Simulation of Rotorcraft Fly-In Noise

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Outline

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- Objective and Approach
- Source Signature Generation
- Source Noise Synthesis
- Simulated Propagation
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Motivation

- Rotorcraft noise can be heard over great distances
  - Can lead to annoyance and detection at greater distances than higher altitude fixed wing aircraft
- Sound jury tests often used to assess human response, but
  - Sound at observer unsteady due to source and propagation
  - Exact reproduction is not possible

Sound Jury [Source: NASA/TM-2010-216206]

Objective and Approach

Objective

- Develop means of creating salient features of rotorcraft fly-in noise for human subject tests conducted in a controlled laboratory setting

Approach

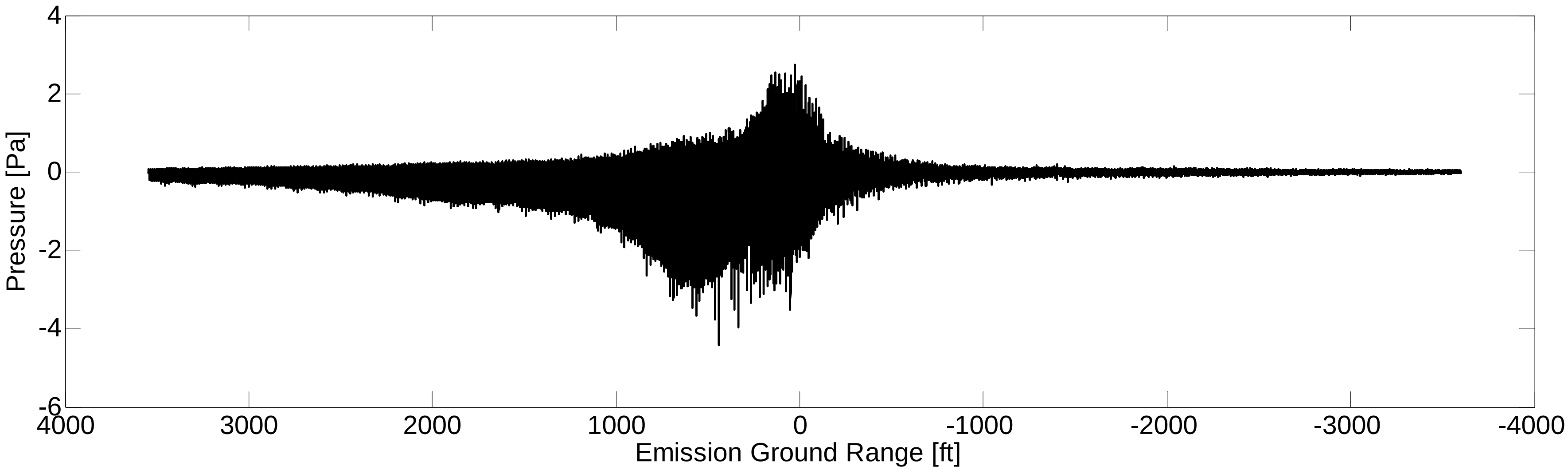
- Synthesize steady source noise pressure time histories using signal blade passage signatures from main and tail rotors
  - Focus is on long-range detection, so we are concerned with low emission angles, not overhead flyovers
- Propagate source noise to observer location according to some prescribed scenario. Effects include –
  - Atmospheric absorption
  - Spreading loss
  - Doppler simulation
  - Ground plane simulation

Test Vehicle

Airbus/Eurocopter AS350B

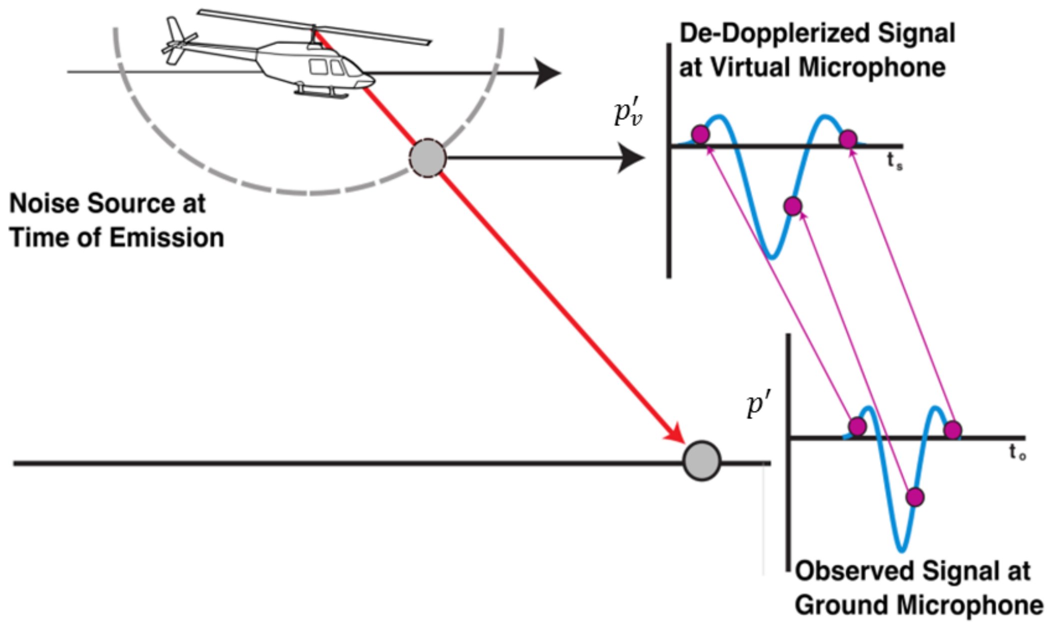
- Main rotor
  - 3 blades
  - 35-ft. 1-in diameter
  - 19.5 Hz BPF
- Tail rotor blade
  - 2 blades
  - 104 Hz BPF

