Trailing Edge Noise Prediction Based on a New Acoustic Formulation

J. Casper and F. Farassat

NASA Langley Research Center
Hampton, Virginia

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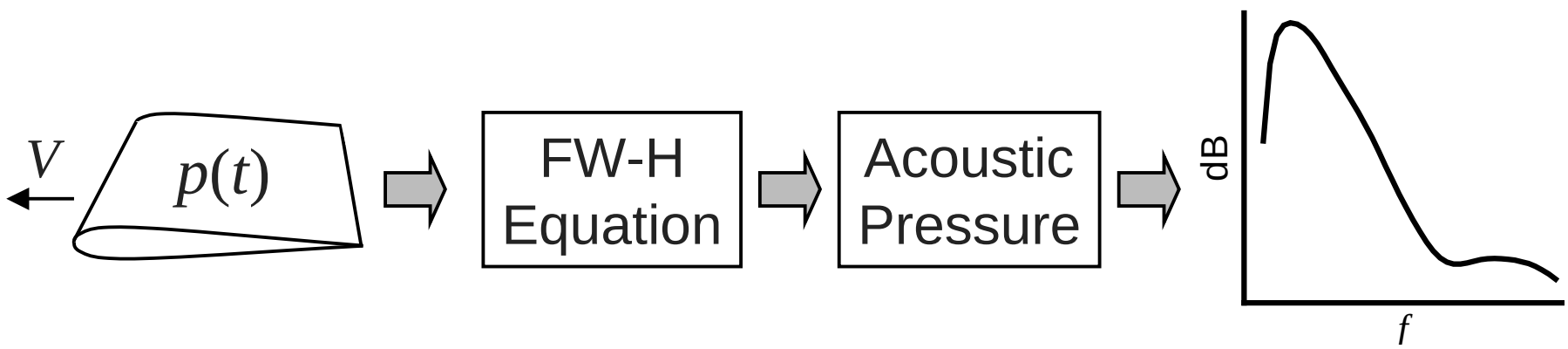
Outline

- Introduction / Motivation
- Acoustic Formulation
- Model Problems – Constant Frequency
  - Surface Pressure from Thin Airfoil Theory
  - Velocity Scaling Properties, Directivity
- Broadband Noise Prediction
  - Trailing Edge Noise
  - Surface Pressure Formulation
    - (Schlinker and Amiet, 1981)
  - Comparison with Experiment
    - (Brooks and Hodgson, 1981)

Introduction / Motivation

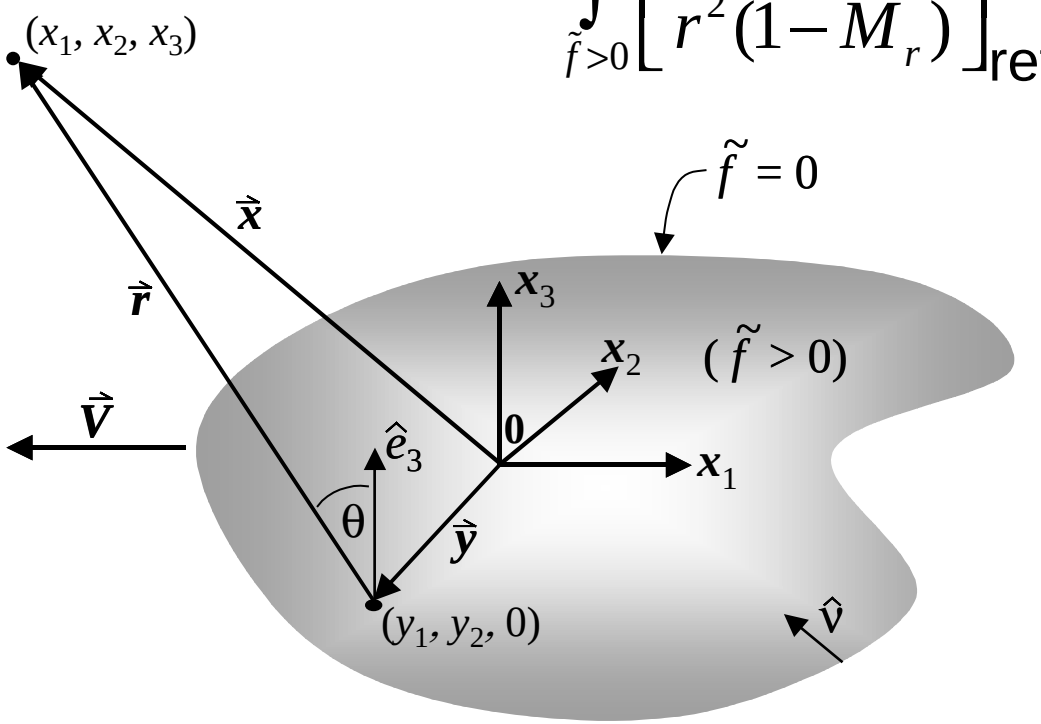
- Broadband Noise Prediction Tools
  - Airframe noise, ducted fan noise
  - Incident turbulence, TE noise
- Time Domain Approach
  - Acoustic Analogy
  - Ffowcs Williams – Hawkings equation
  - Decouples aerodynamics from acoustics
  - Input from CFD or experiment



