Leading-Edge Acoustic Receptivity Measurements Using a Pulsed-Sound Technique

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UNSTEADY WIND TUNNEL

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Objectives

- Present study concerns receptivity of a flat-plate leading edge to planar acoustic waves
- Calculate *linear* receptivity coefficients defined relative to Branch I:

$$K_S = \frac{\left|u'_{\mathsf{TS}}\right|_{\mathrm{I}}}{\left|u'_{\mathsf{ac}}\right|_{\mathsf{LE}}}$$

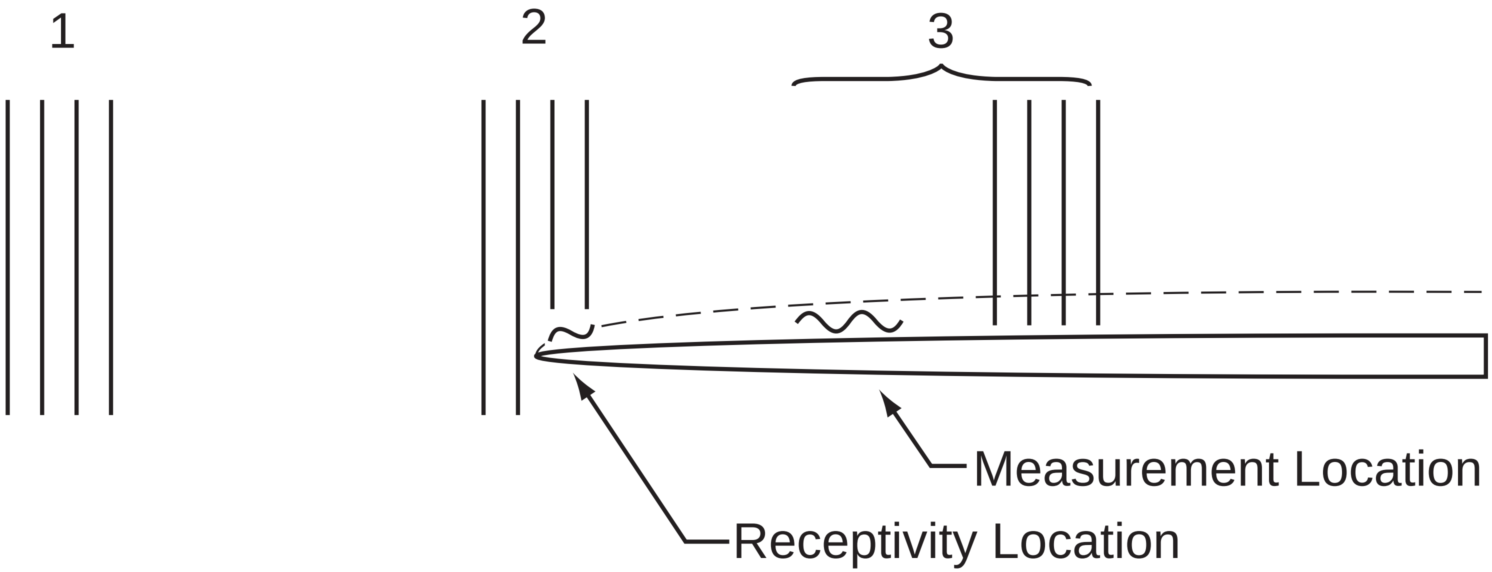
- Provide initial conditions for transition calculations
- Extend measurement range of previous techniques
- Resolve receptivity bandpass issue

Continuous-Sound Technique

- Previous experimental technique used continuous, single-frequency forcing, narrow bandpass filter
- In boundary layer, TS and Stokes waves are superposed
- To separate, traverse hot wire over one TS wavelength, constant phase of acoustic wave, plot amplitude as spiral in complex plane
- Radius of spiral is TS amplitude, displacement of center is Stokes wave and sting vibration amplitude
- Produced “focusing” result, disagreed with expected broadband receptivity