[Source: NASA]



Source Signature Generation from Flight Test Data

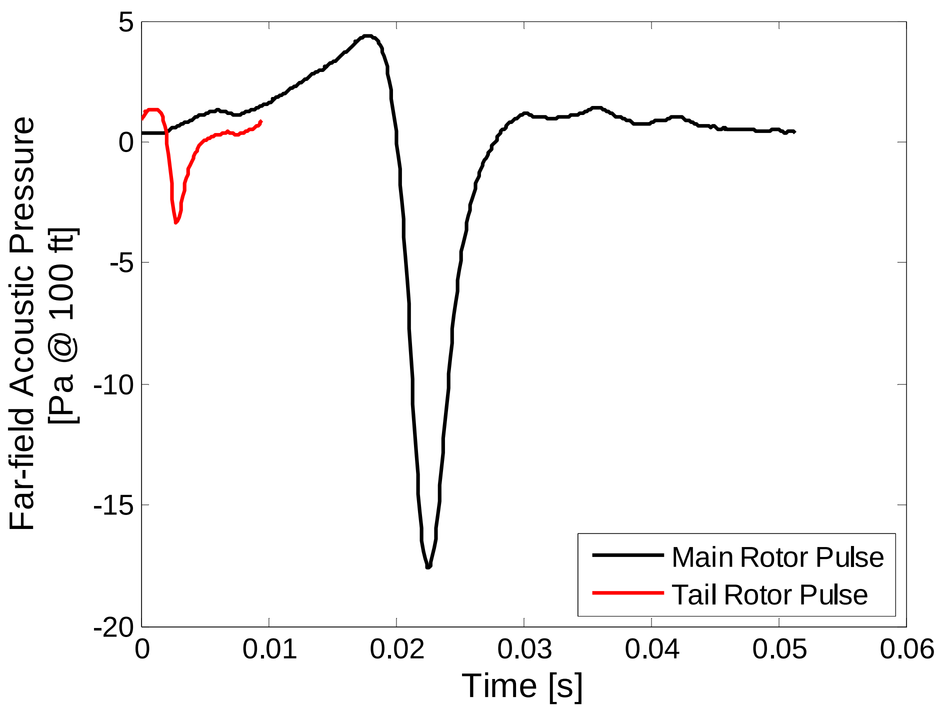
- Back-propagate to source
  - Reverse spreading loss
  - De-Dopplerize via fractional delay line
  - Ignore atmospheric absorption since close range and low frequency



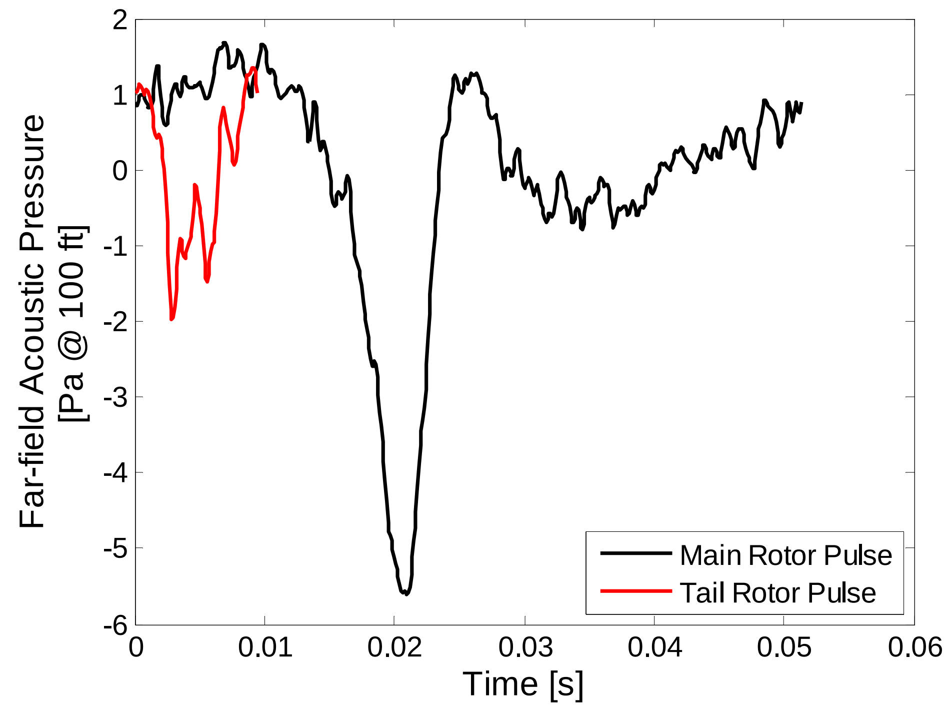
- Segment at emission angles such that signal is stationary
  - Slice and block align at main rotor BPF. Perform synchronous time average.
  - Subtract time averaged main rotor from original record.
  - Slice and block align at tail rotor BPF. Perform synchronous time average.