Formulation 1B

$$4\pi p'(\vec{x},t) = \int_{\tilde{f}>0} \left[\frac{(\partial p/\partial \tau - V \partial p/\partial s)\cos\theta}{c_0\, r\,(1-M_r)} \right]_{\text{ret}} dS$$

$$+ \int_{\tilde{f}>0} \left[\frac{p\cos\theta}{r^2(1-M_r)} \right]_{\text{ret}} dS - \int_{\tilde{f}=0} \left[\frac{M_\nu\, p\cos\theta}{r\,(1-M_r)} \right]_{\text{ret}} d\ell$$



Model Problems

Test Cases

- Directivity
- Velocity Scaling Properties

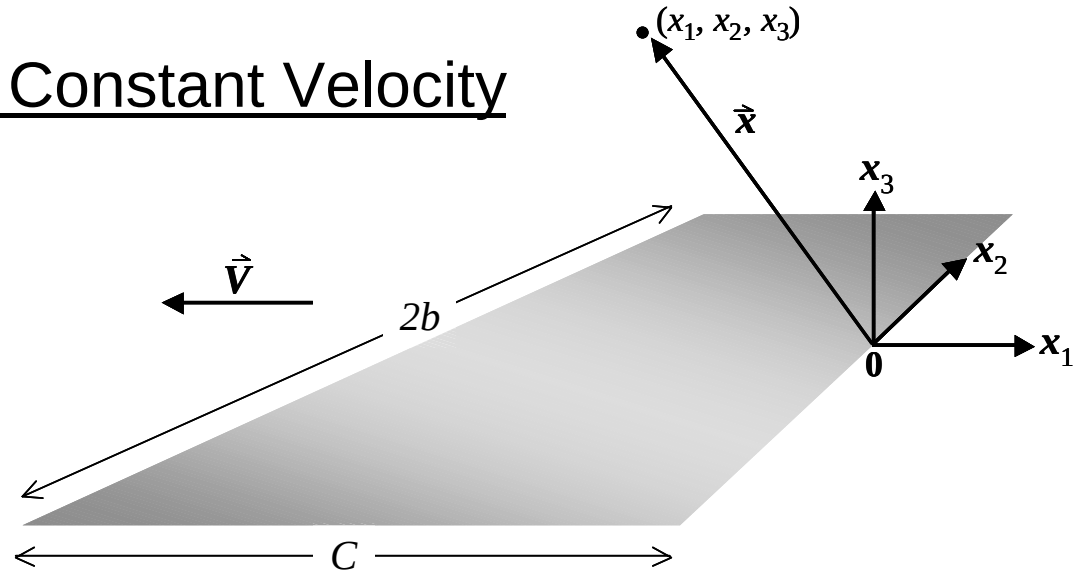
Analytic Surface Pressure

- Thin Airfoil Theory (Amiet, 1975-6)
- Constant Frequency Disturbance
- Flat Plate in Uniform Rectilinear Motion

Analytic Surface Pressure

Rectangular Surface at Constant Velocity

$$-C \le x_1 \le 0\,,$$
$$-b \le x_2 \le b,$$
$$\vec{V} = \left[-U, 0, 0\right]^T$$



