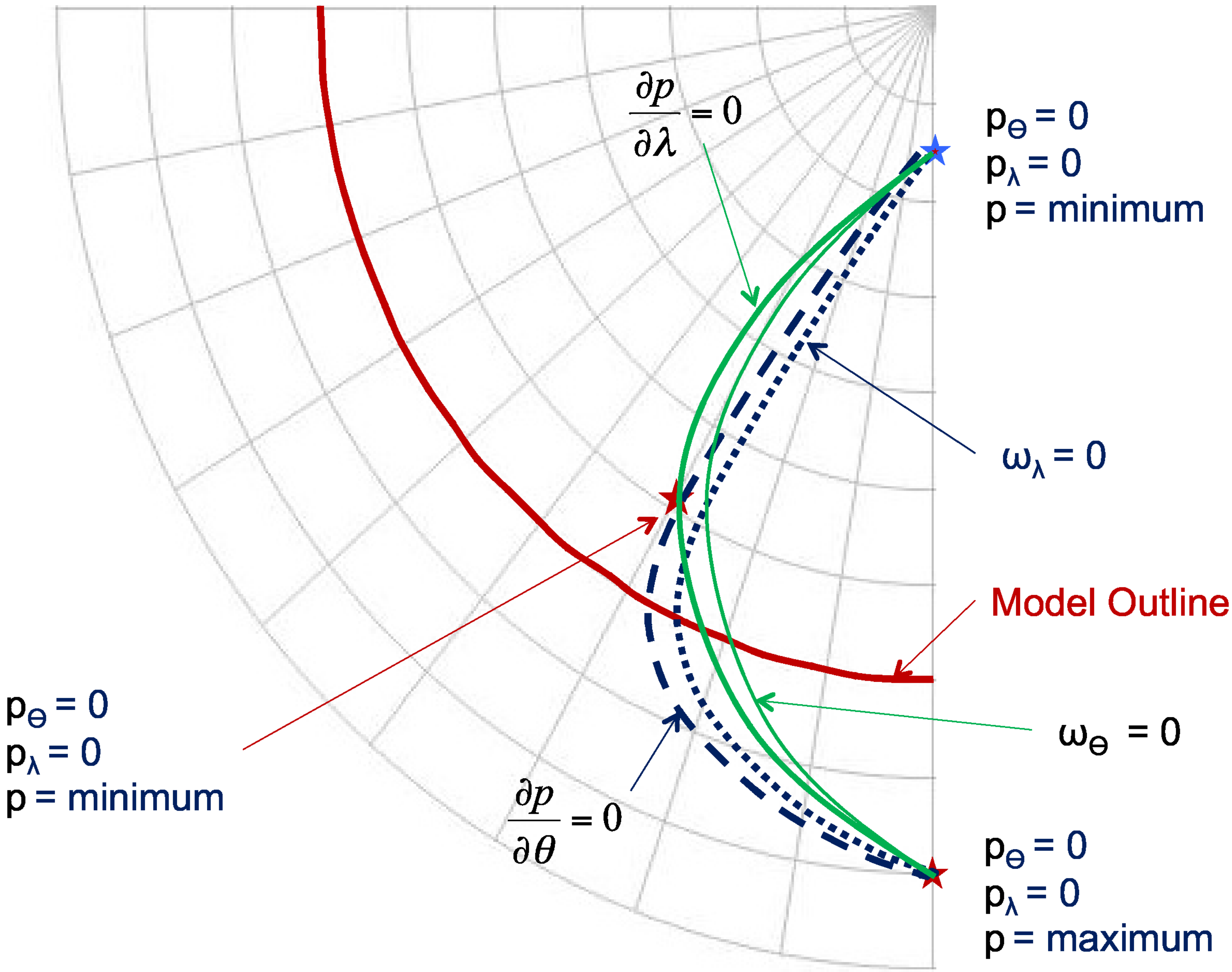




FAITH: Surface Flow Topology



Locus of Points (Top View)