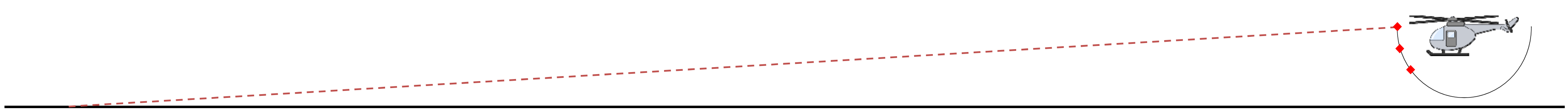
Source Signature Generation

16° elevation, 180° azimuth angle
(nose)



16° elevation, 130° azimuth angle
(retreating side)



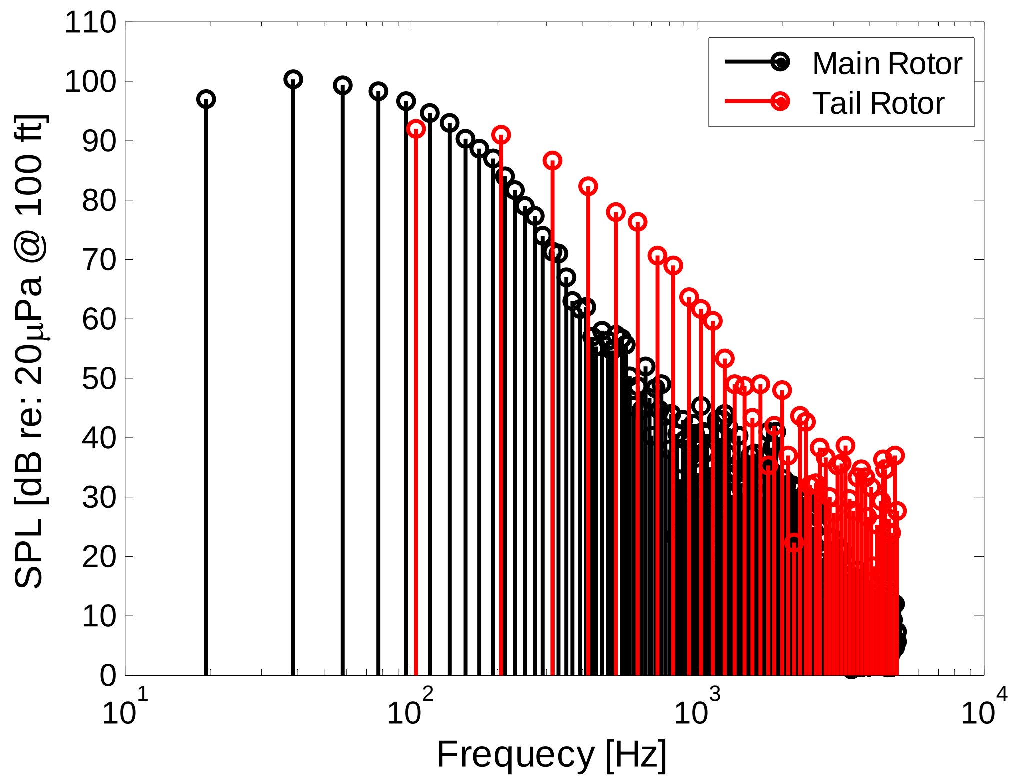


Source Noise Synthesis

Data is provided at 10 kHz sampling rate. This must be changed to 44.1 kHz for reproduction.

