2nd AIAA Sonic Boom Prediction Workshop

January 7-8, 2017 Grapevine, Texas

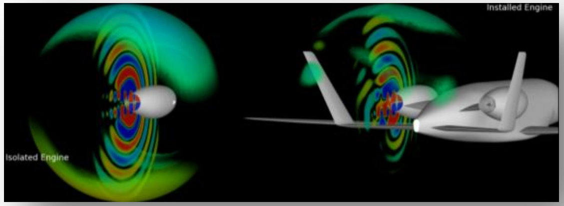
F. Dagrau

HIGHER TOGETHER™

DASSAULT AVIATION

Dassault Aviation Group profile overview

- Dual High-tech company with 100 years of experience in design, manufacture and support both combat aircraft and business jets
- 12,100 employees, more than 9,000 based in France
- Over 8,000 aircrafts delivered worldwide since 1945
- Acting for the environnement: greener Falcon (Noise reduction, Fuel consumption reduction, Eco-design and Manufacturing)
- Worlwide Scientific Cooperation:
  - Scientific exchanges with over 100 universities, institutions and research centers
  - Participation in common research & development programs (Clean Sky,…)
  - Research, technology and development programs coordination (UCAV nEUROn)



Dassault Aviation and the supersonic : Military supersonic experience

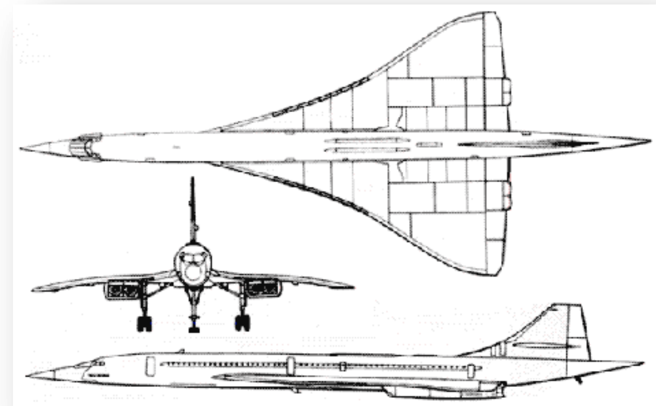
Mirage IV
Persistent Supersonic Flight

Mirage G8
Variable Sweep Wing

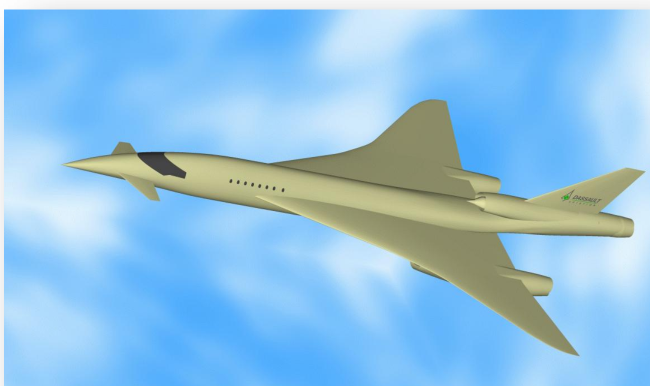
RAFALE
Omni role

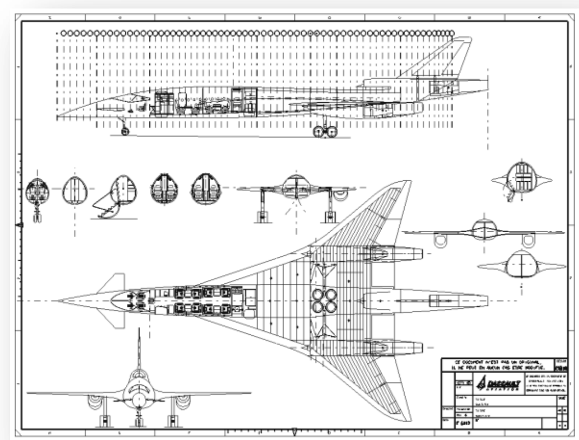
Dassault Aviation and the supersonic : Civil supersonic experience (1/2)

Technical expertise in Concorde design (60's)



SSBJ studies (90's)





Dassault Aviation and the supersonic : Civil supersonic experience (2/2)

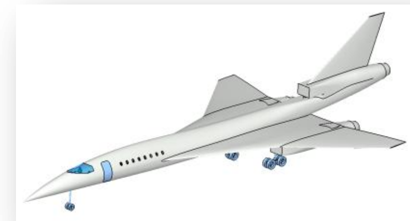
To establish the ***Technological Feasibility of an Environmentally Compliant SuperSonic Small Size Transport Aircraft***

Dassault Aviation lead

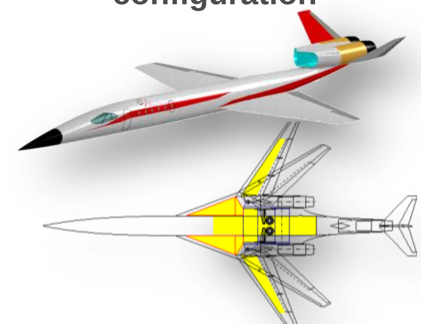
Environmentally compliant **HI**gh-**S**peed **A**ir**C**raft

37 partners - 13 countries

Low noise configuration



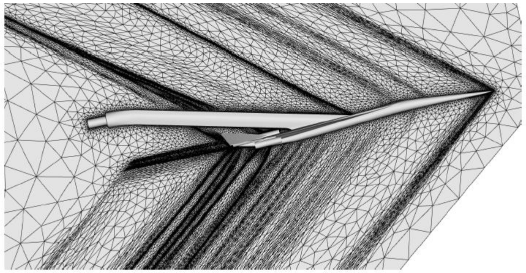
Long range configuration

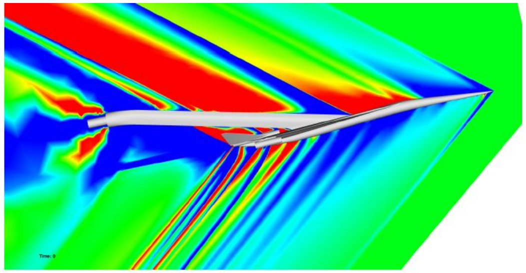


Low boom configuration

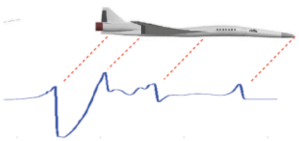
Dassault Aviation and the supersonic : International collaboration on SB activities

- Participation to SSTG discussion within CAEP
- Participation to NASA FAINT flight test campaign
- Participation to the AIAA Sonic Boom Workshop
- Preparation of EU/RU RUMBLE proposal (RegUlation and norM for low sonic Boom LEvels)





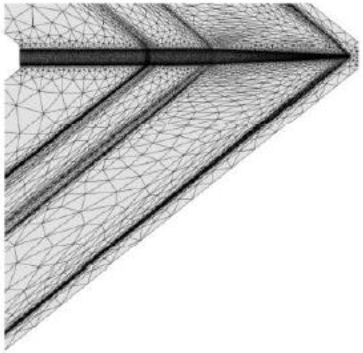
SB prediction process
1st Layer: Near Field



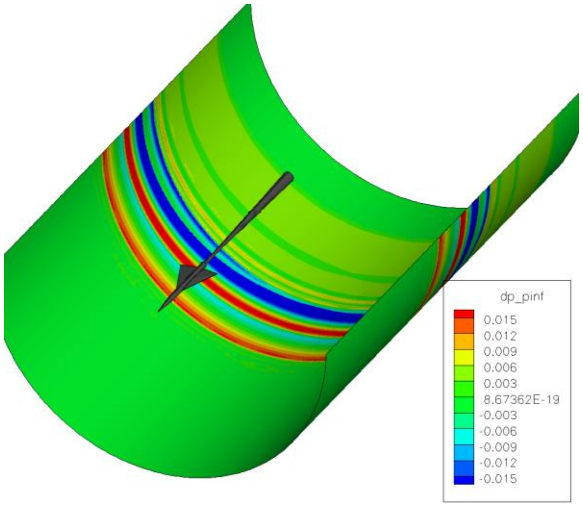
Near field
(aerodynamics)

CFD
Eugenie/Aether

1. Anisotropic mesh adaptation based on adjoint approach

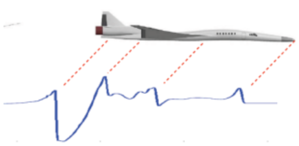


2. Near field computations with Dassault Aviation in-house Flow solver



	EUGENIE	AETHER
• **Solver equations**	Euler	Navier Stokes
• **Grids**	Unstructured tetrahedral elements	
• **Domain decomposition**	Fully Parallelized using MPI	
• **Convergence to steady state algorithm**	Fully implicit iterative time-marching procedure based on GMRES algorithm	
• **Formulation**	Galerkin-Finite Volume cell vertex	Streamline Upwind Petrov Galerkin (SUPG) Stabilized finite element approach
• **Flux**	Lax-Wendroff, Jameson, Osher-MUSCL, Roe…	SUPG + Discontinuity capturing operator
• **Turbulence modelling**		Wall-Law, Spalart-Allmaras, K-ε, K-ω, K-l, K-KL, LES, DES…

SB prediction process
2nd Layer: Mid Field



Near field (aerodynamics)

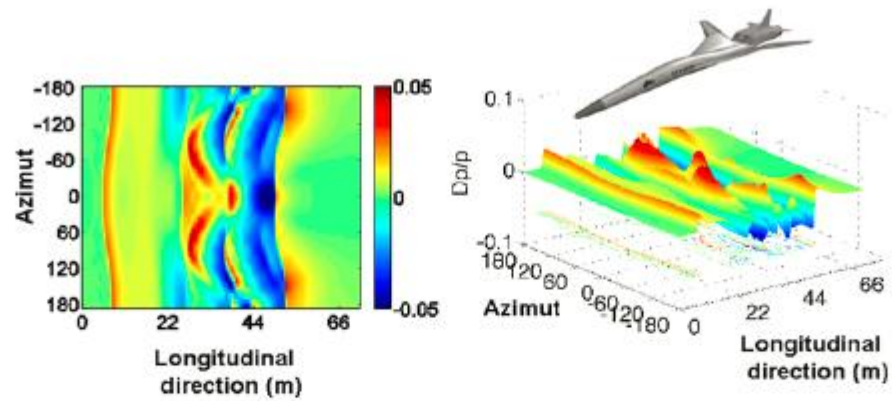
Mid field

Multipole correction

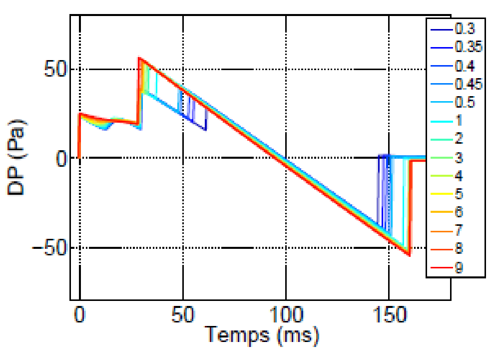
Multipole capabilities wasn't used in this workshop

Mid field: Multipole Approach [1]

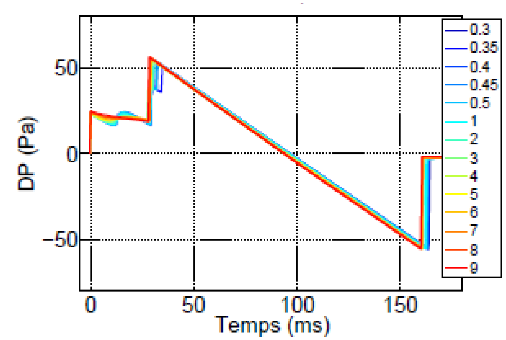
Modal reconstruction of pressure variation, using azimuthal 2π periodicity along aircraft circumference to satisfies the assumption of geometrical acoustics used in the propagation step



Without multipole

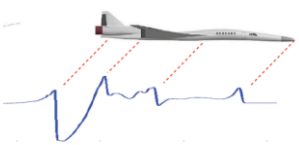


With multipole



[1] K.J Plotkin and J.A Page, Extrapolation of Sonic Boom signatures from CFD solutions, AIAA Paper, 2002-0922, 2002

