3rd AIAA Sonic Boom Prediction Wokshop

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ONERA propagation results using the BANGV code

Gérald Carrier (carrier@onera.fr)
Aerodynamics, Aeroelasticity and Acoustics Department
Civil Aircraft Unit

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Outline

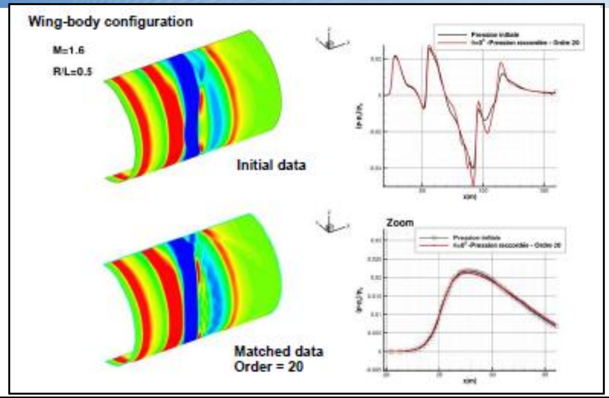
- Description of methods & codes
  - BANGV propagation code
  - Specific parameters/options
- Summary of analysed cases
- Overview of the results:
  - for Case 1
  - for Case 2
- Summary & highlights

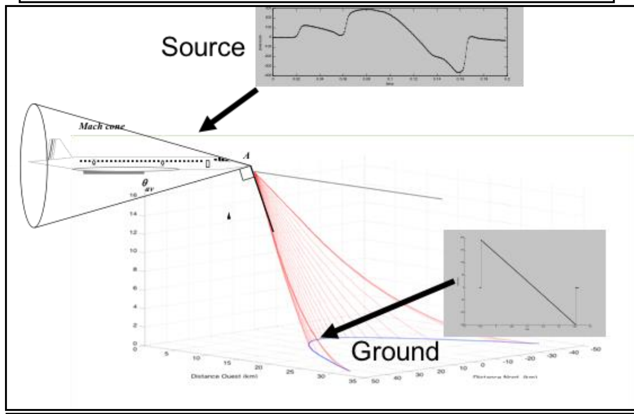
Codes in use at ONERA for Sonic Boom Propagation

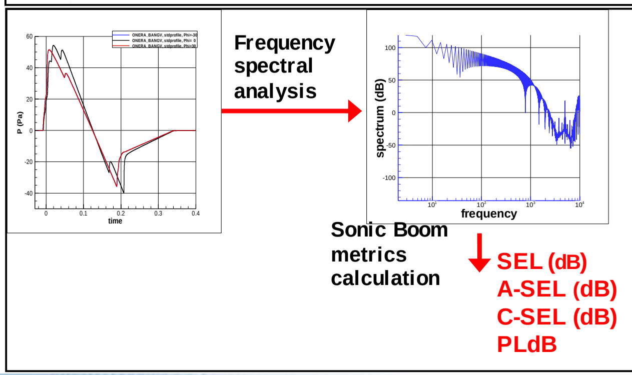
- **Multipole matching code**
  - In-house code based on Plotkin and Page, 2002 [1]

- **Propagation codes:**
  - In-house evolution of the TRAPS [2] code (non viscous)
  - BANGV [3]: developed by Sorbonne University (UPMC/CNRS by F. Coulouvrat et al., Aerospatiale proprietary (now Airbus)

- **Loudness calculation:**
  - pyBoomMetrics: in-house Python code for dB, PLdB, A-, B-, C-, D-SEL metrics calculation
  - Validated with the RUMBLE project

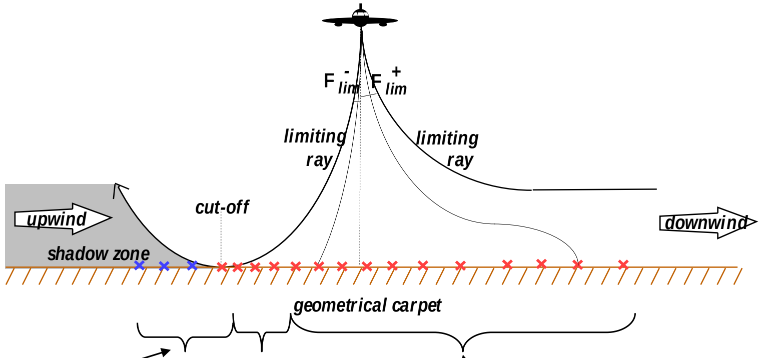






[1] I. Salah El Din et al., « Impact Of Multipole Matching Resolution On Supersonic Aircraft Sonic Boom Assessment », Progress in Flight Physics 5 (2013) 601-620
[2] A. D. Taylor, « The Traps Sonic Boom Program », NOAA Technical Memorandum ERL ARL-87,
July 1980 Air Resources Laboratories, Silver Spring, Maryland
[3] F. Coulouvrat, « Théorie géométrique non linéaire de la diffraction en zone d'ombre », C. R. Acad. Sci. Paris, 325, Série II b, 69-75, 1997

BANGV propagation code



BANGV – v4:

- **Assumptions:**
  - Stratified atmosphere, no turbulence
  - Flat, absorbing ground
- **Methods and models:**
  - Ray tracing: integrating a system of 14 ODEs [4] in dZ (param. near ground using eikonal function)
  - Along rays: solves augmented Burgers equation (with dissipation due to thermoviscous effects + molecular relaxation) using a split-step algorithm
  - Ground interaction: different models (simple rigid round for present study)
  - Diffraction at the limit of carpet by Fock integral
  - Shadow zone after cutoff: creeping wave
  - Caustics identification and pressure signal calculation (Tricomi equation), clouds effects
- **Inputs:**
  - SB near-field modeled by Whitham F function or cylindrical pressure distr. at a given distance of the A/C
  - A/C trajectory interpolated by cubic spline
  - Atmospheric data (T, rho, RH, wind) interpolated by cubic spline
- **Performance:**
  - typical runtime: ~ 1 sec. per ray on (one CPU processor) with viscous effect

[4] S.M. Candel, Numerical solution of conservation equations arising in linear wave theory: application to aeroacoustics, J. Fluid Mech., 83, 465-493. ,1977

Specific parameters/options

- **Data pre/post-processing:**
  - Direct matching (no multipole matching because R/L=3)
  - Change axis to adapt to SBPW3 convention for A/C trajectory (X→-Y, Y→X) and position of ground impacting point
  - Altitude shift of atm. data to have ground at alt. zero
  - Near field tail extension (return to zero)
  - Apply a factor 1.9/2.0 on ground pressures results from BANGV
- **Propagation:**
  - Discretization:
    - Pressure input signal re-sampled every ~0.01 m with 32,768 points
    - Rays integration : 200 steps (for dissipative effects)
    - Vertical atmosp. discretization for carpet limits identification: 500,000 points
- **Loudness metrics calc.:**
  - Sampling at > 50 kHz
  - Max. freq for spectrum integration: 10 kHz

Summary of analysed cases

	Case 1	Case 1 - optional	Case 2 - Balloon	Case 2 – Standard
Near field	NASA C25D (R=100.6 m, R/L=3)		C609 (R=82.3 m, R/L=3)	
Alt	15760 m	13716 m	16459 m	
Mach	1.6	1.4121	1.4	
Ground alt.	264 m	58 m	110 m	
Flight traject.	Steady, (heading East)	Accelerated (heading East)	Steady, (heading East)	
Atmosphere	Atm. 1	Standard	Balloon	Standard
Results	Cut-off angles	Caustic Phi=0	Cut-off angles	
	Ground intersection of iso-emission time rays at specified Phi		Ground intersection of iso-emission time rays at specified Phi	
	Grounds pressure at specified Phi (along carpet)		Grounds pressure at specified Phi (along carpet)	
	Loudness (PL, A-, B-, CSEL)		Loudness (PL, A-, B-, CSEL)	

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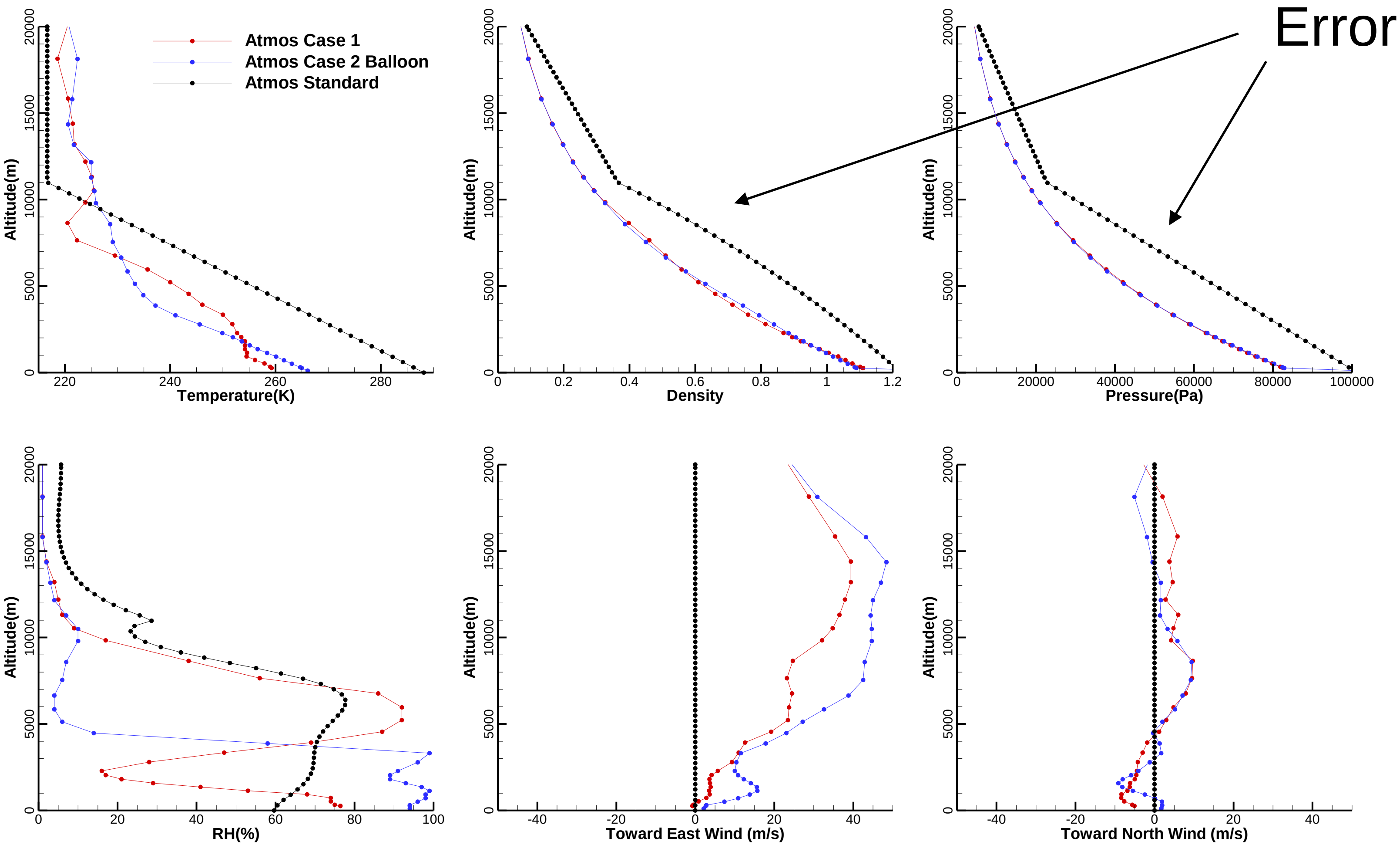
Summary of analysed cases