- Take FFT of each main and tail rotor record
- Each point in the FFT represents the magnitude and phase of the BPF and its harmonics

16° elevation, 180° azimuth angle (nose)



Source Noise Synthesis

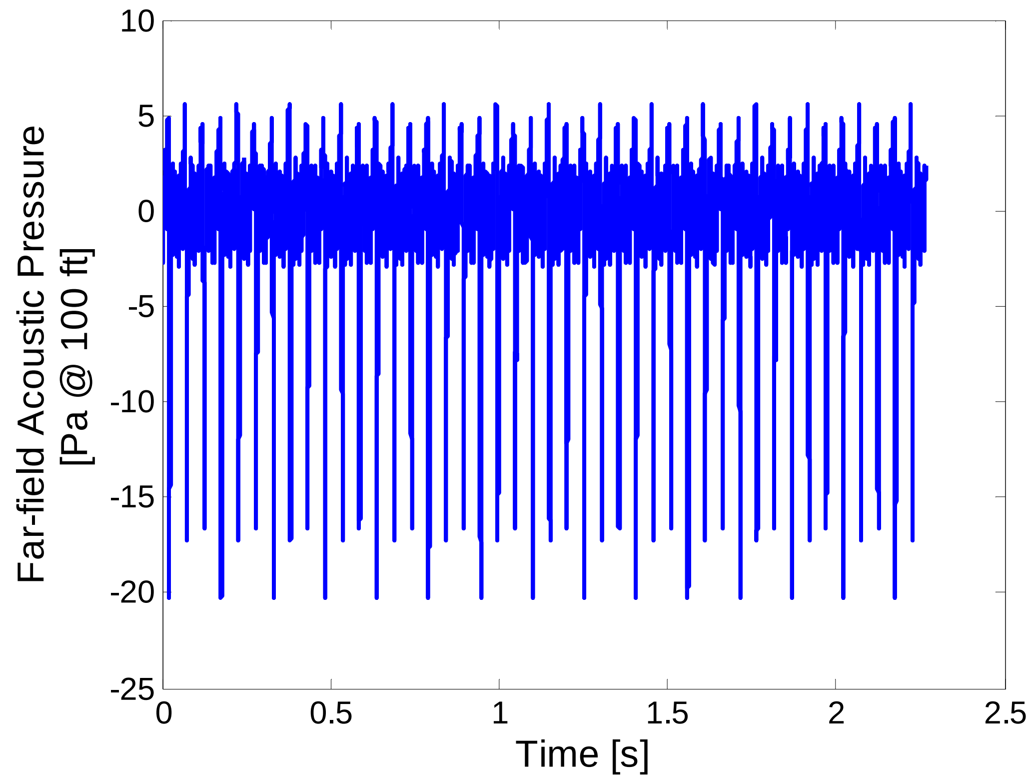
Data is provided at 10 kHz sampling rate. This must be changed to 44.1 kHz for reproduction.

- Take FFT of each main and tail rotor record
- Each point in the FFT represents the magnitude and phase of the BPF and its harmonics
- Synthesize long pressure time histories of main and tail rotors at audio sampling rate of 44.1 kHz.

$$p(t)=\sum_{i=1}^{N} A_i \cos\left(2\pi f_i' t+\varphi_i\right)$$

f_i' are harmonics of the BPF which have been adjusted for crab angle (see next slide)

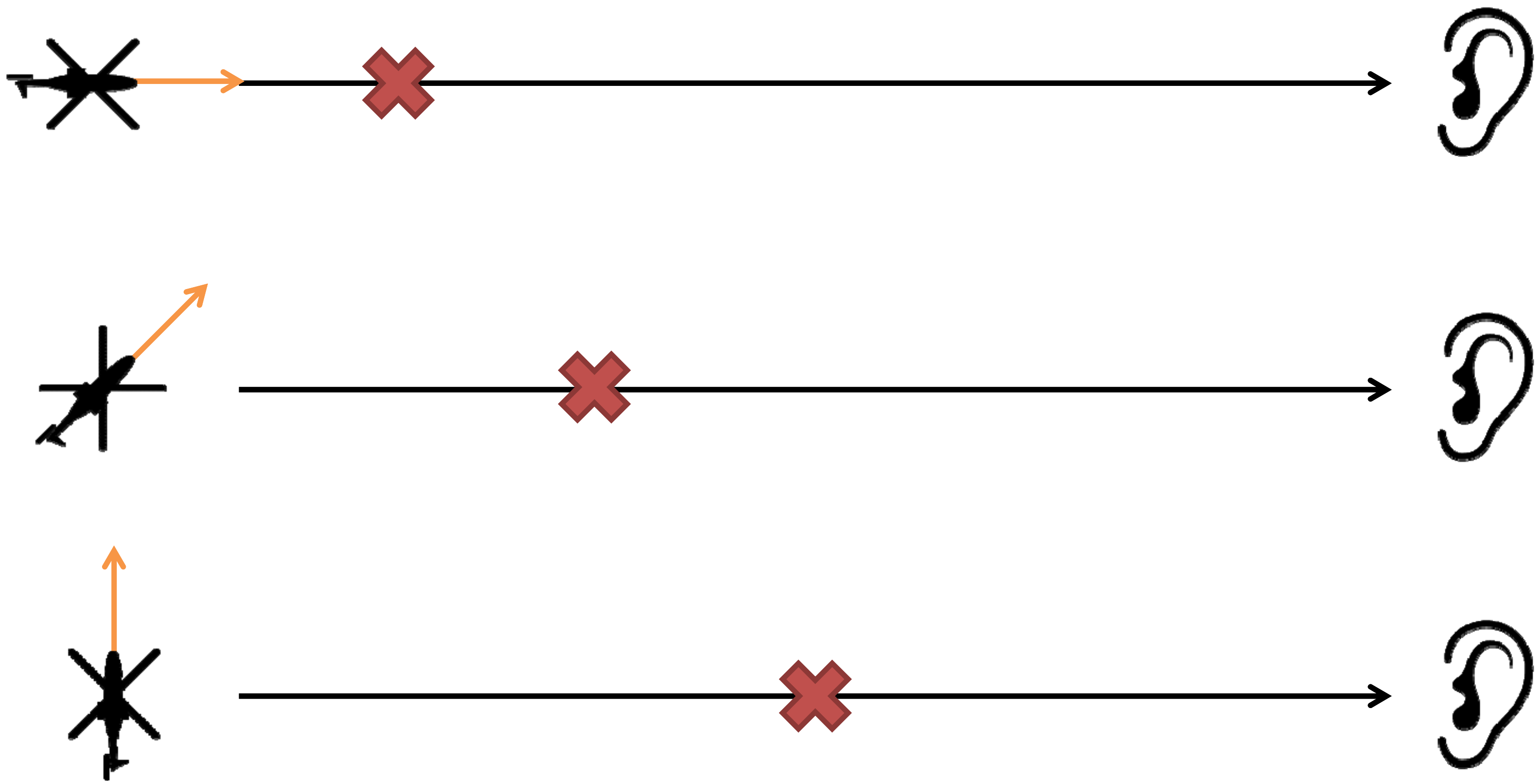
16° elevation, 180° azimuth angle (nose)



