ソニックブーム長距離非線形伝播音響解析ツール開発
および
ソニックブーム波形に対する大気乱流効果に関する研究

航空プログラムグループ公募型研究報告会
2010年11月26日＠JAXA調布航空宇宙センター

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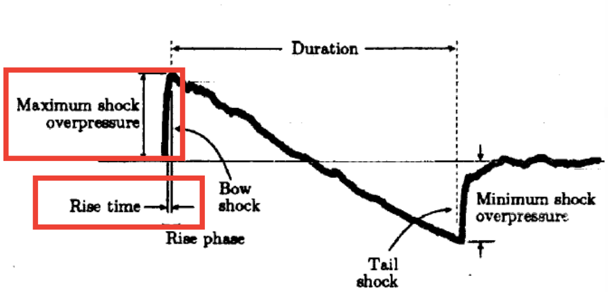
発表内容

- 研究背景
- 最近の研究内容報告
  - ①　大気吸収効果を考慮した音響解析ツール開発
  - ②　大気乱流モデリングの高精度化に関する検討

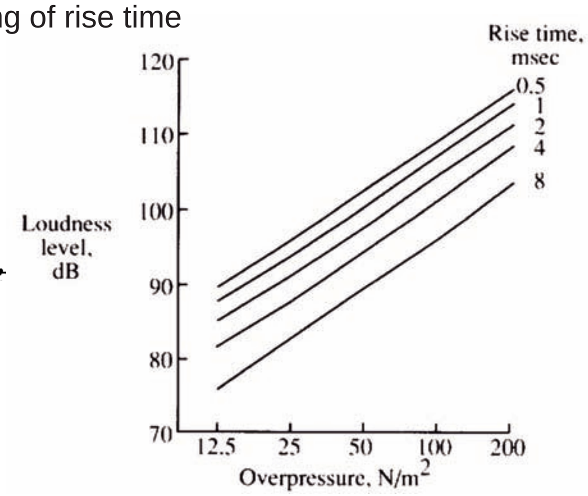
Background

- Sonic boom is characterized by overpressure and rise time

  - Overpressure and rise time strongly affect “loudness level”
    - ✓ Loudness decreases with decreasing of overpressure;
    - ✓ Loudness decreases with increasing of rise time



Carlson, H. W., NASA SP-147, p.10.



Shepherd, K. P., NASA TP-3134, Fig.6

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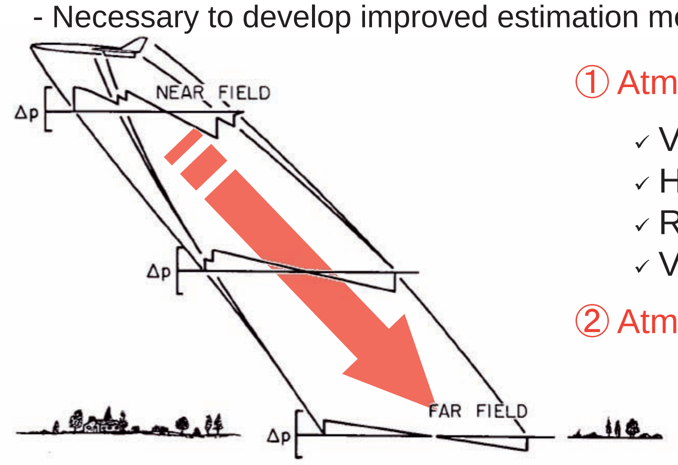
Rise Time Estimation

- Atmospheric absorption and turbulence are important factor on rise time
- Waveform Parameter method cannot estimate rise time

  - Necessary to develop improved estimation method



① Atmospheric absorption effect

- ✓ Viscosity
- ✓ Heat conduction
- ✓ Rotational relaxation
- ✓ Vibrational relaxation of O2 & N2

② Atmospheric turbulence

Carlson, H. W., NASA SP-147, p.10.

