2nd AIAA Sonic Boom Prediction Workshop

sBOOM Propagation for the Second AIAA Sonic Boom Prediction Workshop

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Outline

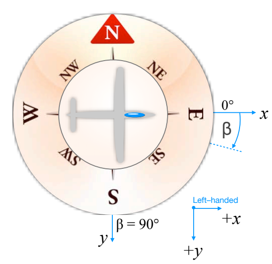
- Intro - codes, conventions and studies
  - Wind Convention
  - Mesh refinement
  - Accuracy requirements
- "Axibody" - Body of revolution
- "LM 1021" - Wind tunnel model of full configuration from 2014 boom workshop
- Summary

Introduction

- Propagation using sBOOM (v2.5)* for all cases
  - Augmented Burgers' eq.
  - Finite-difference with space-operator splitting
  - Most runs under 1 min on laptop
- Loudness metrics computed with LCASB†
- Applied current "best practices"
- Mesh refinement study done for both geometries using std. atm.
- Ran all required & optional cases

* Rallabhandi, S. "Advanced Sonic Boom Prediction Using the Augmented Burgers Equation" *J. of Aircraft* **48**:1245–1253, 2011.
† Shepard & Sullivan, "Loudness Code for Asymmetric Sonic Booms(LCASB)", NASA TP 3134, 1991

Wind Convention



- sBOOM uses left-handed coordinate system for wind
- β = heading,
  - β = 0° A/C pointed East
  - Clockwise = +β
- sBOOM wind tables are in meters vs m/s
- x and y inputs are wind components ("blows toward")

→ (x, y) = (1, 0) is tail wind if heading is East
↓ (x, y) = (0, 1) is tail wind if heading is South
↘ (x, y) = (1, 1) is tail wind if heading is South-East

Net result is that sign on y-component of wind in the workshop wind-specification needs to be flipped. $(Wx,\ Wy)_{\text{sBOOM}} = (Wx,\ \text{-}Wy)_{\text{workshop}}$

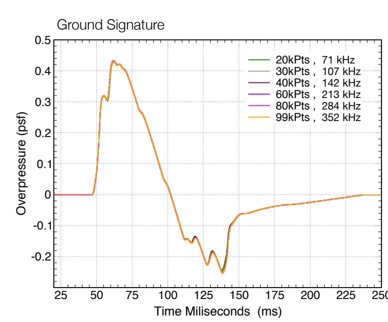
Mesh Convergence

Sensitivity of noise output to mesh refinement

- Propagation code is solving augmented Burgers' via finite difference
- Need to make sure we're getting mesh converged result
- Mesh convergence is case dependent
  - Do for each case, assume std atmosphere
- Dissipation due to truncation error directly impacts accuracy, resolution requirements are driven by need to minimize error in propagation
  - Initial signal typically has < 2 k pts
  - Propagation typically requires 20-50 kpts