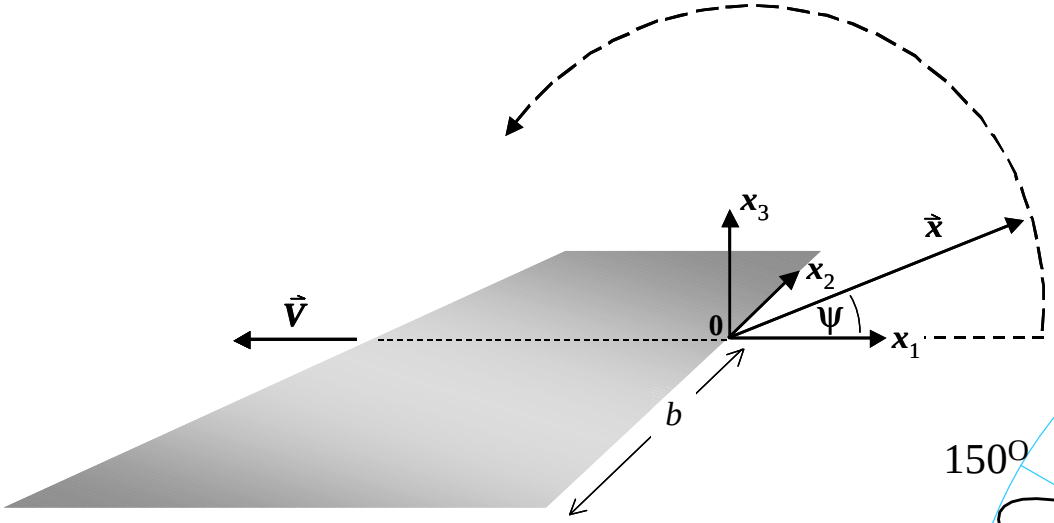
Surface pressure

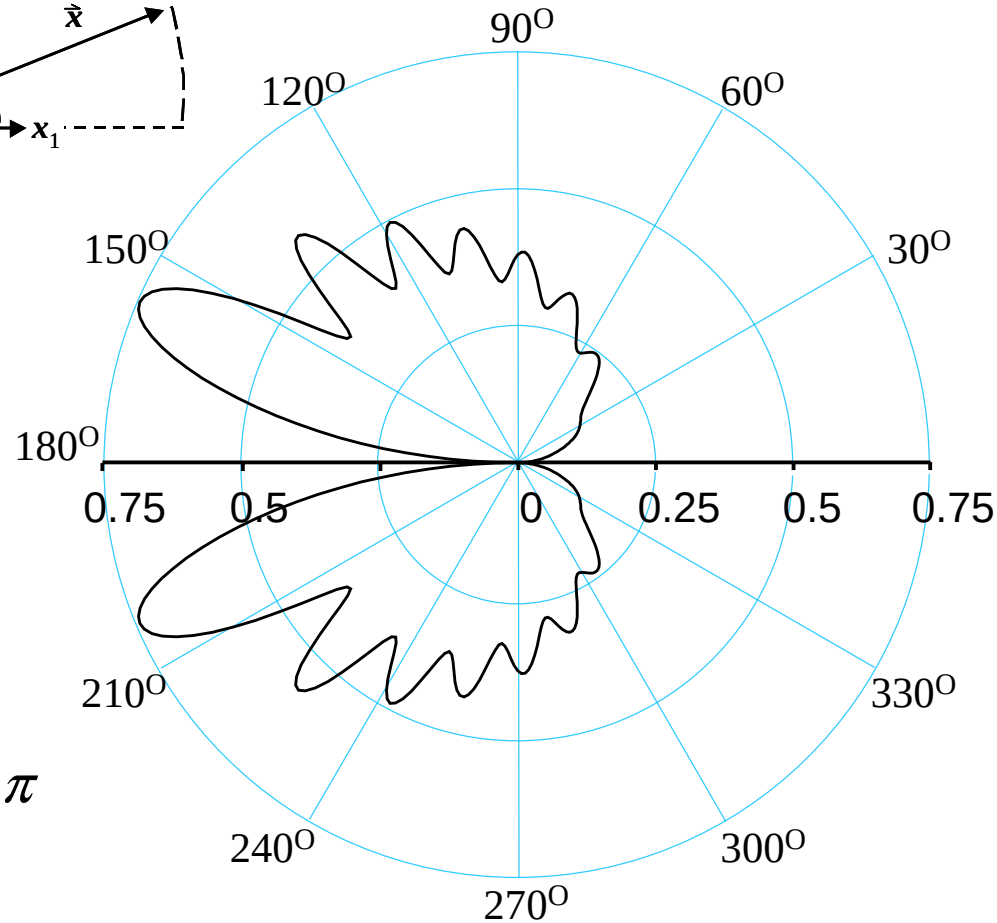
$$\Delta P(x_1, t) = 2P_0\, g(x_1, k_c)\, e^{-i k_c (x_1 - U t)}$$