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MISORA

Research -1

- Development of the estimation method considering the atmospheric absorption effects
- Investigation of the absorption effects on sonic boom waveform

✓ The method is developed based on the waveform parameter method

✓ Numerical analysis is performed with standard atmospheric condition; relative humidity 0-100 [%]

- Comparison of power spectra
- Comparison of sonic boom waveforms
- Variation in overpressure and rise time

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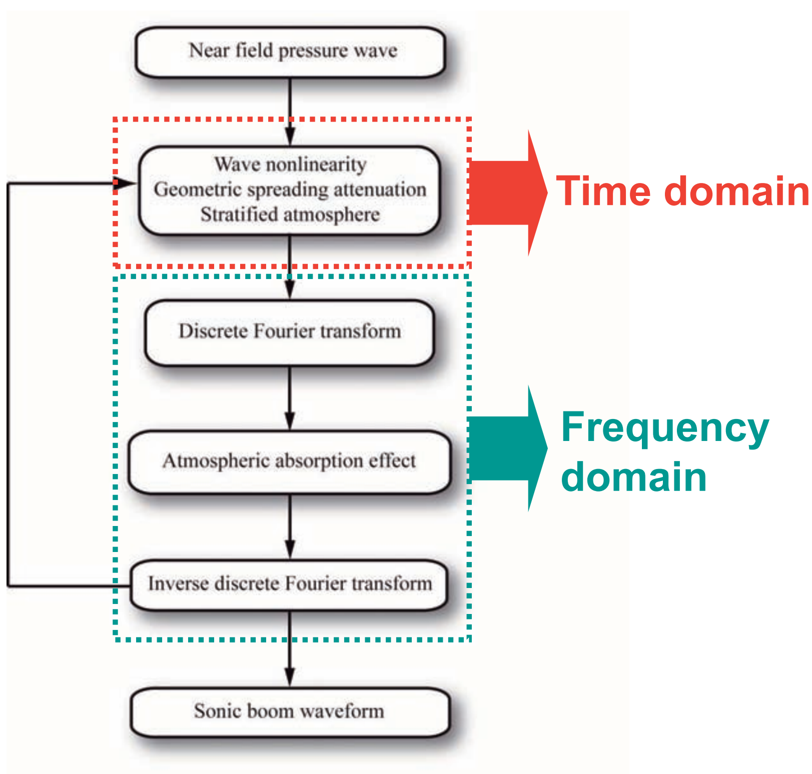
MISORA

Calculation Procedure



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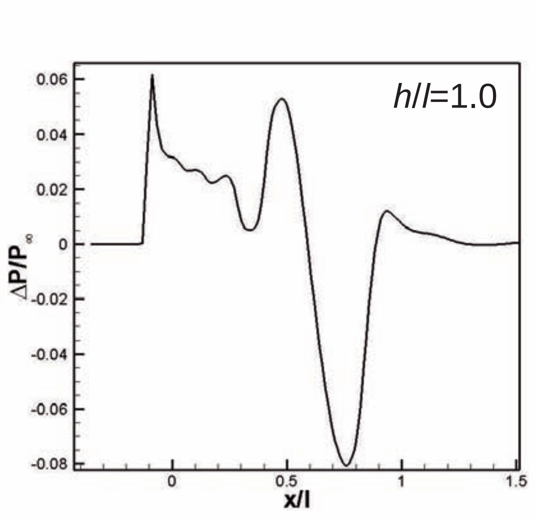
Procedure for Fourier Transformation

- Near-field pressure signature that can produce double N-type boom
- Setups for DFT and IDFT:
  - Sampling rate f_s =27 [kHz]
  - Sample points N=16,564
  - Zero padding between -150～450 [ms]
  - Hanning Window function
  - Amplitude spectrum is subtracted due to the absorption effects
  - Phase spectrum is conserved



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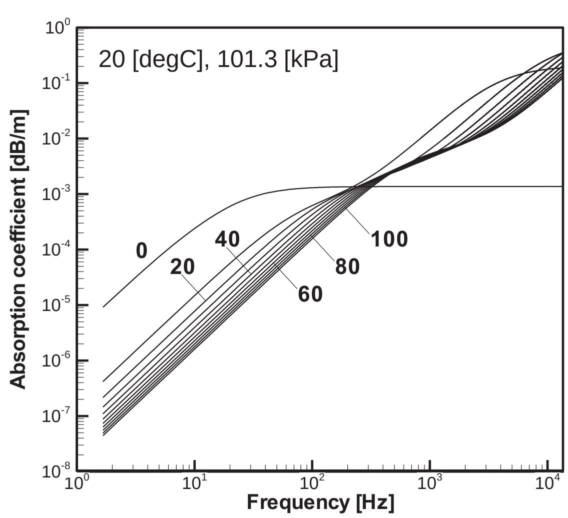
Atmospheric Absorption Coefficient