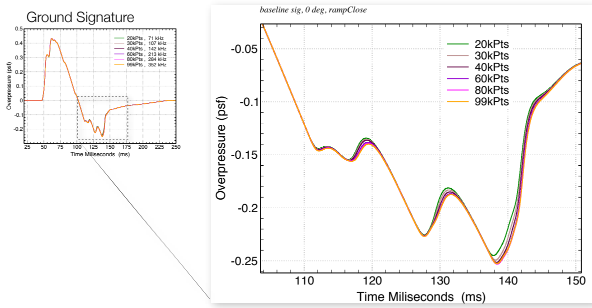
Mesh Convergence

Sensitivity of noise output to refinement of the propagation mesh



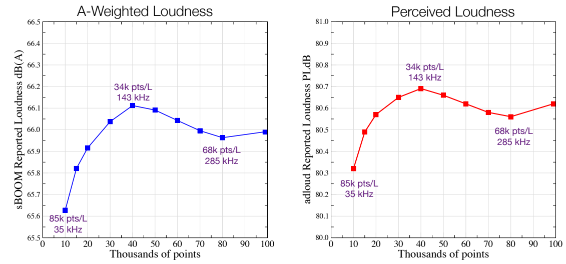
Mesh Convergence

Sensitivity of noise output to refinement of the propagation mesh



Mesh Convergence

Sensitivity of noise output to refinement of the propagation mesh

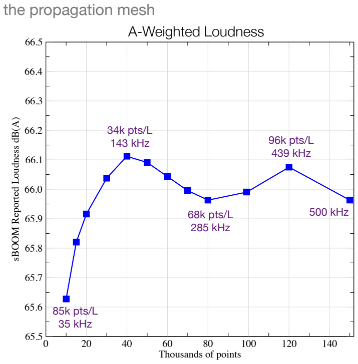


- Both dB(A) and PLdB show similar behavior
- Lower than 35 kHz, noise outputs drops quickly
- However, mesh convergence not convincing, even at higher frequencies

Mesh Convergence

Sensitivity of noise output to refinement of the propagation mesh

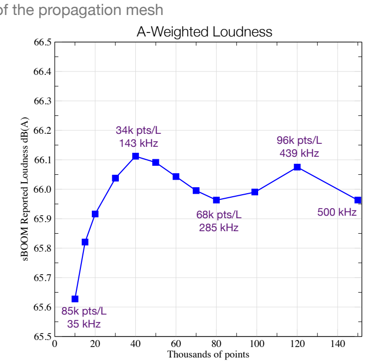
- Ran up to 500 kHZ
- Mesh convergence still not convincing
- At 500 kHZ, oversampling original signal by nearly 100:1
- Possibility of aliasing due to oversampling



Mesh Convergence

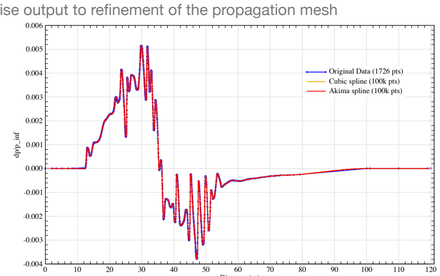
Sensitivity of noise output to refinement of the propagation mesh

- Slow mesh convergence not surprising
  - Signal is non-smooth, and integrated loudness outputs are very sensitive
  - Oversampling introduces higher frequencies which may effect loudness output



Mesh Convergence

Sensitivity of noise output to refinement of the propagation mesh



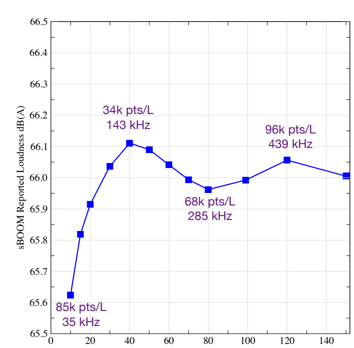
- Spline data at high resolution with Akima spline
- Pass high-resolution data from splined signal into sBOOM to avoid aliasing high-frequencies

Mesh Convergence

Spline data to avoid aliasing

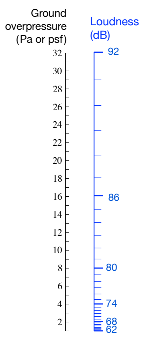
- Somewhat better mesh behavior at high frequencies, but...
- Mesh convergence still not really convincing
- Need to investigate more

- Used un-splined data sampled at 107 kHz (30 kpts) for runs



Caveats on Accuracy Requirements

Decibels are logarithmic units!



Double the loudness ⟶ ~10 dB more sensed loudness level (psycho acoustic)
Double the sound pressure level ⟶ 6 dB more measured sound pressure level)

Caveats on Accuracy Requirements

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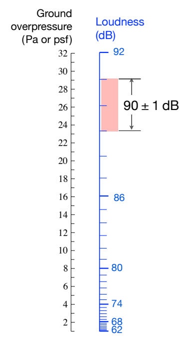

Double the loudness ⟶ ~10 dB more sensed loudness level (psycho acoustic)
Double the sound pressure level ⟶ 6 dB more measured sound pressure level)

- We propagate pressure signals to the ground
  - → *Propagation error* has units of pressure
- *e.g.*
  - If error of ±2 Pa on a 90dB signal is less than ± 1dB
  - The same error on a 70dB signal may be ± 6dB
- Propagation accuracy requirements increase logarithmically as signals get quieter!
- Sampling frequency for a 90 dB signal is likely to be insufficient for a 70 dB signal

