Potential Flow Model of a Vortex Street Near a Fish-like Body

Joshua Brulé, University of Maryland/TREND 2012
Dr. Derek Paley, CDCL

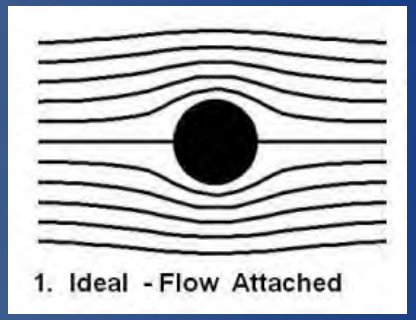
Flow past a bluff object

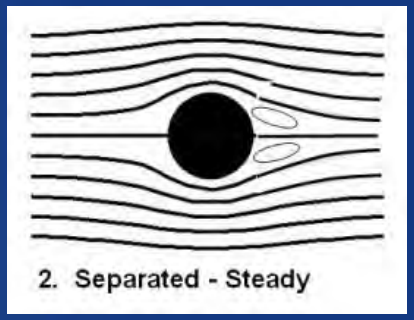
- Fluid dynamics is governed by the Navier-Stokes equations:

$$\rho\left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v}\cdot\nabla\mathbf{v}\right) = -\nabla p + \nabla\cdot\mathbf{T} + \mathbf{f},$$

- $1,000,000 prize for proving/disproving **existence** and **smoothness**

Low velocity (Easy)

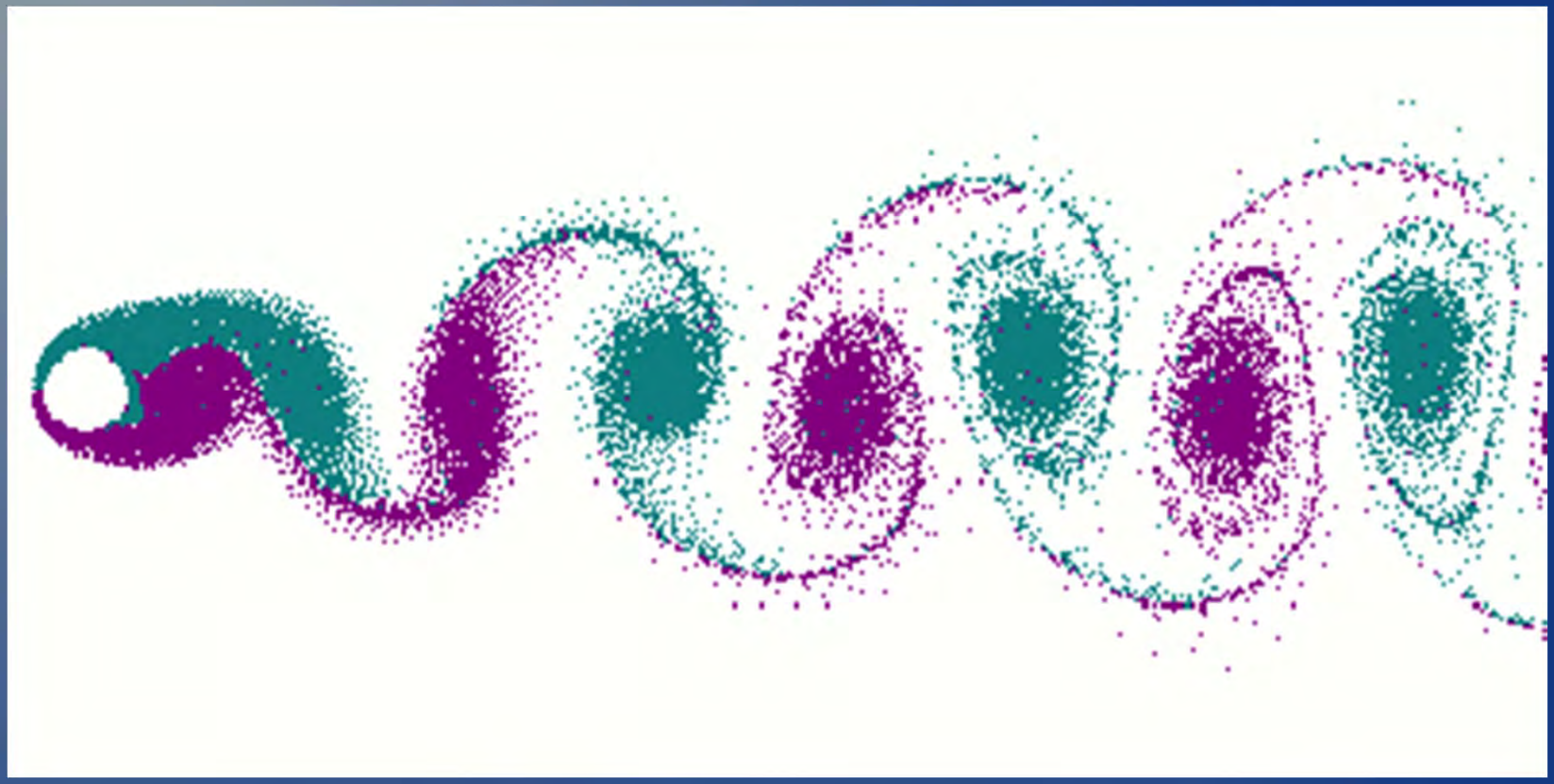




High velocity (Hard)

http://www.grc.nasa.gov/WWW/k-12/airplane/dragsphere.html

Kármán vortex street

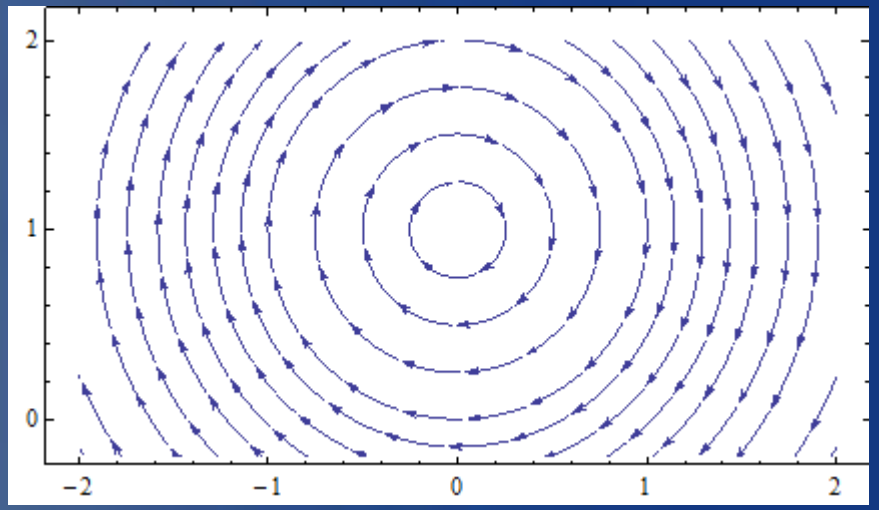


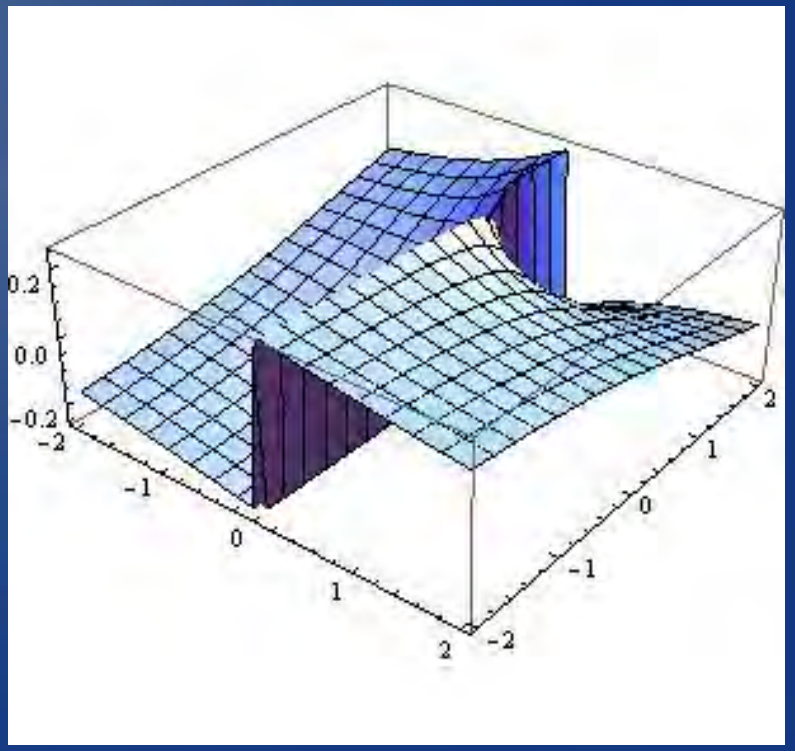
Courtesy of Cesareo de la Rosa Siqueira, University of Sao Paulo, Brazil