- The coefficient α [dB/m] is function of...
  - Frequency f [Hz]; Temperature T [K]; Pressure [Pa]; Humidity h [%]
- The coefficient represents pure tone attenuation in air



ISO-9613-1 “Acoustics-Attenuation of sound during propagation outdoors-Part-1”

- Viscosity
- Heat conduction
- Rotational relaxation
- Vibrational relaxation of O_2 & N_2

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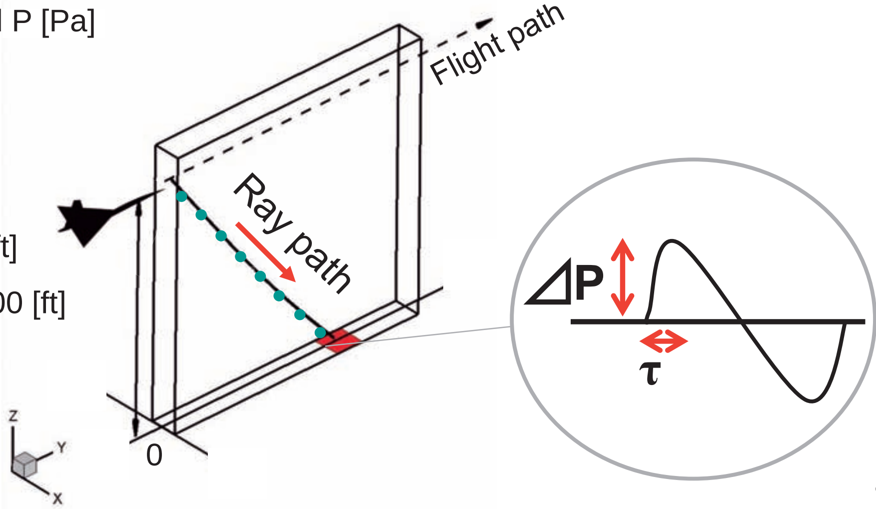
Sonic Boom Calculation

- Waveform Parameter method
  - Standard atmosphere; no winds
  - Relative humidity was fixed between 0 to 100 [%] for each calculation
  - Absorption effect is applied every 500 [ft] propagation by reference to the ambient T [K] and P [Pa]

- M = 2.0
- Aircraft 300 [ft]
- Altitude 60,000 [ft]



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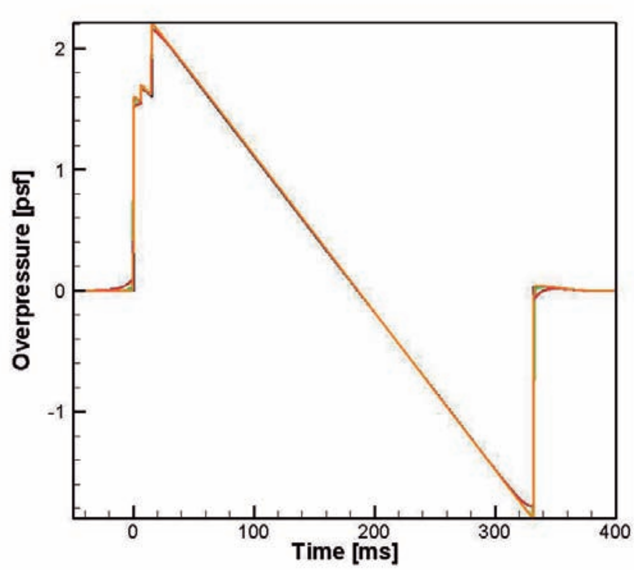
Comparison of Sonic Boom Waveforms

- Waveforms change from abrupt waveform into round-peak waveform
  - Rounded parts are found at every abrupt shock parts