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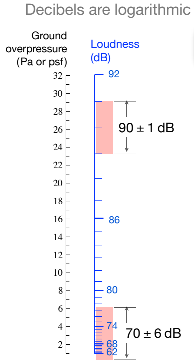

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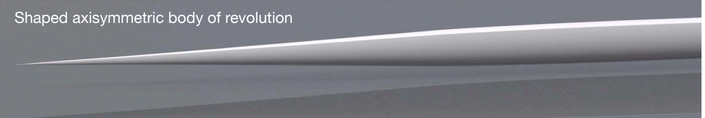
Axibody

Shaped axisymmetric body of revolution

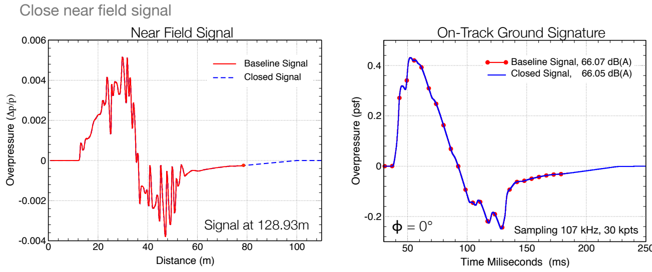


Conditions:
- M_∞ = 1.6
- Altitude = 15849.6 m (52 kft)
- *Lref* = 42.98m (141 ft)
- *r/L* = 3.0 at signal extraction
- Ground reflection factor = 1.9
- Heading East (β = 0°)

Cases:
- Required: Atm #3
- Optional #1: Std. Atm.
- Optional #2: Atm #4
- Optional #4: Std. Atm. with 70% humidity

Axibody

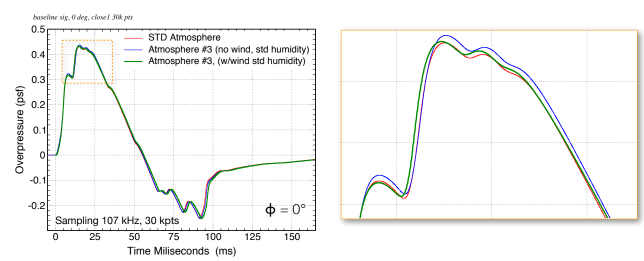
Close near field signal



- Compared 2 different closures (both linear ramps) gave consistent results
- Closed signal using linear ramp to 0 at 100 m
- Ground signals & noise both virtually identical

Axibody

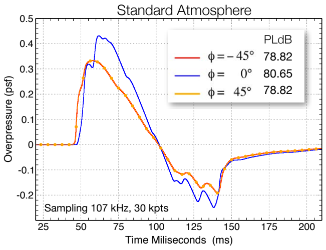
Ground signature – Atmosphere #3 vs Standard Atmosphere



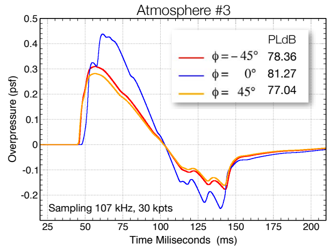
- Atmosphere 3 was required case
- ~0.6 PLdB louder than standard atmosphere