3 different atmosphere profiles considered :



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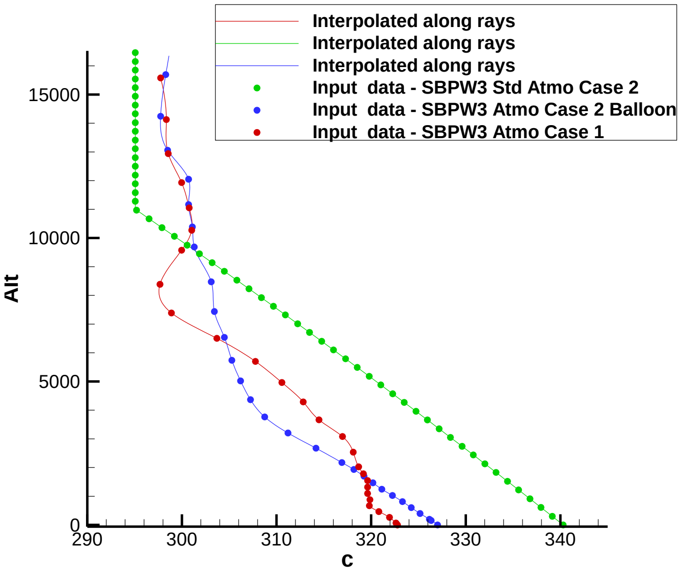
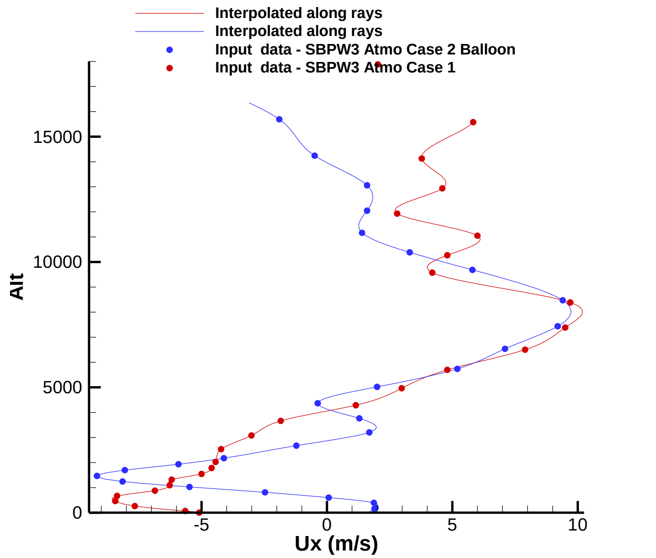
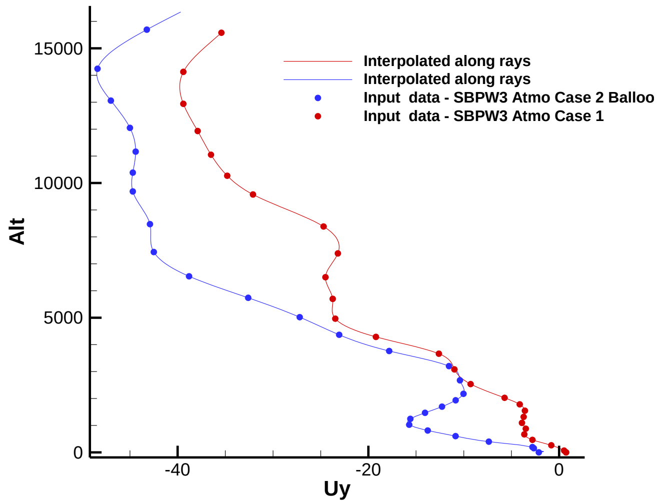
Interpolation of atmospheric data in BANGV

Cubic spline used in BANGV:
Check of the internally interpolated data







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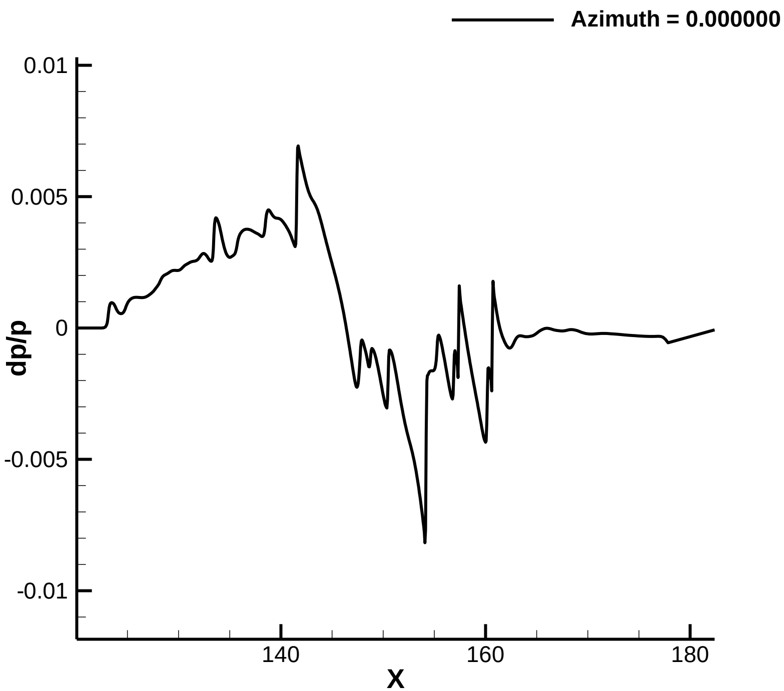
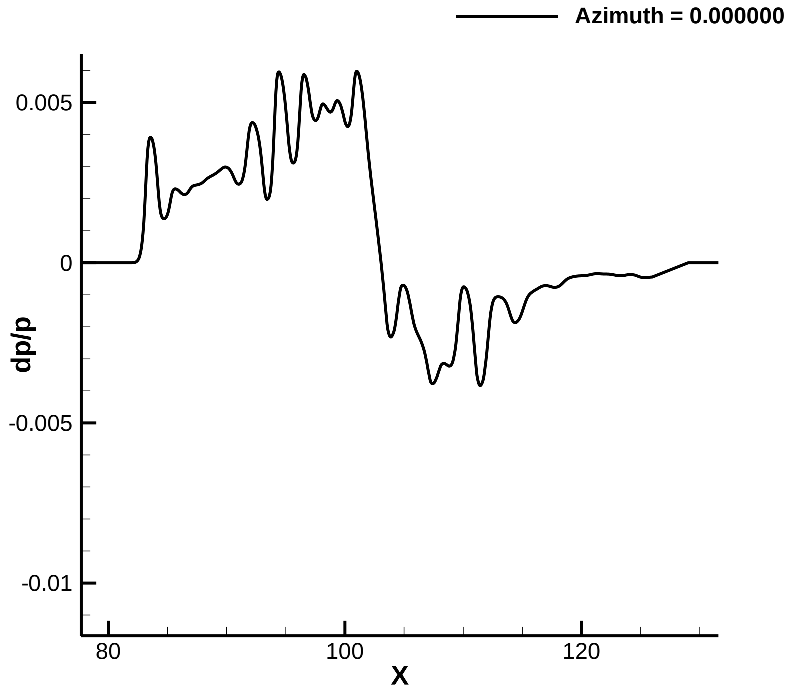
Summary of analysed cases