Very long source noise records are synthesized and propagated to generate pseudo-recordings which serve as test stimuli.

Source Noise Synthesis

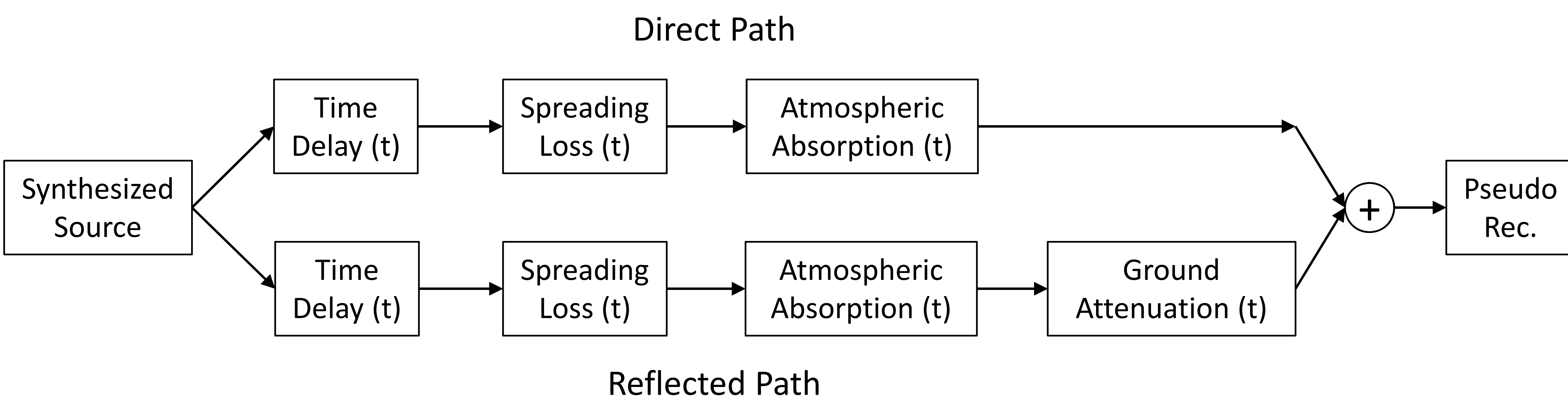
Fly at Crab Angle



Simulated Propagation

- Propagation processing modifies the synthesized source pressure time histories and generates a pseudo-recording at the desired observer position
  - The pseudo-recording is what a microphone would have recorded at the observer position, hence its name.