Axibody

Ground signature – Standard Atm. vs Atmosphere 3, ϕ = {-45°, 0°, 45°}



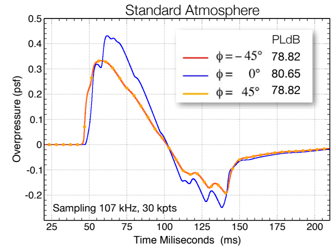
Optional #1



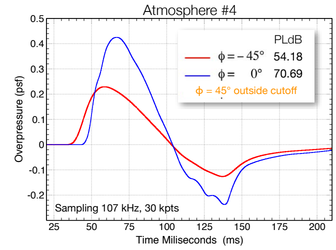
Required

Axibody

Ground signature – Standard Atm. vs Atmosphere 4, ϕ = {-45°, 0°, 45°}



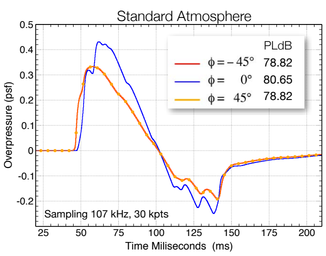
Optional #1



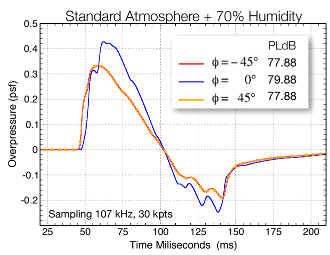
Optional #2

Axibody

Ground signature – Standard Atm. vs Standard Atm. + 70% Relative Humidity



Optional #1

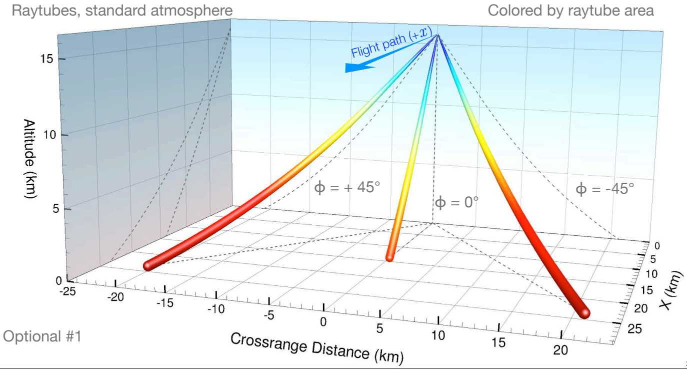


Optional #3

Axibody

Raytubes, standard atmosphere

Colored by raytube area

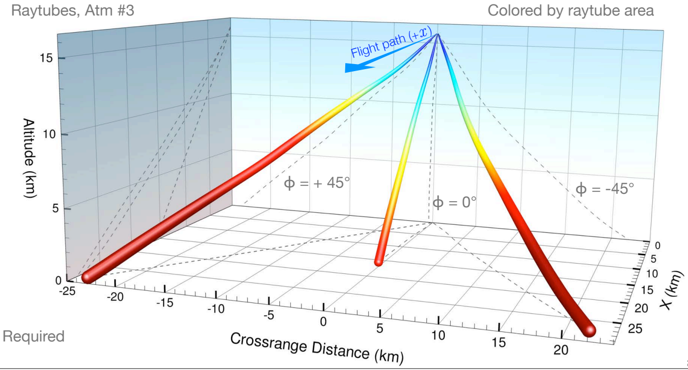


Optional #1

Axibody

Raytubes, Atm #3

Colored by raytube area

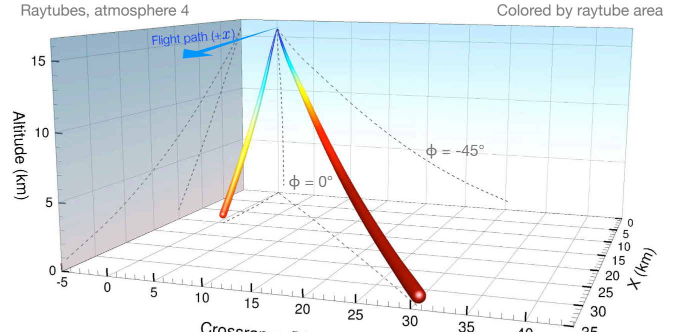


Required

Axibody

Raytubes, atmosphere 4

Colored by raytube area

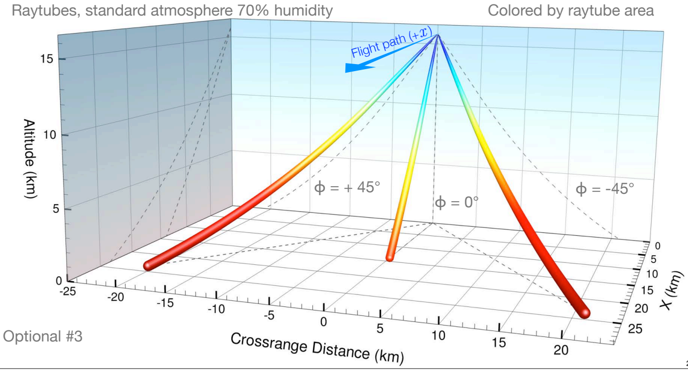


Optional #2: ϕ = + 45° outside cutoff

Axibody

Raytubes, standard atmosphere 70% humidity

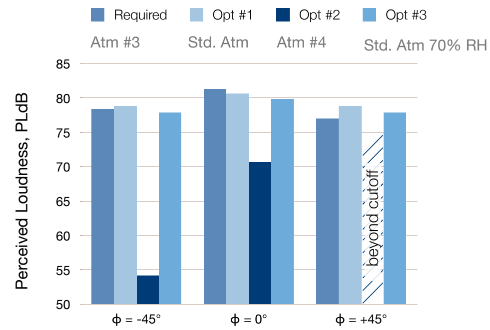