$$k_c = \omega / U_c = \text{ constant}$$

$$g(x_1, k_c) \text{ from thin airfoil theory (Amiet, 1975)}$$

Directivity



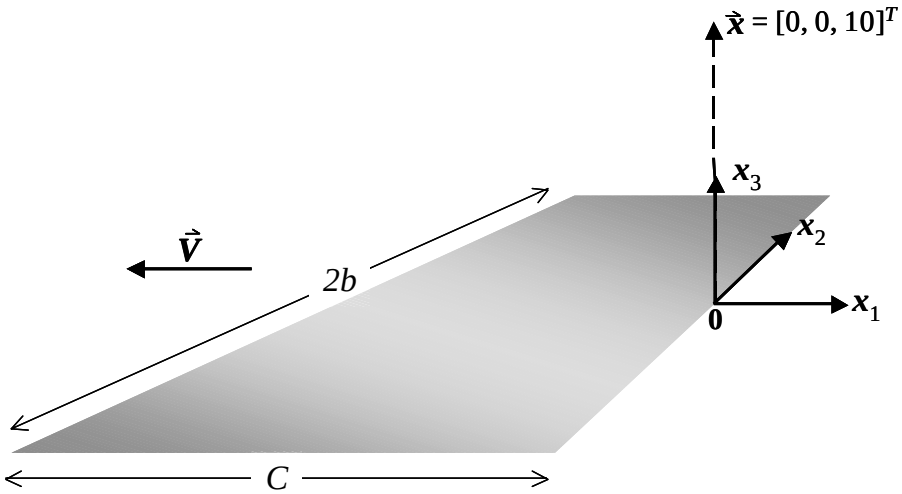


$$L_C = 0.5 \text{ m}, \; 2b = 2.0 \text{ m}$$

$$M = 0.2, \; P_0 = 0.01 \frac{\rho U^2}{2}$$

$$f = 2.5 \text{ kHz}, \; r = 2.0 \text{ m}, \; 0 \le \psi \le 2\pi$$

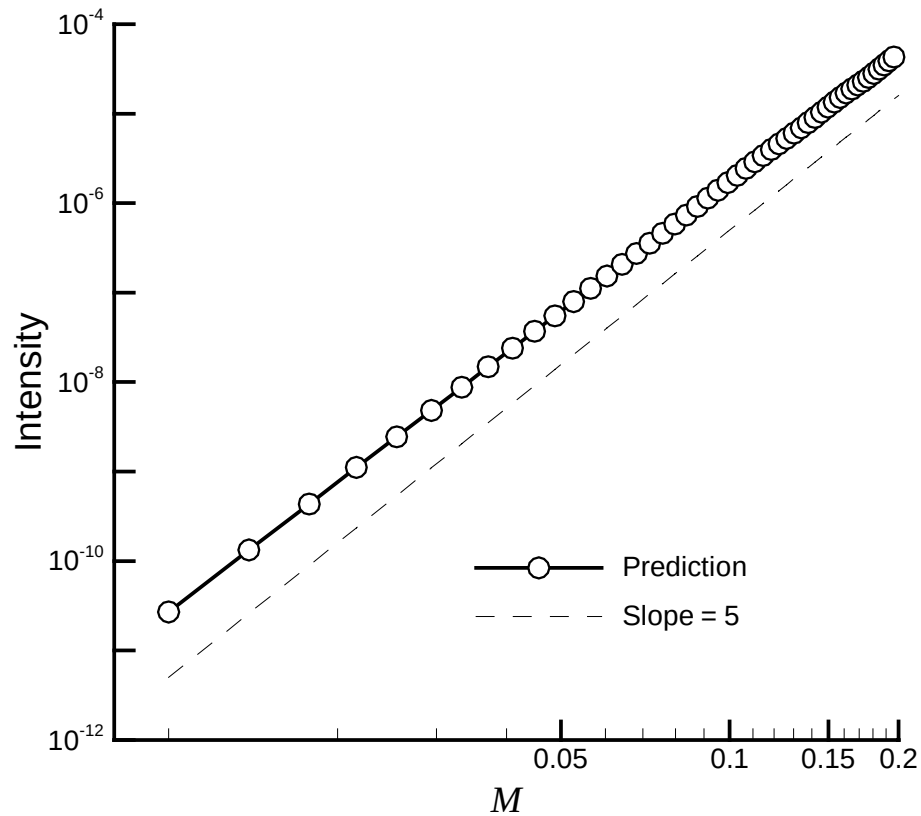
Velocity Scaling



$$L_C = 0.5 \text{ m}, \; 2b = 2.0 \text{ m}$$

$$0.01 \le M \le 0.2, \; P_0 = 0.01 \frac{\rho U^2}{2}$$

$$f = 2.5 \text{ kHz}, \; r = 10 \text{ m}, \; \psi = 0$$



Broadband Trailing Edge Noise

Experiment: Brooks and Hodgson (1981)