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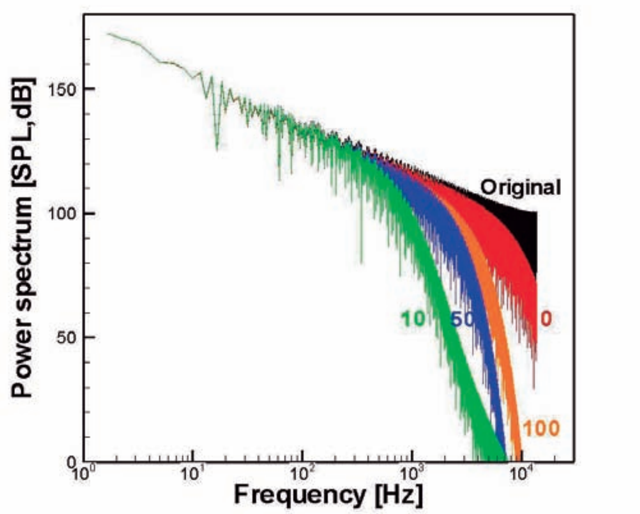
Comparison of Power Spectra

- Power spectra are similar in lower frequency area below f < 100 [Hz]
- The spectra are reduced in higher frequency area
  - Result of hr = 10 [%] shows significant reduction in the spectrum



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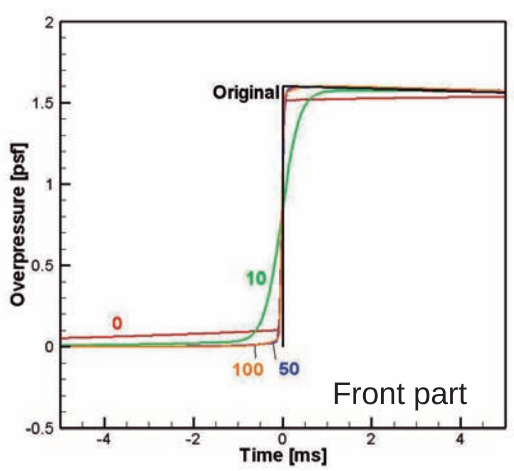
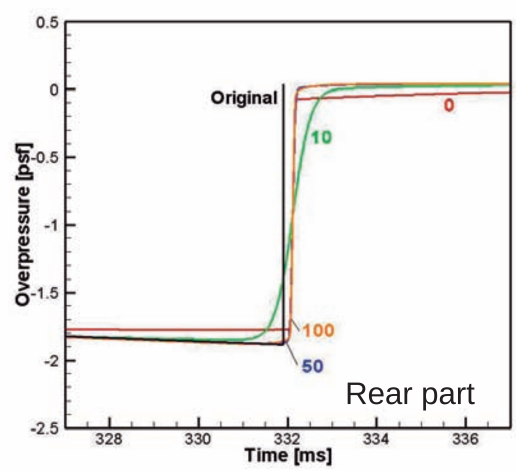
Front and Rear Shocks

- Original waveform has actually “zero” rise time at front and rear shocks
- Finite rise time occurs due to atmospheric absorption effects
  - Result of 10 [%] relative humidity has larger rise time, due to significant reduction of power spectrum in high-frequency domain





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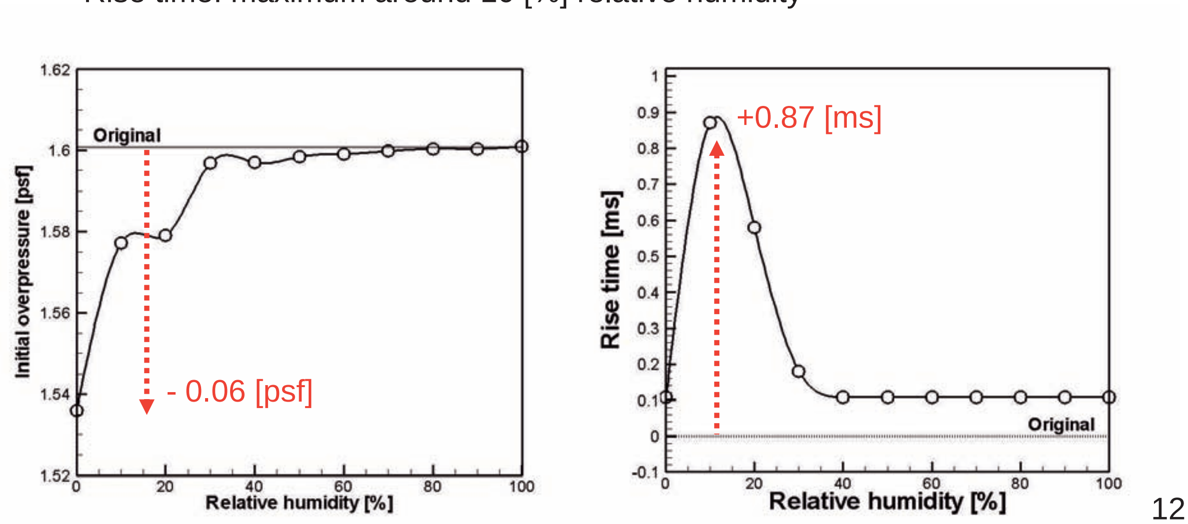
Variation in Overpressure and Rise Time