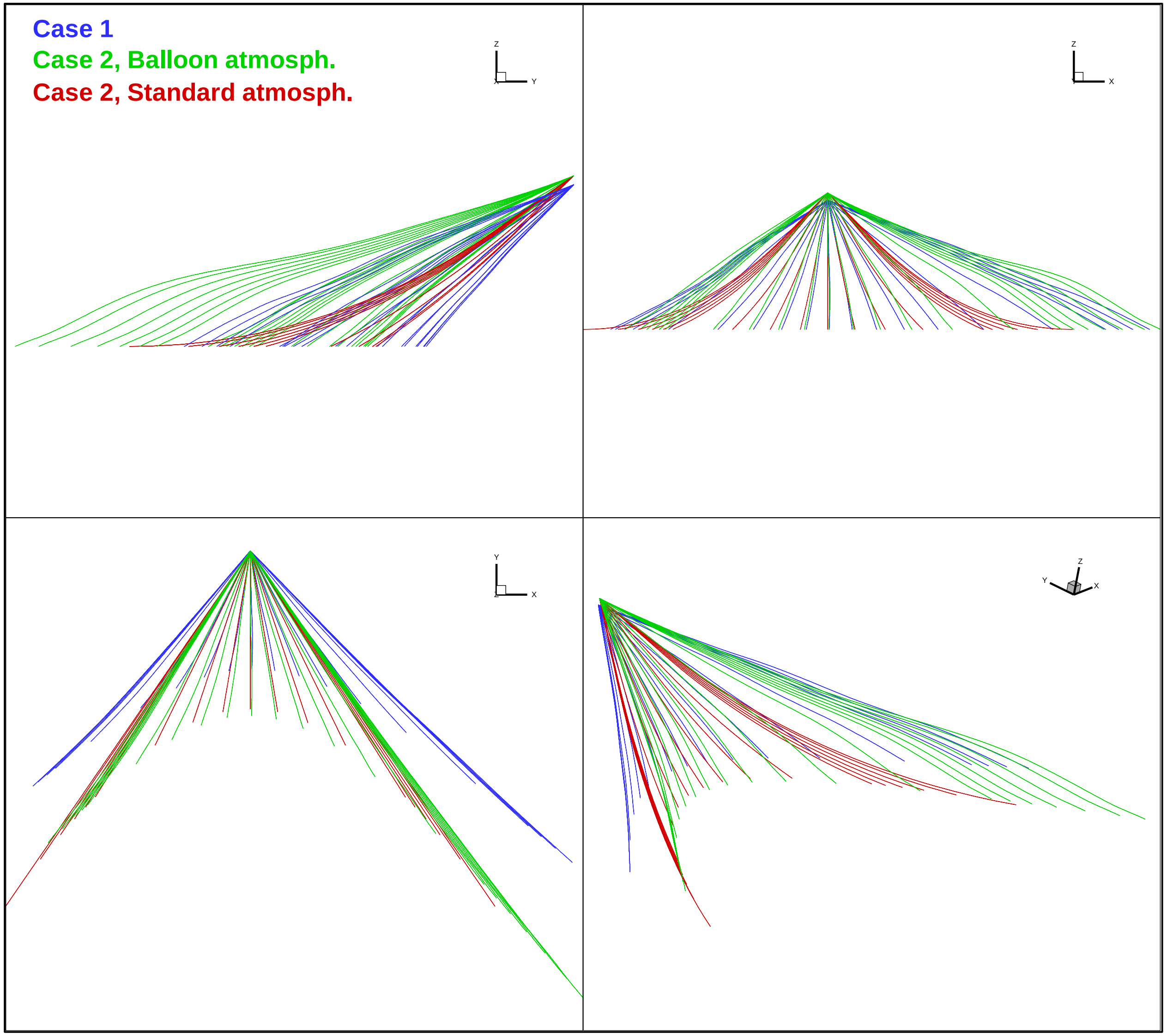
Case 1 near-field: C25P at R/L=3



Case 2 near field: C609 at R/L=3



Results for ray trajectories

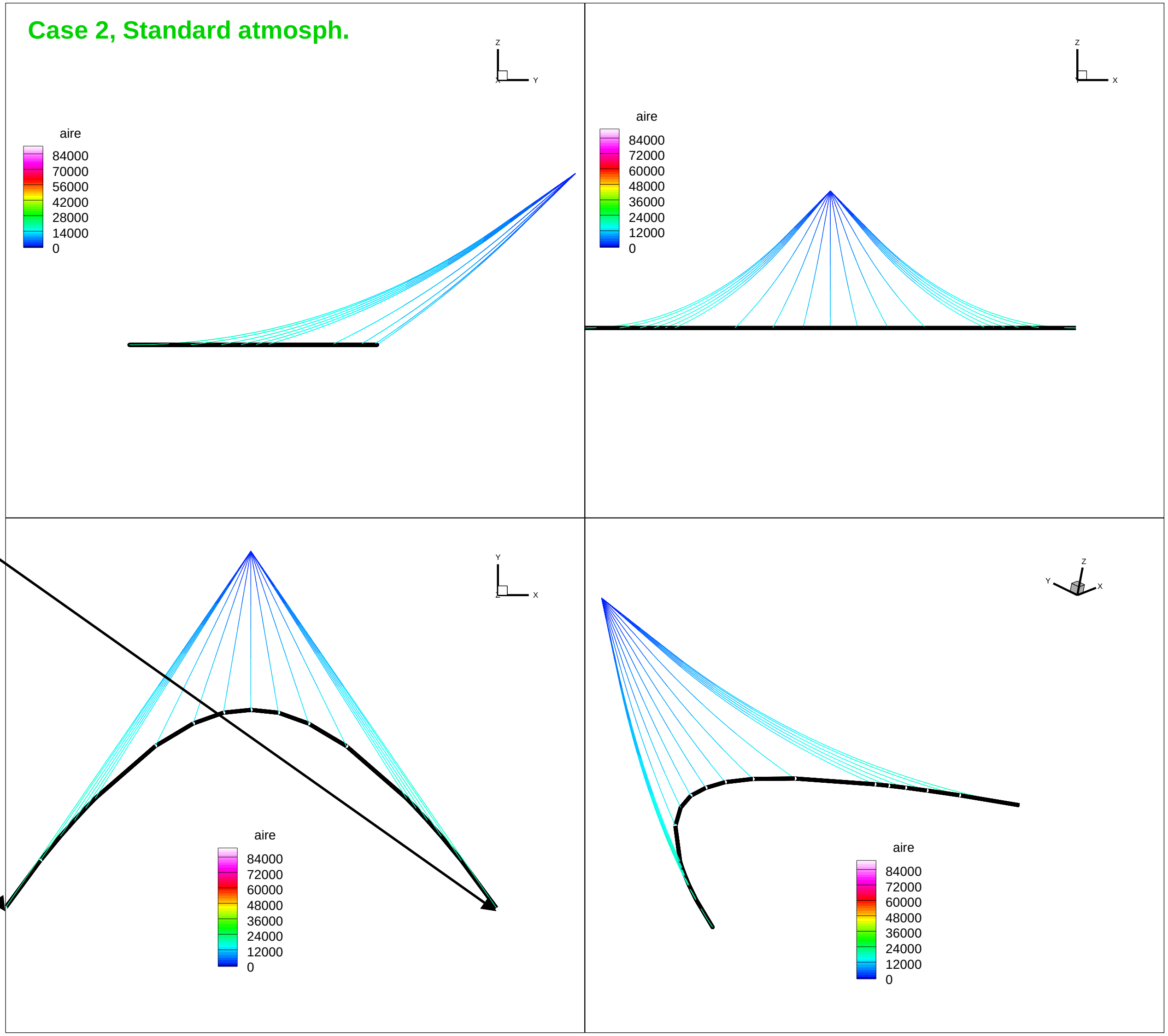


Results for ray trajectories : Case 2 Standard atm.

Cut-Off angles:

- Φ= -44.62°
  X=-29,295 m
  upward

- Φ= 44.62°
  X= 29,295 m
  upward



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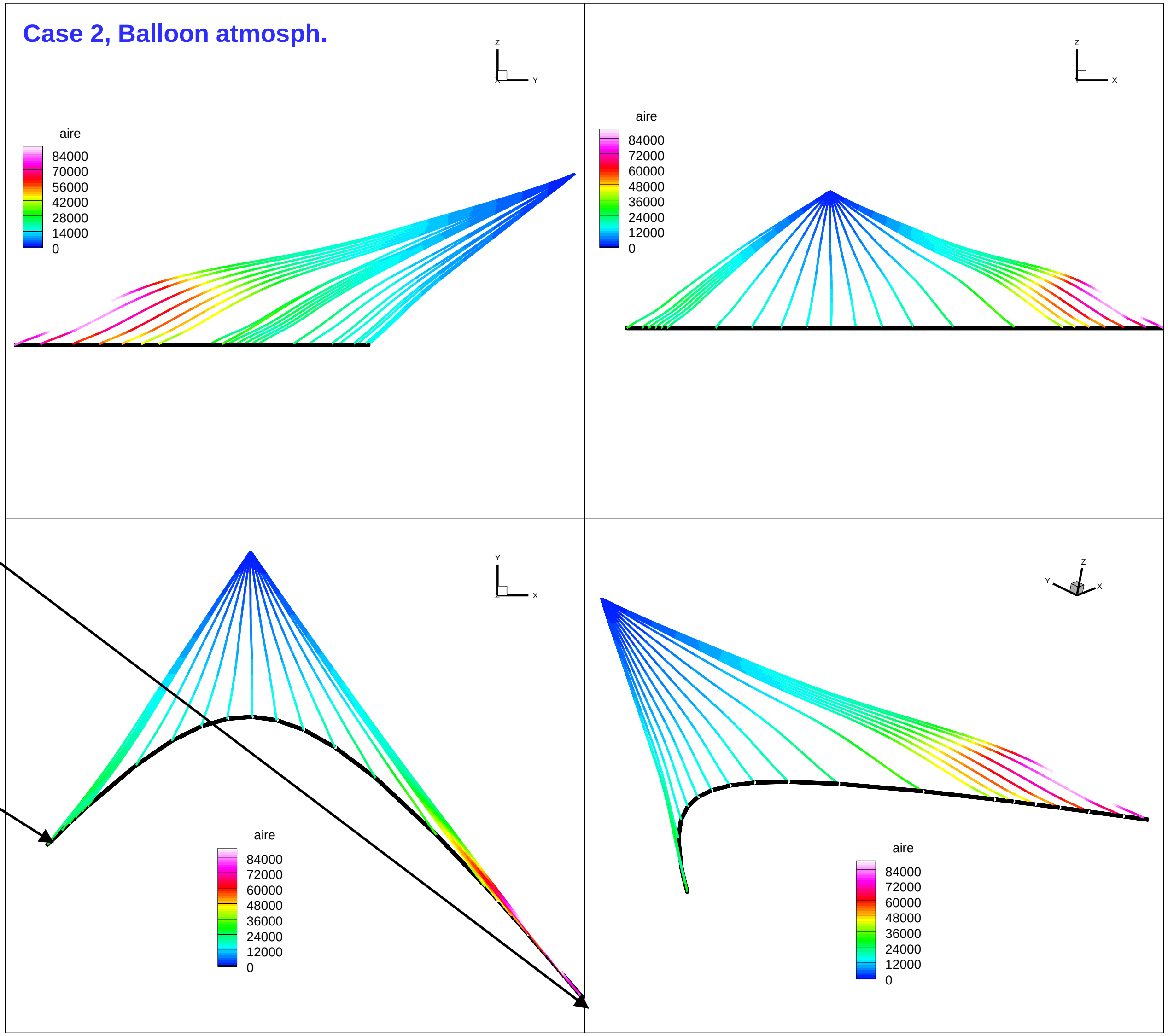
Results for ray trajectories : Case 2 Balloon atm.