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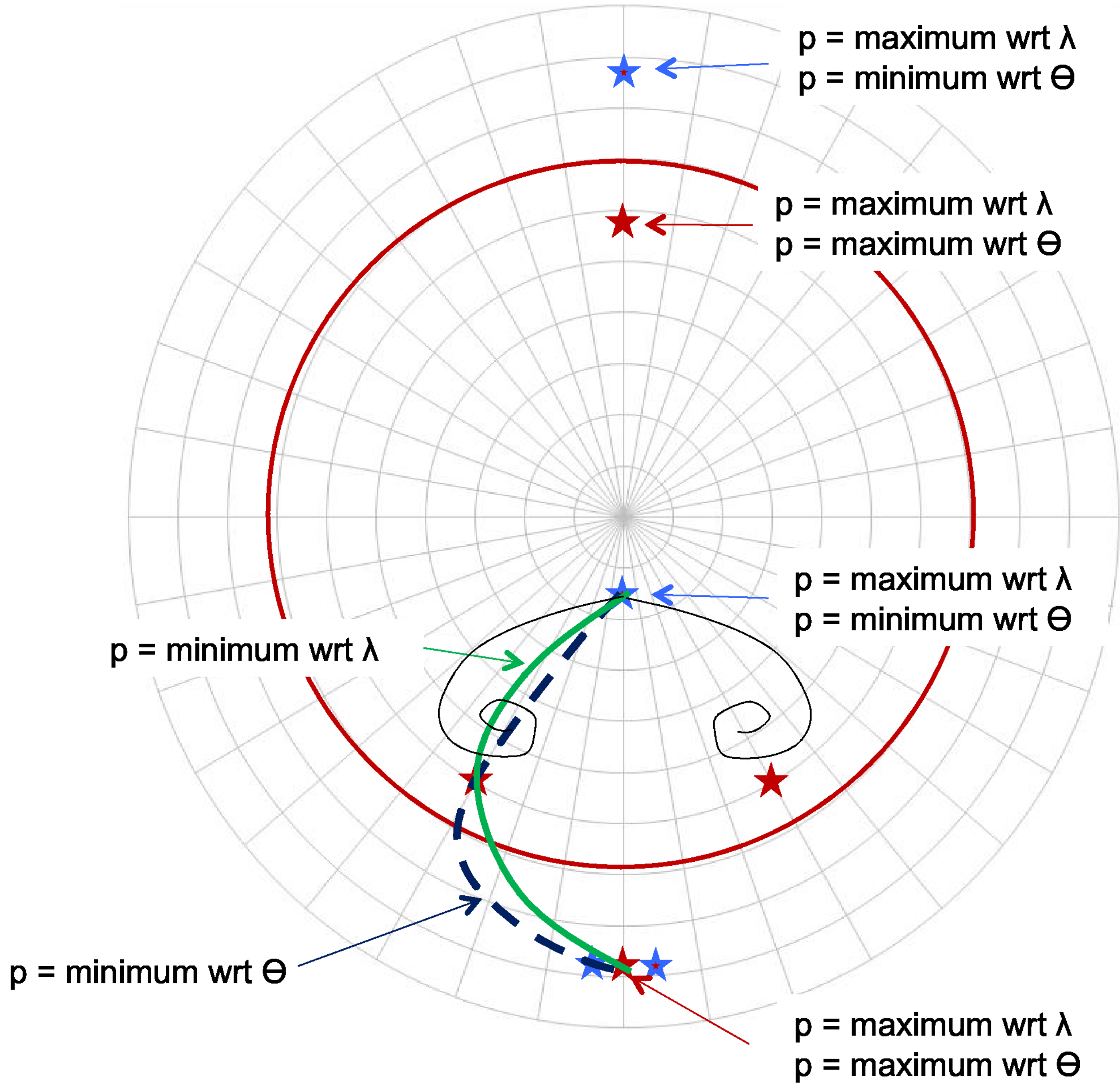