- Almost all cases have decreased overpressures
  - Initial overpressure decreases with lower humidity
- All cases have finite rise time
  - Rise time: maximum around 10 [%] relative humidity



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Future Works -1

大気吸収効果を考慮した音響解析ツール開発

- プログラムの改良
  - 適切な数値解析パラメータの探索
    適切な大気減衰計算の回数，解析対象とする周波数領域の決定など
  - 計算コストの削減
- 数値解析結果の検証
  - 代表波形を用いて比較
  - CFDベースの非線形伝播解析モデルと比較
- 波形パラメータ法への組込
  - 超音速機設計ツールとして望まれるプログラム形態を確認

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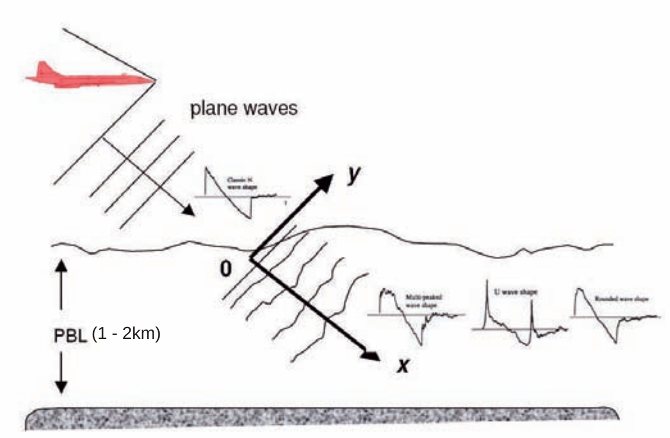
Atmospheric Turbulence Effect

- Investigate the variability of overpressure in PBL due to atmospheric wind fluctuation



Ollivier, Sébastien; Blanc-Benon, Philippe., "Numerical simulation of "low level" sonic boom propagation through random inhomogeneous sound speed fields," ICA2007.