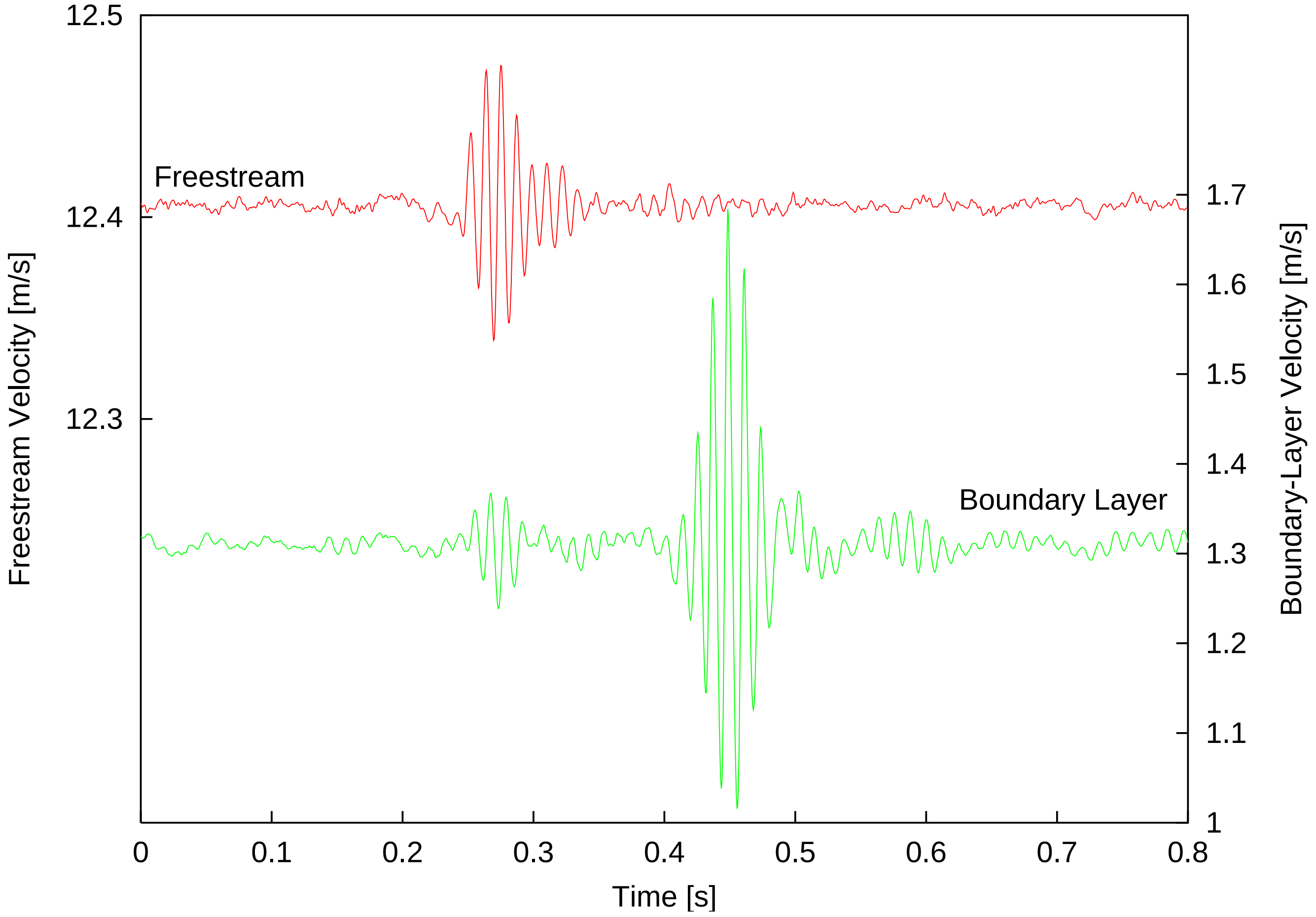
Pulsed-Sound Technique

Physical Process



Pulsed-Sound Technique

Signal Traces



Experimental Setup/Basic State

- Flat plate in Blasius flow
- 20:1 super ellipse leading edge only receptivity location—no gaps, no curvature discontinuities
- Use trailing-edge flap to set leading edge $\Delta p = 0$, symmetric stagnation streamline
- Zero pressure gradient verified by shape factor, $H = 2.59 \pm 0.02$
- Document virtual leading edge
- Measure leading-edge vibration with laser vibrometer
- With a well-controlled basic state, measure TS waves near Branch II and calculate K_S (defined at Branch I)