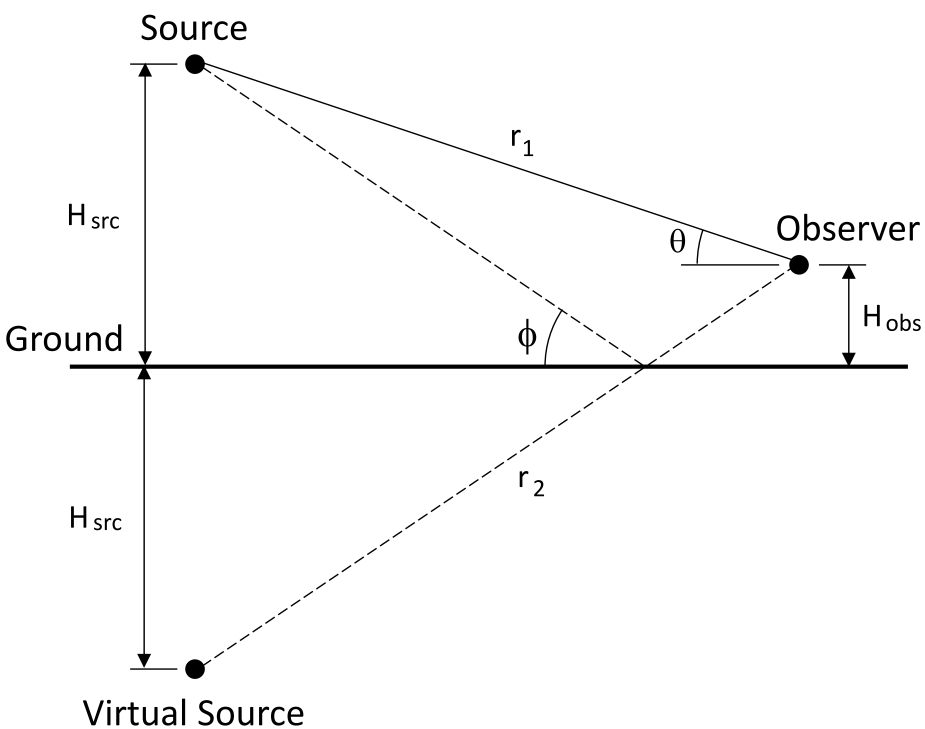
- Propagation processing applies 4 physical models for
  a) Absolute time delay
  b) Spherical spreading loss
  c) Atmospheric absorption
  d) Ground attenuation



Simulated Propagation

Ground Attenuation

Apply range and angle-dependent filter according to a specified ground plane impedance:



$$\frac{p}{p_o} = \frac{1}{r_1} e^{-ikr_1} + \frac{R_p}{r_2} e^{-ikr_2} + (1 - R_p) \frac{F}{r_2} e^{-ikr_2}$$

Direct Path; Reflected Path (plane wave); Reflected Path (spherical correction)

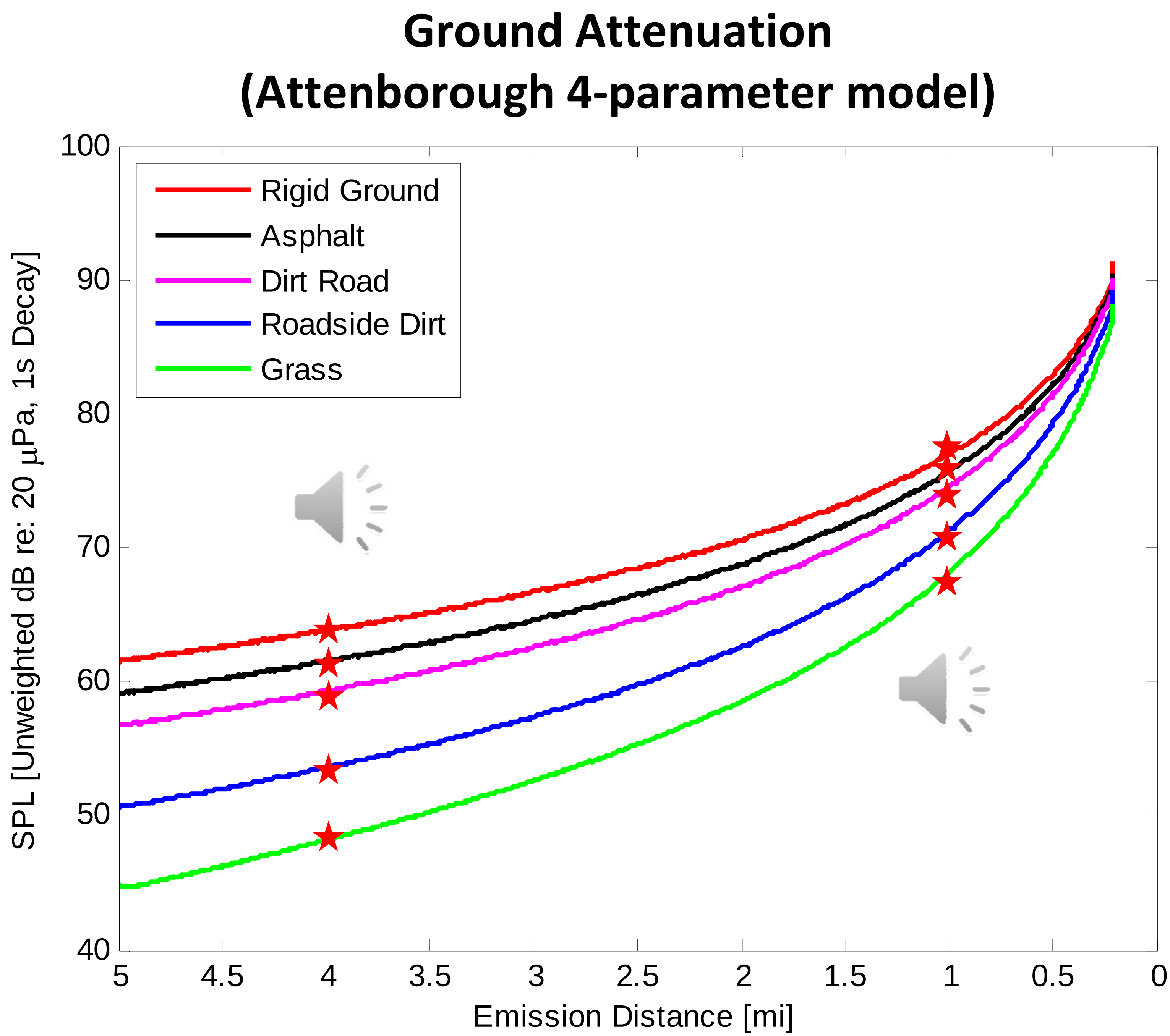
$$R_p = \frac{\sin\phi - Z_1/Z_2}{\sin\phi + Z_1/Z_2}$$ Reflection coefficient