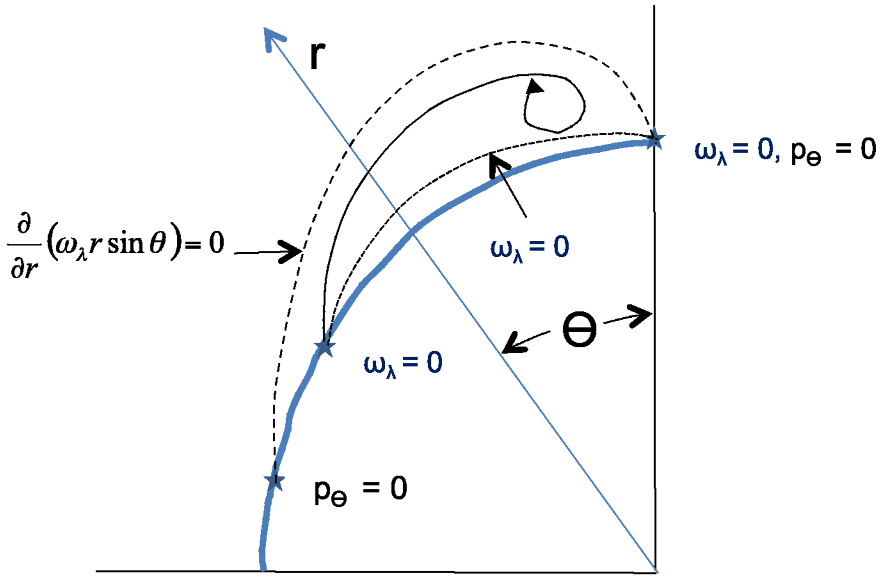
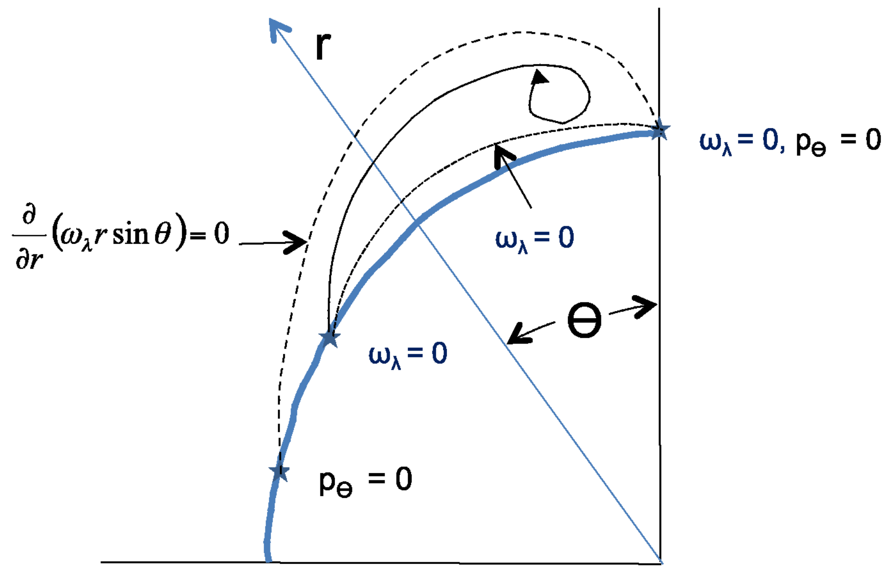