SB prediction process
3rd Layer: Far field



Near field
(aerodynamics)

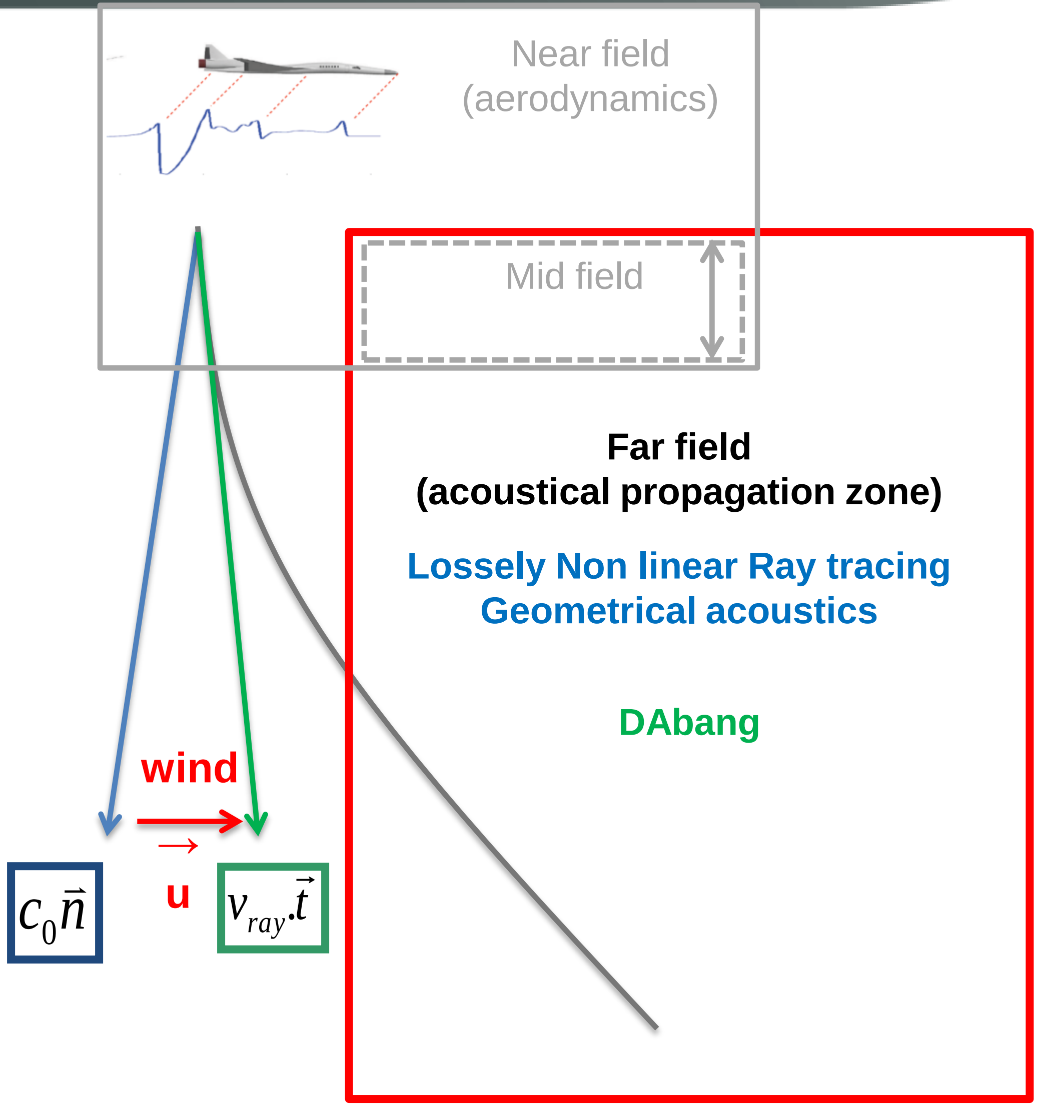
Mid field

Far field
(acoustical propagation zone)

Lossely Non linear Ray tracing
Geometrical acoustics

DAbang

SB prediction process
3rd Layer: Far field - Ray tracing

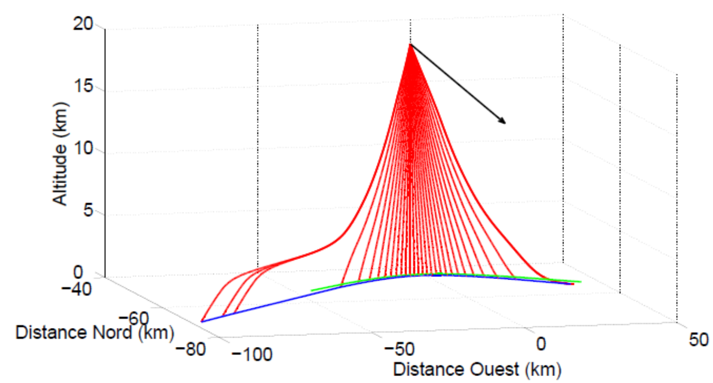


The acoustic far field propagation follows 4 steps:

At first order, the path of the sonic boom rays from the aircraft to the ground is modeled by ray theory according to Fermat's principle so that the propagation time Ψ (eikonal function) between the source and the receiver is minimal

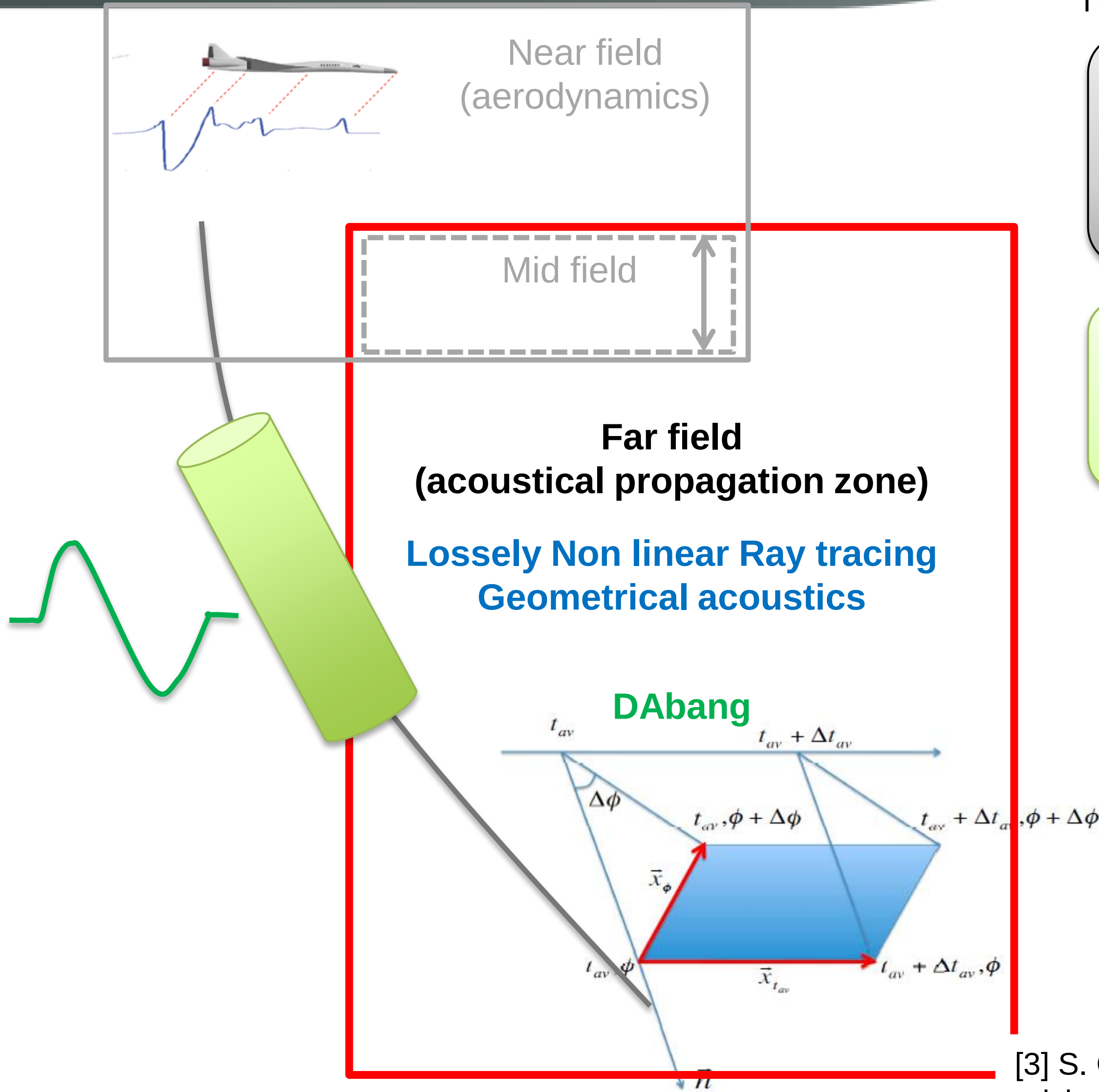
6 ordinary differential equations [2]:

- **3 equations for the position of a point along ray**
- **3 equations for the normal vector to the wavefront**



[2] A. D. Pierce : Acoustics: an introduction to its physical principles and applications. Acoustical Society of America (New York) (1989)

SB prediction process
3rd Layer: Far field - Tube area



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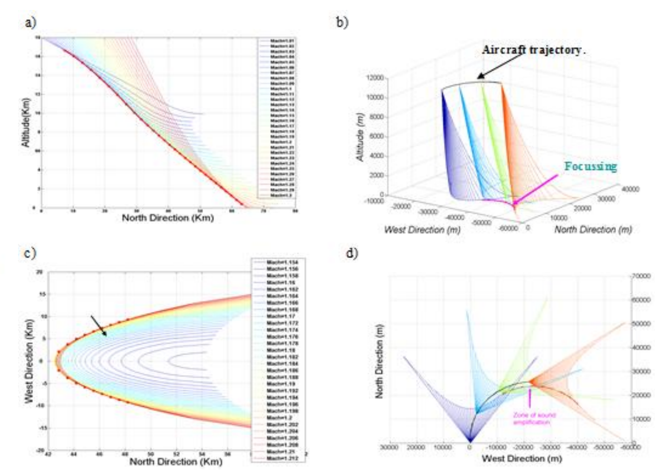
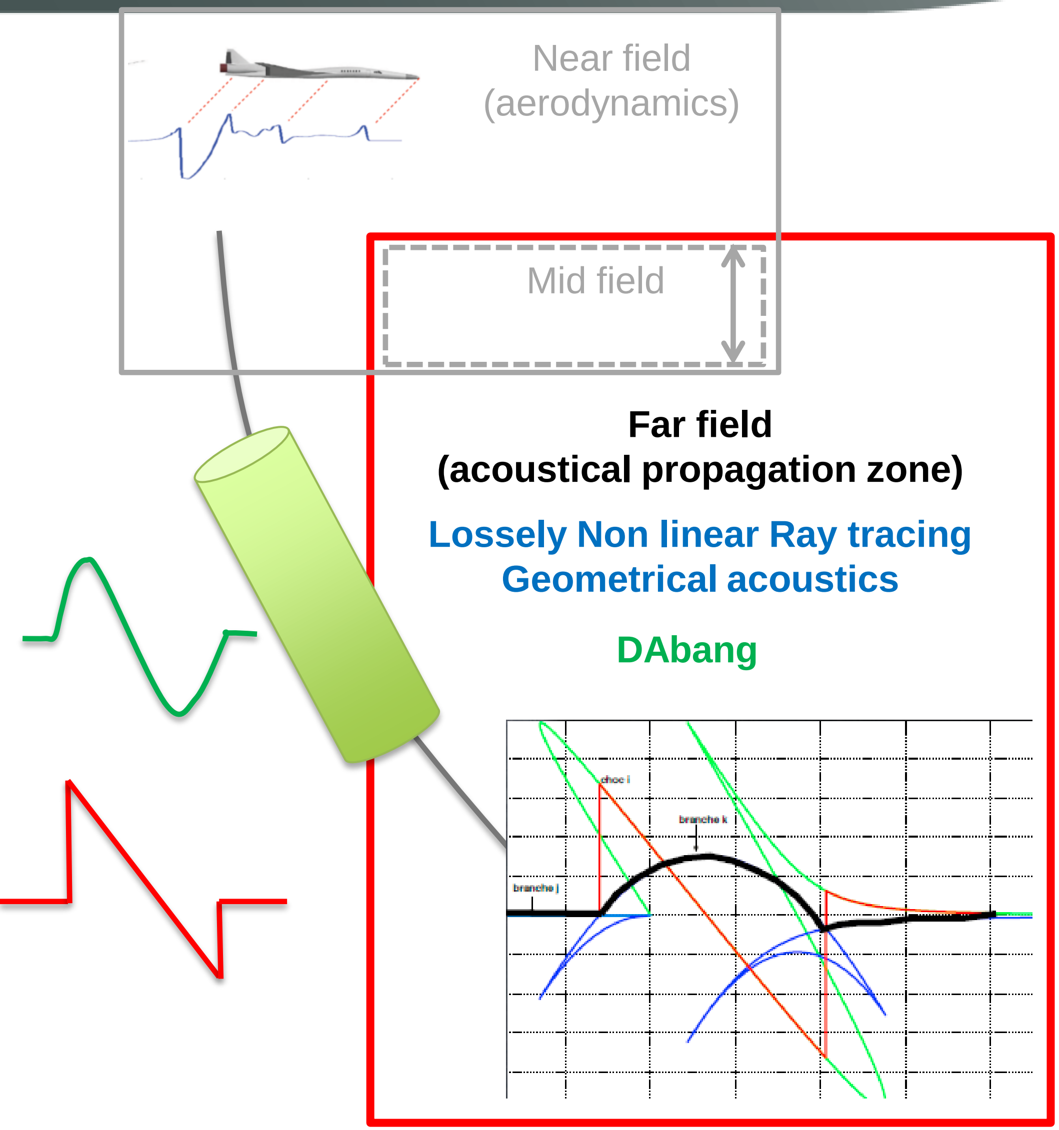
At first order, the path of the sonic boom rays from the aircraft to the ground is modeled by ray theory according to Fermat's principle so that the propagation time Ψ (eikonal function) between the source and the receiver is minimal