Potential Flow Modeling

- Flow velocity represented via complex potential function W(ζ, t)
- Real part is x-axis, Imaginary part is y-axis
- Equivalent to **inviscid**, **irrotational** solutions of Navier-Stokes
- Vortex potential:

$$\frac{i\Gamma_j}{2\pi}\log(\zeta - \zeta_j)$$

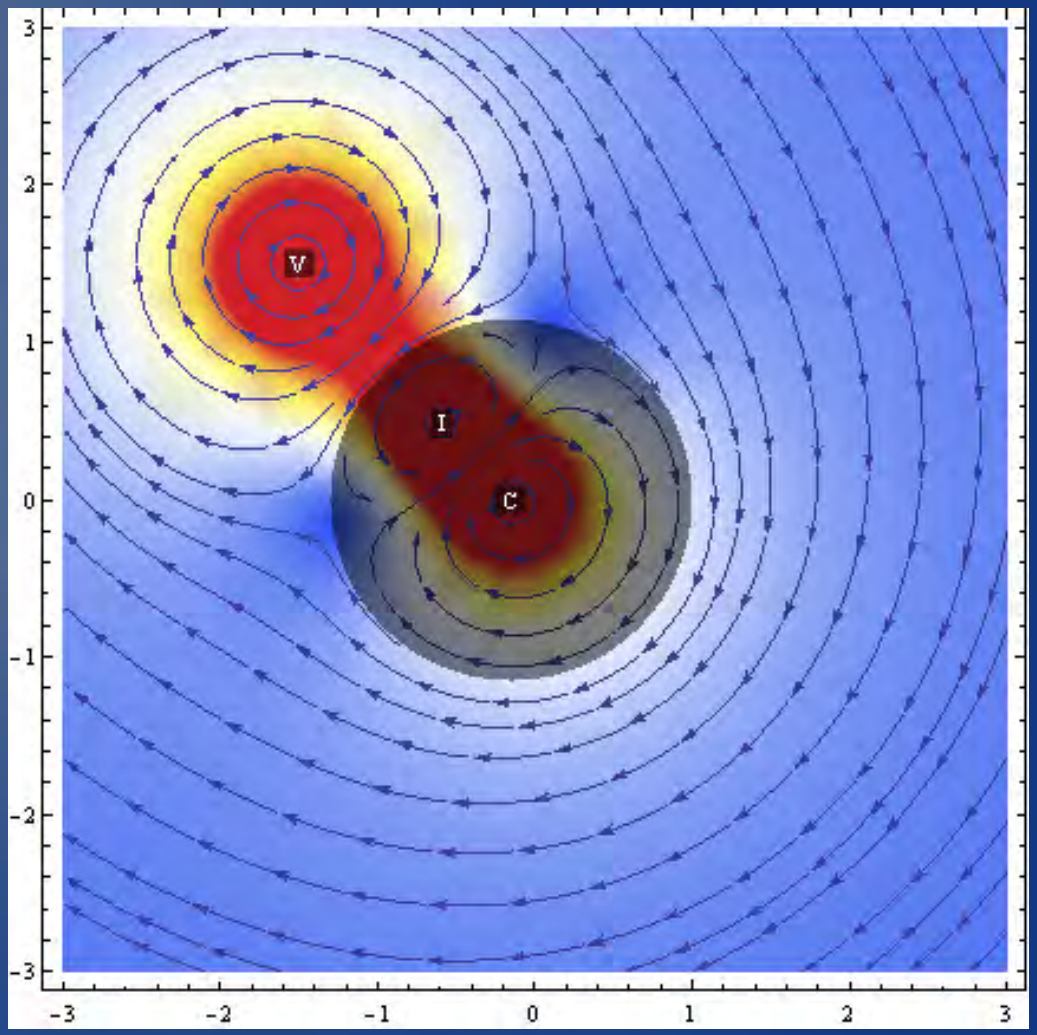




"A model of the lateral line of fish for vortex sensing."
Ren Z, Mohseni K. 2012

Vortex near a (circular) fish

- (Insert your own spherical cow joke)
- Boundary conditions (i.e. no flow through fish surface) are satisfied by adding 'mirror' vortices inside the circle
- Complex potentials are linear; easy to add in freestream velocity and additional vortices



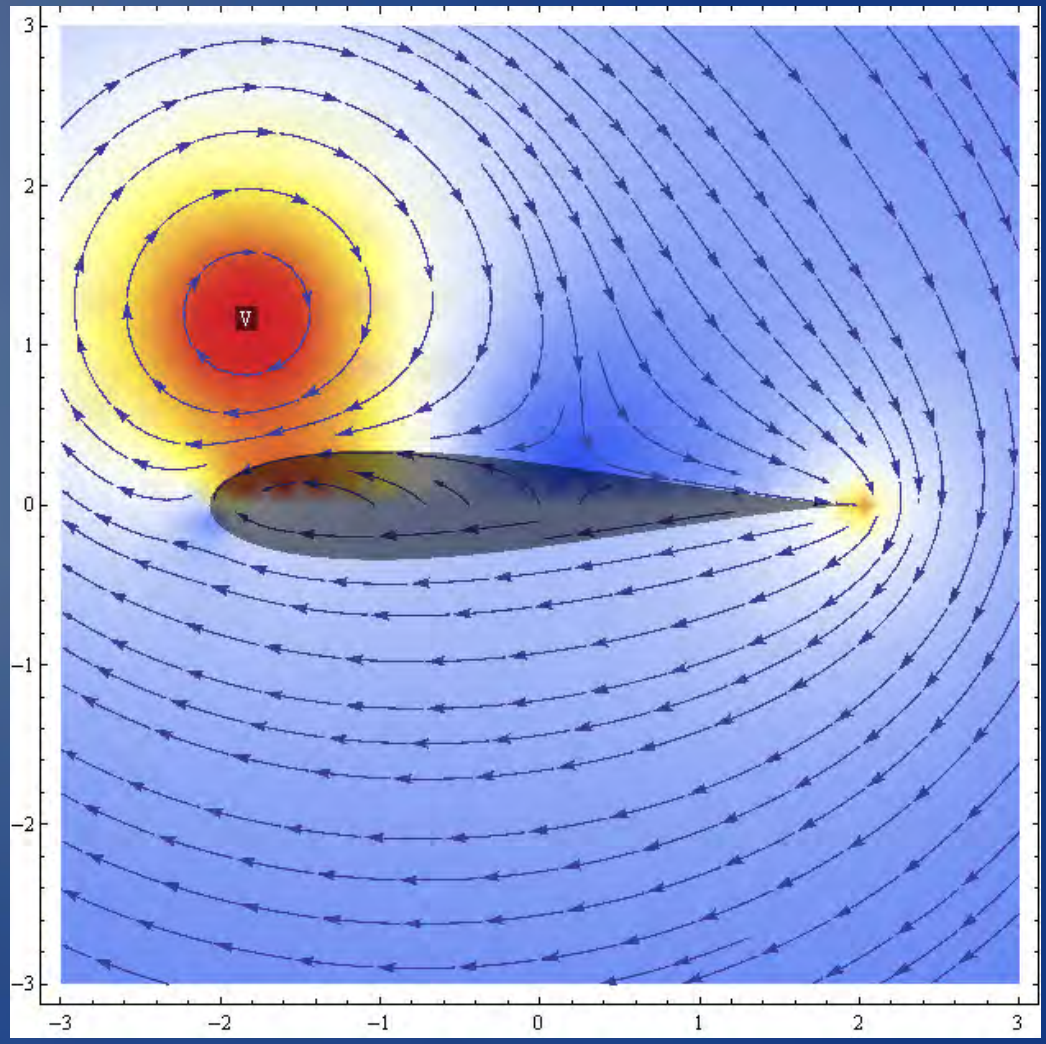
"A model of the lateral line of fish for vortex sensing."
Ren Z, Mohseni K. 2012