Colored by raytube area



Optional #3

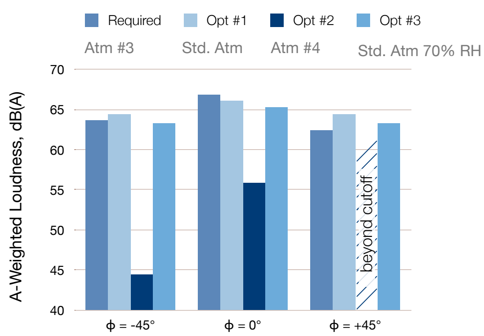
Axibody

Perceived loudness at ground level



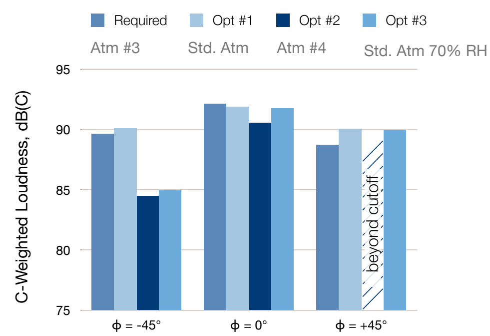
Axibody

dB(A): Optional Atmosphere profiles



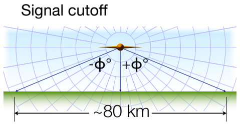
Axibody

dB(C): Optional Atmosphere profiles



Axibody

Signal cutoff



	Atmosphere Profile	Cutoff (−ϕ°) (x, y) km	Cutoff (+ϕ°) (x, y) km	Track Width
Required	# 3	-50.28° (44.1, 39.3) km	53.08° (48.5, -46.1) km	85.4 km
Optional 1	Standard Atm	-50.38° (35.9, 34.5) km	53.38° (35.9, -34.5) km	69.0 km
Optional 2	# 4	-46.70° (44.9, 40.8) km	43.89° (35.9, -30.7) km	71.5 km
Optional 3	Standard + 70% humidity	-50.38° (35.9, 34.5) km	53.38° (35.9, -34.5) km	69.0 km

LM 1021

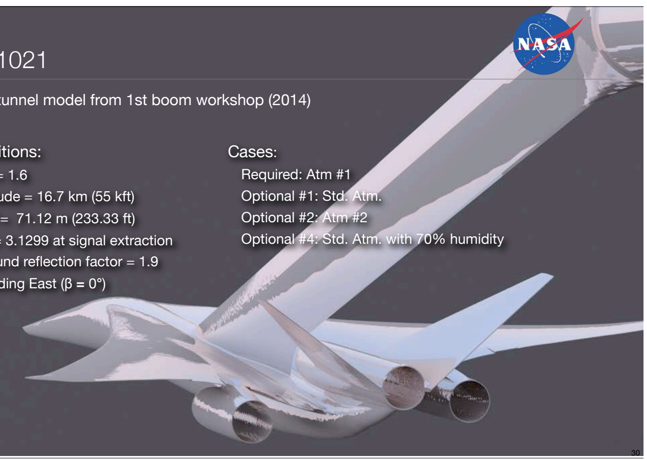
Wind tunnel model from 1st boom workshop (2014)

Conditions:

- M_∞ = 1.6
- Altitude = 16.7 km (55 kft)
- *Lref* = 71.12 m (233.33 ft)
- *r/L* = 3.1299 at signal extraction
- Ground reflection factor = 1.9
- Heading East (β = 0°)