Cut-Off angles:

- Φ= -60.61˚
  X=-39,843 m
  downward

- Φ= 55.98˚
  X= 24,229 m
  downward



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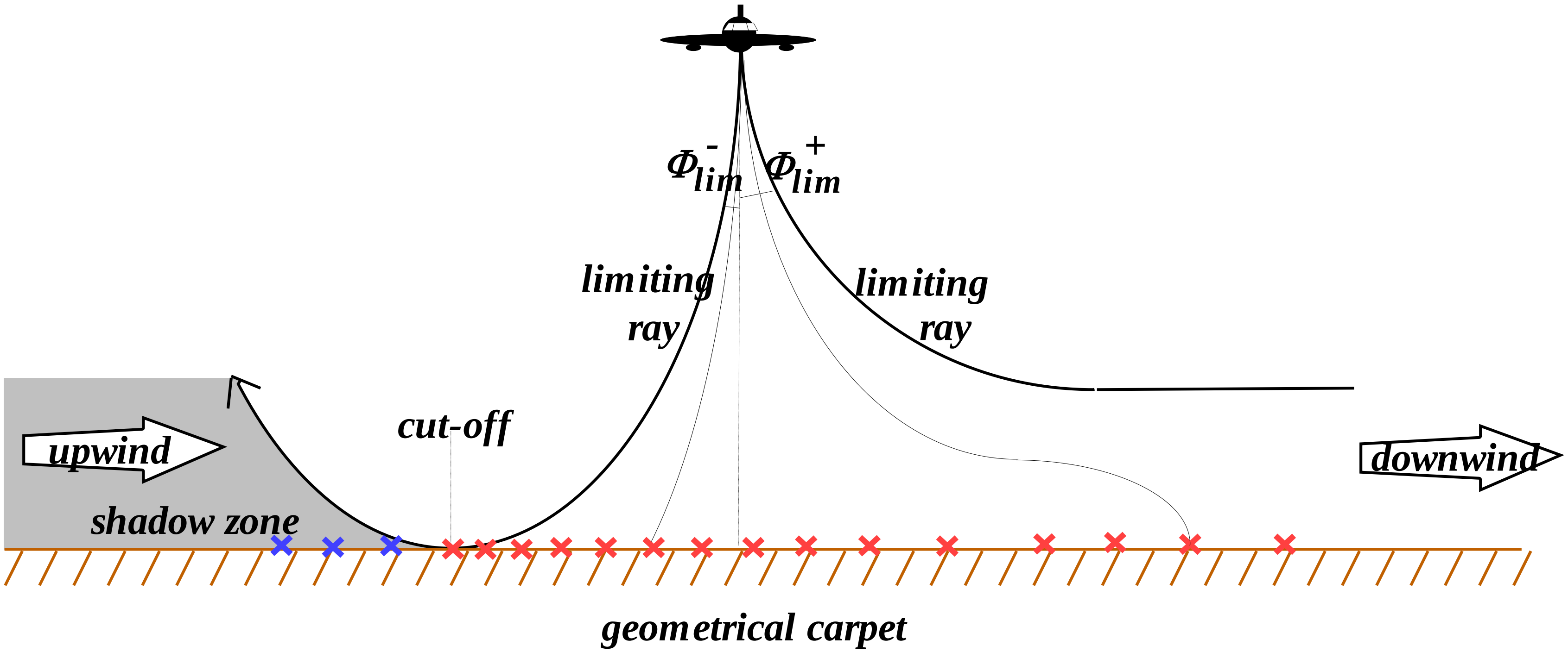
Upward versus downward cutoff rays