At second order, the linear pressure disturbance amplitude is given by the principle of conservation of acoustical intensity along a ray tube defined by of a bundle of 4 neighboring rays.

12 ODE additional [3]



[3] S. Candel : Numerical solution of conservation equation arising in linear wave theory: application to aeroacoustics, J. Fluid Mech. 83 (1977) 465-493



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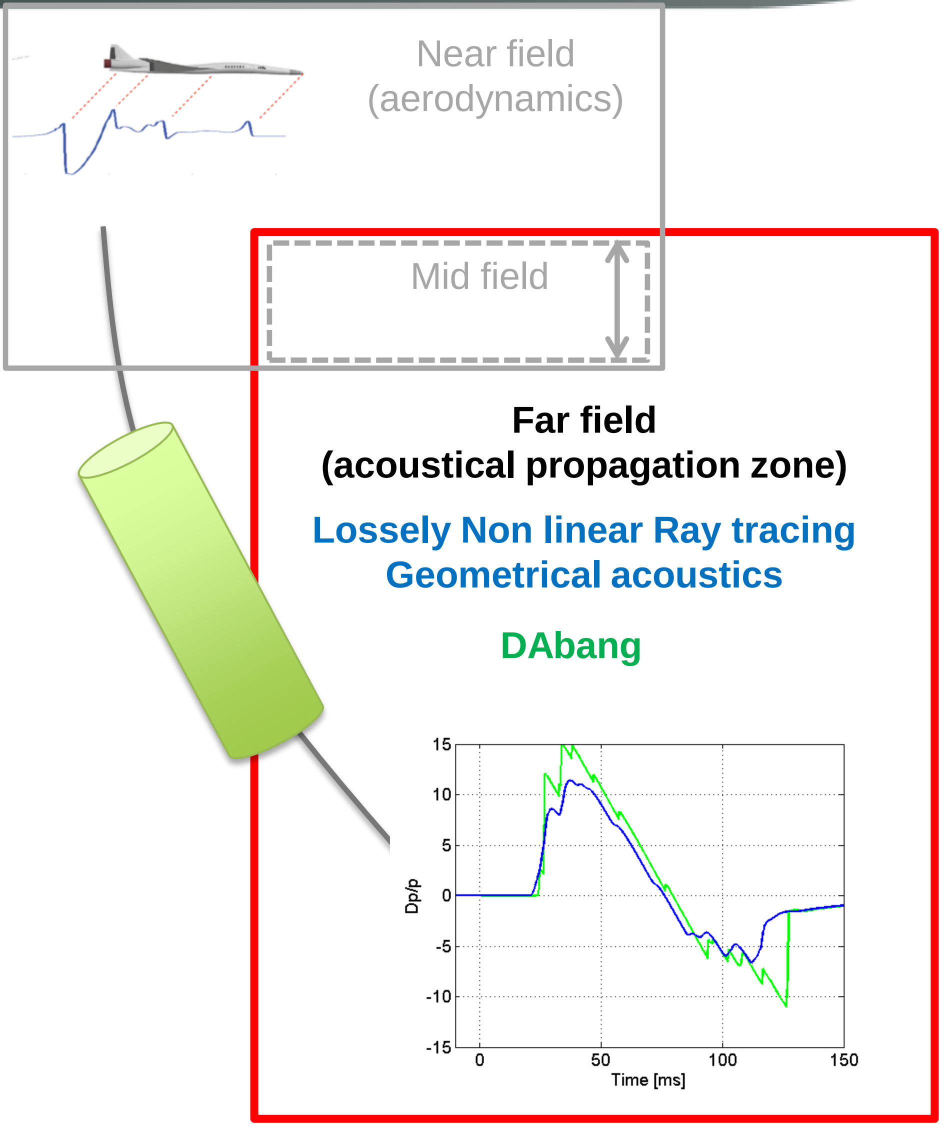
Along a given ray, nonlinear effects are modeled as a 1D inviscid Burger's equation [4].

1 additional equation for age variable

[4] W. D. Hayes, R. C. Haefeli, H. E. Kulsrud : Sonic boom propagation in a stratified atmosphere with computer program, NASA CR-1299 (1969)

SB prediction process
3rd Layer: Far field - Absorption effect



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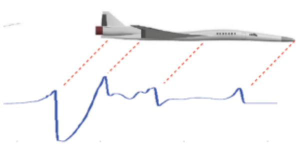
At second order, the linear pressure disturbance amplitude is given by the principle of conservation of acoustical intensity along a ray tube defined by of a bundle of 4 neighboring rays.

Along a given ray, nonlinear effects are modeled as a 1D inviscid Burger's equation .

Absorption and dispersion effects due to molecular relaxation are solved by lossless burgers' equation Fourier transformed into the frequency domain

Complete system resolution: 19 ODE solved by runge kutta 5 order method

SB prediction capabilities



Near field
(aerodynamics)

Mid field

Far field
(acoustical propagation zone)

Lossely Non linear Ray tracing
Geometrical acoustics

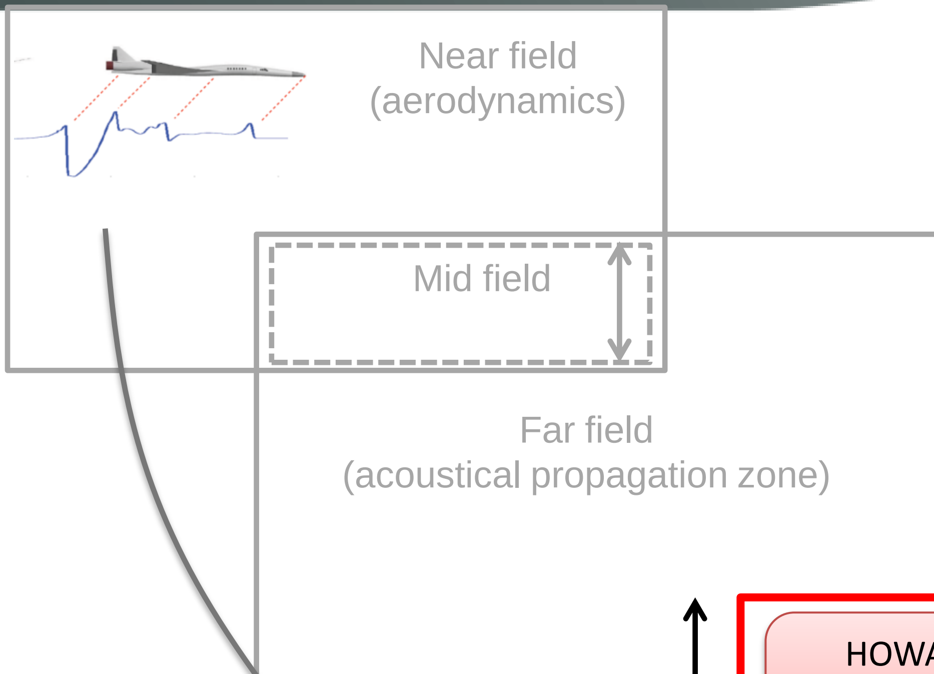
DAbang

Dabang Lossely non linear Ray tracing code capabilities:

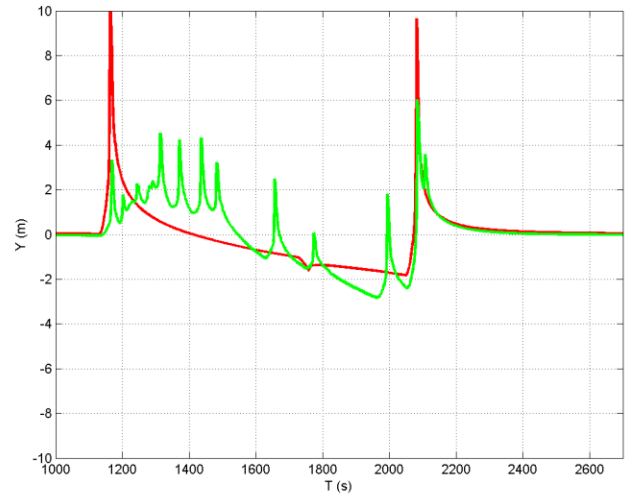
+ 3D SB prediction in stratified heterogeneous, moving and absorbent atmosphere.
+ Fast simulation → design tool
+ Caustics localisation.