NACA 0012 Airfoil

Chord = 0.61 m

Span = 0.46 m

$\alpha = 0$ degrees

Tunnel Speeds

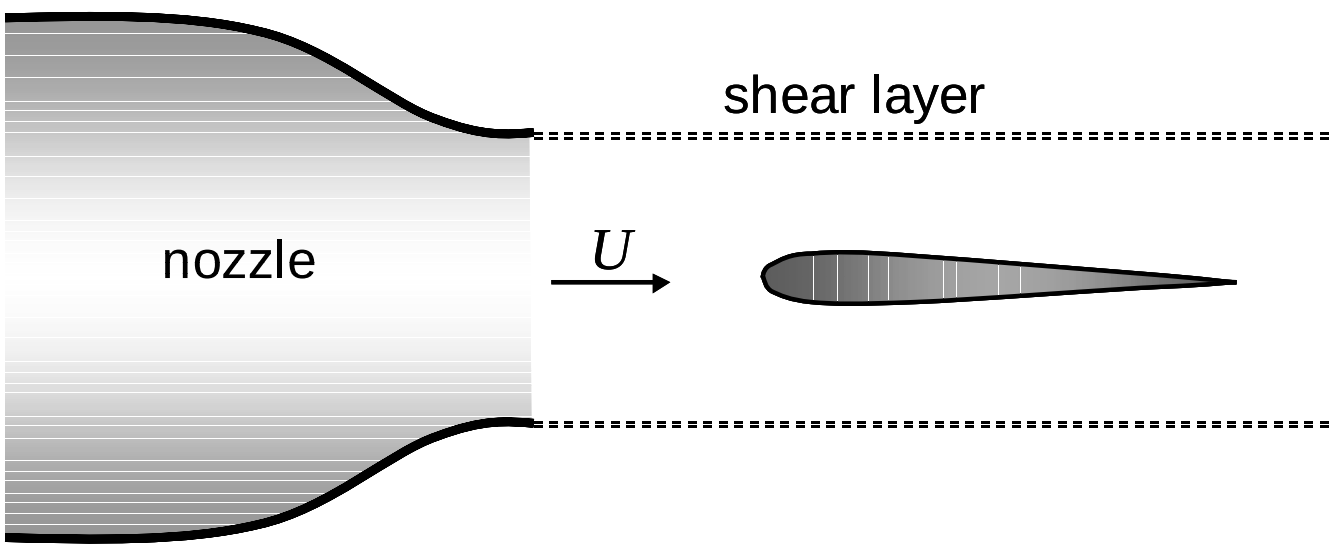
$U = 38.6$ m/s

$U = 69.5$ m/s

Microphone

$r = 1.22$ m

$\theta = 90$ degrees



Broadband Surface Pressure

Broadband extension:

$$\Delta P(x_1, x_2, t) =$$

$$2\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \tilde{P}(k_c, k_2)\, g(x_1, k_c, k_2)\, e^{-i\left[k_c(x_1 - U_c t) + k_2 x_2\right]}\, dk_c\, dk_2$$

For acoustic prediction:

$$\Delta P(x_1, x_2, t) = 2\pi \int_{-\infty}^{\infty} \tilde{P}(k_c, 0)\, g(x_1, k_c, 0)\, e^{-i k_c (x_1 - U_c t)}\, dk_c$$

Broadband Surface Pressure

Stochastic model:

$$\Delta P(x_1,t) \approx 2\pi \sum_{n=-N}^{N} A_{n,0}\, e^{i\varphi_n}\, g(x,k_{c,n},0)\, e^{-i k_{c,n}(x_1 - U_c t)}$$

$$A_{n,0} = \left[\Phi_{PP}(k_{c,n},0)\,\Delta k_c\right]^{1/2}$$

$\Phi_{PP}(k_c,k_2) =$ PSD of surface pressure

$\varphi_n =$ random phase angle on $[0,2\pi]$

Surface Pressure PSD

Schlinker and Amiet (1981)