Signal Processing I

Frequency Behavior

- Examine input acoustic pulse and TS response in frequency domain using a Fourier transform of windowed pulses
- Pulses are short in the time domain, extended in the frequency domain—each pulse contains all or most frequencies of interest
- To generate K_S, use the ratio of the TS-pulse Fourier coefficient and the acoustic-pulse Fourier coefficient at each frequency
- If receptivity and growth are linear, ratio is independent of amplitude

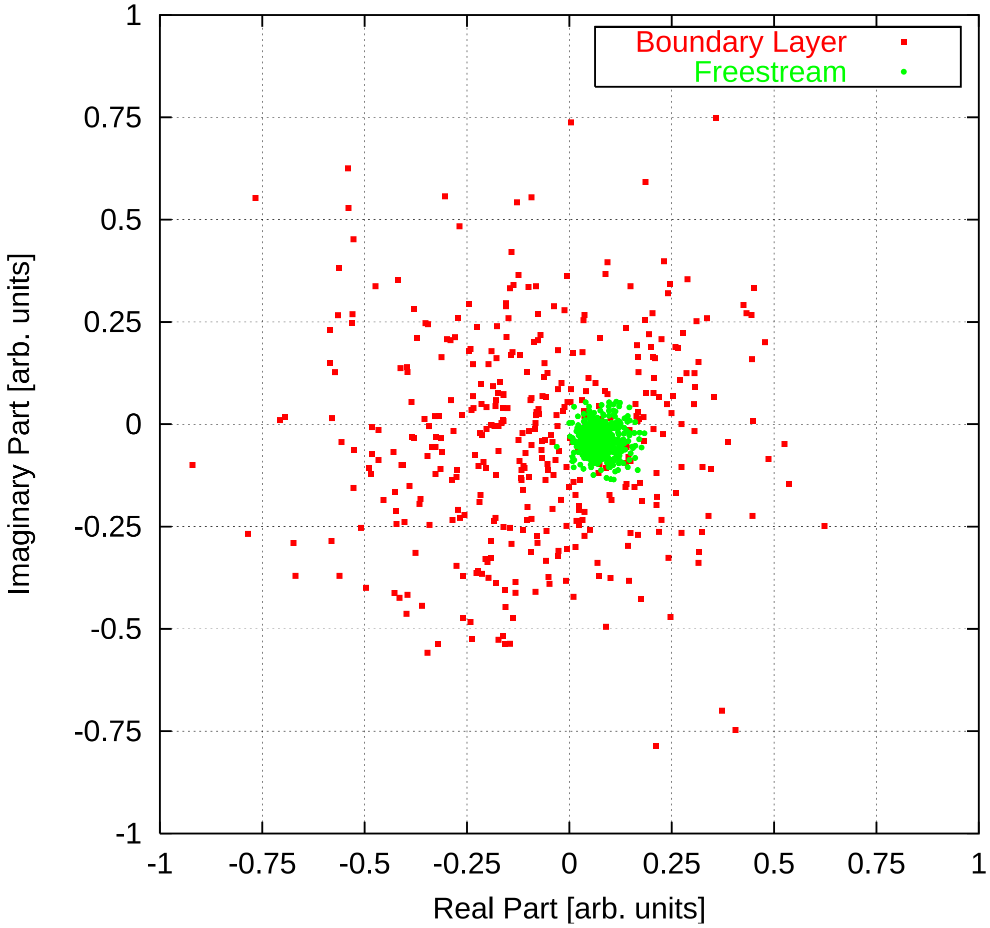
Signal Processing II

Averaging

- Reduce variance by ensemble averaging over many pulses
- First used magnitude averaging—successful for high-amplitude signals (Saric and White 1998)
  - Verified limits of linearity for 2D roughness receptivity
  - Produced preliminary K_S for 20:1 leading edge at 8 m/s
- Now use complex averaging, real and imaginary parts computed separately
- Since the signal due to input sound always has the same phase, complex averaging removes random, uncorrelated signal
- Two orders of magnitude improvement in signal-to-noise performance