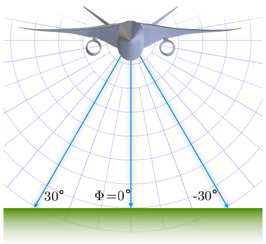
Cases:

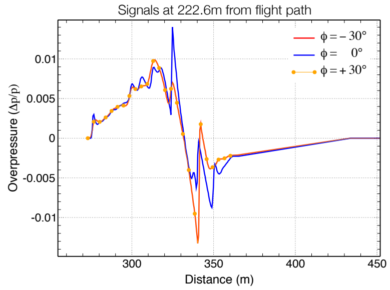
- Required: Atm #1
- Optional #1: Std. Atm.
- Optional #2: Atm #2
- Optional #4: Std. Atm. with 70% humidity



LM 1021

Near Field Signatures

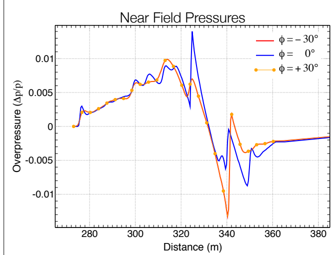


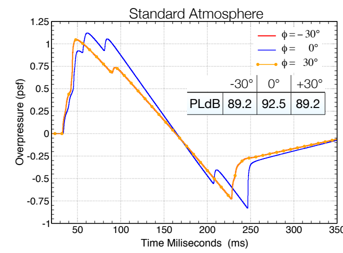


Signals closed with a linear ramp to 435 m

LM 1021

Ground signature: Standard Atmosphere, ϕ = {-30°, 0°, 30°}



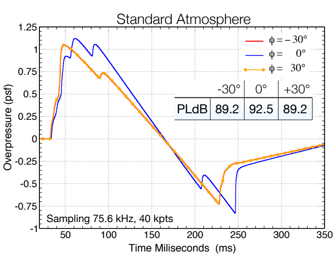


	-30°	0°	+30°
PLdB	89.2	92.5	89.2

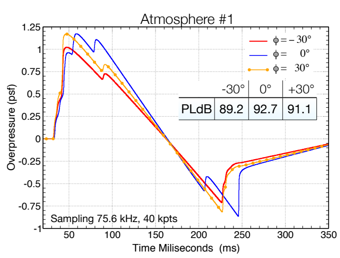
Sampling Frequency = 75.6 kHz, 40 kpts

LM 1021

Ground signature – Atmosphere #1, , ϕ = {-30°, 0°, 30°}



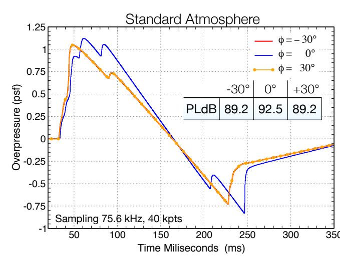
	-30°	0°	+30°
PLdB	89.2	92.5	89.2



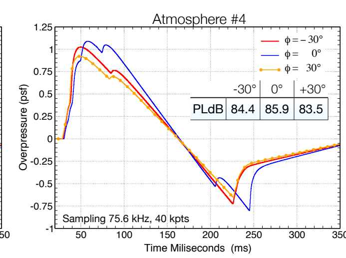
	-30°	0°	+30°
PLdB	89.2	92.7	91.1

LM 1021

Ground signature – Optional #2, Atmosphere #4, , ϕ = {-30°, 0°, 30°}



	-30°	0°	+30°
PLdB	89.2	92.5	89.2

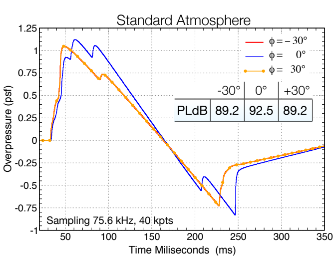


	-30°	0°	+30°
PLdB	84.4	85.9	83.5

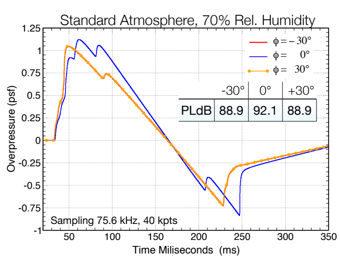
~5 dB quieter than Std. Atm. conditions

LM 1021

Ground signature – Optional #3, std/ atm. +70% relative humidity, ϕ = {-30°, 0°, 30°}