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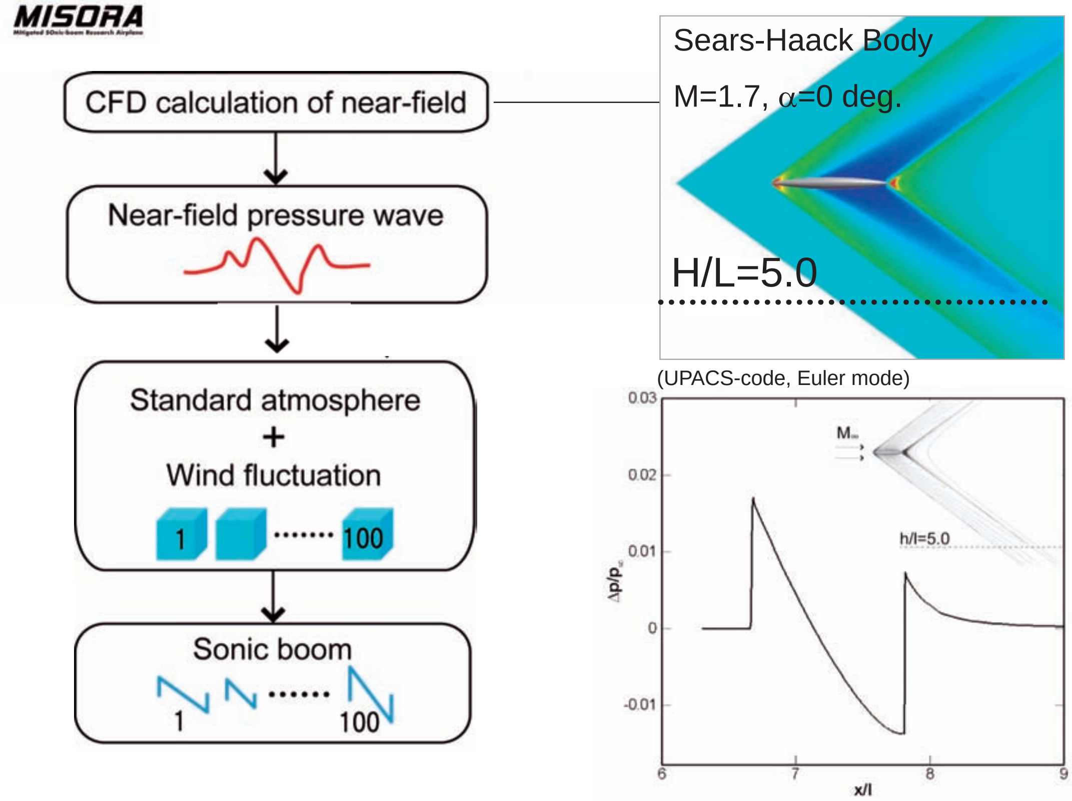
Calculation Procedure



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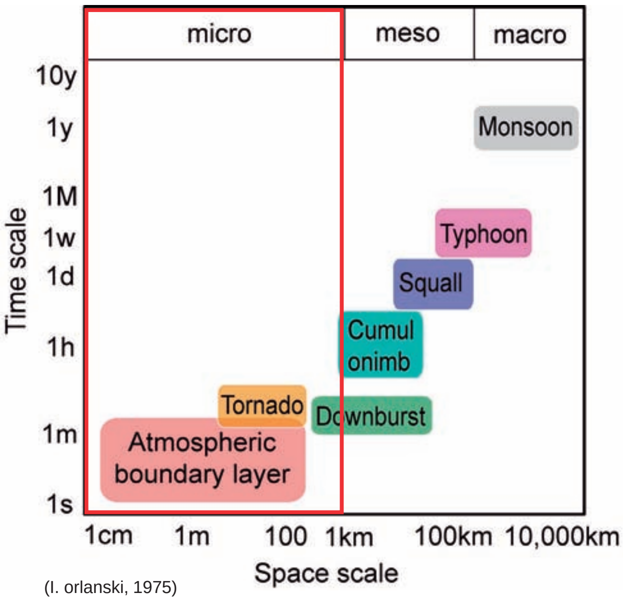
Wind Fluctuation Model



(I. orlanski, 1975)

Random Fourier mode

$$u_t(y)=2\sum_{n=1}^{N}\tilde{u}_{tn}\cos(\mathbf{k}_n\cdot y+\Psi_n)\sigma_n$$

Energy spectrum of von Karman and Pao

$$E(k)=\left(\frac{2}{3}\right)^{\frac{3}{2}}\frac{K^{\frac{5}{2}}}{\varepsilon}\frac{(k/k_e)^4}{\left[1+(k/k_e)^2\right]^{\frac{17}{6}}}\exp\left[-\frac{9}{4}\left(\frac{k}{k_d}\right)^{\frac{4}{3}}\right]$$

➔ V_{rms} = 2.5 (m/s)