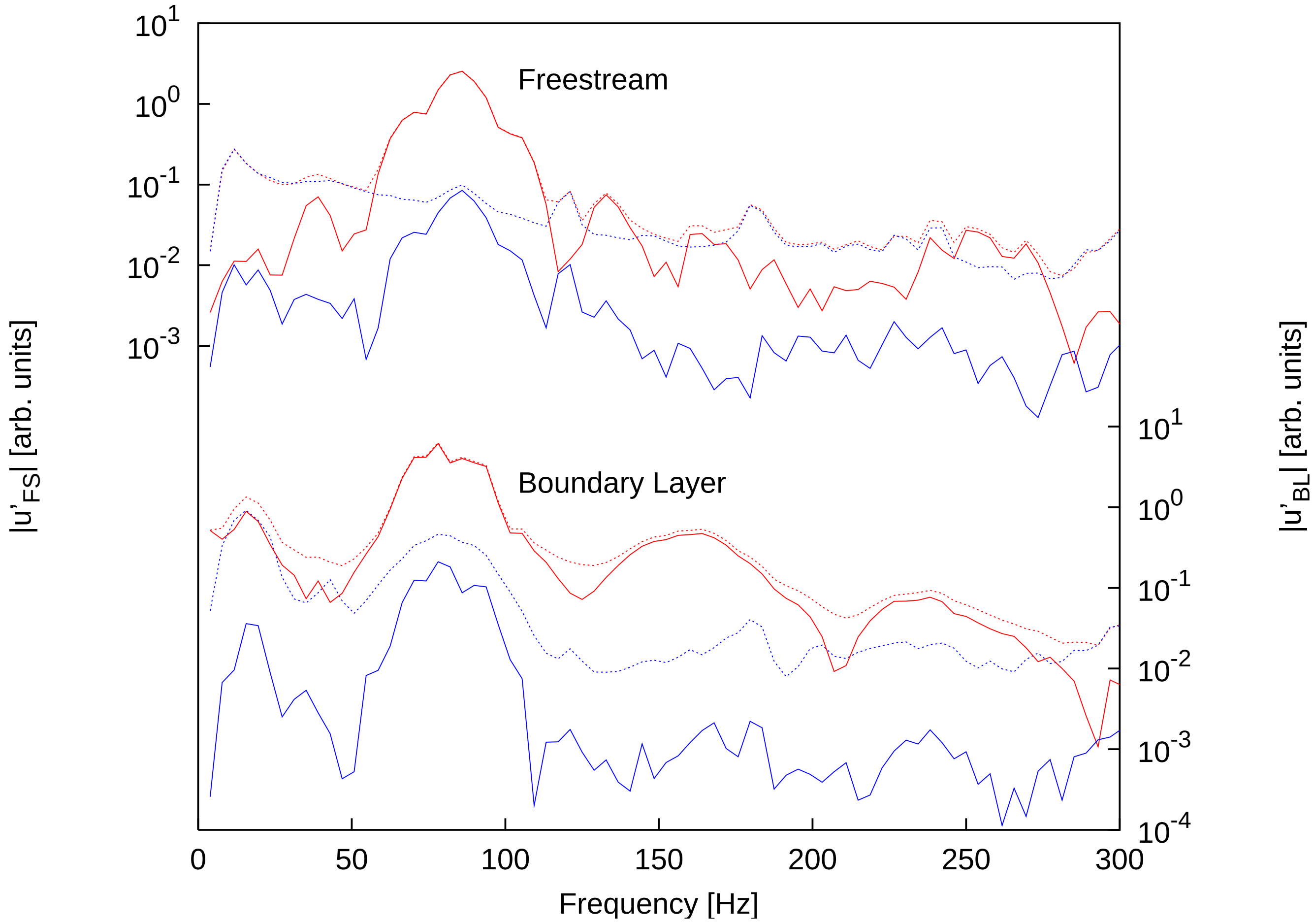
Complex Fourier Coefficients

$U_\infty = 12.4\,\mathrm{m/s}$, $U/U_\infty = 0.12$,
$f = 85.9\,\mathrm{Hz}$, $F = 58$