$$\Phi_{PP}(k_c, 0) = \frac{U_c}{\pi} \ell_2(\omega) S_{qq}(\omega, 0)$$

$$\ell_2(\omega) = \text{spanwise correlation length}$$

$$S_{qq}(\omega, \Delta x_2) = \text{surface pressure correlation function}$$

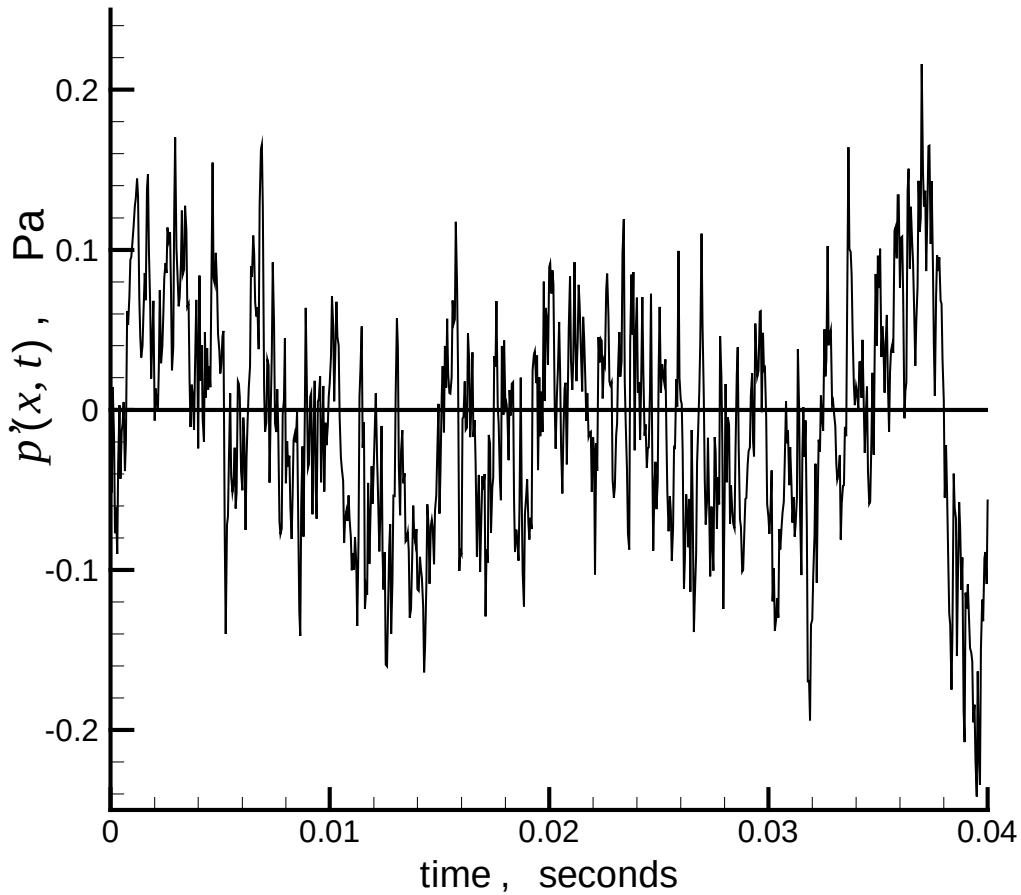
First-Cut Prediction:

Evaluate $\ell_2(\omega)$ and $S_{qq}(\omega, 0)$ by empirically determined flat plate formulations.