	-30°	0°	+30°
PLdB	89.2	92.5	89.2



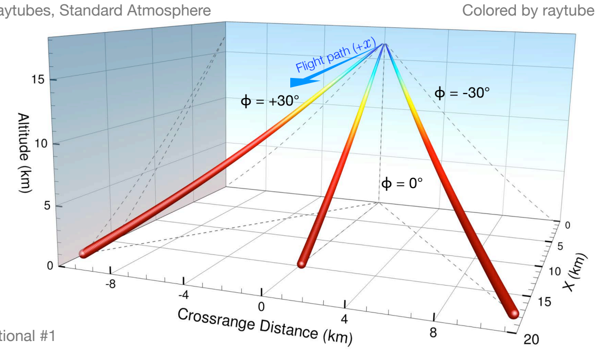
	-30°	0°	+30°
PLdB	88.9	92.1	88.9

Slightly quieter (0.3-0.4 dB) than in std atmosphere

LM 1021

Raytubes, Standard Atmosphere

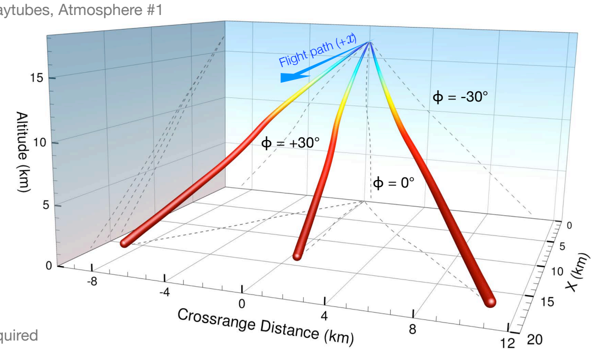
Colored by raytube area



Optional #1

LM 1021

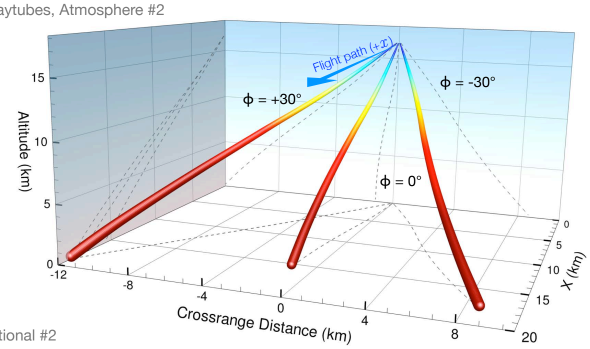
Raytubes, Atmosphere #1



Required

LM 1021

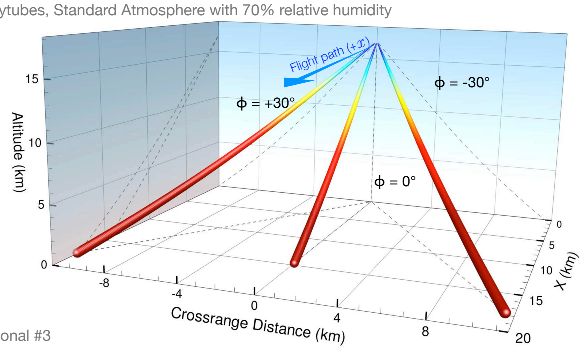
Raytubes, Atmosphere #2



Optional #2

LM 1021

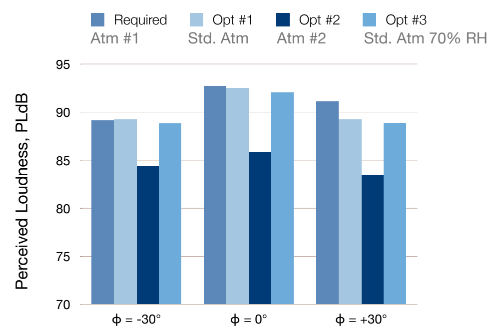
Raytubes, Standard Atmosphere with 70% relative humidity