- No Diffraction → several points poorly or not simulated (Shadow zone, Cut-off, focussing, turbulence)

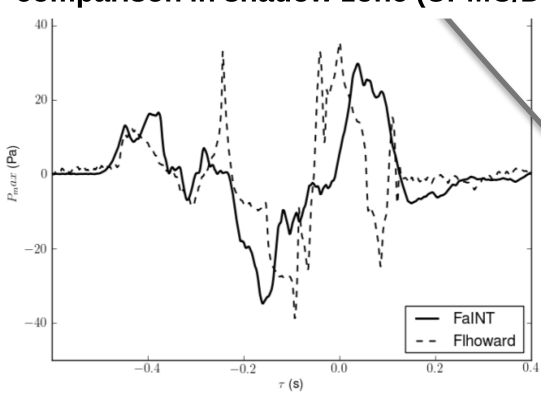
SB prediction capabilities
Beyond the geometrical approximation



Focussing of conventional « N » wave vs « Low Boom» (HOWARD2D)



FLOWARD/Flight test Sonic Boom comparison in shadow zone (UPMC/DA)

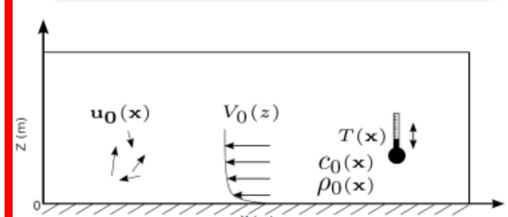


~1 km

HOWARD capabilities wasn't used in this workshop

Far field (planetary BL)

Diffraction, turbulence, non linearity



HOWARD2D (DA/UPMC) [5]/ FLHOWARD3D (UPMC) [6]

[5]: Dagrau, F. Coulouvrat, R. Marchiano, JASA, 2011
[6]:UPMC, Luquet PhD dissertation, AIAA Paper 2015-2685

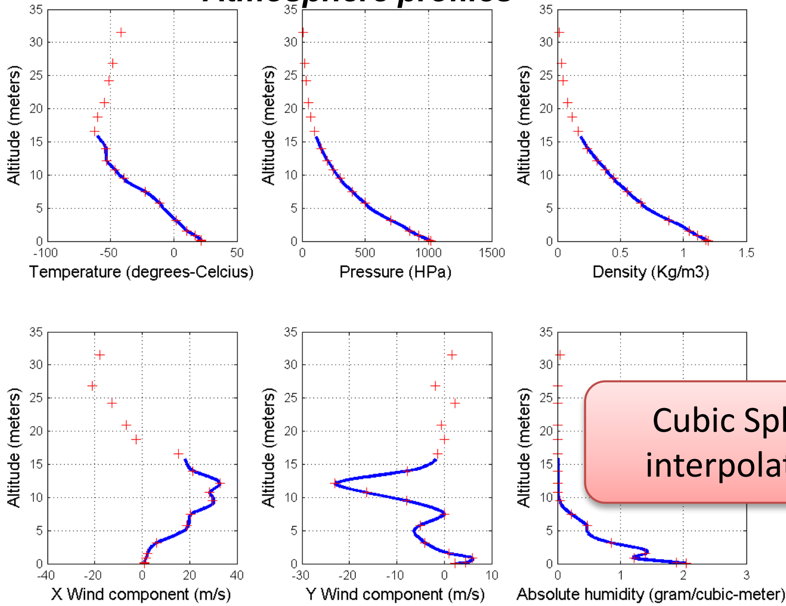
Summary of cases analyzed

	Required Run 1	Optional Run 1	Optional Run 2	Optional Run 3
Axibody	• 3 Ground signatures • Lateral cutoff angles & Location • Lateral cutoff signatures • Loudness values	• 3 Ground signatures • Lateral cutoff angles & Location • Lateral cutoff signatures • Loudness values	• 3 Ground signatures • Lateral cutoff angles & Location • Lateral cutoff signatures • Loudness values	• 3 Ground signatures • Lateral cutoff angles & Location • Lateral cutoff signatures • Loudness values
LM1021	• 3 Ground signatures • Lateral cutoff angles & Location • Lateral cutoff signatures • Loudness values	• 3 Ground signatures • Lateral cutoff angles & Location • Lateral cutoff signatures • Loudness values	• 3 Ground signatures • Lateral cutoff angles & Location • Lateral cutoff signatures • Loudness values	• 3 Ground signatures • Lateral cutoff angles & Location • Lateral cutoff signatures • Loudness values

Computed (required)
Not computed (optional)

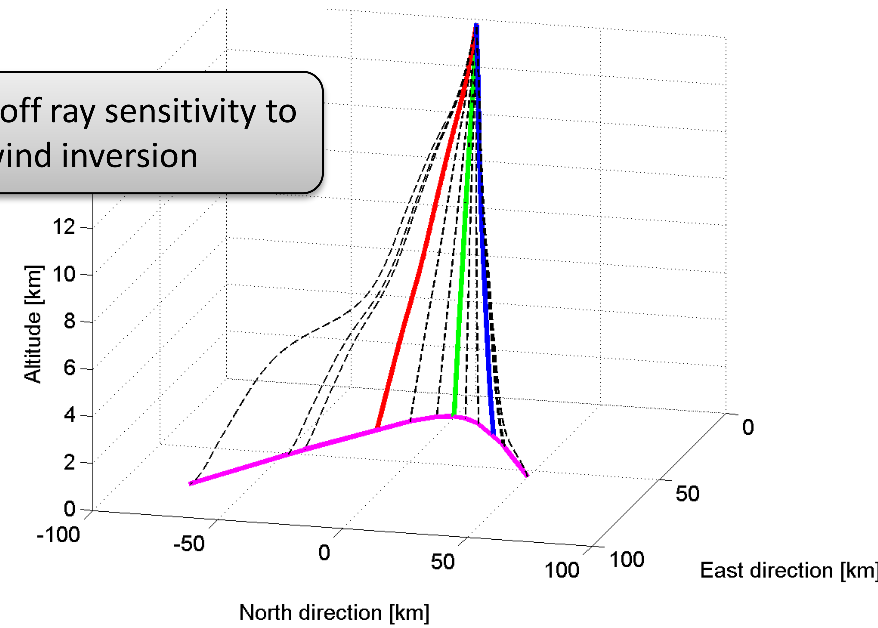
Test case results:
Required Run 1: Axibody – Atmo 3

Atmosphere profiles



Cubic Spline interpolation

3D Ray tracing

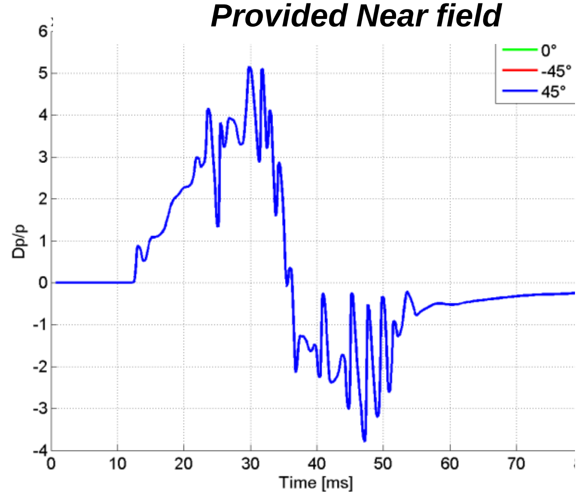


Big cut off ray sensitivity to wind inversion

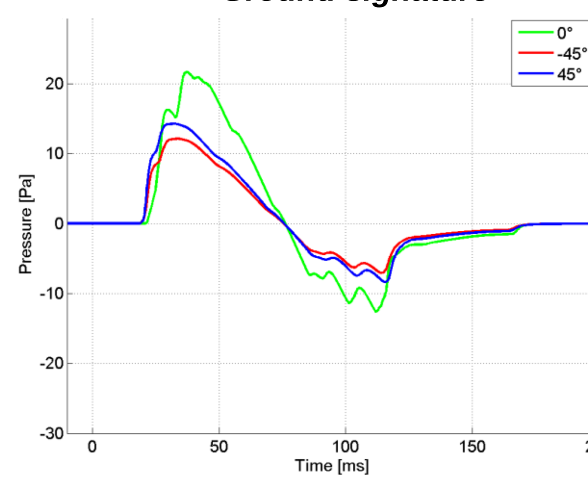
Lateral Cut off Angles

- **PHI min=-53.22455**
- **PHI max=50.68961**

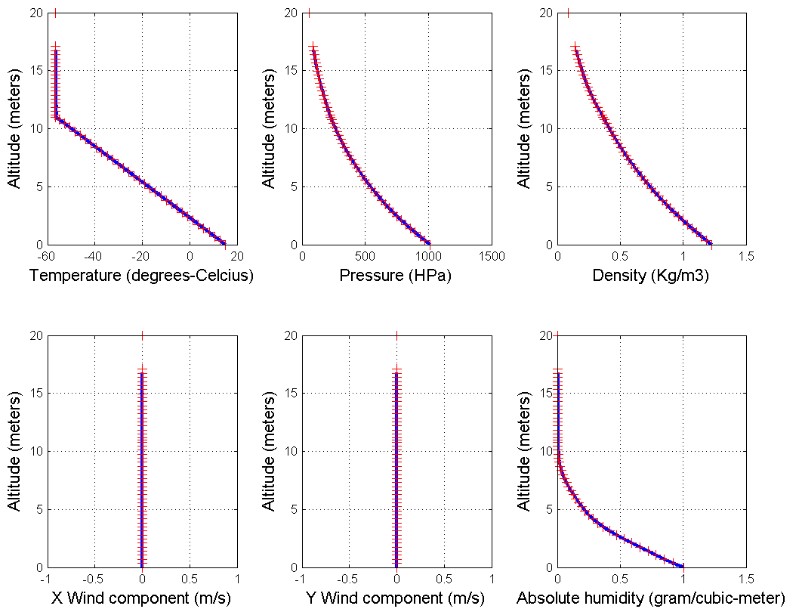
Provided Near field

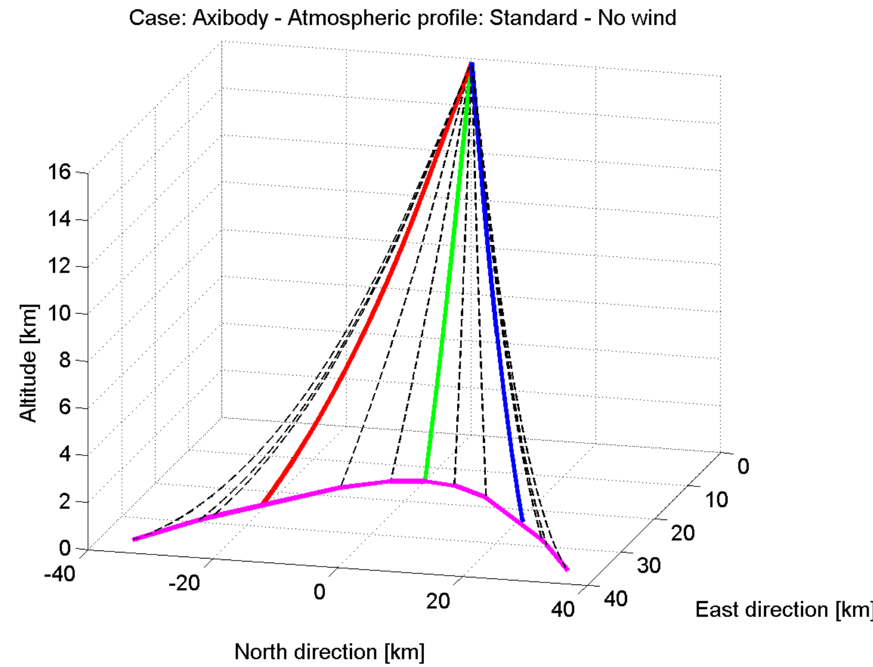


Ground signature



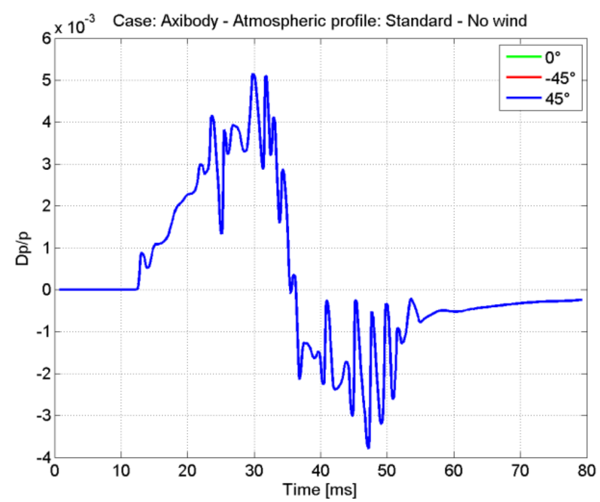
Test case results:
Optional Run 1: Axibody – Atmo Standard