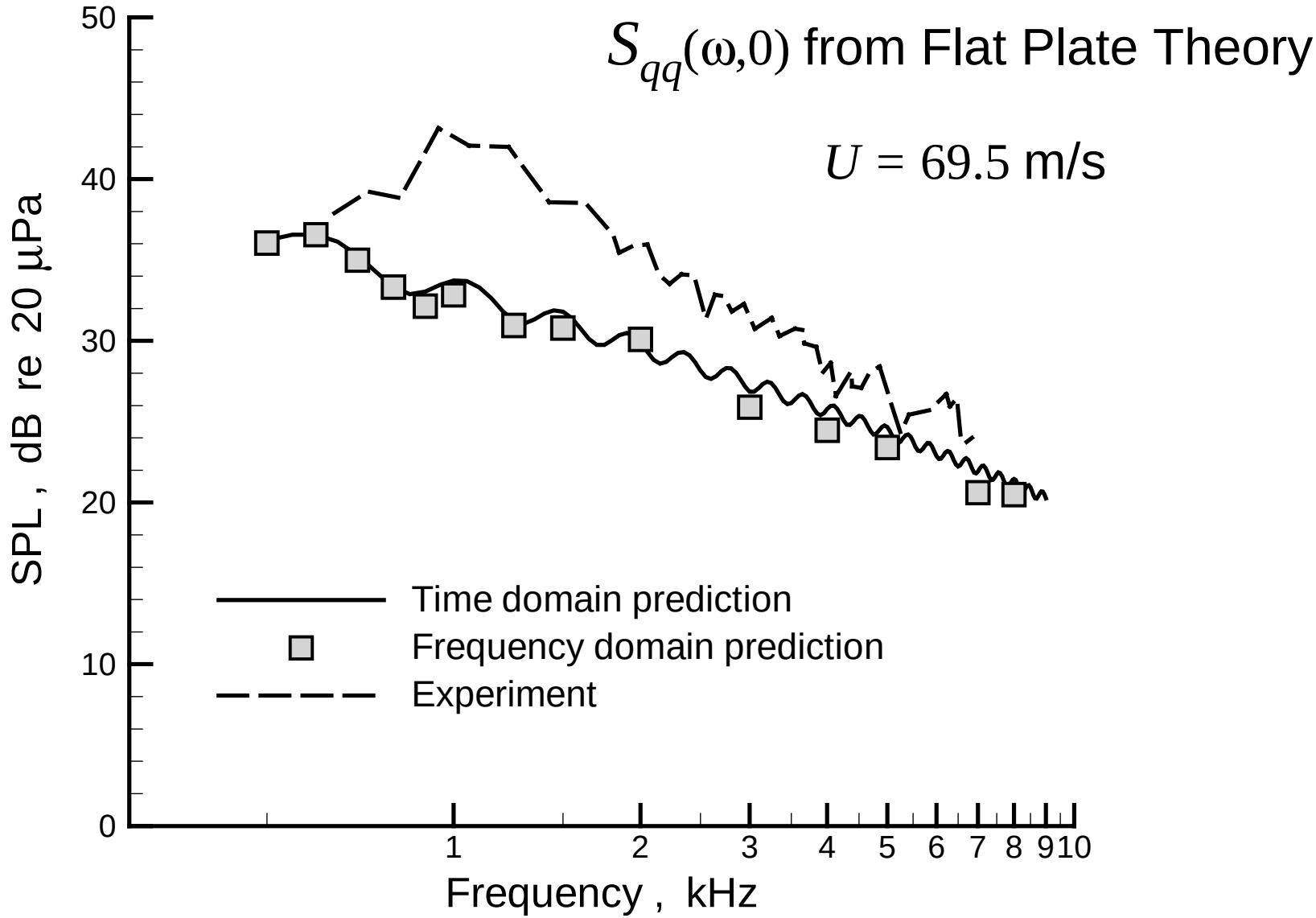
Broadband Prediction in Time

- Surface pressure input to Formulation 1B
- 25 Hz < f < 10 kHz
- Acoustic pressure Fourier analyzed to convert to narrowband SPL