Optional #3

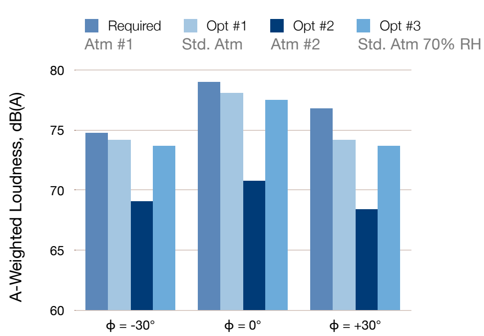
LM 1021

Perceived loudness at ground level



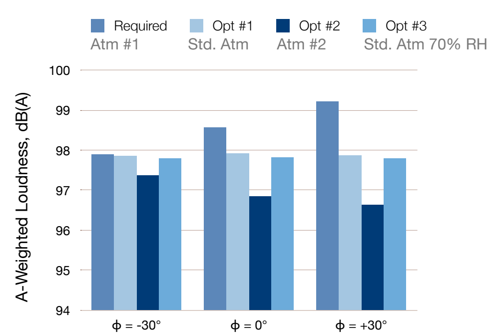
LM 1021

A-Weighted Loudness at ground level



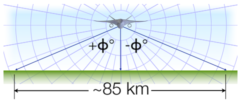
LM 1021

A-Weighted Loudness at ground level



LM 1021

Signal cutoff



	Atmosphere Profile	Cutoff ($-\phi°$) (x, y) km	Cutoff ($+\phi°$) (x, y) km	Track Width
Required	# 1	-57° (40.0, 42.3) km	74° (39.4,-44.6) km	86.9 km
Optional 1	Standard Atm	-50.38° (37.0, 35.6) km	50.38° (37.0, -35.6) km	71.2 km
Optional 2	# 2	-64.65° (43.9, 41.7) km	59.35° (67.0, -69.7) km	111.4 km
Optional 3	Standard + 70% humidity	-50.38° (37.0, 35.6) km	50.38° (37.0, -35.6) km	71.2 km

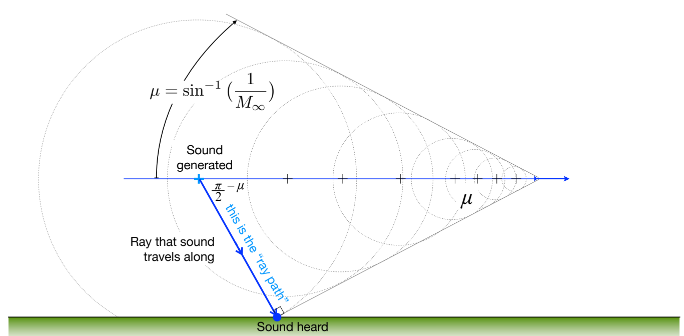
Summary

- Applied sBOOM and LCASB for all required and optional cases
- Showed difficulty in obtaining mesh-converged loudness metrics
  - Noted issues due to oversampling
  - Noted that resolution requirements increase as signals get quieter
- Open questions & Opportunities
  - Impact of step-size on mesh convergence?
  - Splining of the input
  - Consider higher-order discretization to control truncation error at lower sampling rates
  - Automatic output-based adaptation of sBOOM propagation mesh for loudness functional

Questions?

understanding the ray path

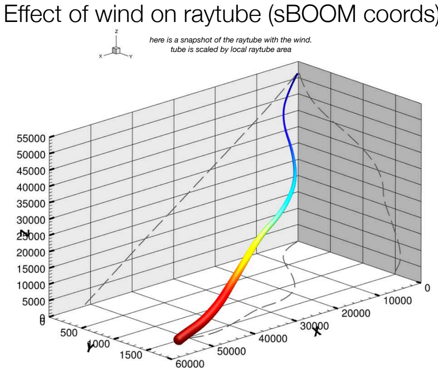
2017.08.11



Effect of wind on raytube (sBOOM coords)

2017.08.27

here is a snapshot of the raytube with the wind.
tube is scaled by local raytube area



- "% sBOOM_2.5 -v -d" reports:

```
Ground intercept for Azimuth: 0.000000
— Propagation time: 68.010707 (s)
— X = 51811.993216 (ft)    Y= 1478.793091 (ft)
```