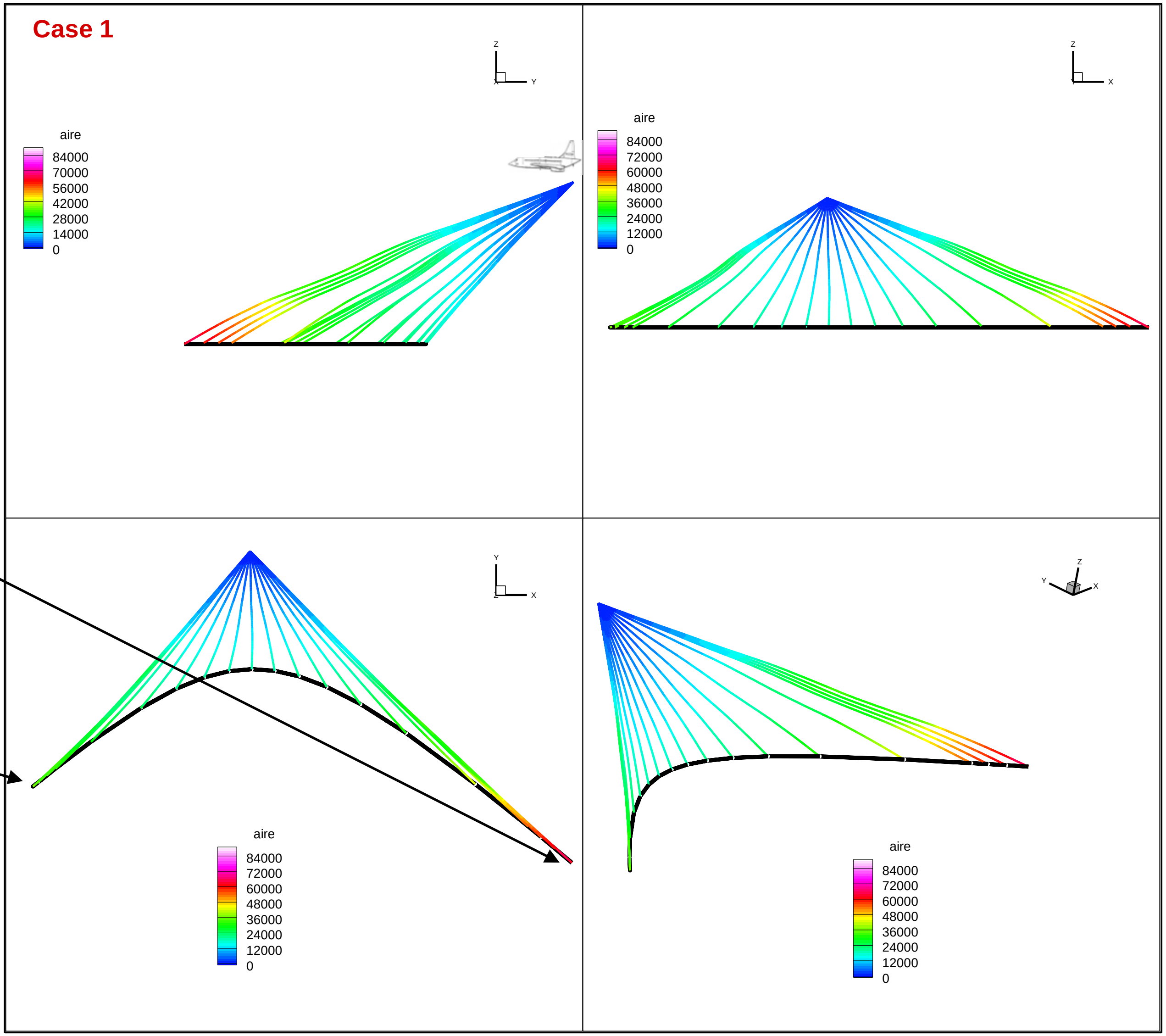
Upward

downward

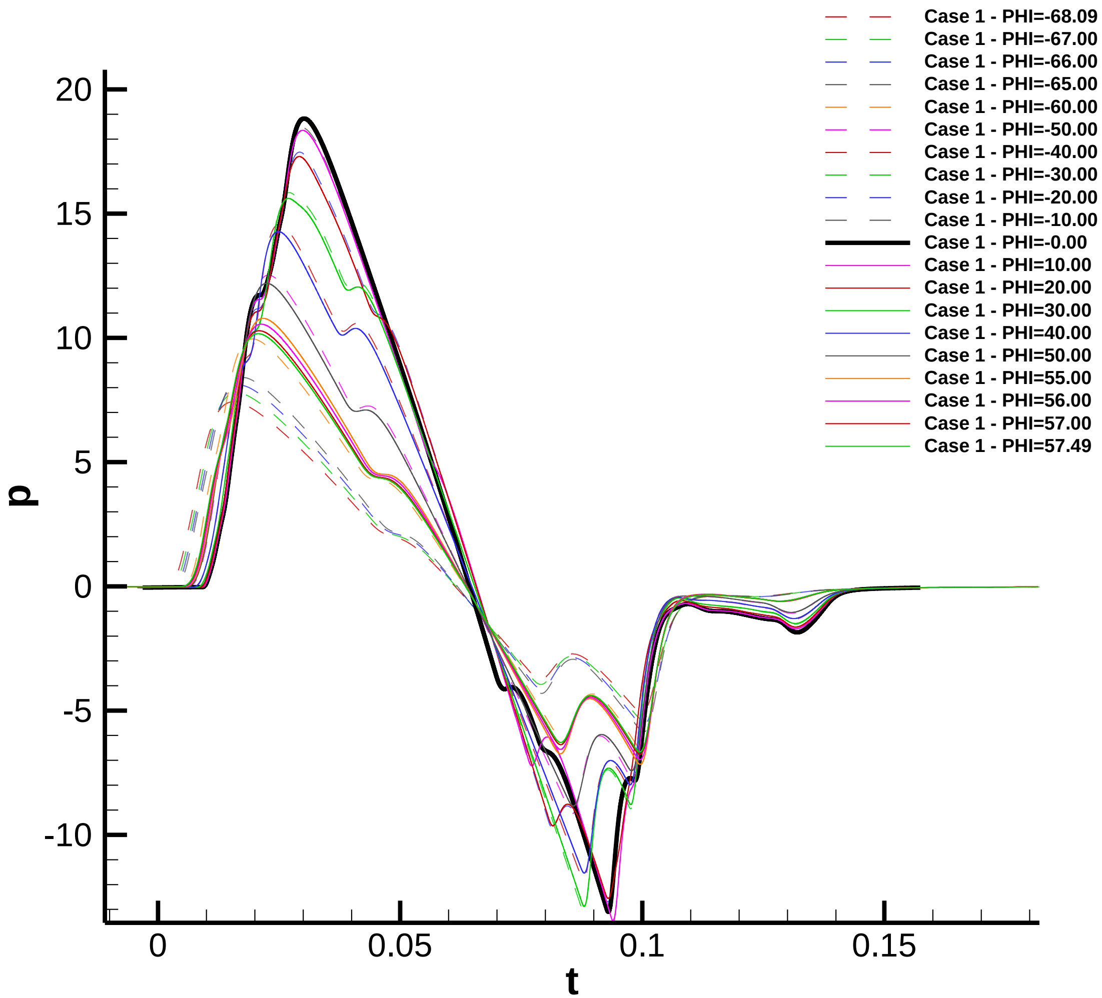
Results for ray trajectories : Case 1

Cut-Off angles:

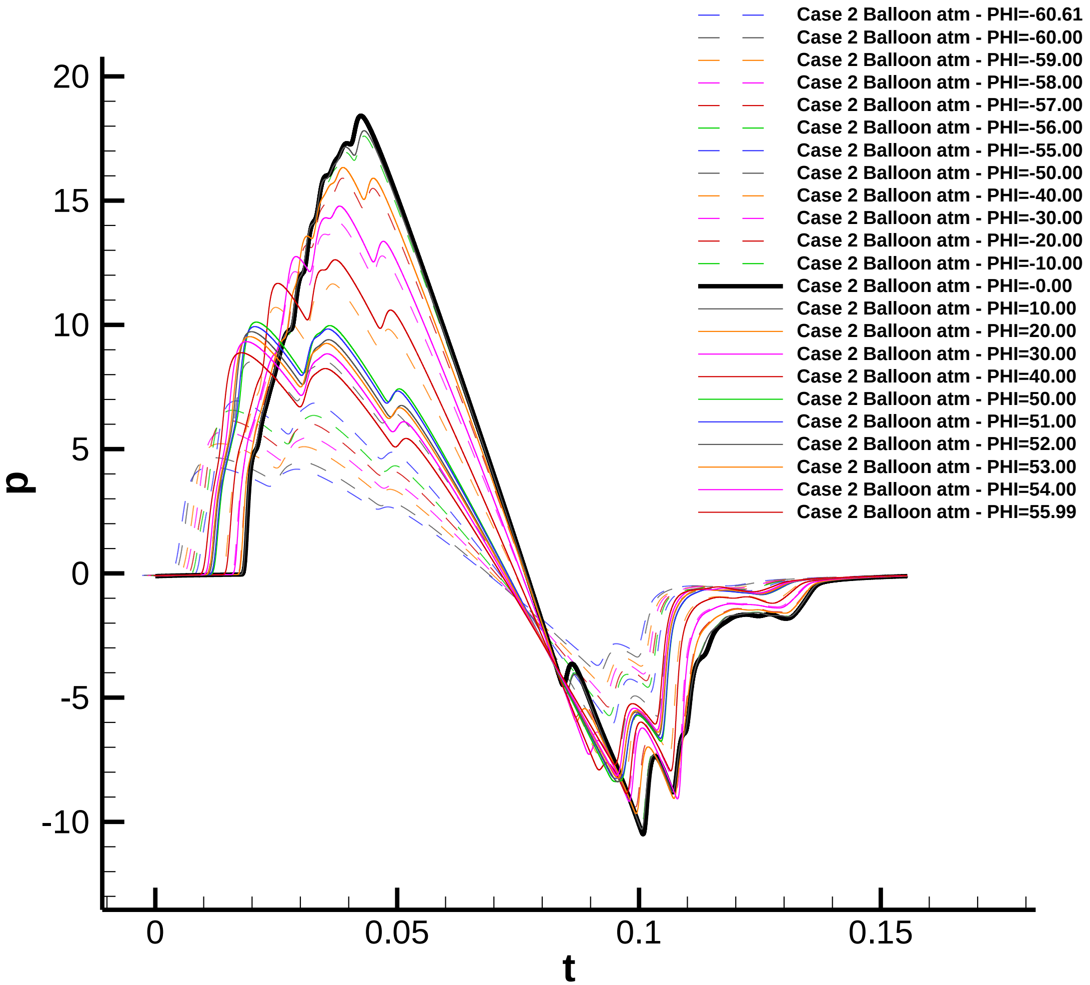
- Φ= -68.09° X=-38,549 m downward
- Φ= 57.5° X=26,017 m downward



Results : ground signatures, Case 1



Results : ground signatures, Case 2, Balloon atmos.



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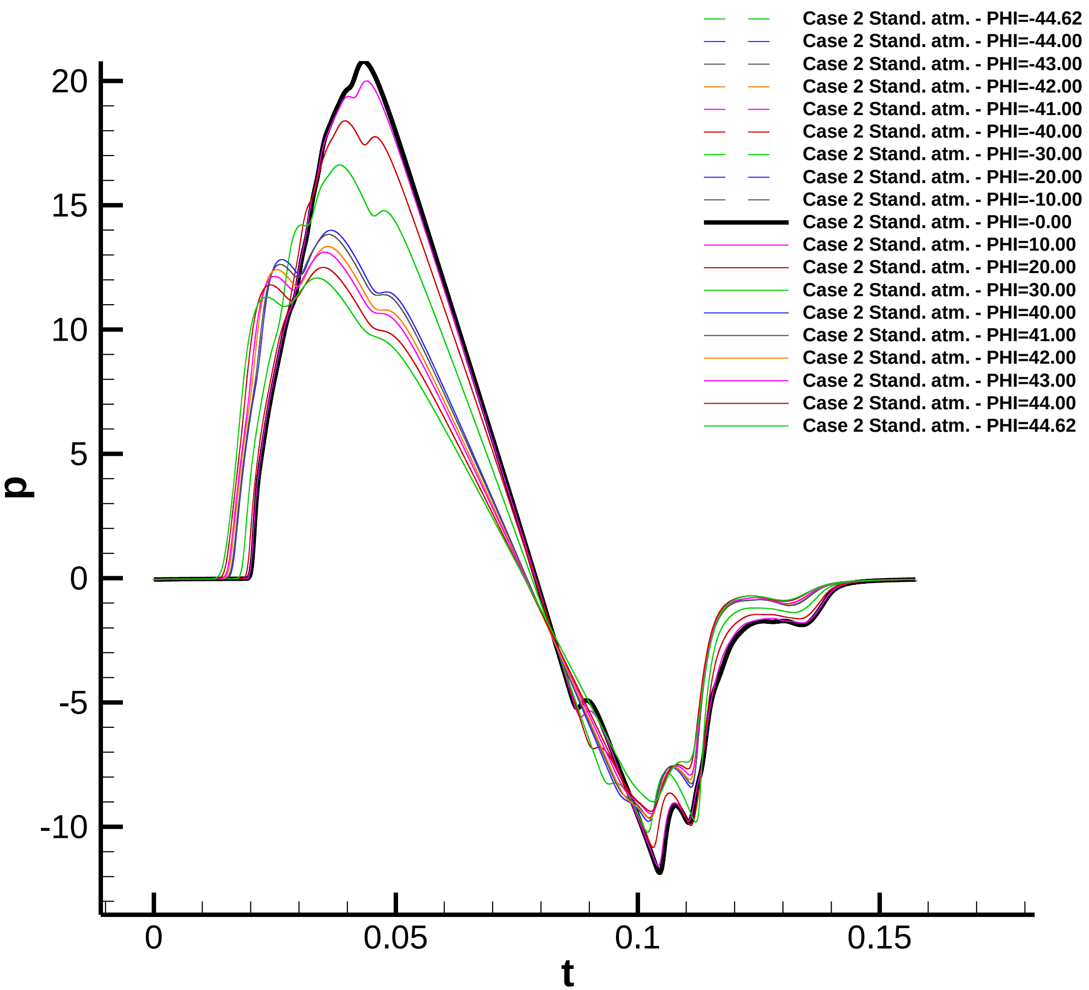
Results : ground signatures, Case 2, Standard atmos.