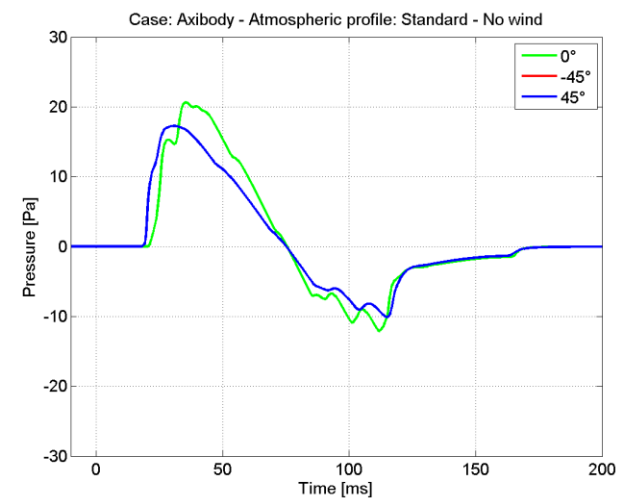




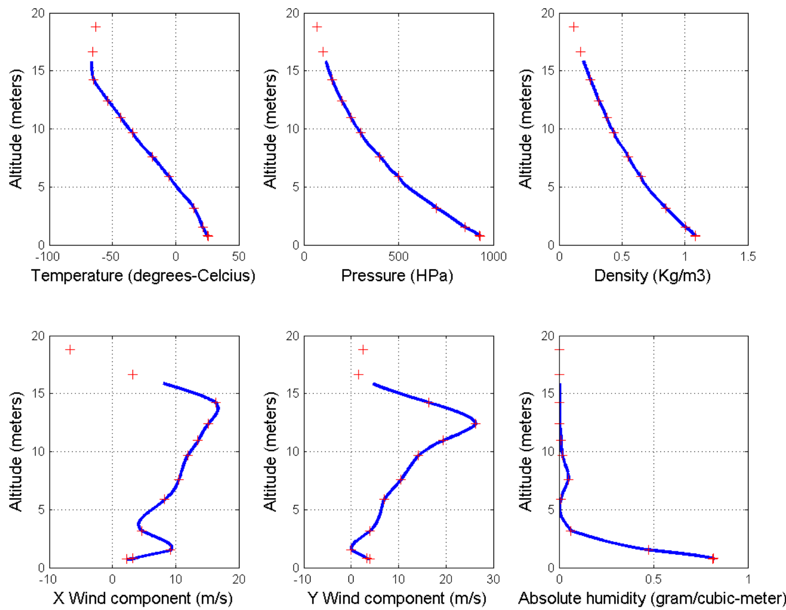
Lateral Cut off Angles

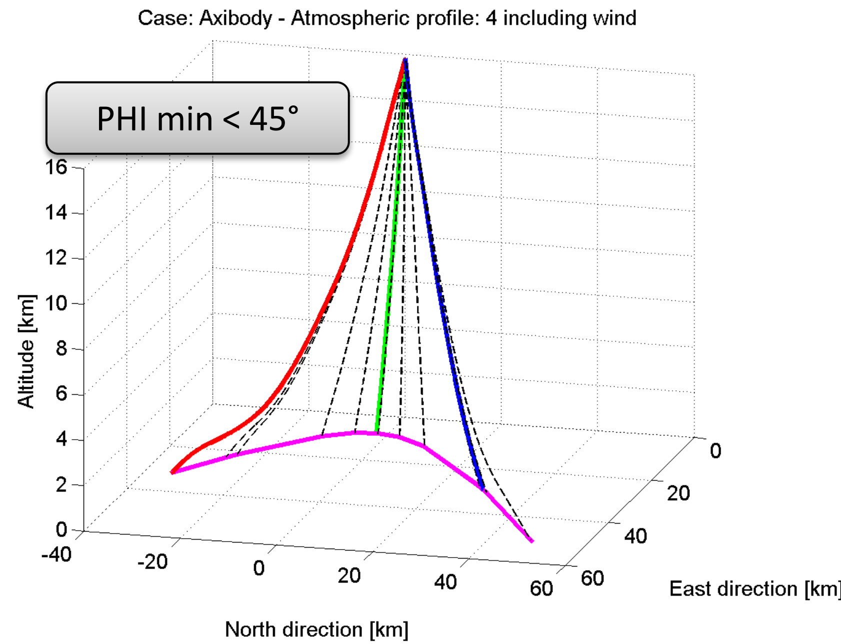
- **PHI min=-49.76462**
- **PHI max=49.76462**





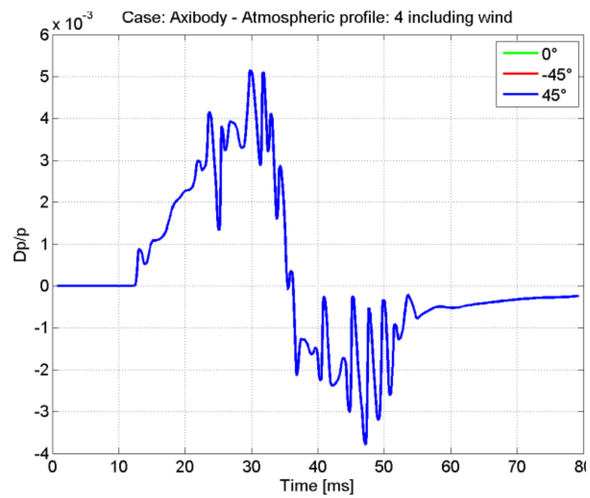
Test case results:
Optional Run 2: Axibody – Atmo 4

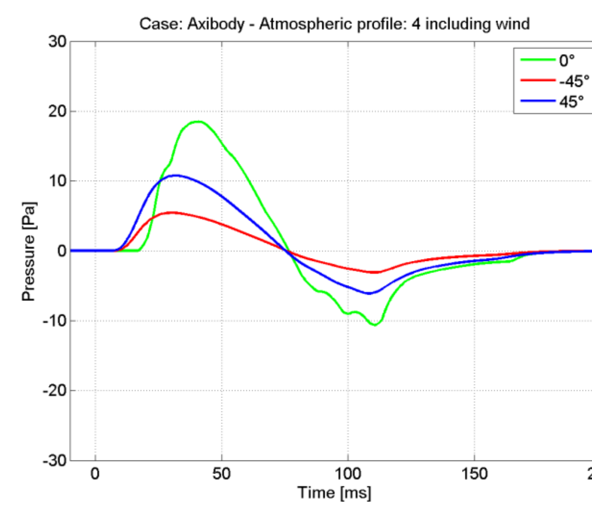




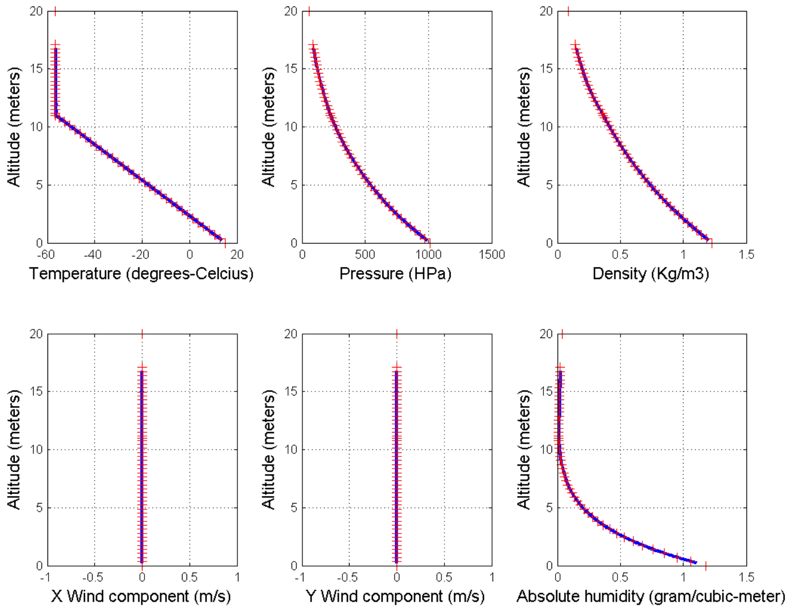
Lateral Cut off Angles

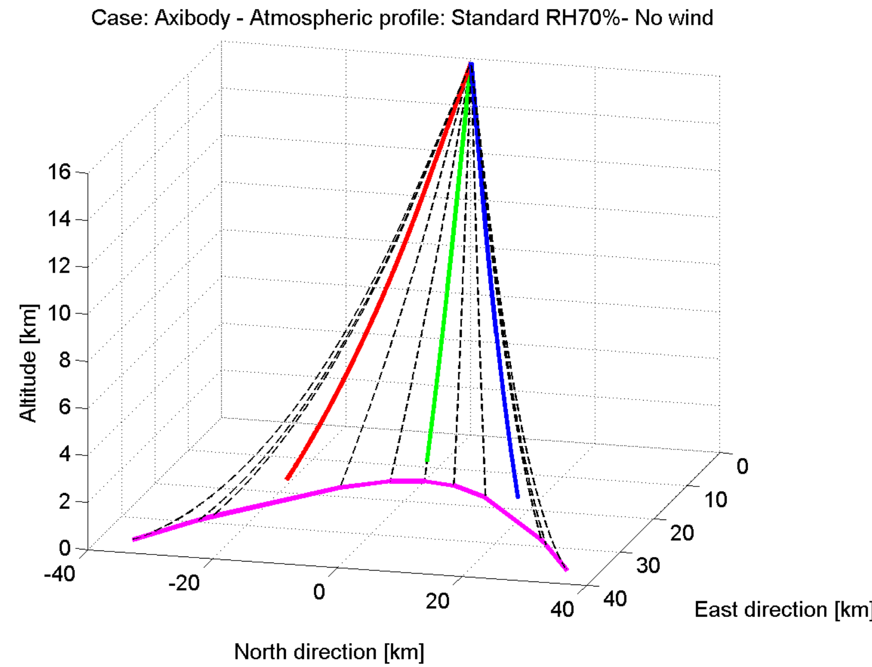
- **PHI min=-43.53432**
- **PHI max=45.80809**





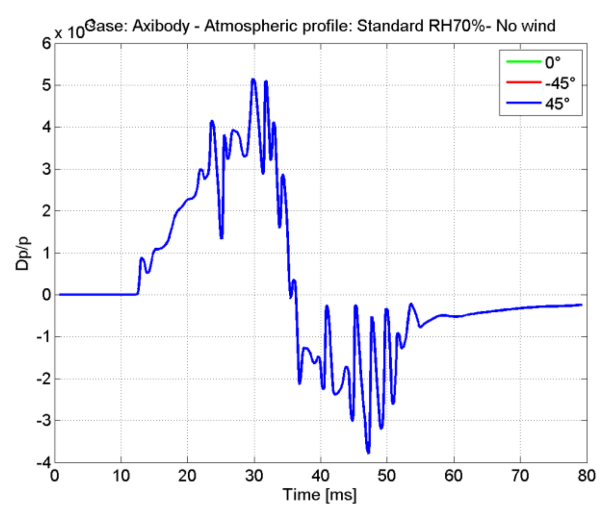
Test case results:
Optional Run 3: Axibody – Atmo Standard + RH=70%