Vortex Near Airfoil

- Joukowsky transformation maps circles (ζ plane) to airfoils (z plane)

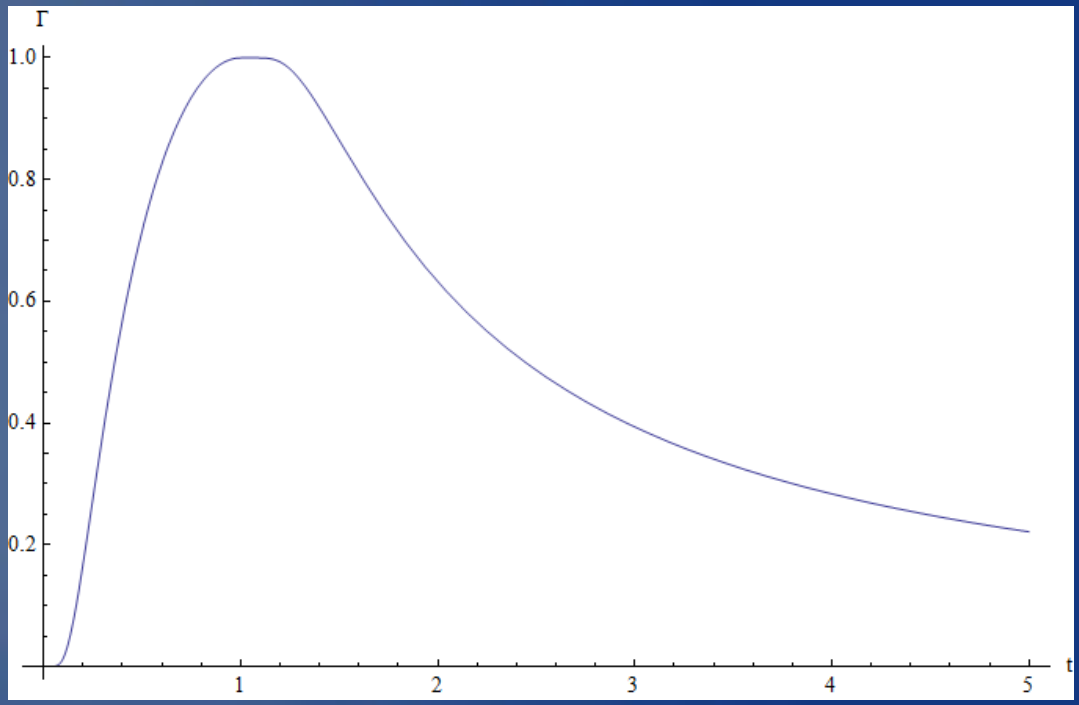
$$z = \zeta + \frac{c_0^2}{\zeta}$$

- By varying the transform coefficient and the location of the circle (in the ζ plane) we can produce every fish height/width ratio



Vortex Decay / Position

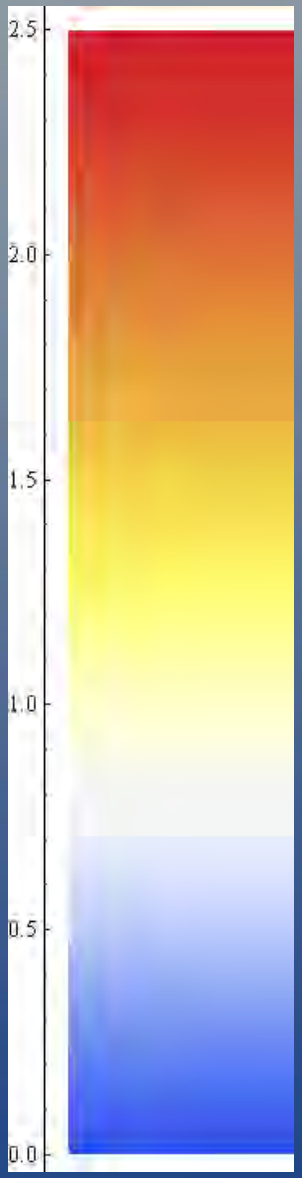
- An actual vortex decays over time due to viscous effects
- For potential flow models, we have to add that in 'by hand'
- Vortex position is prescribed by a path function (in this model, a straight line in the z plane)

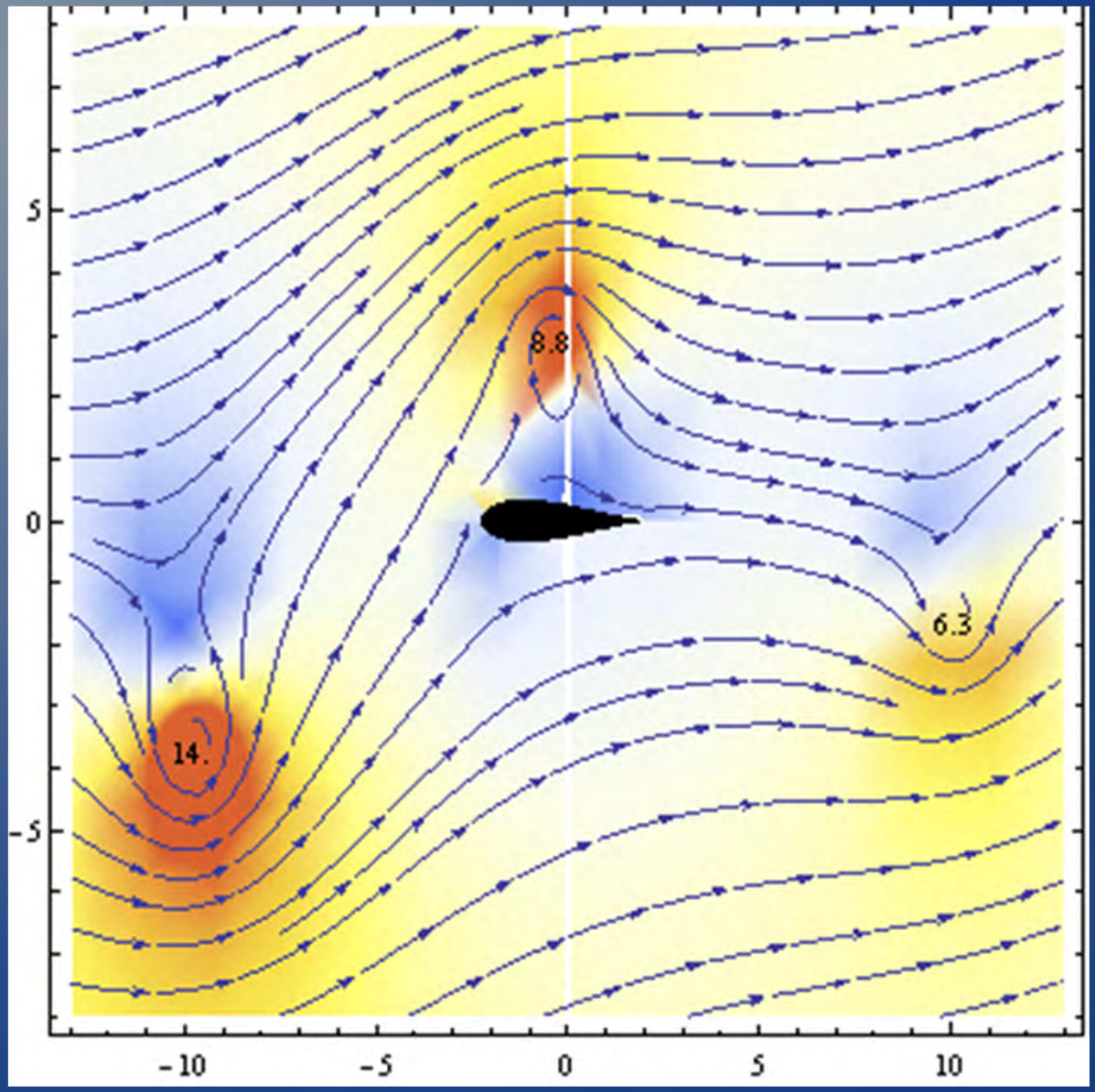


$$\Gamma(t) = \begin{cases} 1 - e^{-\frac{\beta}{t-\mu}} & t > \mu \\ e^{\frac{(t-\mu)^2}{(t-\mu)^2-\mu^2}} & t > 0 \\ 0 & t \leq 0 \end{cases}$$

