GROUND ELEVATION EFFECTS ON SONIC BOOM REFLECTION

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1. INTRODUCTION

Sonic boom prediction is tackled within the EU project RUMBLE. Its aim is to determine the acceptable level of overland sonic booms and the appropriate ways to comply with it [1]. To achieve this, sonic boom prediction tools are developed and assessed, the human response to sonic boom is studied and findings are validated using wind-tunnel experiments as well as actual flight tests. This study focuses on prediction tool development, for which there is a need for better understanding of sonic boom propagation, and in particular the impact of meteorological phenomena and both terrain nature and irregularities. Few studies of the latter have been led. Classically, sonic boom studies consider a flat surface, on which reflection is applied by multiplying the incident wave by a constant factor to obtain the reflected wave.

The objective of the current study is to identify and understand ground elevation effects which may have a significant impact on perceived sonic boom noise. To do so, the numerical methods used are presented first, before an analysis of the impact of terrain irregularities on sonic boom propagation and the resulting perceived noise, and conclusions are finally drawn.

2. NUMERICAL SIMULATIONS

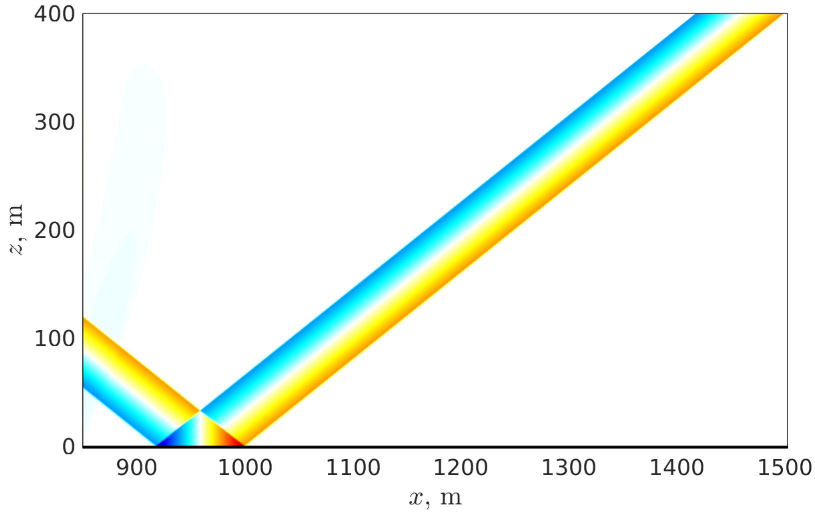
Numerical simulations are performed to investigate sonic boom propagation and its reflection on irregular terrain. The Euler equations are chosen because they allow to simulate all waves including diffracted waves without approximation, unlike parabolic or ray-tracing methods. Adiabatic flow is considered, with ideal and calorically perfect fluid. The 2D non-linear equations are solved in the time domain using finite difference schemes. High-order schemes allow to capture the propagation of acoustic waves accurately [2]. An optimised fourth-order scheme using an eleven point stencil is chosen in space along with a selective filter, and an optimised fourth-order six-step Runge-Kutta scheme is applied in time. A shock-capturing methodology is also used, applying adaptative second-order filtering to handle discontinuities in combination with background selective filtering to remove grid-to-grid oscillations [3]. The equations are solved in a supersonic moving frame, so that non-reflective acoustic boundary conditions are not required along the outlet boundary of the domain. Ground elevation variations are taken into account by using a curvilinear coordinate system which allows the mesh to adapt to the ground profile.

For this study, the Mach number is set to 1.6. The mesh size is 0.1 m in both directions, and the moving frame is incremented every two iterations only, to limit the CFL number. Realistic ground profiles are used, from different regions of France, thanks to the data bank of the French National Institute of Geographic and Forest Information (IGN). In addition, both a classic N-wave and the C25D low-boom wave are injected into the computational domain and investigated. The code has been parallelised using OpenMP.

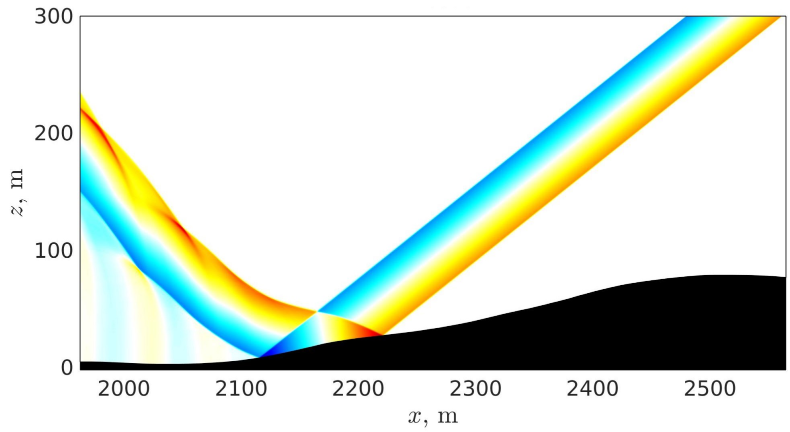
3. EFFECT OF GROUND ELEVATION VARIATIONS

Pressure fluctuation maps resulting from such simulations are shown in Fig. 1 in the case of flat and irregular terrain. Comparing them, one may first notice the reflected wave is heavily affected. Its angle is modified as the slope of the ground profile varies, and focal zones appear. In Fig. 1b weaker waves also travel back down towards the ground. Pressure fluctuations are also affected at ground level, where noise affects the population the most. Indeed, the wave is more spread out along the ground in Fig. 1b than in the flat case. In addition, its amplitude is reduced, and the noise perceived is reduced. The opposite is true in the case of a downward slope, hit by the sonic boom wave with at a smaller angle. This mechanism is responsible for the focal zones which are propagated along the reflected wave. It also affects waveforms at ground level, in particular the peak pressure and the rising time.

These waveforms are used to calculate metrics allowing to estimate the perceived noise on the ground. Metrics sensitive to different frequency ranges are used : PL (Perceived Level), A-SEL, B-SEL, C-SEL, D-SEL, E-SEL and ISBAP (Indor Sonic Boom Annoyance Predictor), which is used to determine the sound perceived inside a building. The influence of waveform variability on these metrics is analysed in an effort to assess the significance of ground elevation on sonic boom propagation, highlight the physical mechanisms involved and identify significant parameters.



(a) Flat ground



(b) Varying elevation

Figure 1: Pressure fluctuation maps (-50 to 50 Pa) of an N-wave reflecting on (a) flat and (b) irregular ground.

4. CONCLUSIONS

This study allows to highlight the effect of ground elevation variations on sonic boom propagation, using simulations which include diffracted waves in particular, without approximations, by resolving the Euler equations. Their effect is discussed in terms of pressure fluctuations and waveforms, but also in terms of perceived noise. These effects are expected to be multiplied in three-dimensions, as well as to be significant in the presence of buildings, notably affecting the sound perceived in cities, which present exciting questions for further study.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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