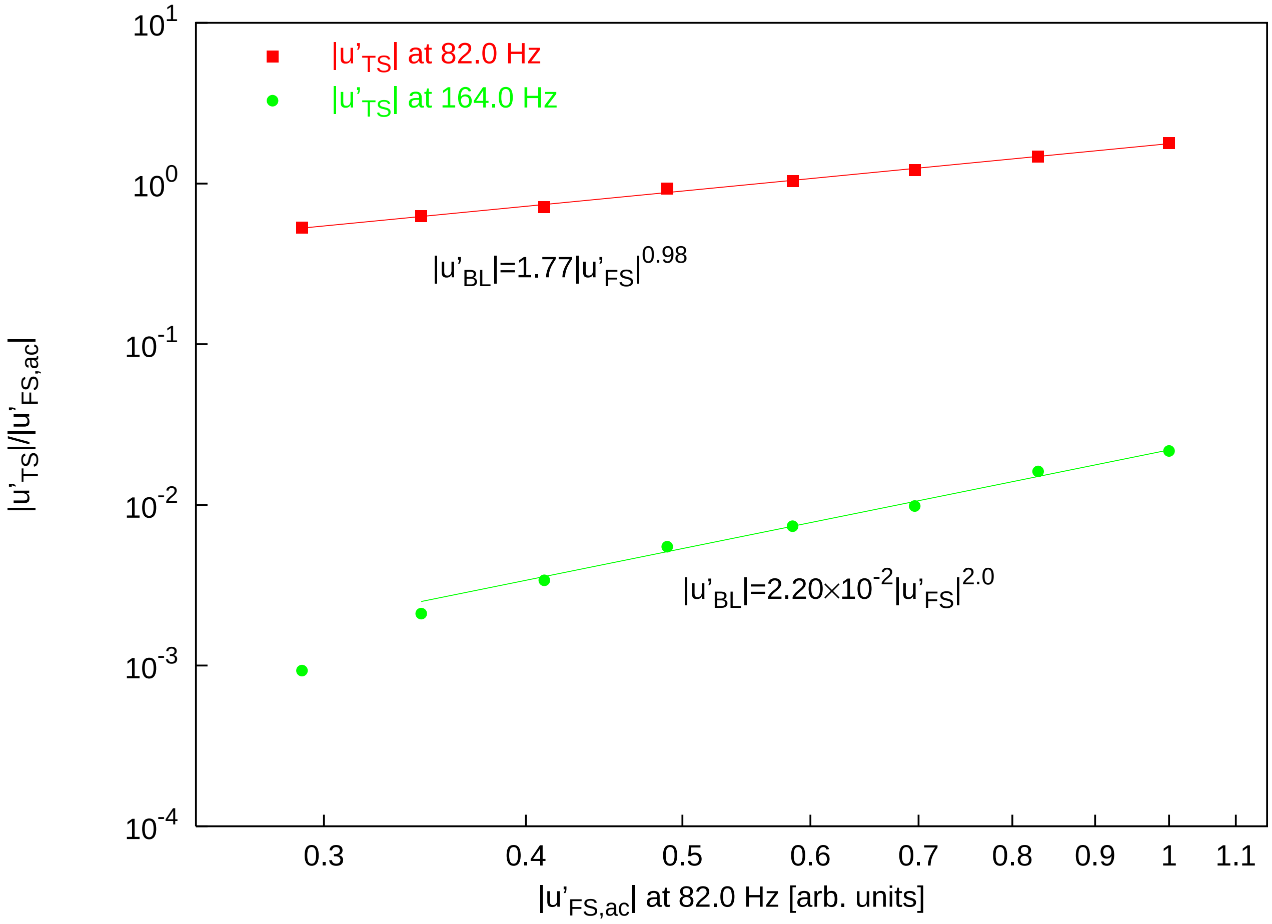
Pulse Velocity Spectra

$U_\infty = 12.4\,\mathrm{m/s}$, $U/U_\infty = 0.12$,
Measure at $R = 990$, 400 Averages