Based on Saffman, P.G. Vortex Dynamics. 1992

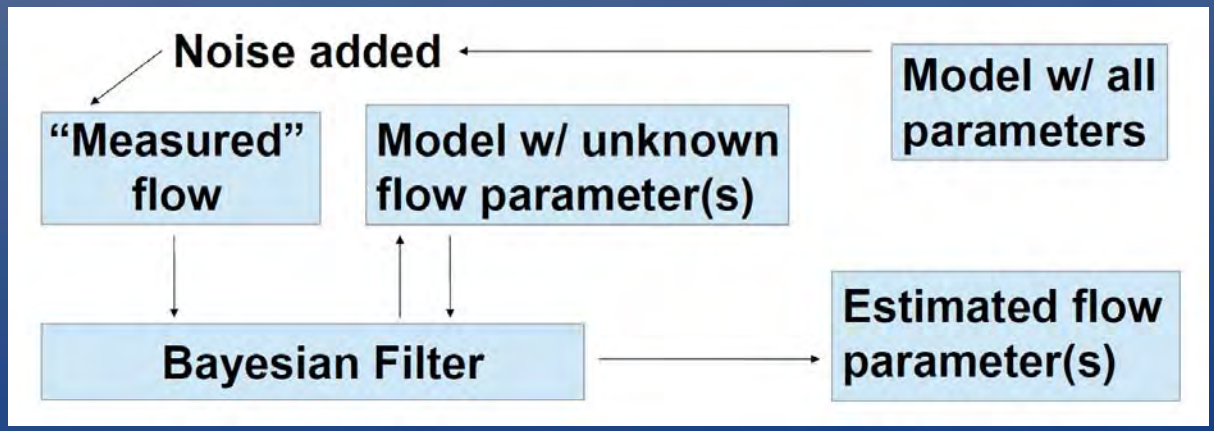
Potential Vortex Street





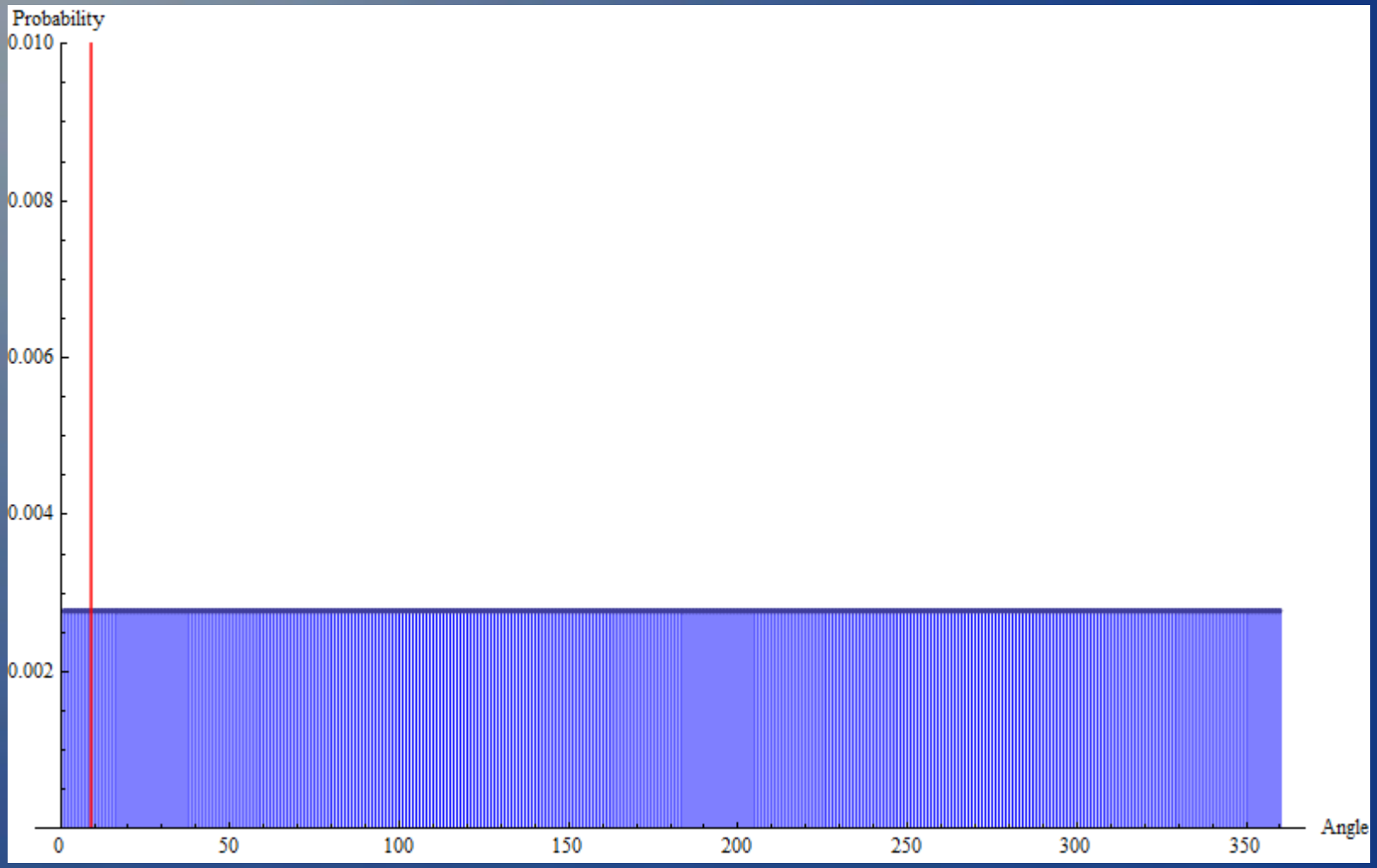
(Simulated) Flow field estimation

- "A blind fish can school" (Pitcher, T.J. et. al. 1976)
- Fish can navigate by detecting pressure and velocity distributions on their body's surface
- What about robot-fish?