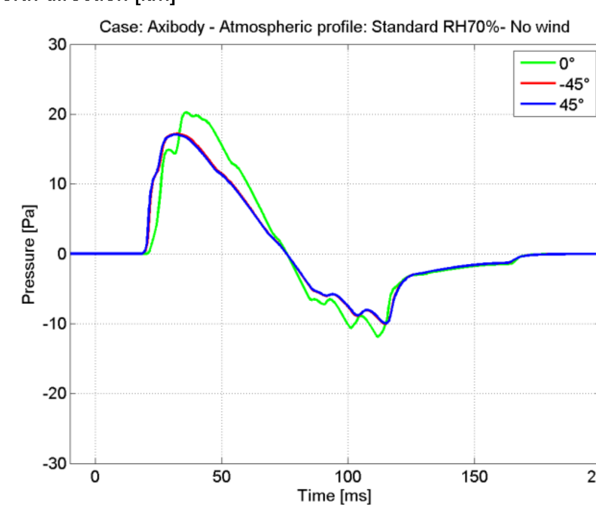




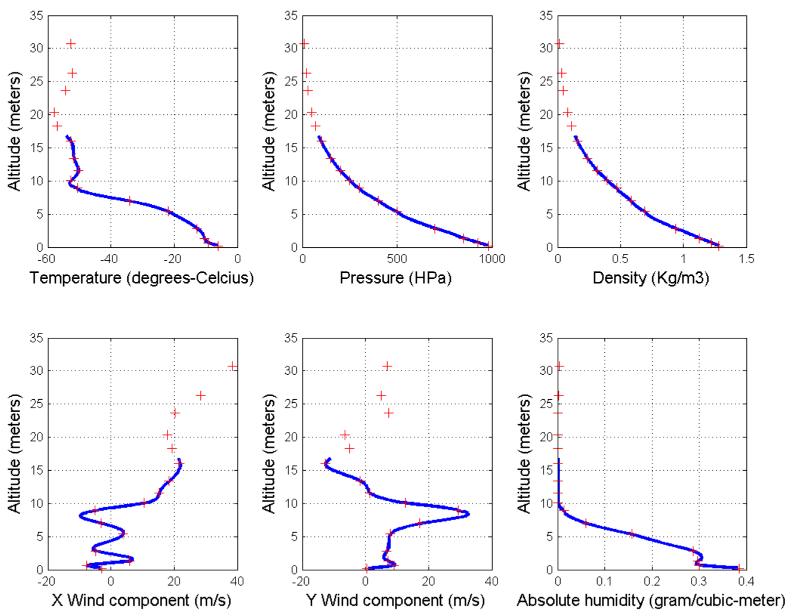
Lateral Cut off Angles

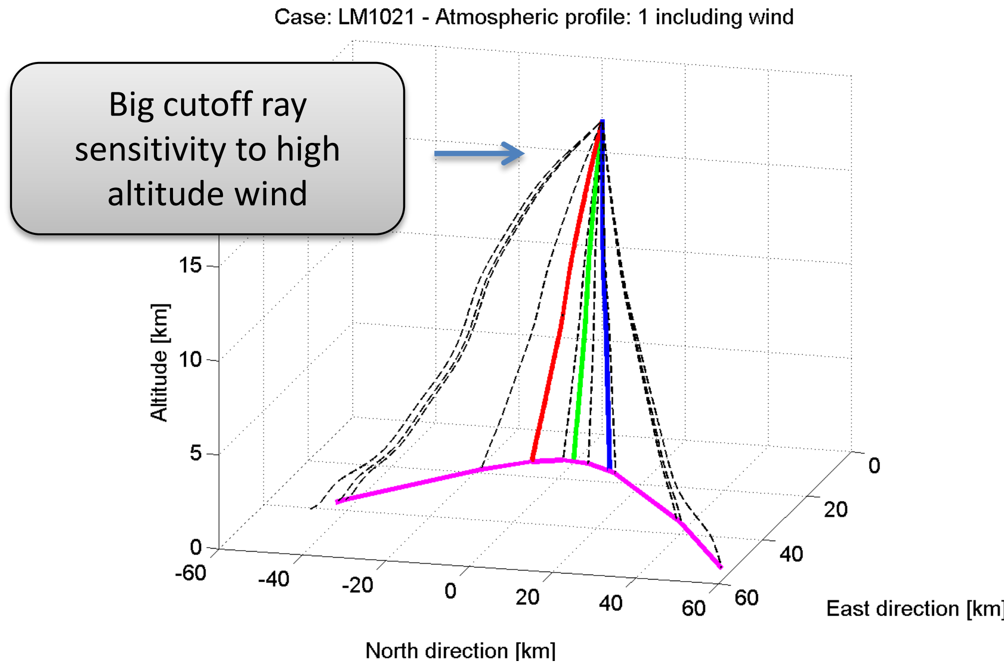
- **PHI min=-49.76462**
- **PHI max=49.76462**





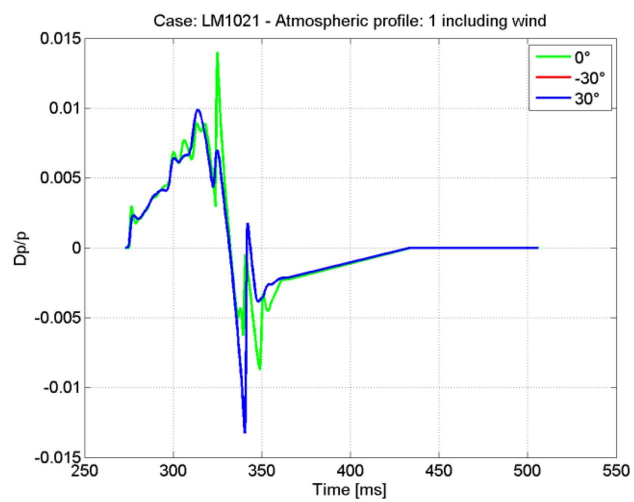
Test case results:
Required Run 1: LM1021 – Atmo 1 including wind

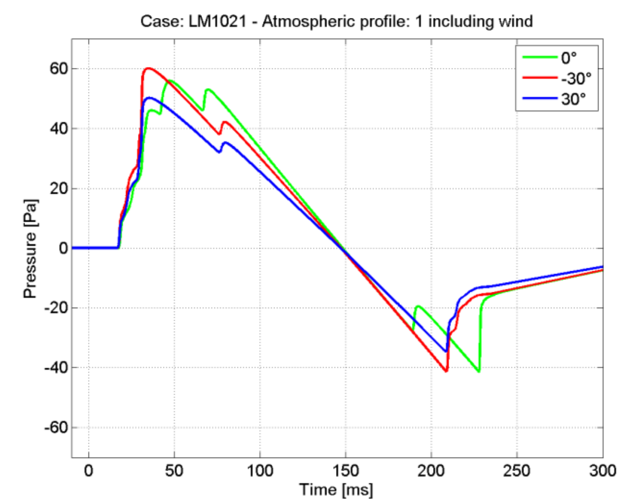




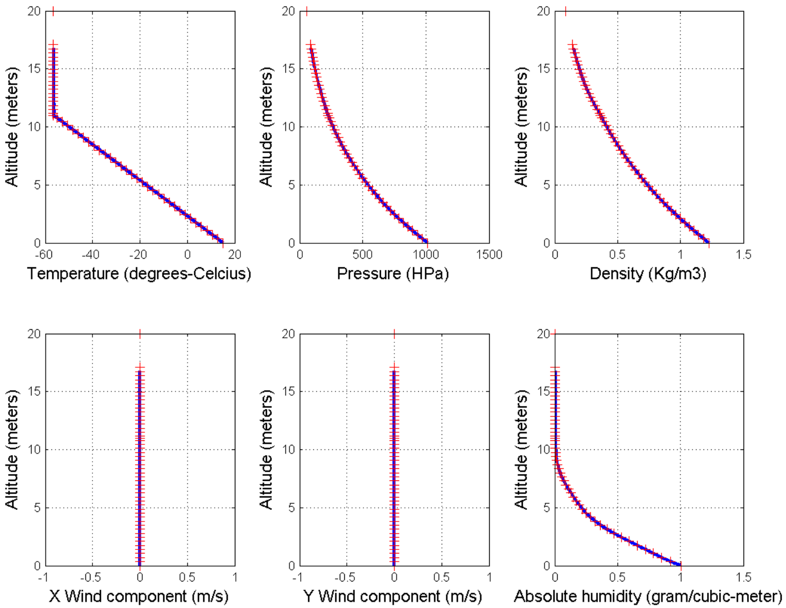
Lateral Cut off Angles

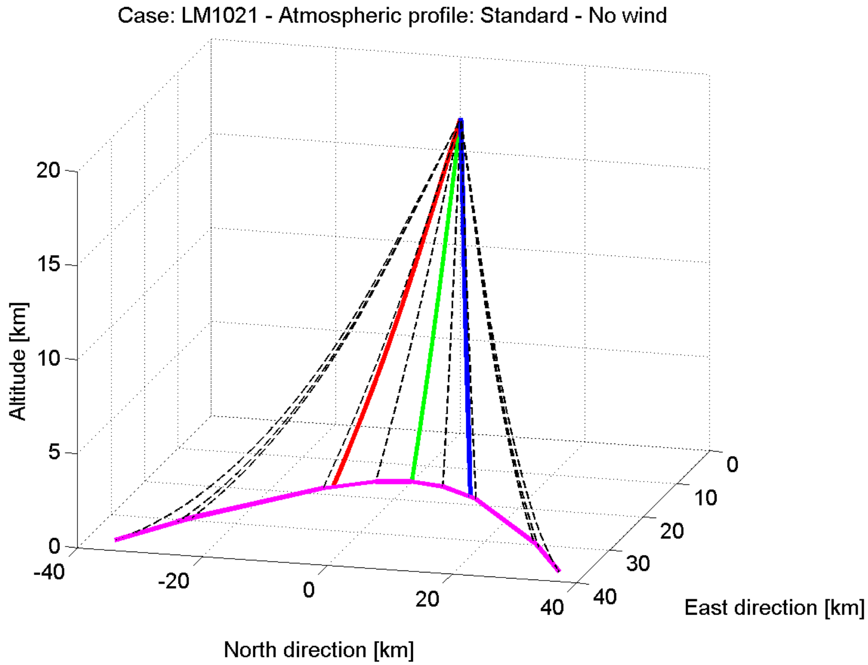
- **PHI min=-73.88688**
- **PHI max=56.63105**





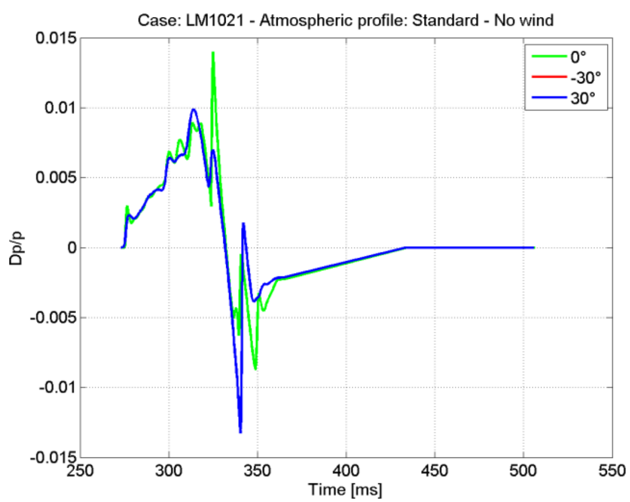
Test case results:
Optional Run 1: LM1021 – Atmo Standard