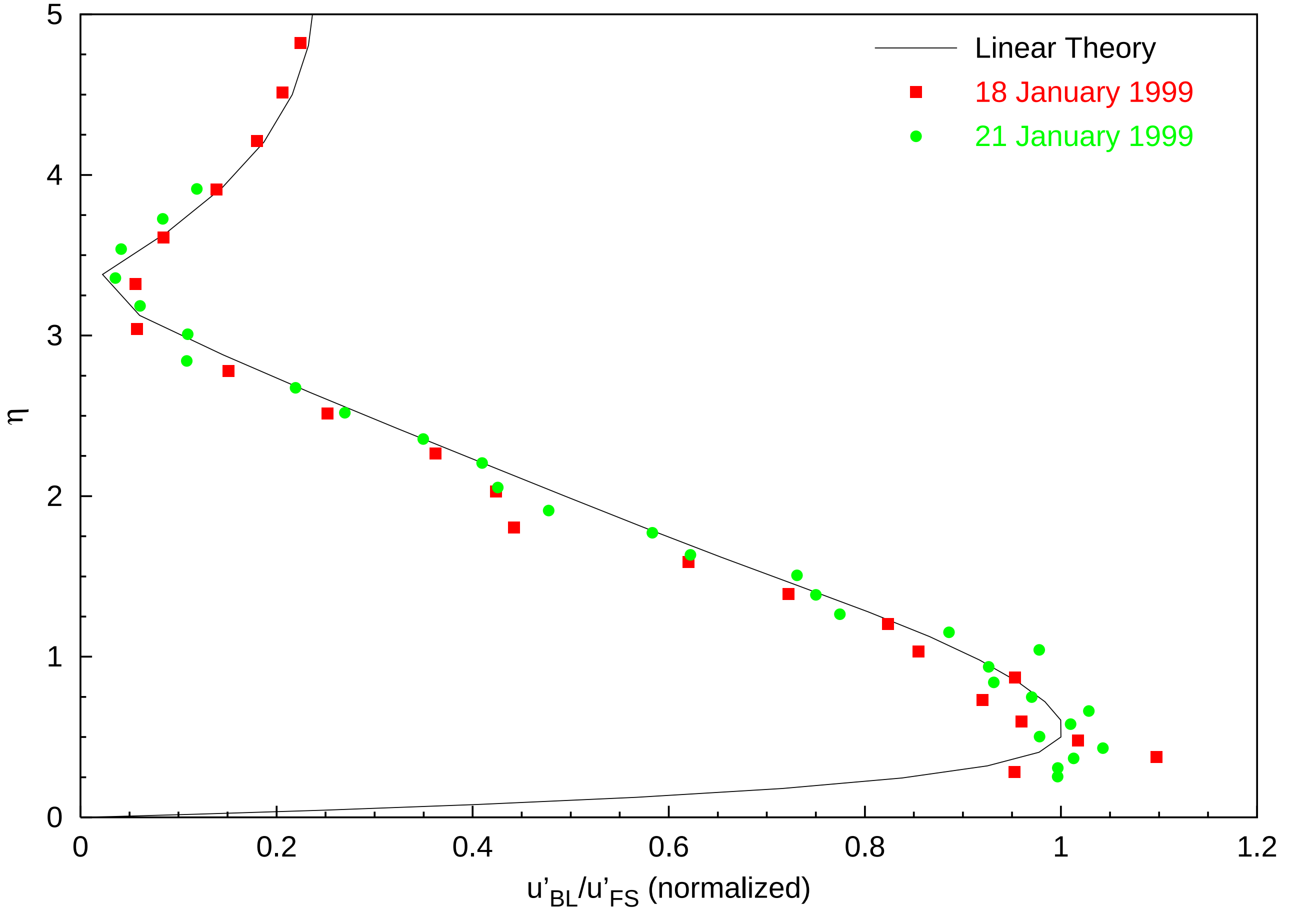
Response Linearity

$U_\infty = 12.0\,\mathrm{m/s}$, $U/U_\infty = 0.20$,
Measure at $R = 1050$, 400 Averages