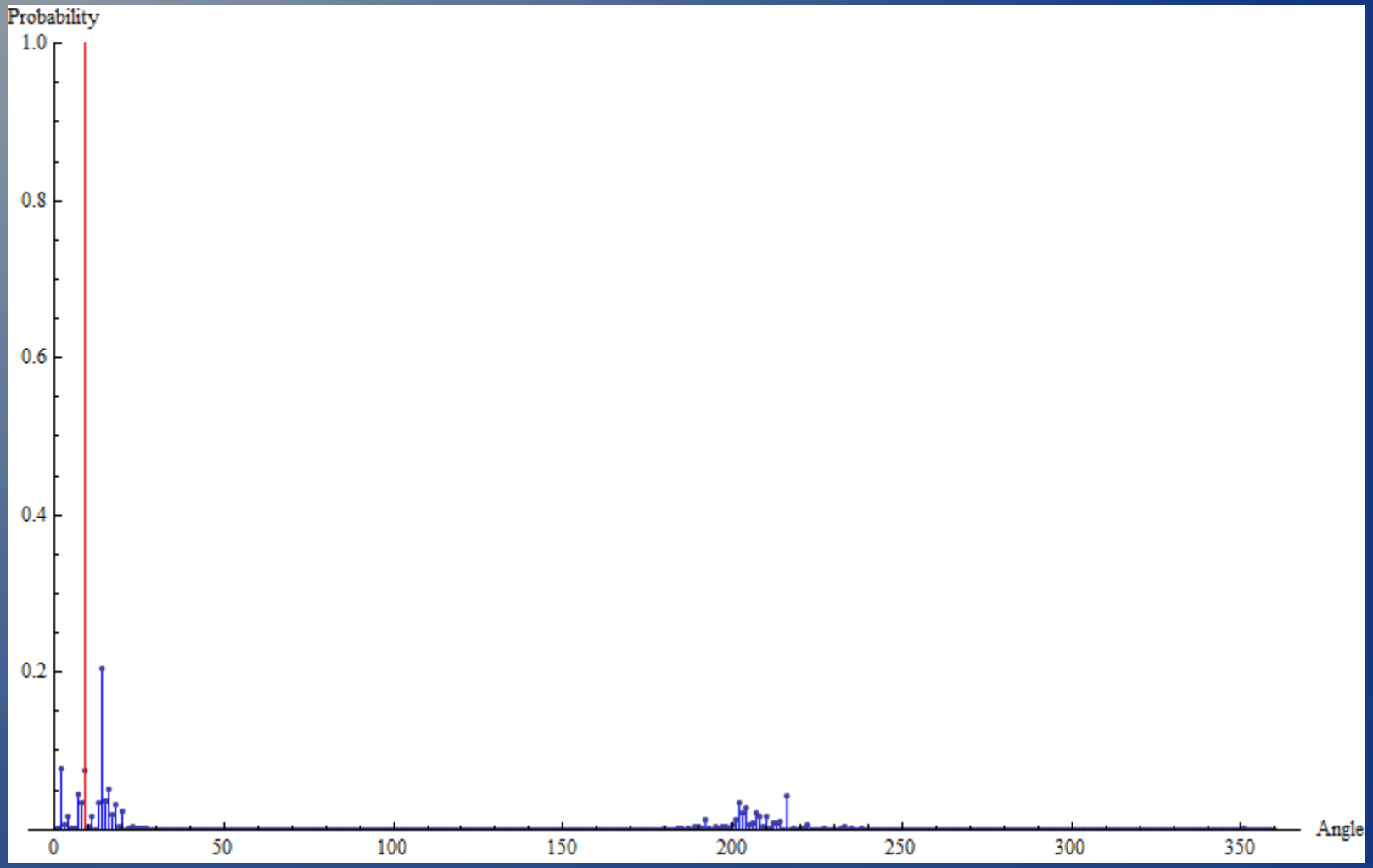
xkcd, Randall Munroe

Estimating angle of attack (prior)

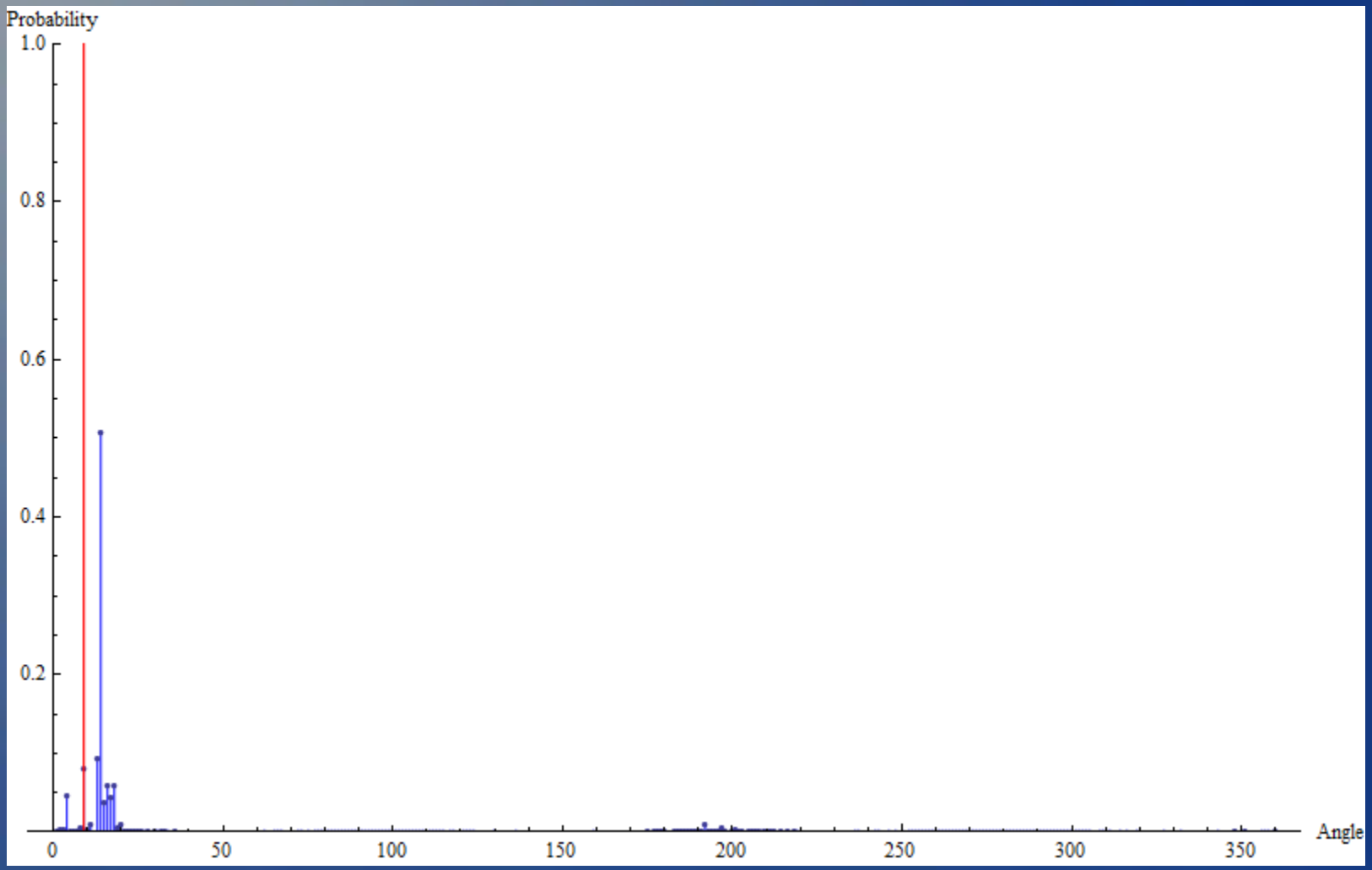


23 virtual velocity sensors, with N(0,.15) noise, freestream velocity 1, actual AoA = 9 degrees

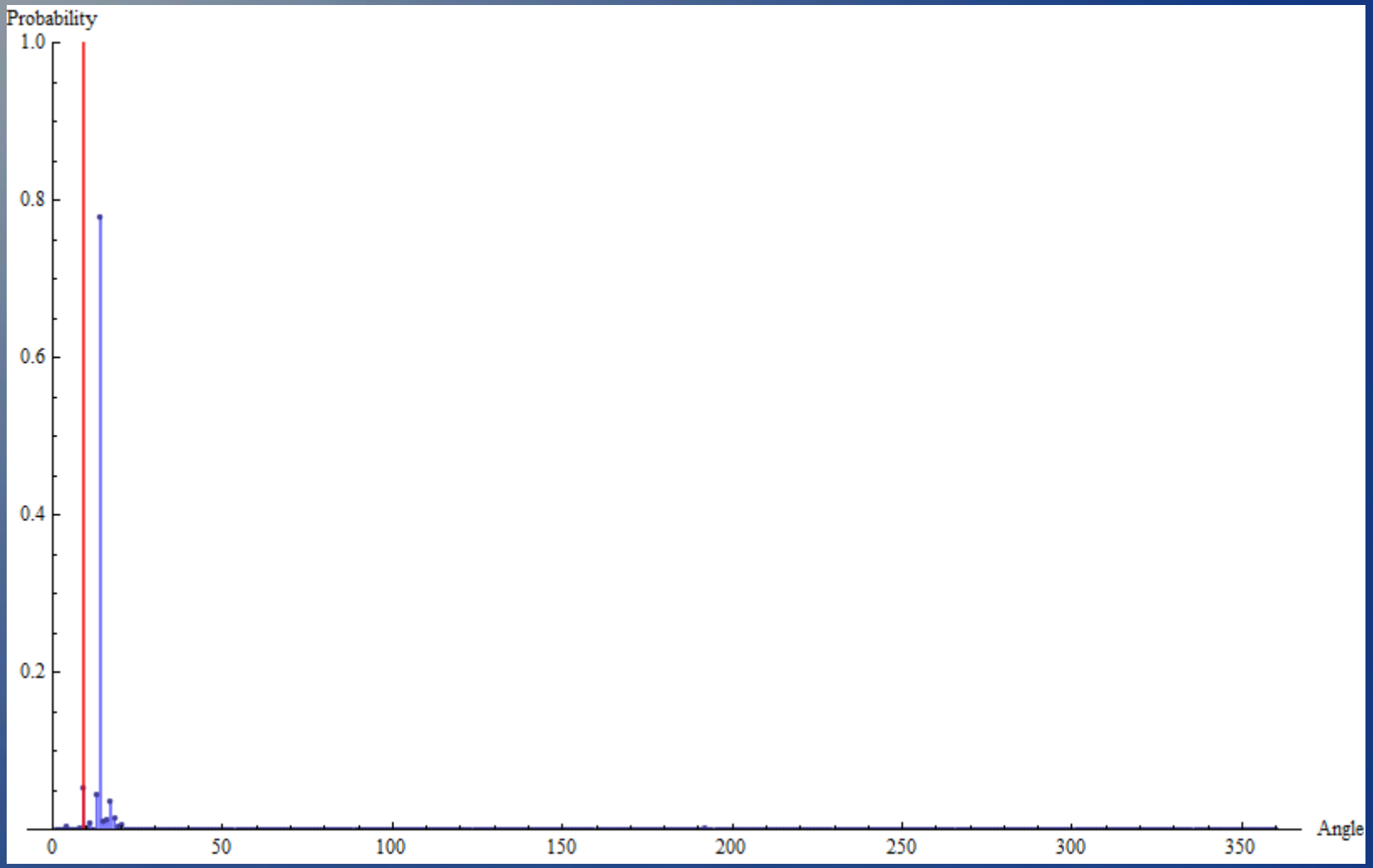
Estimating angle of attack (t = 0)