$$F(w) = 1 + iw\sqrt{\pi} e^{-w^2} \operatorname{erfc}(-iw)$$ Amplitude factor

$$w^2 = ik\frac{r}{2}\left(\sin\phi + \frac{Z_1}{Z_2}\right)^2$$ Numerical distance

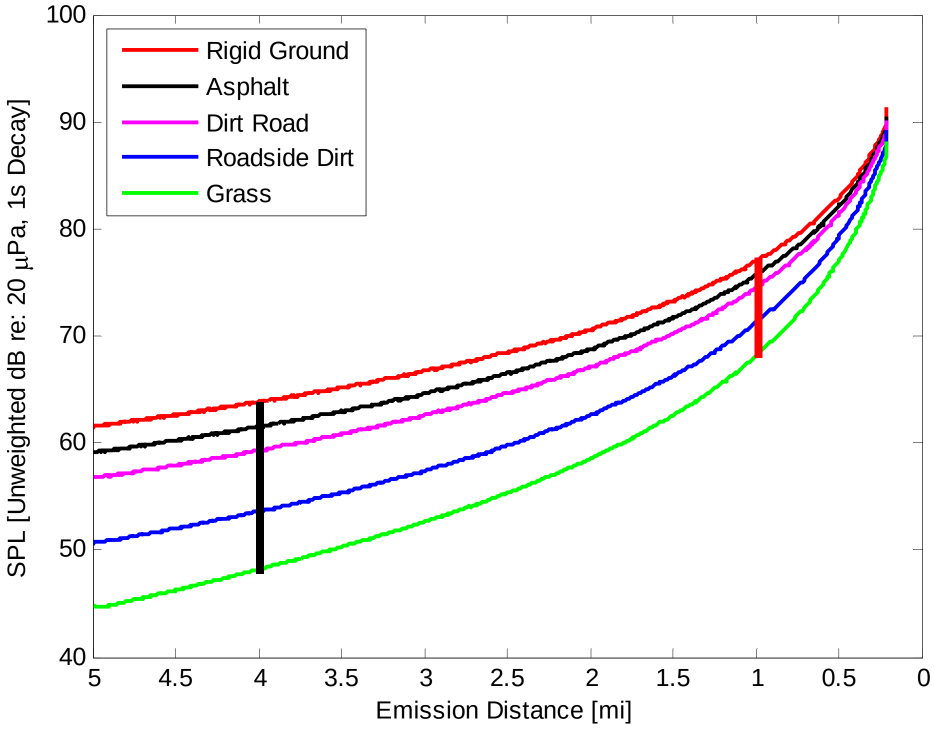
Z_1/Z_2 Specified by complex frequency dependent impedance model