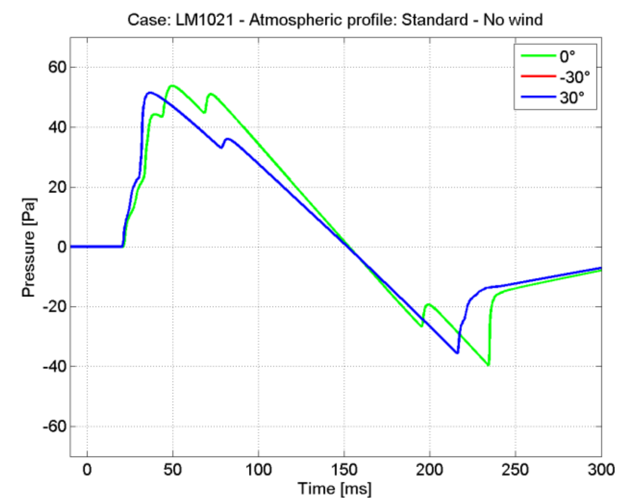




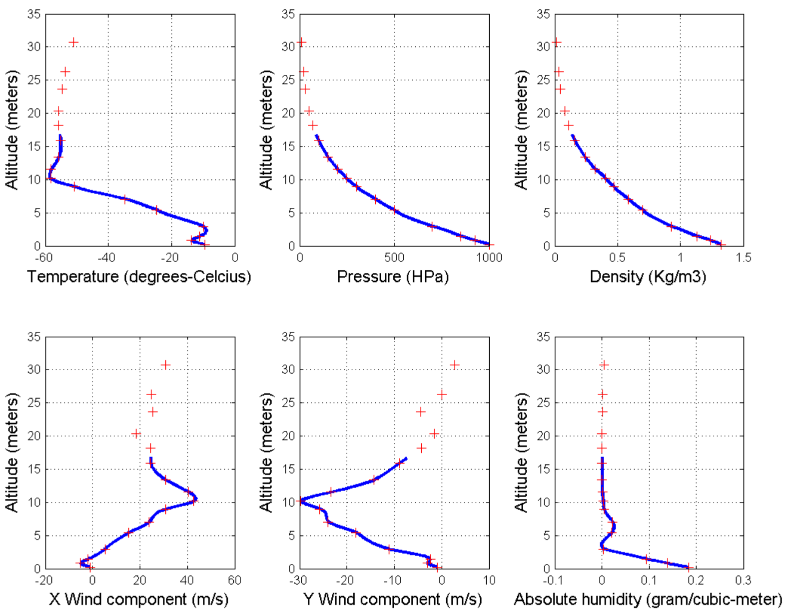
Lateral Cut off Angles

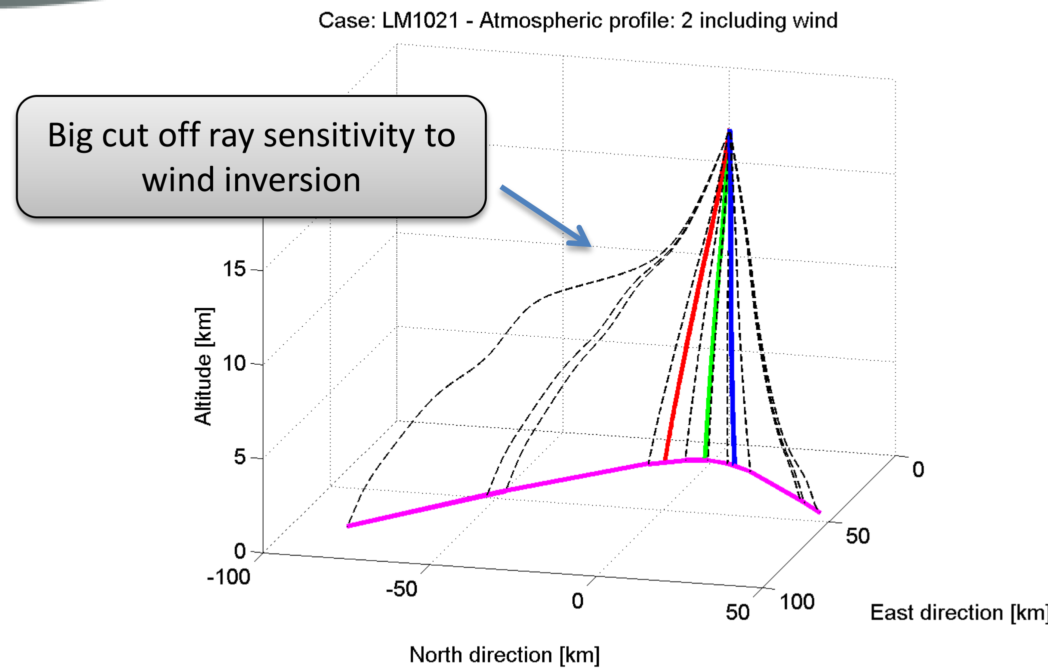
- **PHI min=-50.33222**
- **PHI max=50.33222**





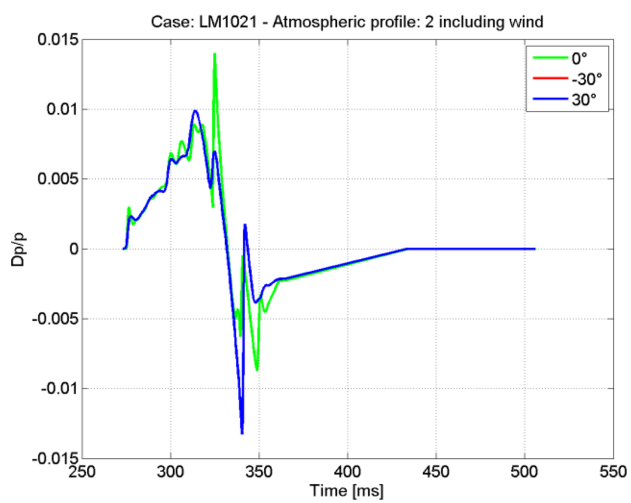
Test case results:
Optional Run 2: LM1021 – Atmo 2 including wind

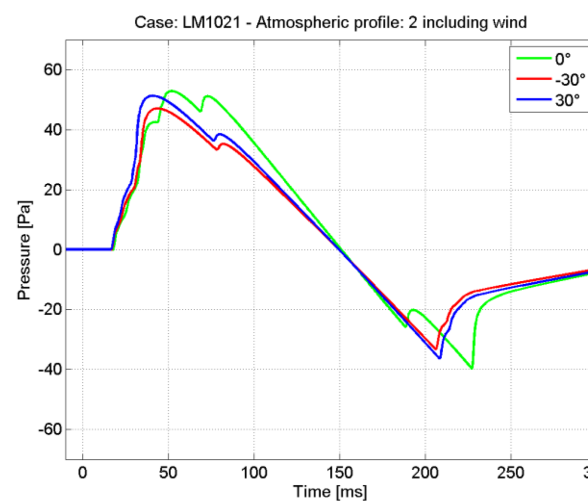




Lateral Cut off Angles

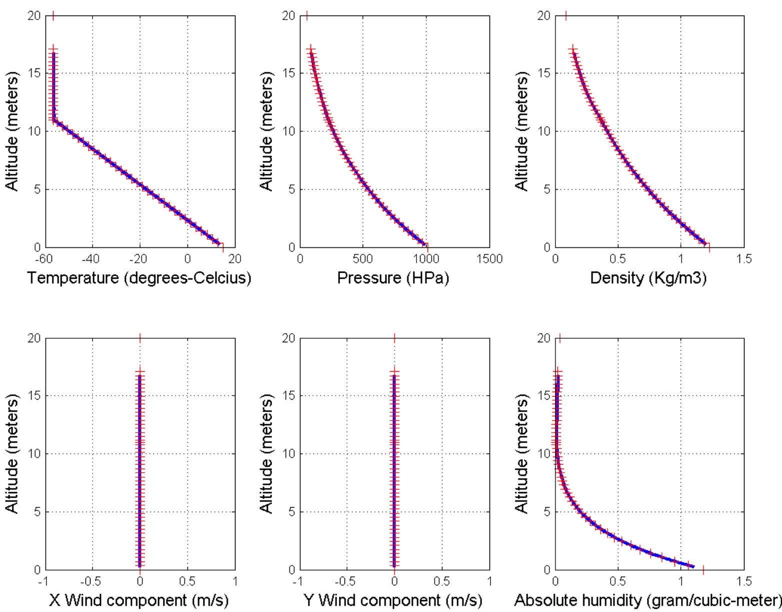
- **PHI min=-59.22792**
- **PHI max=64.53056**

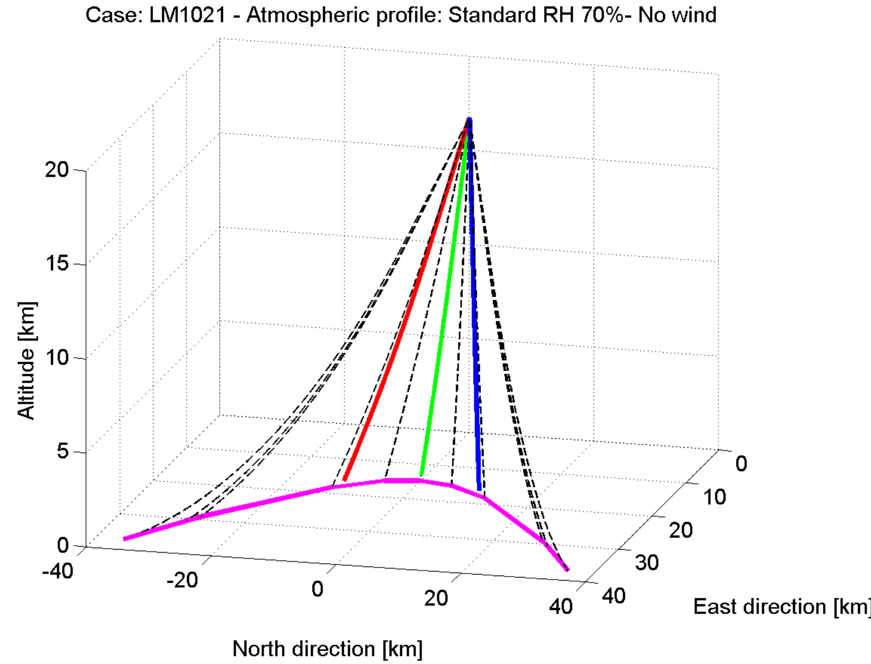




Test case results:

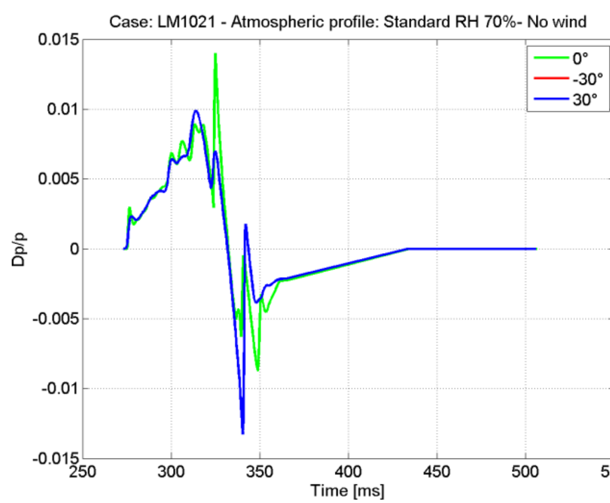
Optional Run 3: LM1021 – Atmo Standard + RH=70%