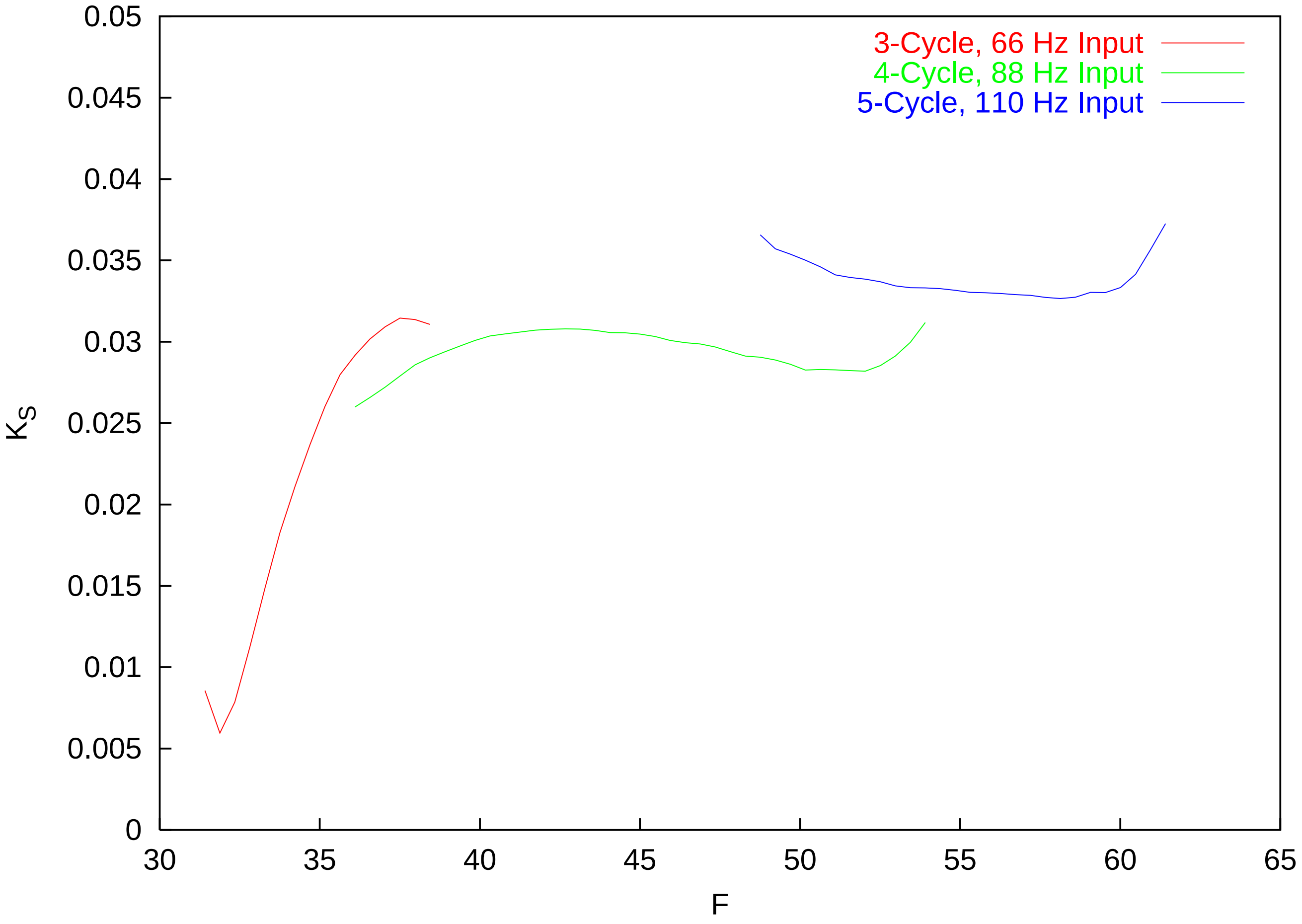
TS Mode Shape

$U_\infty = 12$ m/s, $F = 55$,
Measure at $R = 960$, 200 Averages



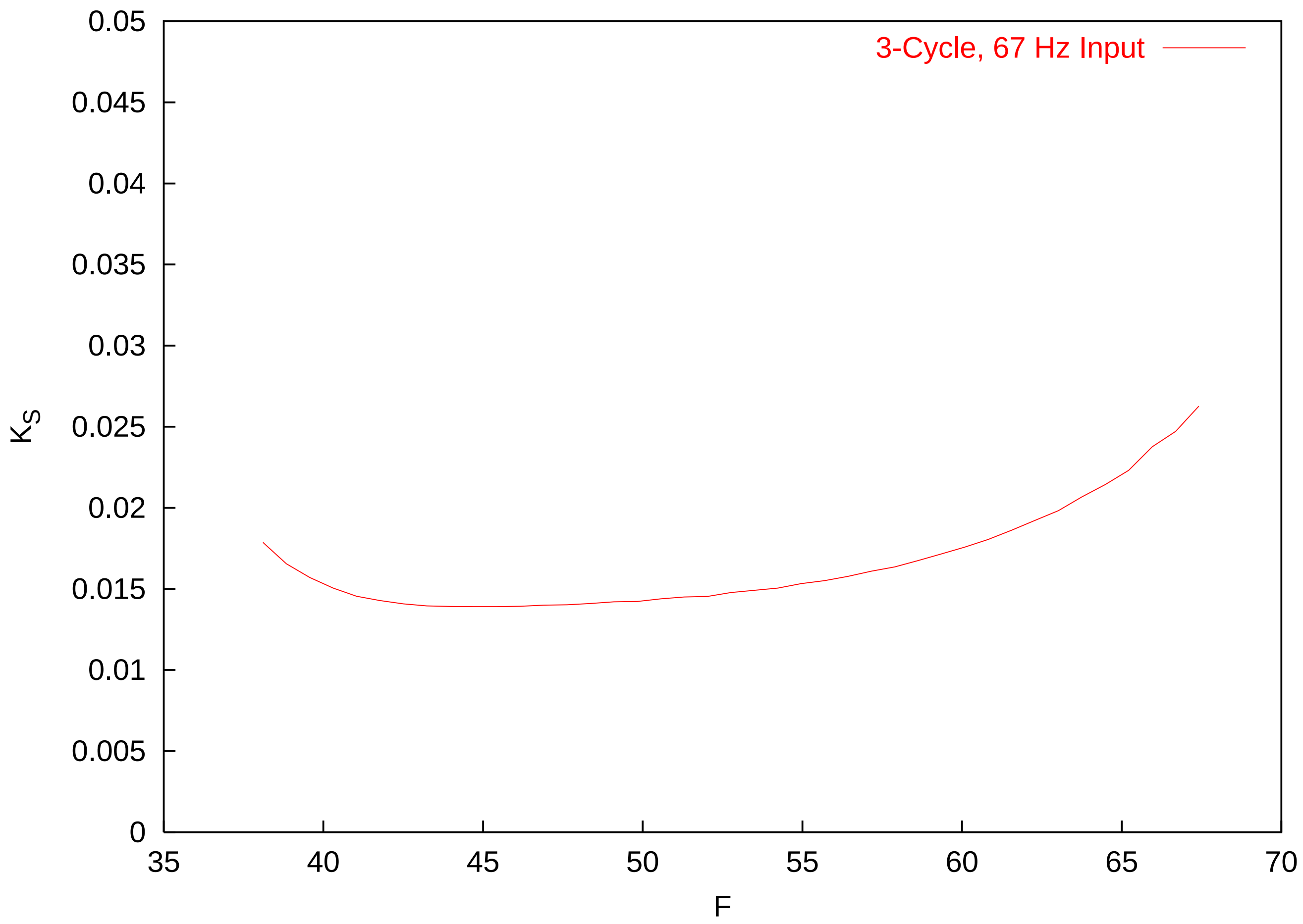
Receptivity Coefficients

$U_\infty = 15$ m/s



Receptivity Coefficients

$U_\infty = 12$ m/s



Summary of Results

15 m/s: $K_S =$0.03–0.035 over $F =$35–60

12 m/s: $K_S =$0.015–0.02 over $F =$40–65

8 m/s: $K_S = 0.05$ at $F = 90$, limited by frequency resolution, magnitude averaging (Saric and White 1998)

Validates DNS result, $K_S = 0.048$ (Fuciarelli, Reed, and Lyttle 1998)

Conclusions

Pulsed-Sound Method

- Most significant drawback: limited frequency resolution
- Does not address sting vibration
- Faster than complex spiral technique
- Avoids echo problems
- Good spectrum tailoring capability
- Overall, has proved useful for TS/Stokes separation
- Good candidate for studying *transient* events in boundary layer

Conclusions

Receptivity

- Focusing effect seen in continuous-forcing experiments artifact of duct acoustics
- Correct measurements are made with conditional sampling of sound pulses
- Actual receptivity is broadband
- Need to improve patching of various frequency inputs
- Extend to other sound-incidence configurations