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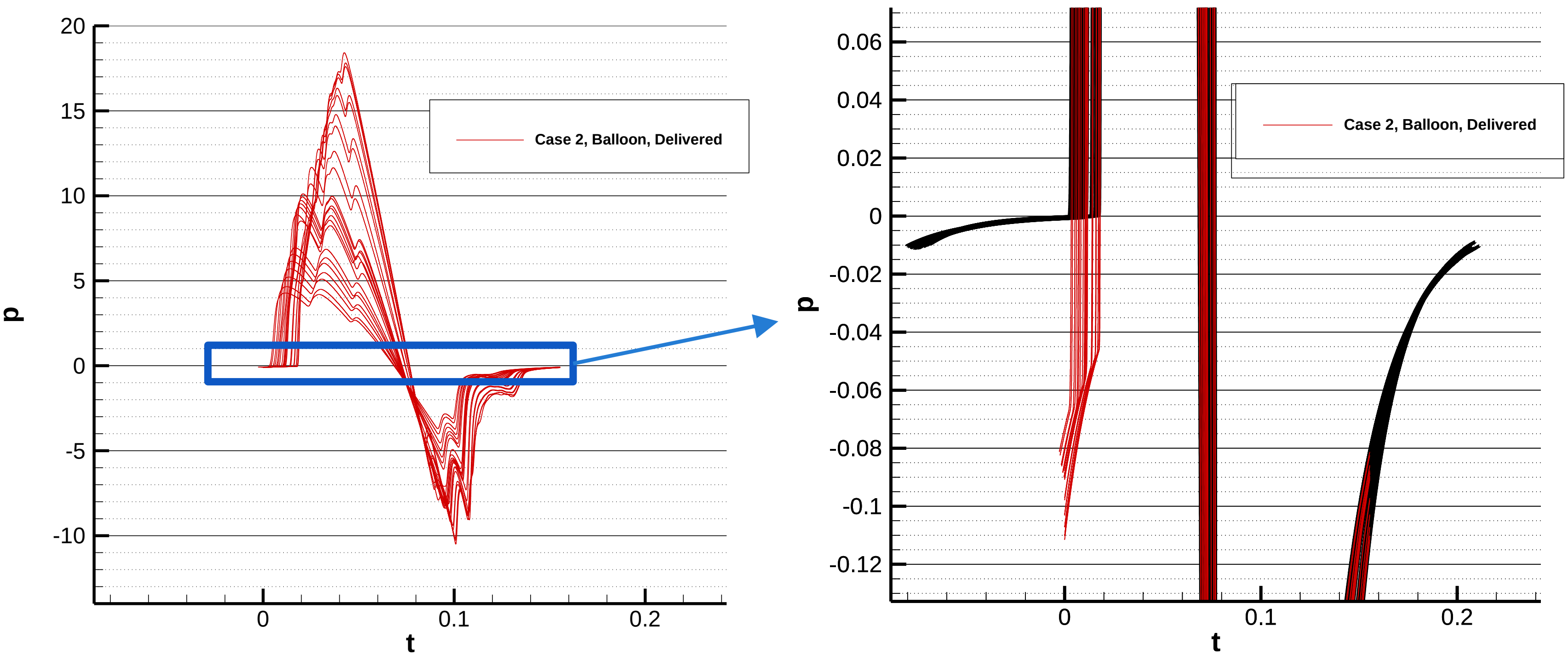
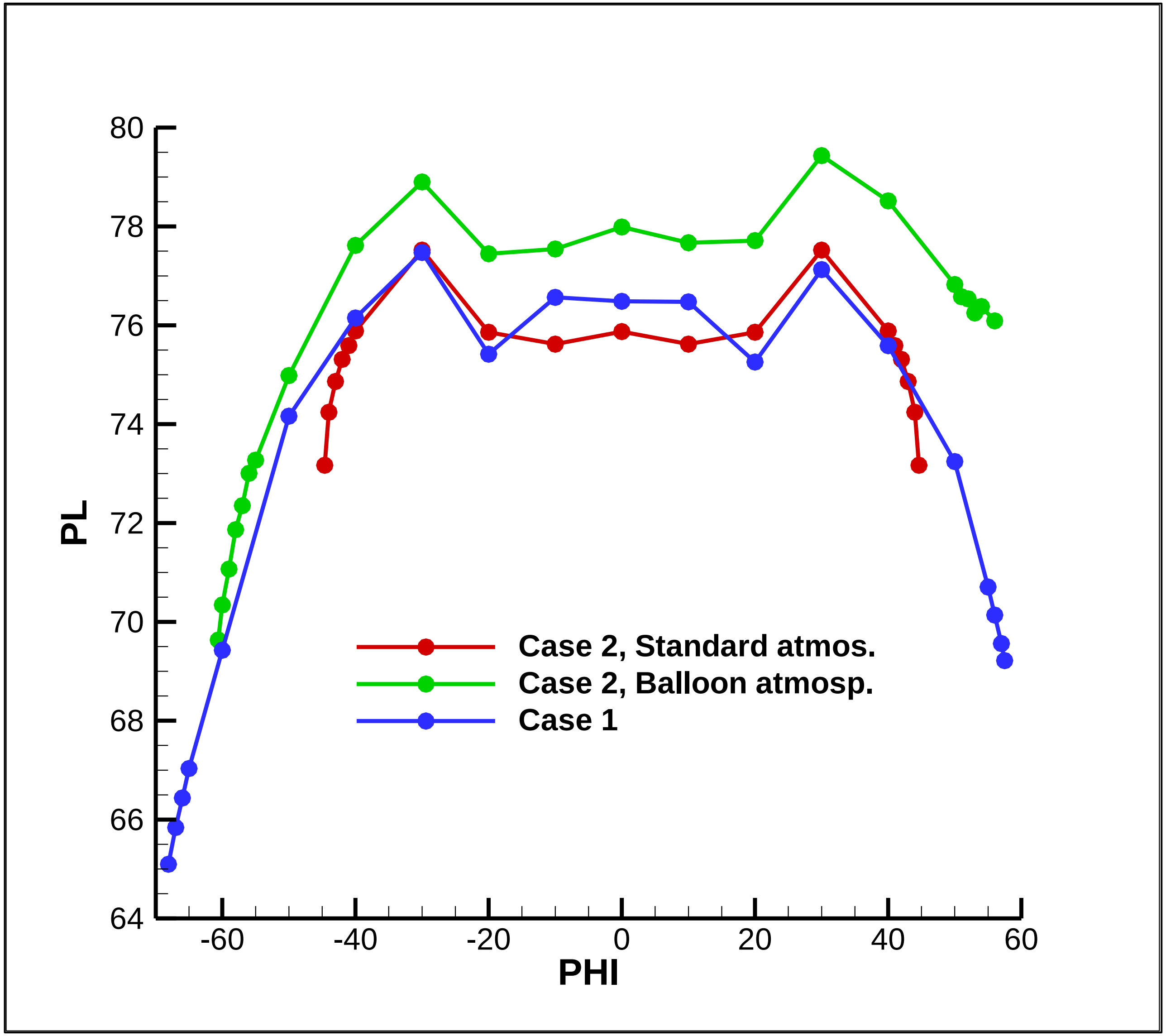
Error detected in front part of signature

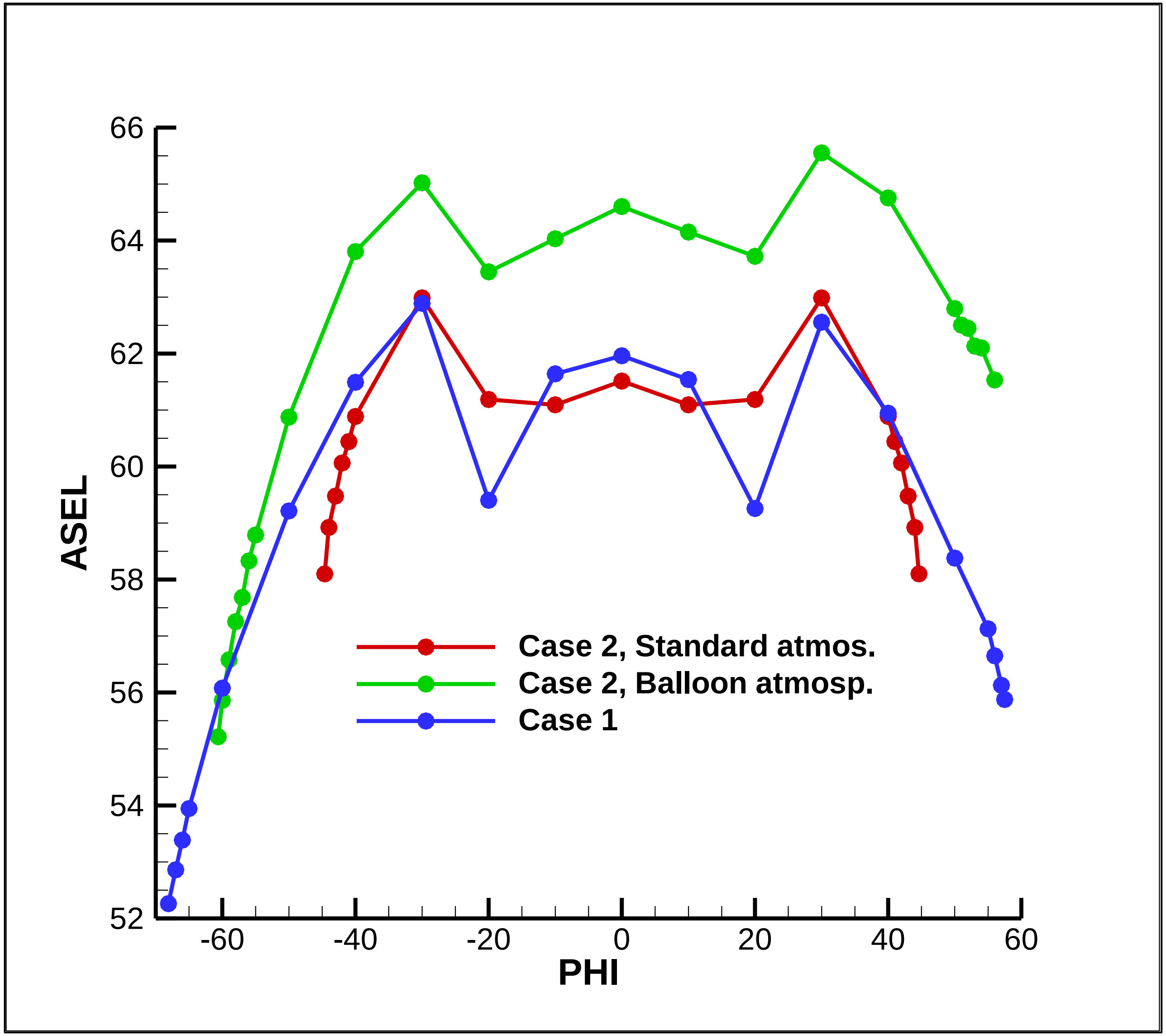


- Cause: successive direct/inverse Fourier transforms in case of signal with insufficient signature tail pressure relaxation to zero
- No impact on significant part of signature, moderate impact on loudness (+.5 dB)