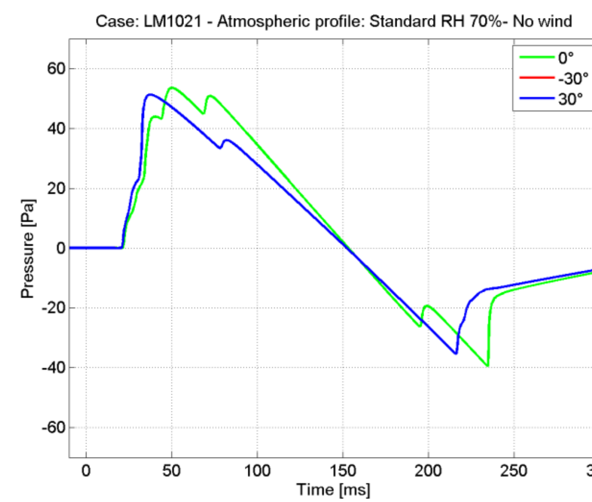




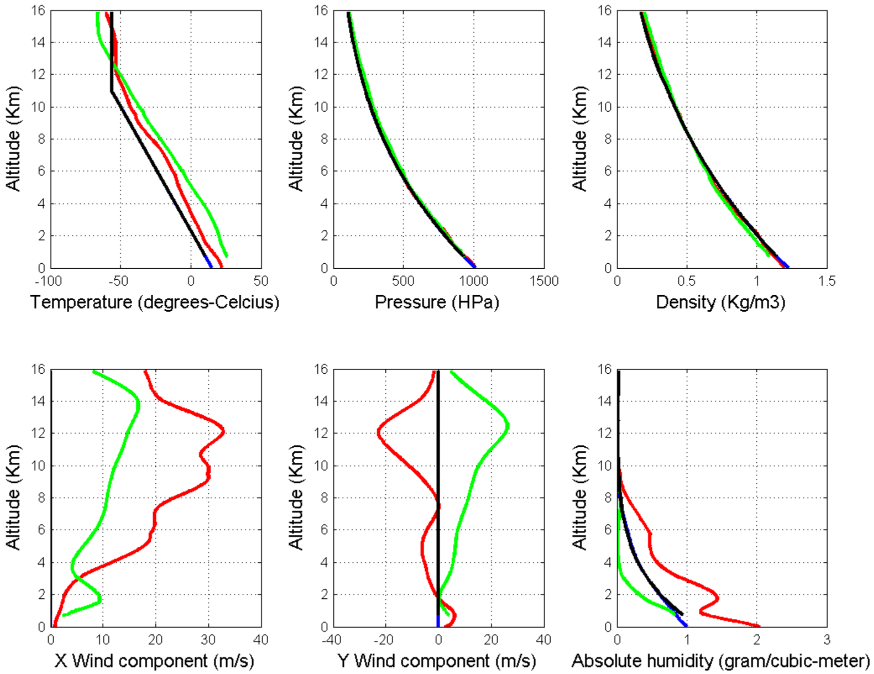
Lateral Cut off Angles

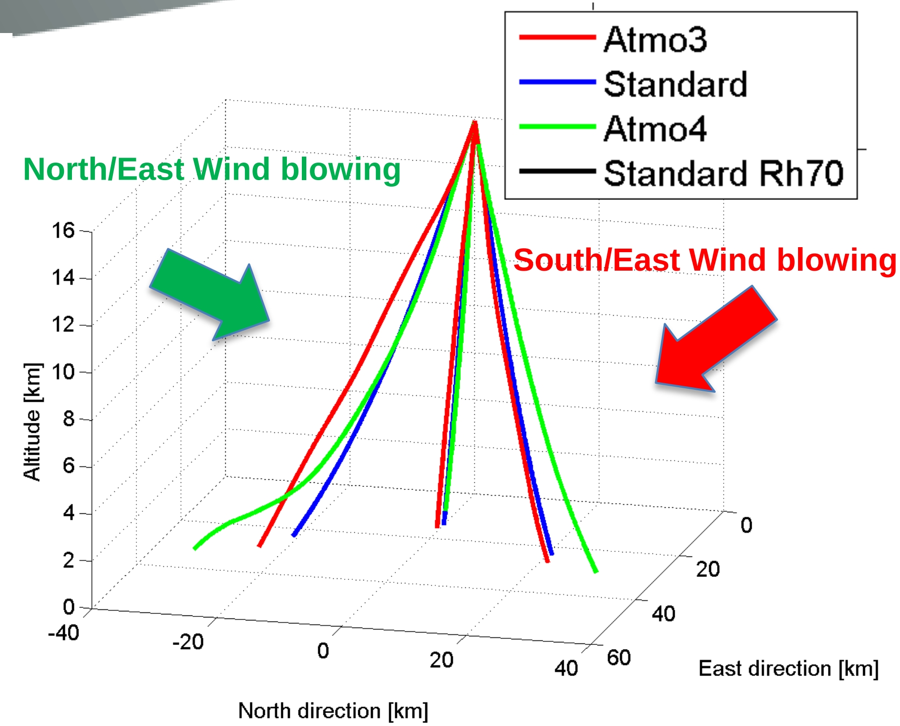
- **PHI min=-50.33222**
- **PHI max=50.33222**

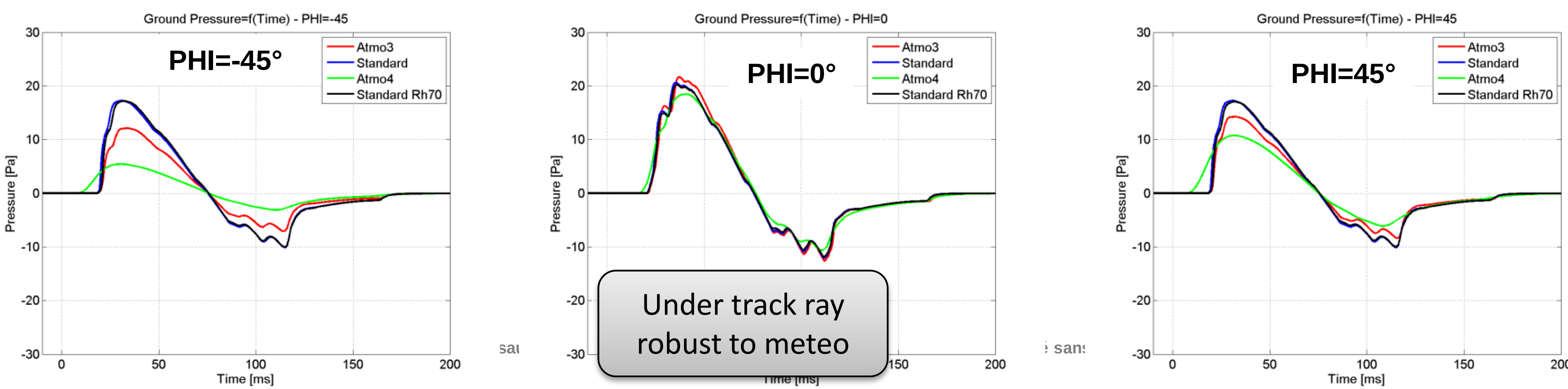




Test case Analysis: Axibody

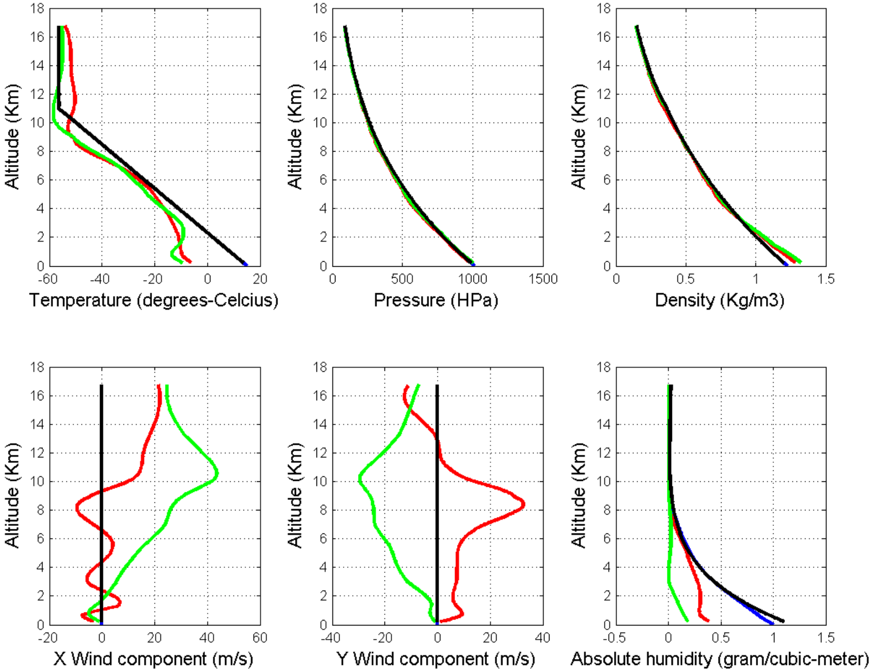


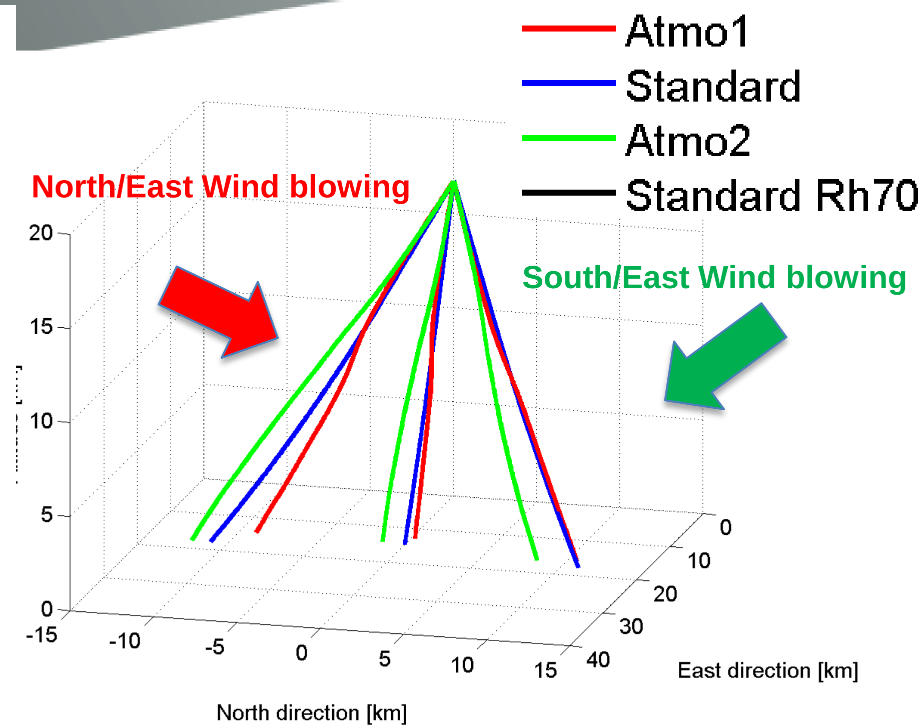


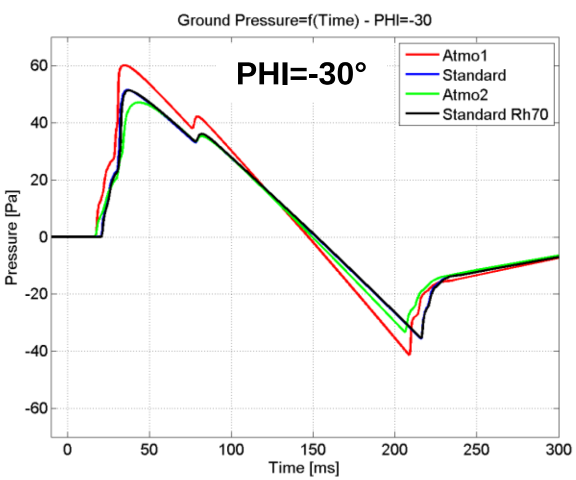


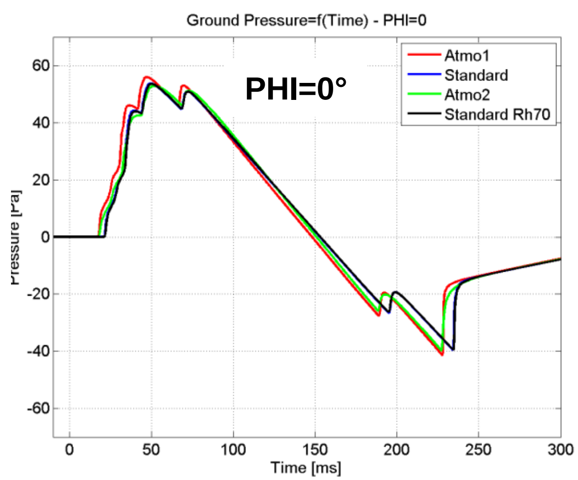
Under track ray robust to meteo

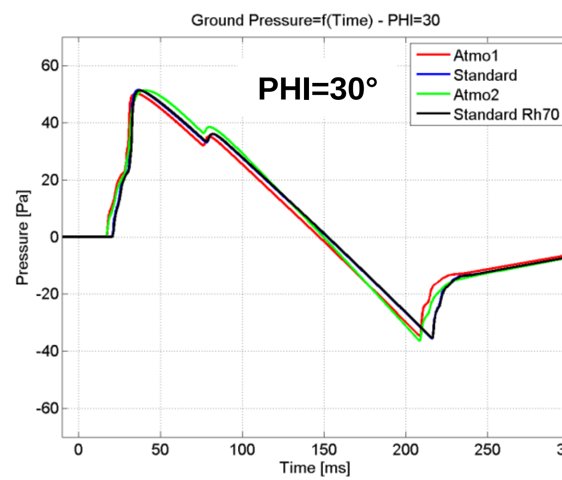
Test case Analysis: LM1021











Conclusion / Prospects

Propagation prediction code

• DAbang SB prediction code consists in solving a 19 ODE (6 for ray tracing, 12 for tube area, 1 for non linearities) by Runge Kutta order 5 algorithm.

• Atmospheric profiles interpolation based on cubic spline method

• Geometrical acoustics methodology is well adapted for prediction of 3D ray tracing in a moving heterogeneous and absorbent medium.

• Important atmosphere sensibility has been observed on lateral cutoff angle and ground location. Under track rays are robust to meteorological profile.

Conclusion / Prospects

Proposal for 3rd SB propagation workshop:

- Additional possible comparisons on 2rd SBPW test case:
    - Include one case without absorption effect (less physical but more discriminating)
    - Compare ground impact location to analytic solution in standard atmosphere
    - 3D Ray tracing
    - Propagation time along carpet
    - Tube area
    - Age variable for quantifying non linear effect.
    - Ground pressure spectra

- New test cases
    - Focussing test case (acceleration, turns and cut off trajectory)
        - Geometrical location of caustics
        - Pressure signal in focussing zone.
    - Lateral shadow zone test case
        - Ground pressure signal with cutoff distance

Acknowledgments

- SB prediction workshop committee is thanked for organizing, providing test cases and making synthesis

- Questions ?