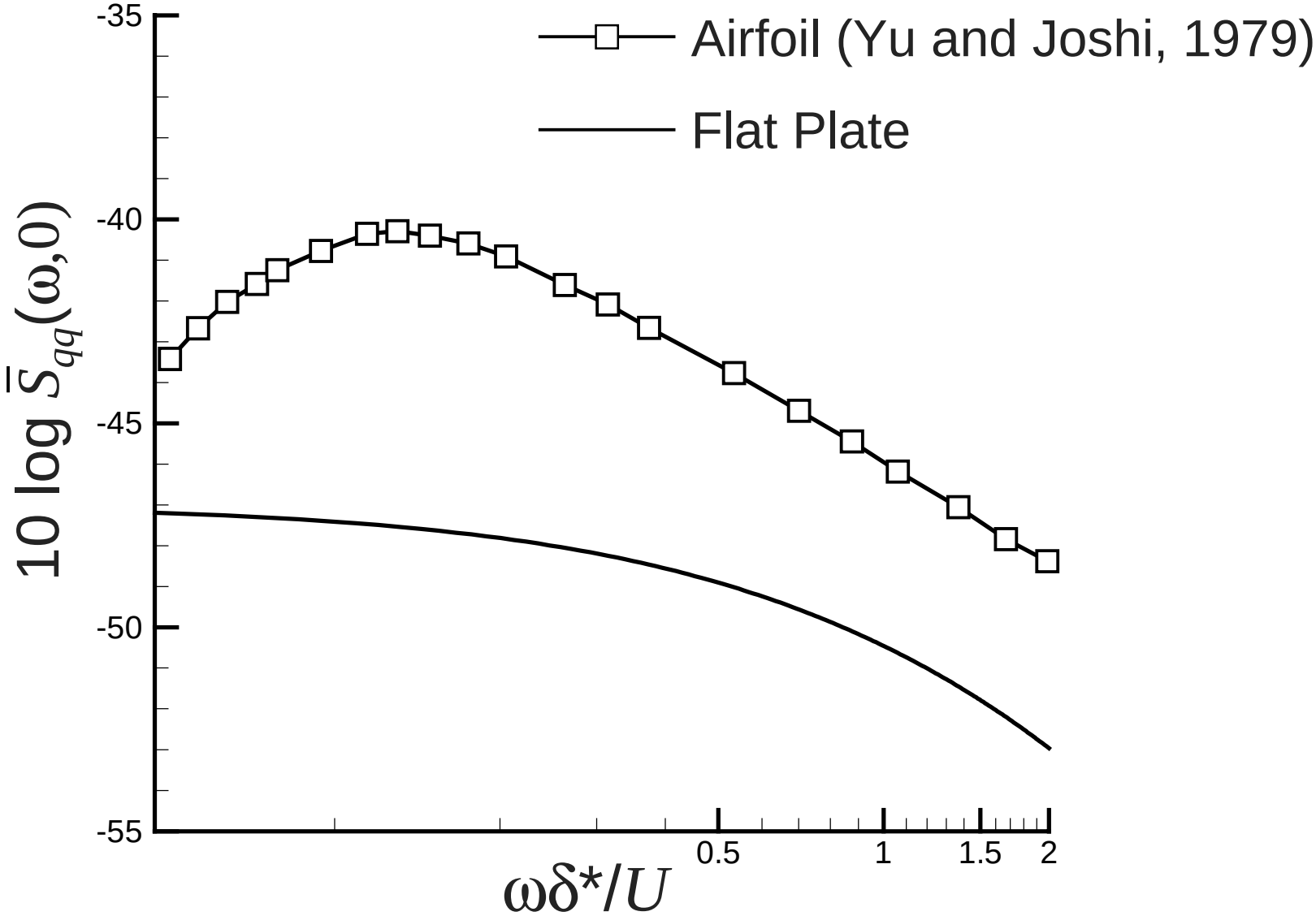
Predicted Signal
U = 69.5 m/s



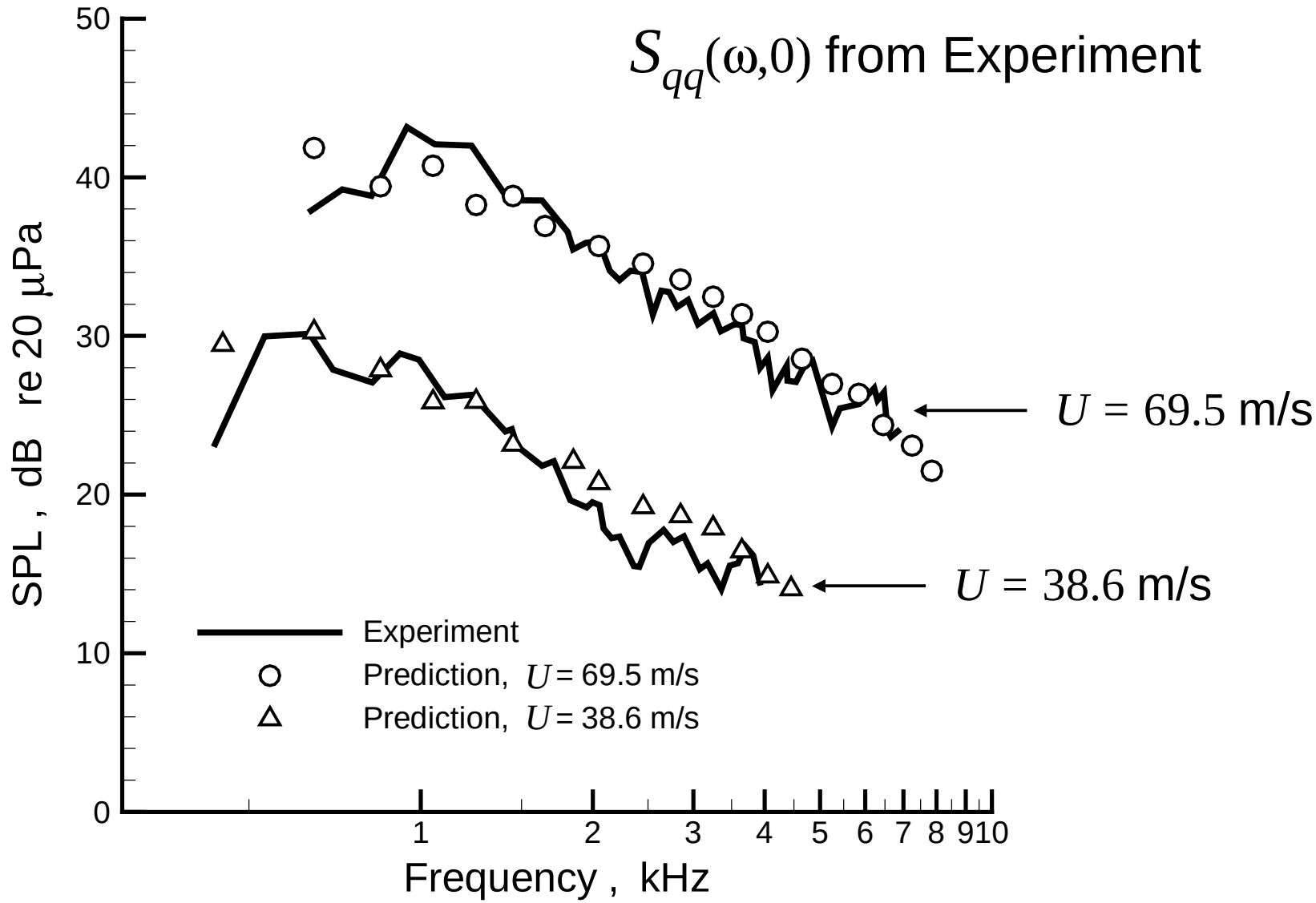
Far Field Noise Spectrum



Surface Pressure Correlations



Far Field Noise Spectrum



Concluding Remarks

- First successful broadband TE Noise predictions in the time domain.

- A new solution to the FW-H equation
  - Acoustics decoupled from aerodynamics
  - Valid for general surface motion
  - Statistical formulation