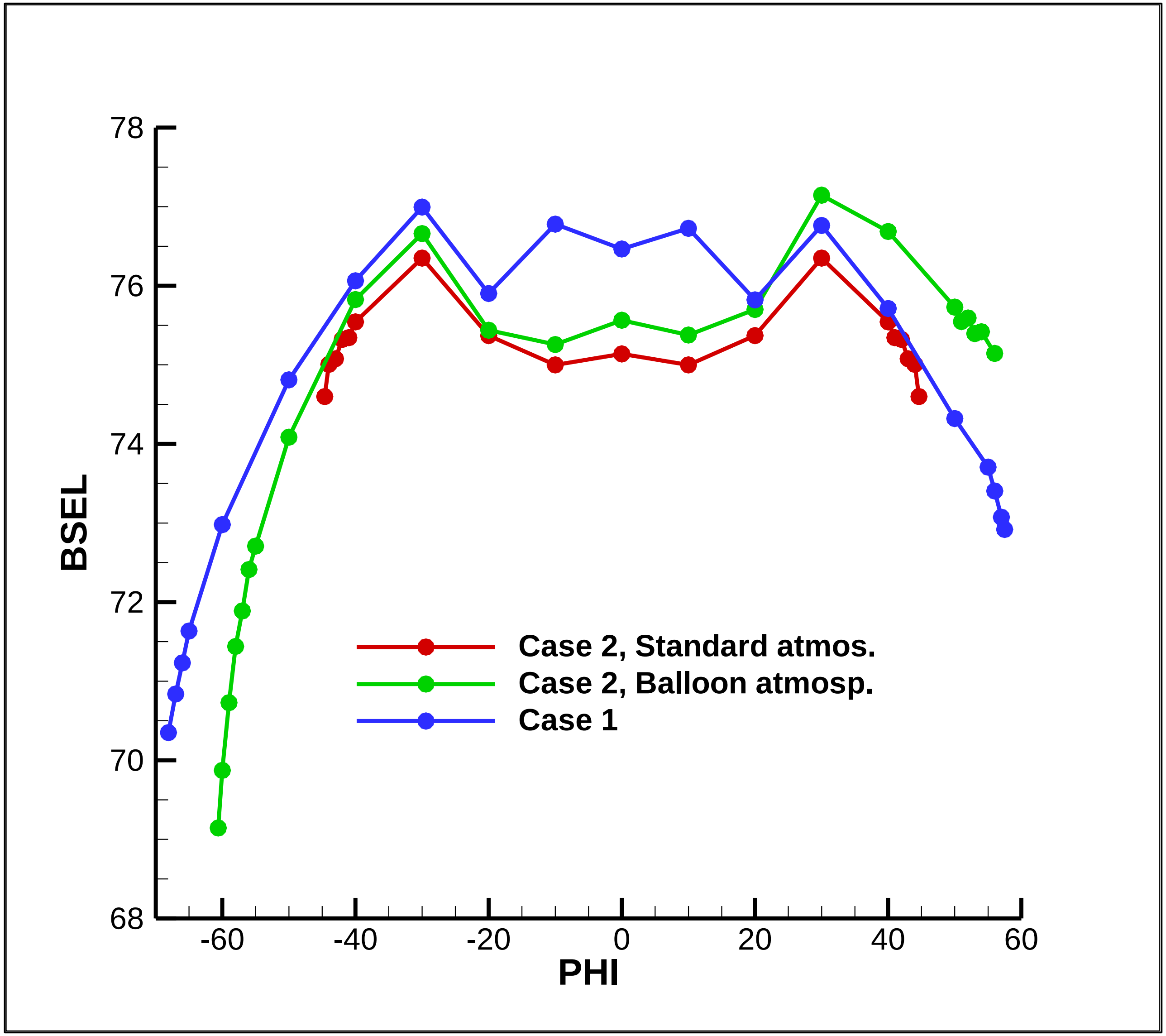
Results : PLdB



Results : A-SEL



Results : B-SEL



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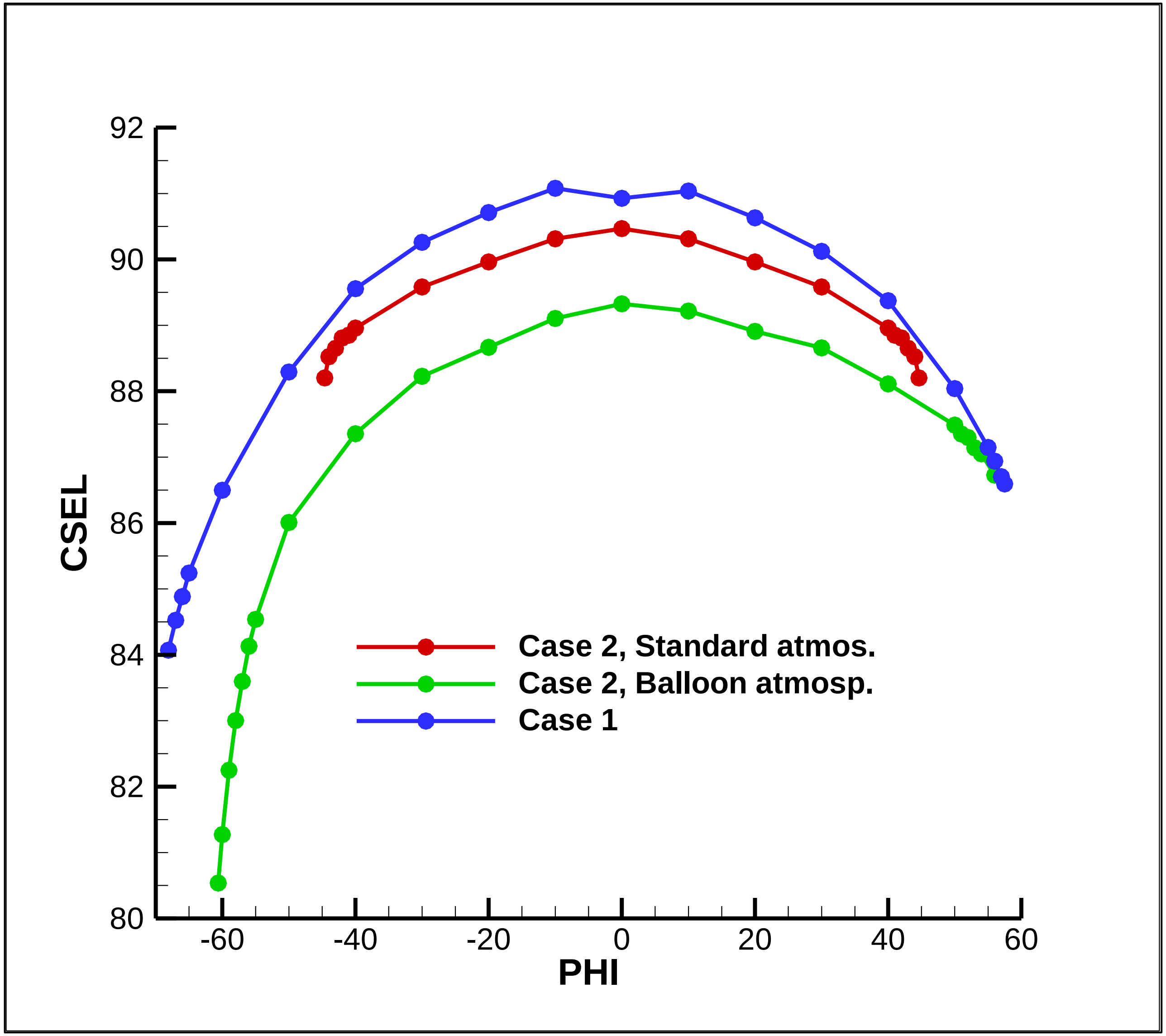
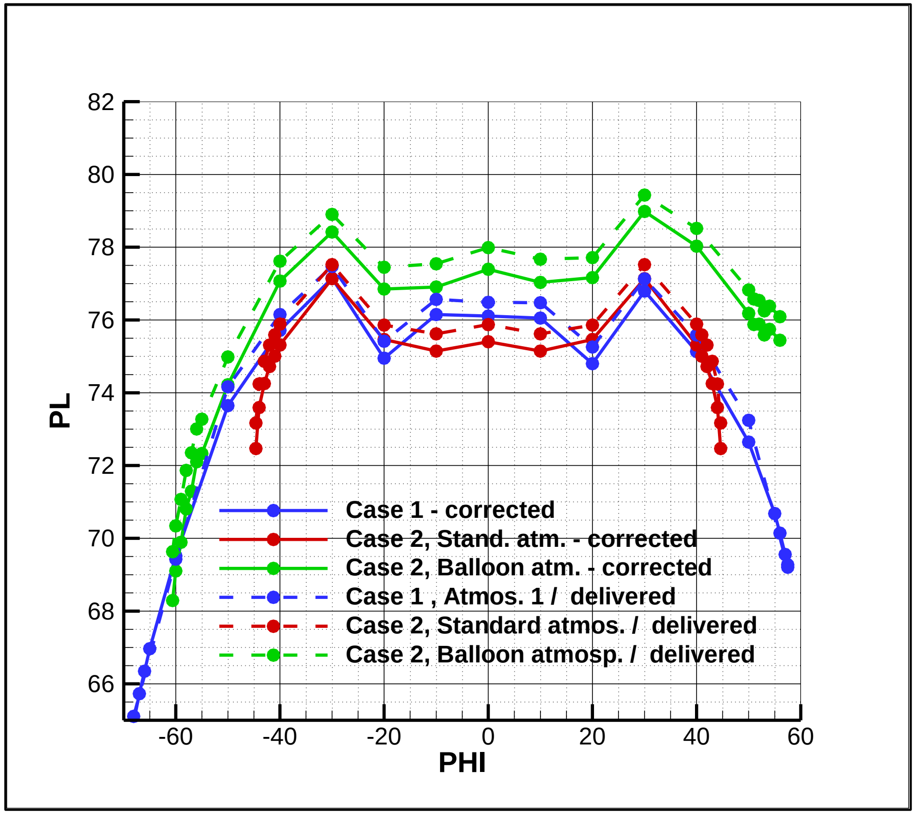
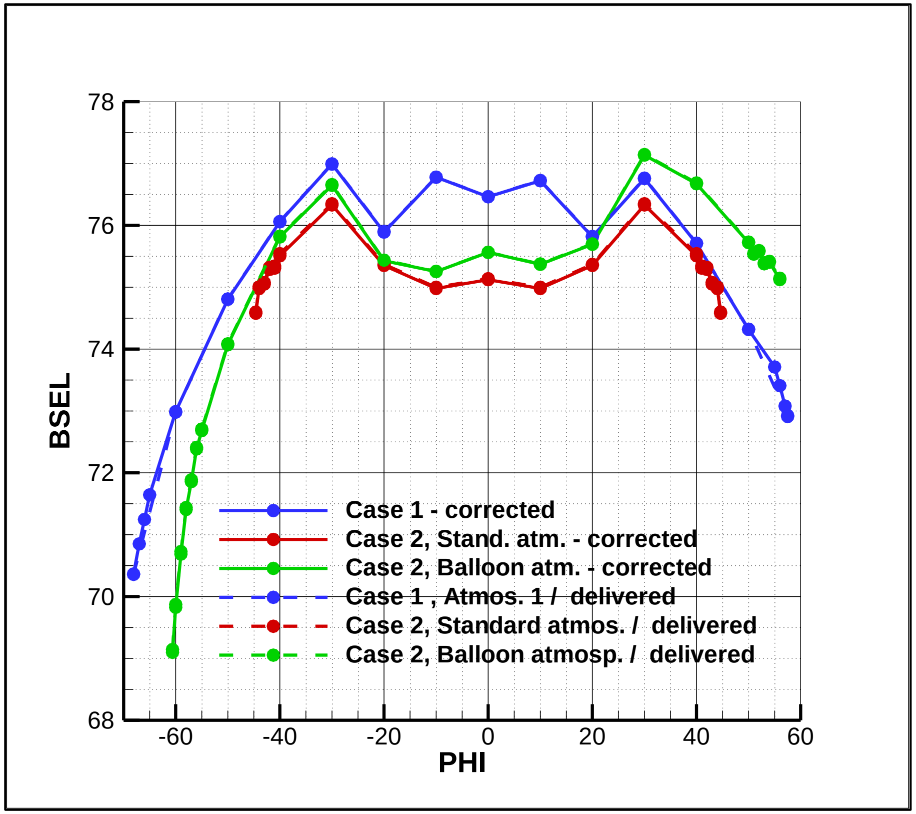
Results : C-SEL