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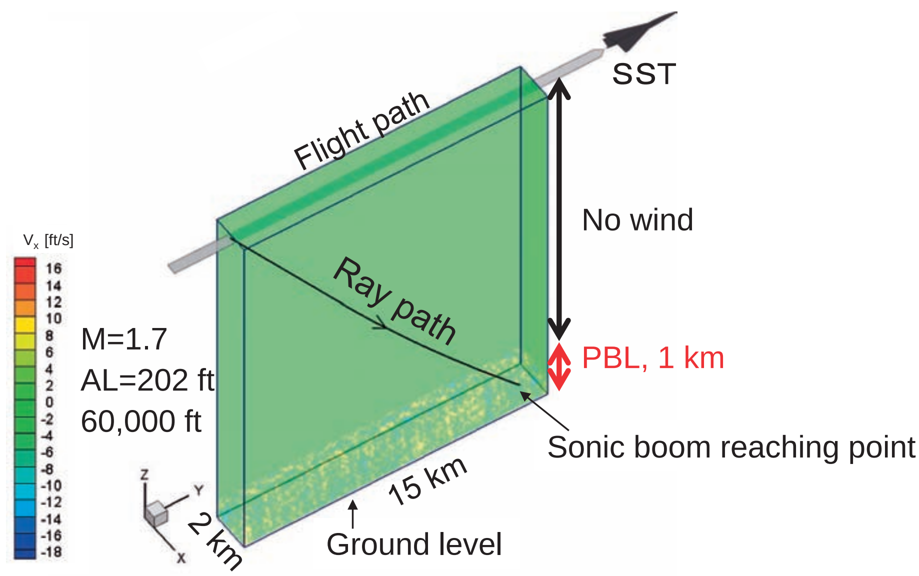
Sonic Boom Calculation

- Homogeneous wind fluctuation was generated in PBL (1 km)
- Modified Waveform Parameter method



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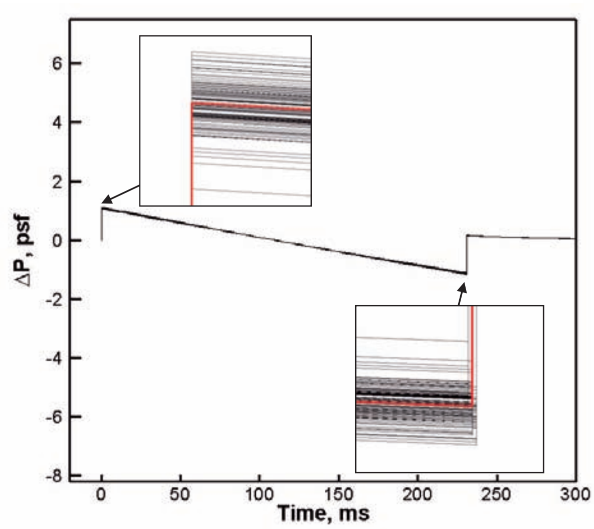
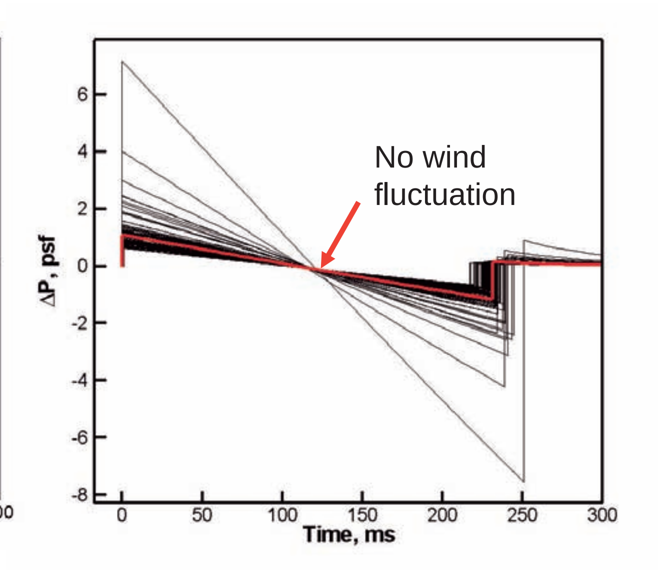
Variability of Sonic Boom Overpressure



PBL (V_{rms} = 2.5, m/s)



Whole region (V_{rms} = 2.5, m/s)