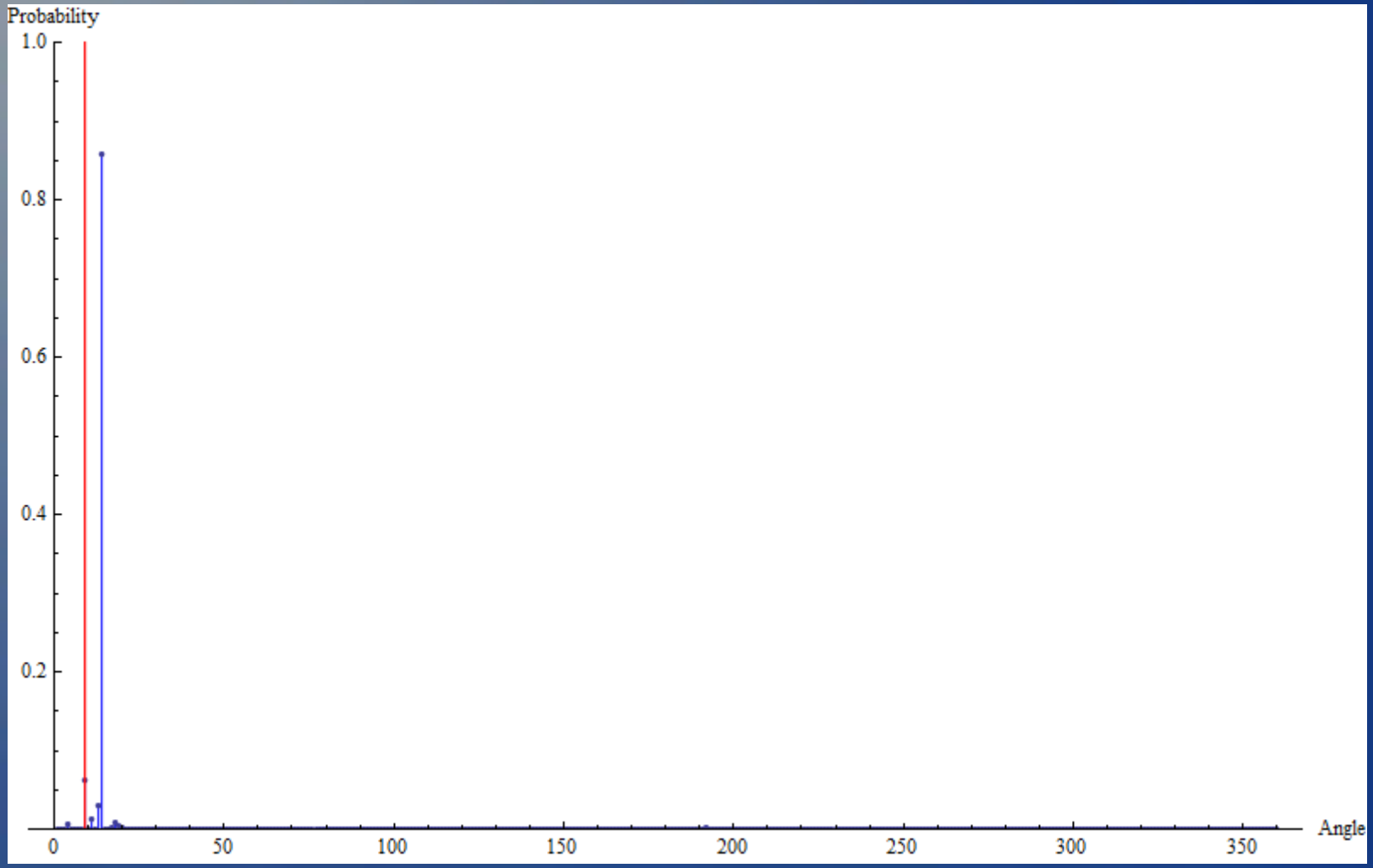
Estimating angle of attack (t = 1)



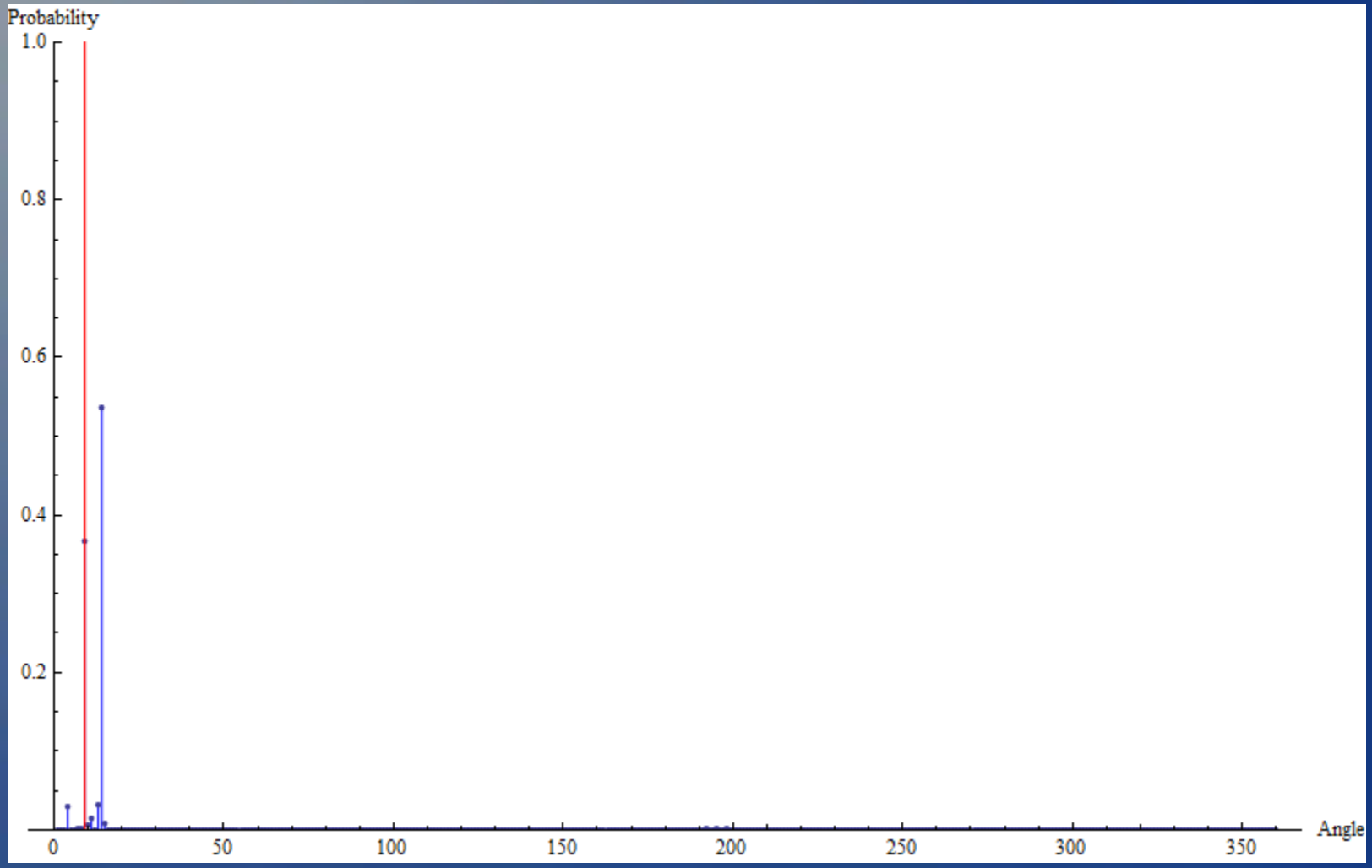
Estimating angle of attack (t = 2)