Impact on loundnesses of signature head non-return to zero





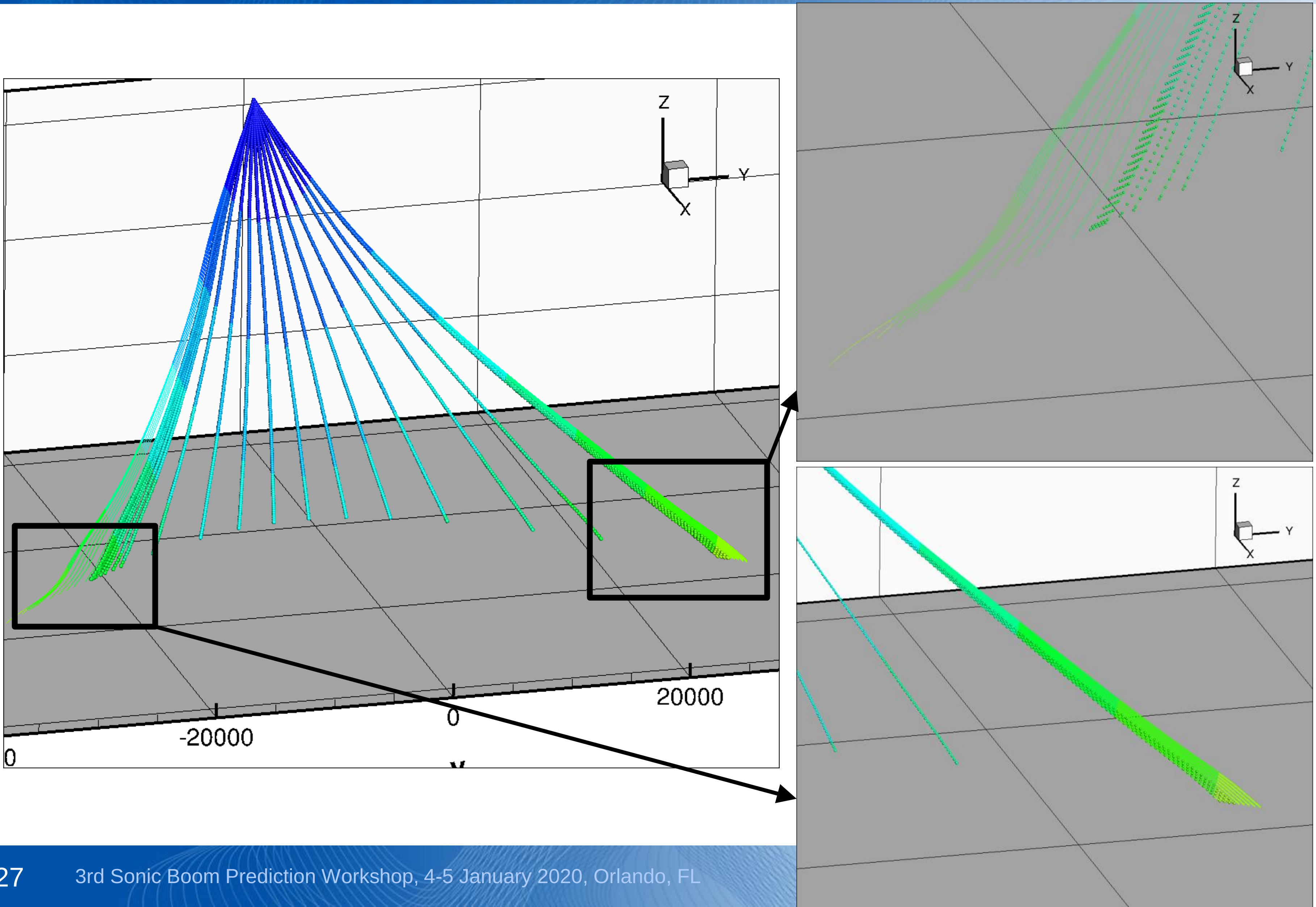
Summary & highlights

- BANGV propagation code has been applied to the two workshop cases (three atmosphere profiles)

- **Good relaxation to zero of the tail of the signature is needed** for treatment of absorption with split-step algo. (non-linear effect in time domain and linear absorption effect in freq. domain)
- **Issues in the detection of cut-off angles** in the case of **downward refraction (no shadow zone**): BANGV detects cut-off earlier than other codes? Why?
- Acceleration case (case 1, optional) **tried but no satisfactory results** -> to be solved after the SBPW3

- **Careful verifications of ray-propagation codes still useful**, even for steady flight in the case of complex atmos. profiles
- **Unsteady flight (caustics, focusing) even more requiring**
- Other issues to be dealt with: ground nature and topography, **turbulence** -> RUMBLE project and follow-up, internal ONERA project starting in 2020 (WT experiments)

Any question?


Z
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Z
Y
X

Noise metrics 2/2

A-SEL

	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
ONERA	61,5	58,5	61	61,3	78,8	60,2	69,1	60,9
NASA	61,3	58,5	61	61,1	79	60,5	69	60,9

B-SEL

	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
ONERA	74,7	73	72,7	72,8	88,8	77,9	83	75,4
NASA	74,7	73	72,8	72,9	89	77,9	83,2	75,5

D-SEL

	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
ONERA	74,9	77,3	76,4	75,8	88,4	79,1	83,8	81,7
NASA	75	77,4	76,5	75,9	88,6	79,3	84,1	81,8

E-SEL

	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
ONERA	70,6	69,5	70,3	70,4	86	72,5	78,5	74,3
NASA	70,7	68,3	69,2	69,2	86,3	72,4	78,5	70,9

Perceived Level

	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
ONERA	75,6	73	75	75,3	92,3	75,9	85,7	76,4
NASA	75,3	73	74,5	75	92,5	75,7	85,5	75

Indoor Sonic Boom Annoyance Predictor

	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
ONERA	85,8	85,7	85,8	85,7	100	89	97	89,4
NASA	85,6	85,6	85,3	85,5	100,2	88,7	96,8	88