FAITH: Surface Flow Topology



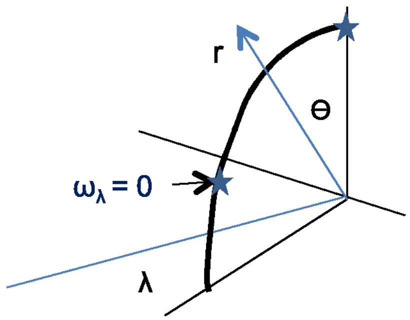
λ = constant

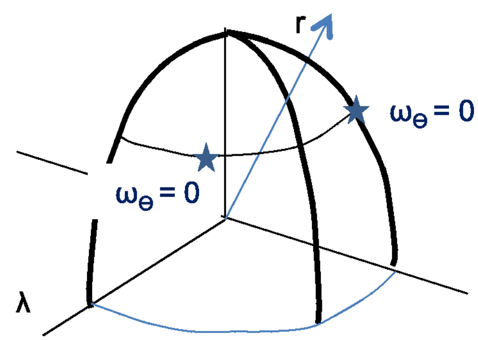


Θ = constant

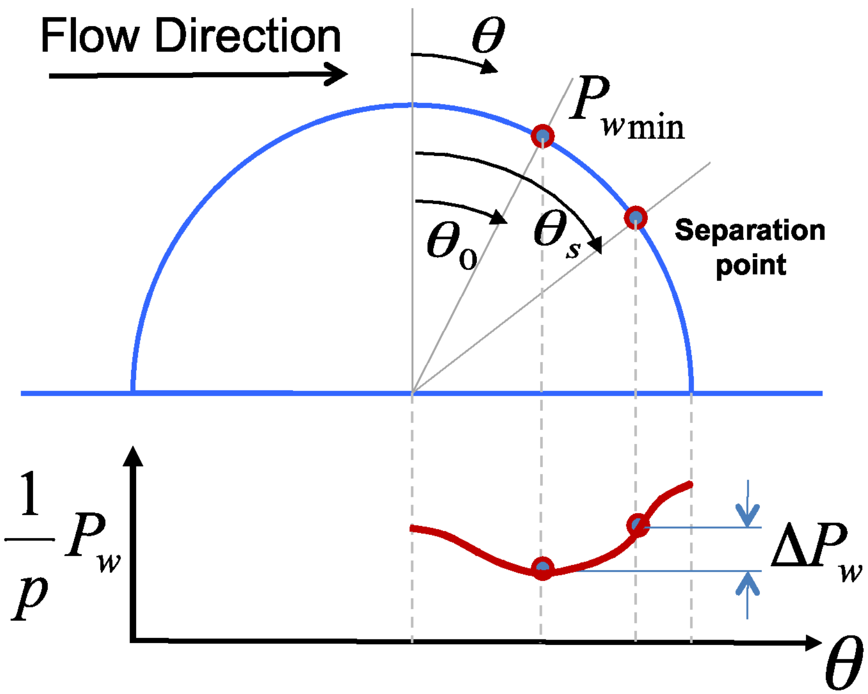
$$\frac{1}{r} p_\theta = \frac{\mu}{r\sin\theta}\frac{\partial}{\partial r}\left(\omega_\lambda r \sin\theta\right) = 0$$

$$\frac{1}{r\sin\theta} p_\lambda = \frac{\mu}{r}\frac{\partial}{\partial r}\left(r\omega_\theta\right) = 0$$





Separation Onset Condition for Laminar Flow (Wall-Mounted Hemisphere)



$$\frac{1}{p}\Delta p_w\left(\frac{\partial}{\partial\theta}\frac{p_w}{p}\theta_s\right)^2 = \frac{1}{9}\left(\frac{\mu}{\rho}\right)^2(\omega_w\theta_0)^4$$

$$\frac{1}{p}\Delta p_w\left(\frac{\partial}{\partial\theta}\frac{p_w}{p}\theta_s\right)^2 = C$$

Summary

- Oil flow alone doesn't allow us to determine whether it's a saddle point of attachment or separation
  - From the upper left picture, you would think that this is a line of separation emanating from a saddle point of separation. (At a saddle point of attachment, flow moves outwards.)
  - From the upper right picture, separation happens because we think that there is no outward flow from the center plane.
- Effort provides evidence that

– All singular points occur at pressure extrema?

– All extrema occur at singular points?

- Generalized Theory

– Two more cases, add to two previous one

Ongoing Work

- Develop General Proof of Pressure Extrema
- Mapping topology from hemisphere to FAITH
- Extend topology to external (wake) flow
- Extend to unsteady flow

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