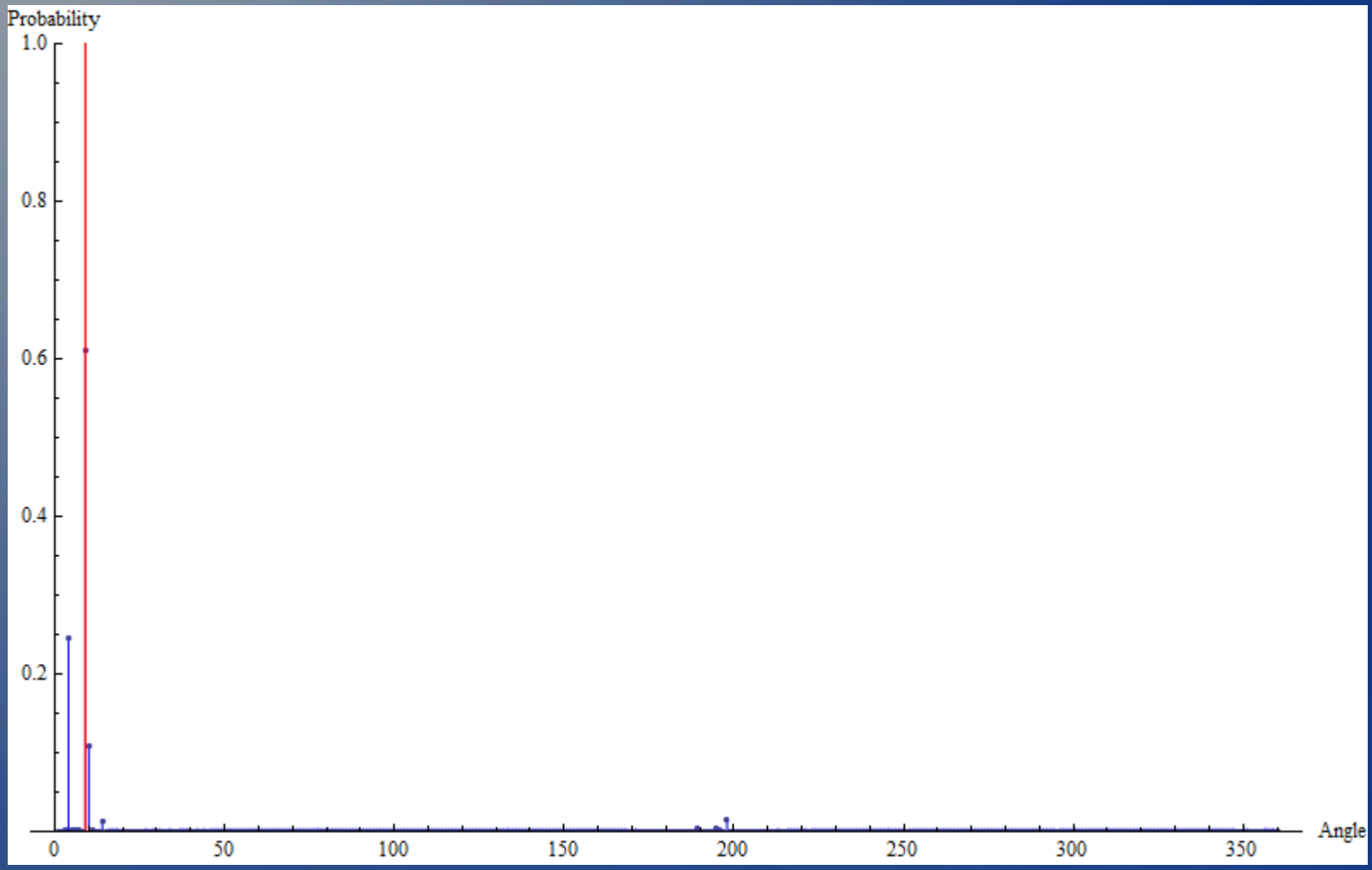
Estimating angle of attack (t = 3)



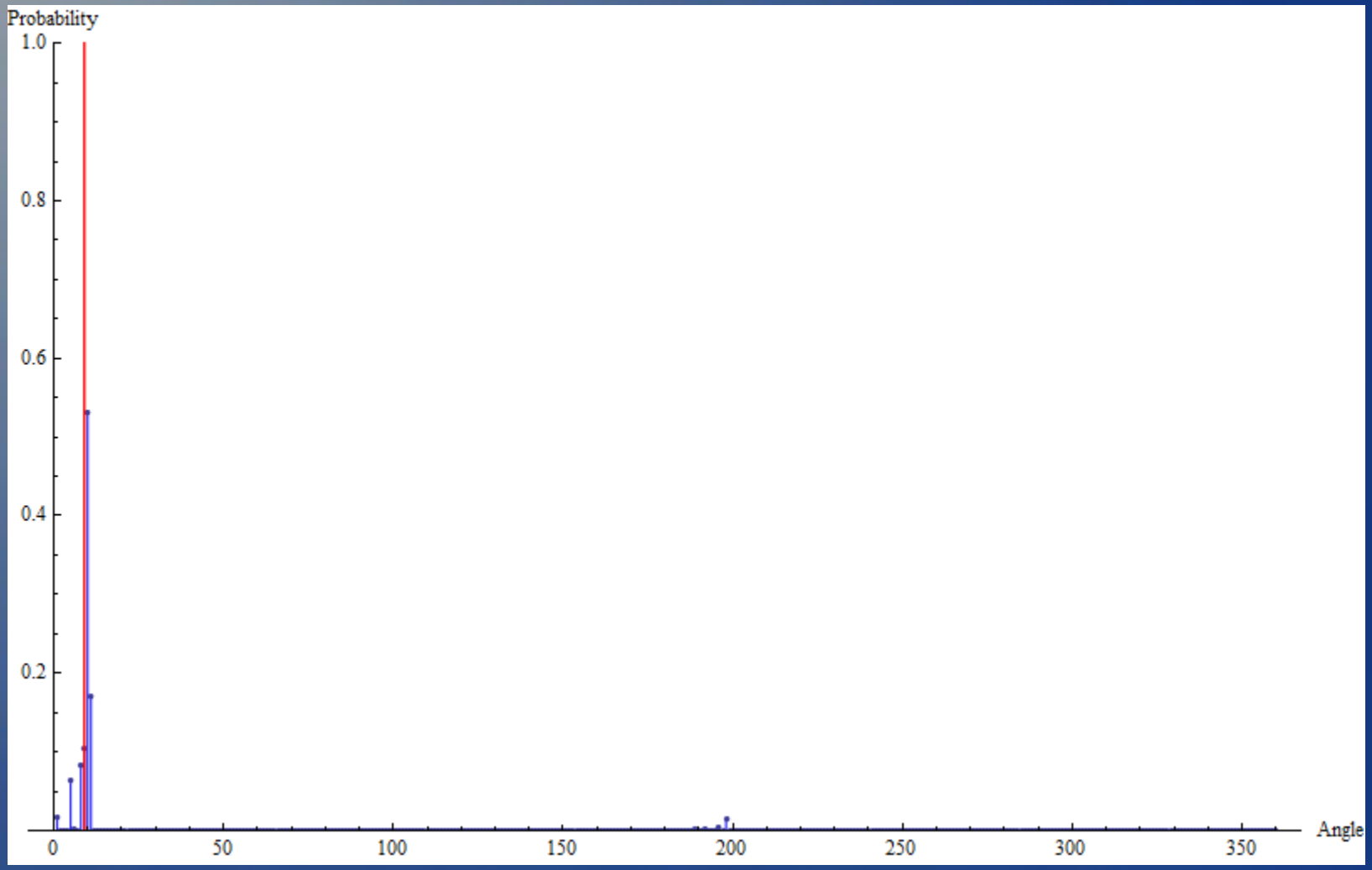
Estimating angle of attack (t = 4)