Simulated Propagation

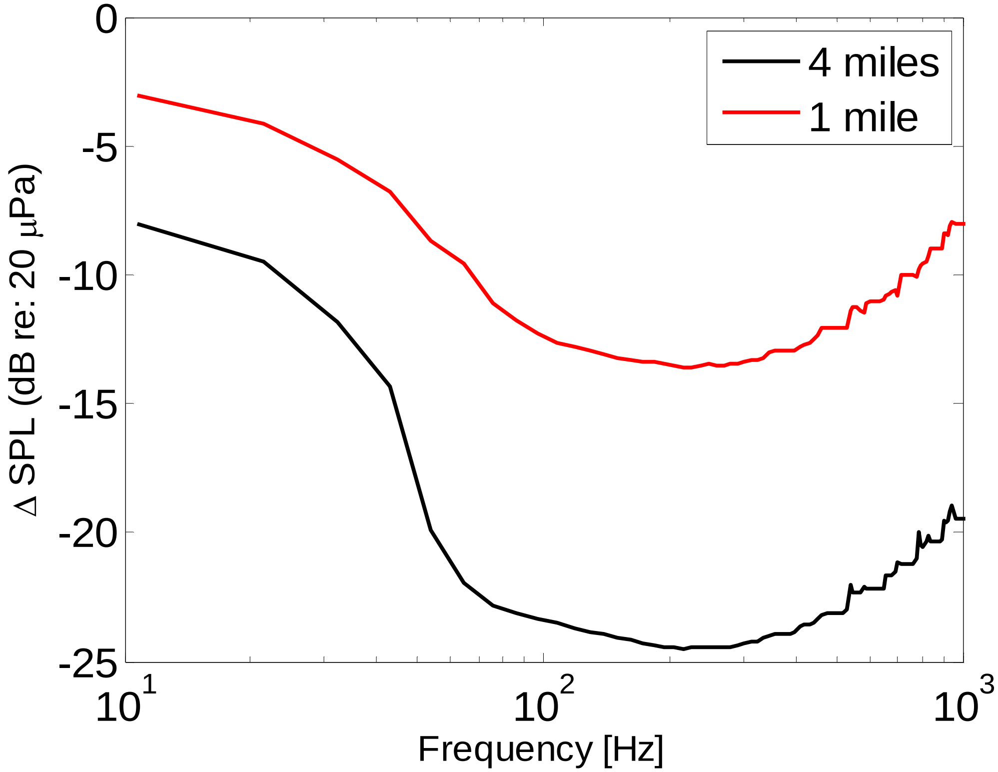


Simulated Propagation

Ground attenuation
as function of distance



Change in ground attenuation
between rigid ground and grass
as a function of frequency



- Change in ground attenuation is a function of frequency and distance
- Can't reproduce with a simple gain change

Simulated Propagation

Example Pseudo-Recording

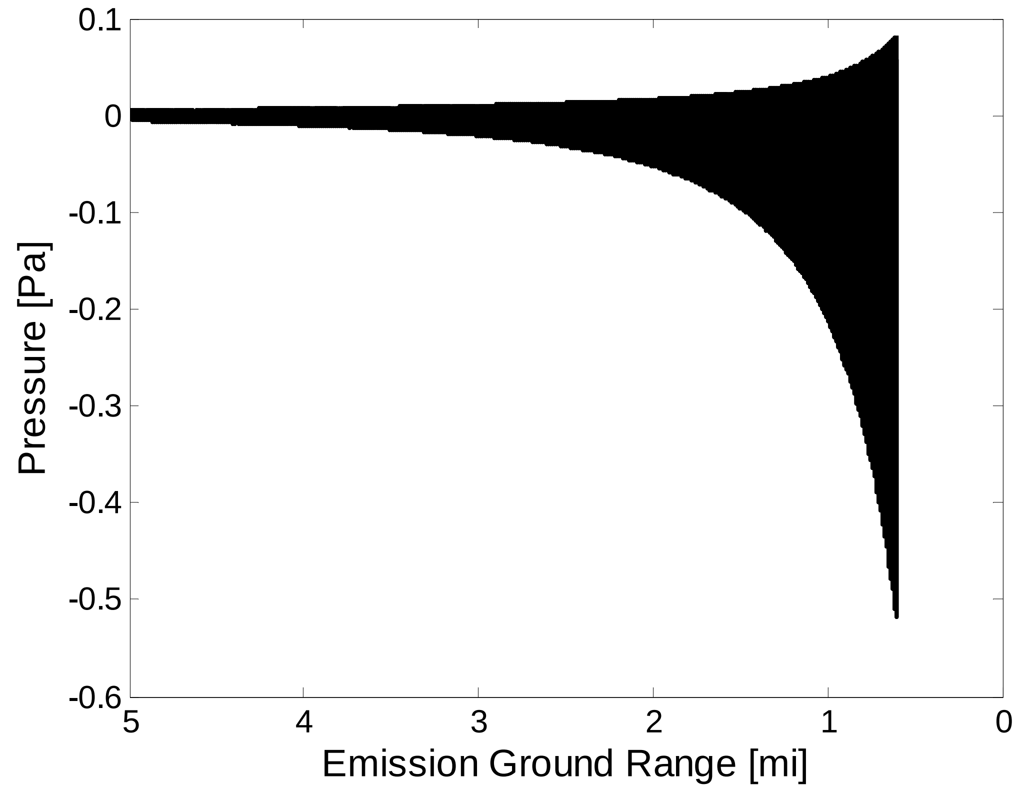
Scenario:

- 100 ft AGL straight & level, 105 kt
- Ground: Grass
- Observer: 4 ft
- Atmosphere: Uniform

Note:

- Monotonic increase in rate of change of sound pressure with increasing time.

16° elevation, 180° azimuth angle (nose)



Closing Remarks

- Method developed for simulation of low altitude rotorcraft fly-in noise
  - Source noise synthesized from single blade passage of main and tail rotors at low emission angles. Data may be obtained from flight tests or predictions (not shown).
  - Inclusion of spherical correction in ground attenuation model has large effect on amplitude and spectral content of received signal.

- This capability has been used to measure human response in the controlled laboratory environment of the Langley Exterior Effects Room.