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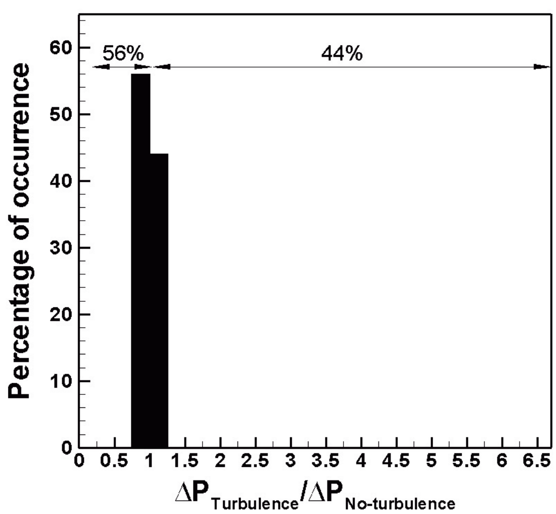
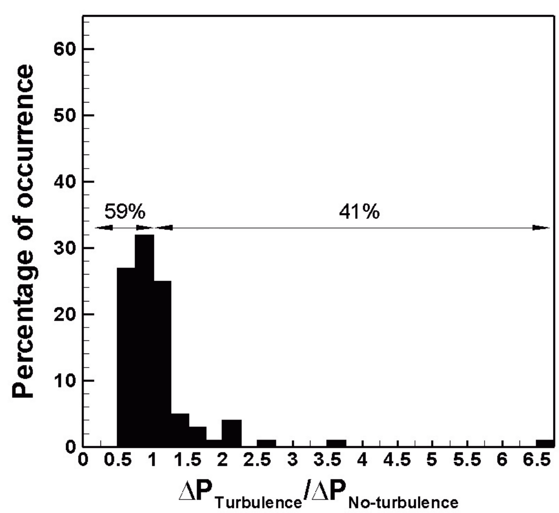
Histogram of Initial Overpressure

- Overpressure is likely to be reduced statistically



PBL (V_{rms} = 2.5, m/s)



Whole region (V_{rms} = 2.5, m/s)

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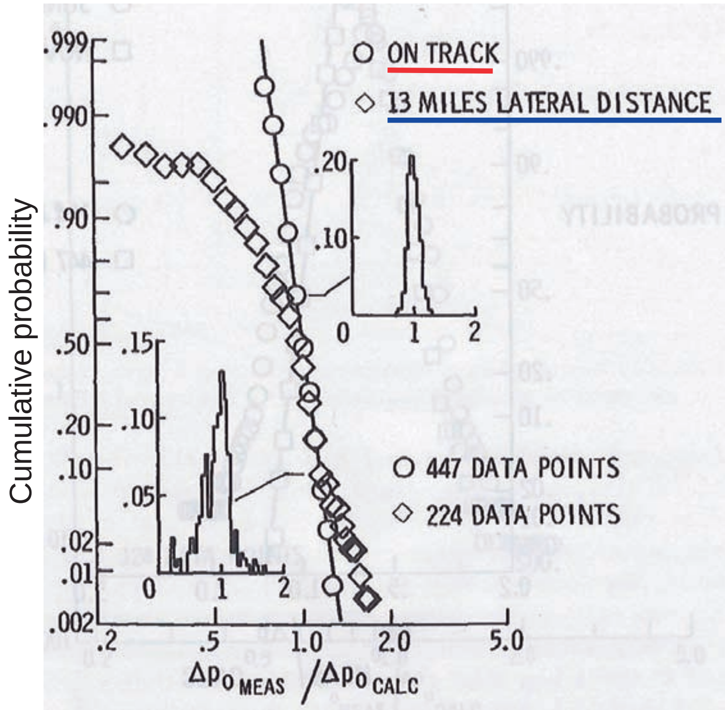
Cumulative Probability from XB-70 Flights

XB-70

(Nov. 1966 - Jan. 1967)

http://www.dfrc.nasa.gov/Gallery/Movie/XB-70/HTML/EM-0039-05.html



Domenic, H., Maglieri, "Sonic Boom Flight Research-Some Effects of Airplane Operations and the Atmosphere on Sonic Boom Signatures," NASA SP-147

Future Works -2

大気乱流モデリングの高精度化に関する検討

- ブーム強度のばらつきに関して実測データと定性的に一致
  - 波線追跡計算に擾乱効果を取り込み，波管断面積変化を通じて地上ブーム強度のばらつきを表現
  - 波形全体に効果が反映　→　Focusing / Defocusing を表現している
- 大気乱流による波形変化に関するモデルを検討
  - 波形変化の明確なメカニズムは未解明
  - 実験的研究との連携が必要

名古屋大学 "ソニックブーム波形に対する大気乱流効果モデル構築のための実験的研究"