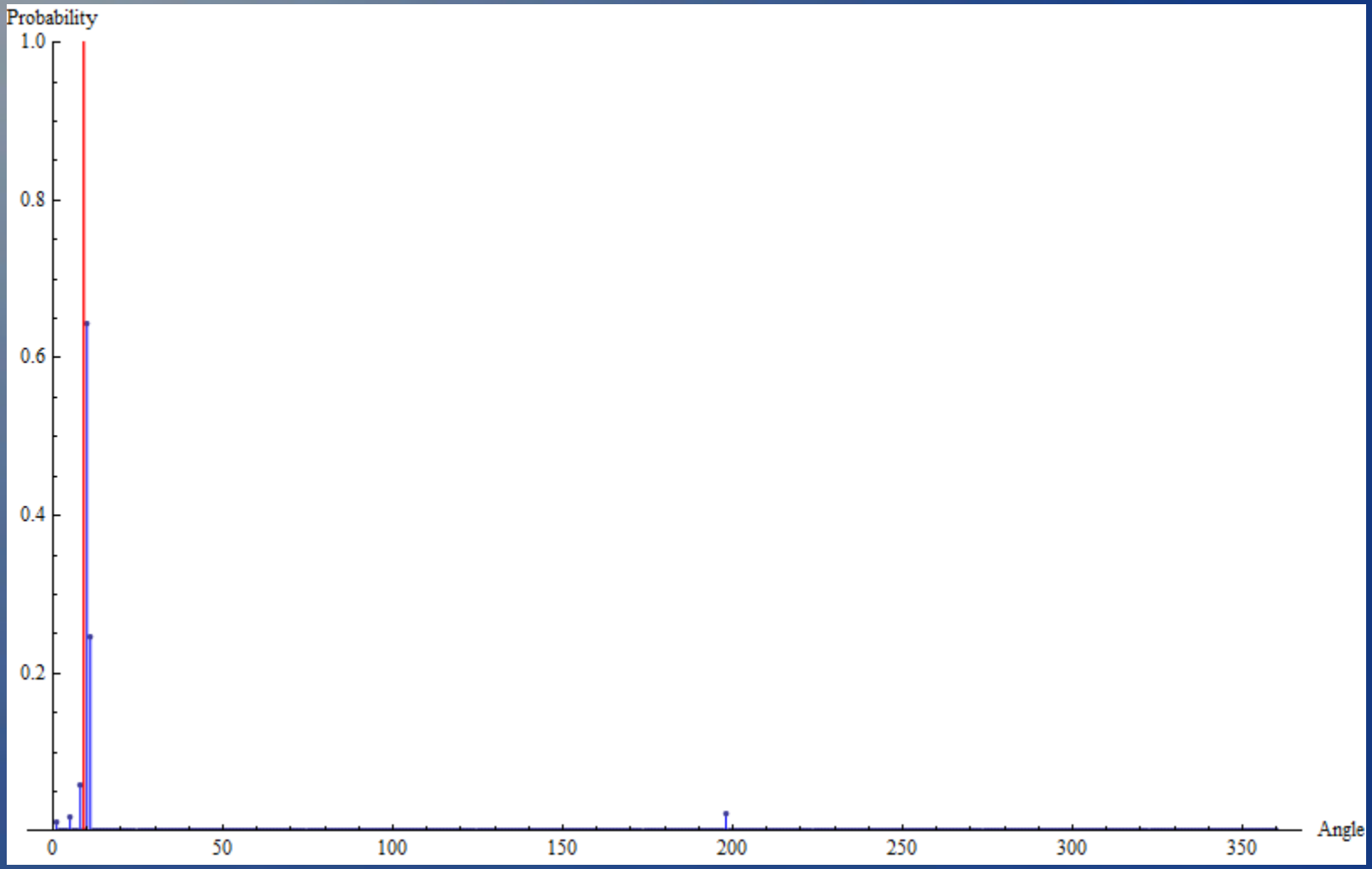
Estimating angle of attack (t = 5)



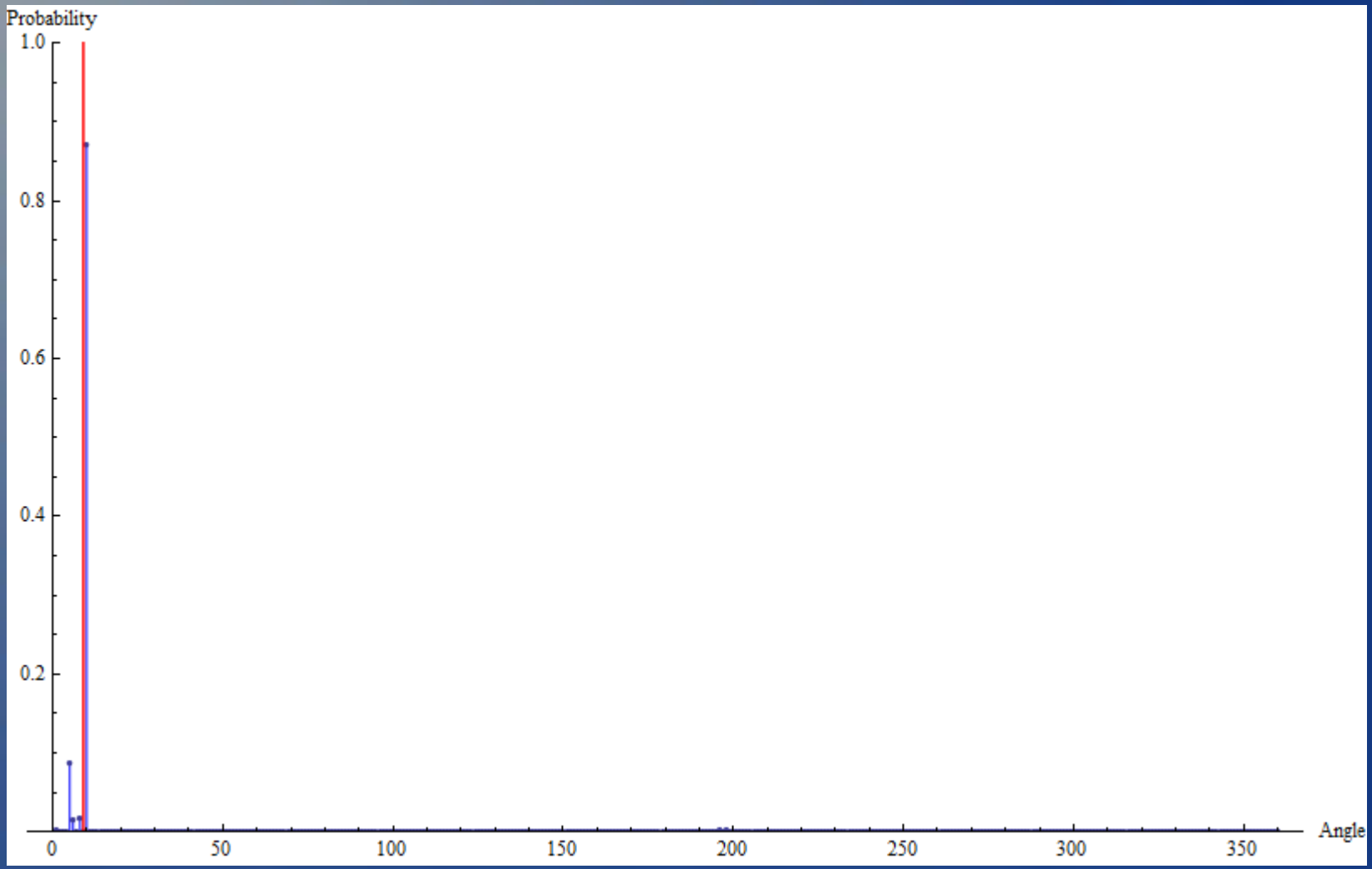
Estimating angle of attack (t = 6)



Estimating angle of attack (t = 7)



Estimating angle of attack (t = 8)



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