OPTIMIZATION OF BRASS INSTRUMENTS BASED ON PHYSICAL MODELING SOUND SIMULATIONS

Jean-François PETIOT[1] , Robin TOURNEMENNE[1], Joël GILBERT[2]

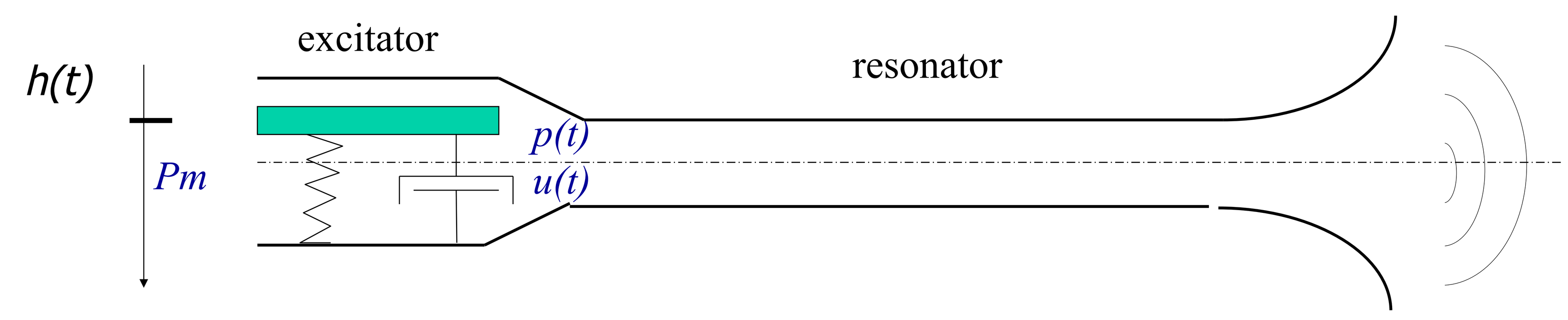
(1): Laboratoire des Sciences du Numérique de Nantes (UMR CNRS 6004), Ecole Centrale de Nantes, France – Jean-Francois.Petiot@ec-nantes.fr

(2): Laboratoire d'Acoustique de l'Université du Maine (UMR CNRS 6613), Le Mans, France

ABSTRACT

- physical modeling based simulations are integrated in the optimization process of the bore of a brass instrument, a trumpet
- the novelty of the approach lies in the fact that the objective function concerns the sound of the instrument, as simulated when in interaction with a virtual musician
- given the computationally expensive function evaluation and the unavailability of gradients, a surrogate-assisted optimization framework is implemented using the mesh adaptive direct search algorithm (MADS) [1].

1. Physical modelling of brass



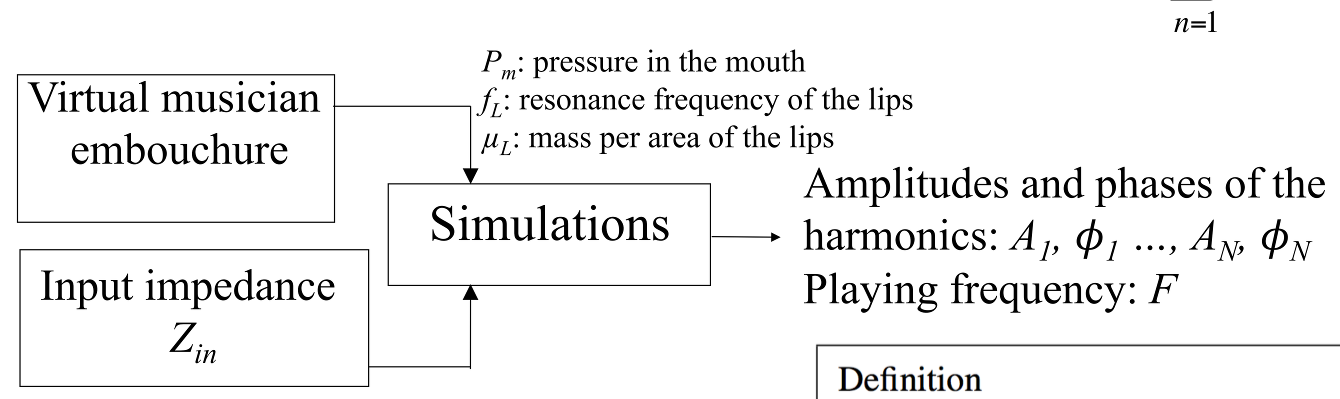
Coupling of a non-linear excitator (characterized by mechanical parameters) with a linear resonator (characterized by the input impedance Z_{in})

- 3 time-varying variables: opening height $h(t)$ of the lips, volume flow $u(t)$ and pressure in the mouthpiece $p(t)$

$$\begin{cases} P(j\omega) = Z_{in}(j\omega).U(j\omega) \\ \dfrac{d^2h(t)}{dt^2} + \dfrac{2\pi f_l}{Q_l}\dfrac{dh(t)}{dt} + (2\pi f_l)^2(h(t)-h_0) = \dfrac{P_m - p(t)}{\mu_l} \\ u(t) = b.h(t)\sqrt{\dfrac{2(P_m - p(t))}{\rho}} \end{cases}$$

2. Simulations with the harmonic balance technique

In permanent regime (frequency domain) $p(t) = \sum_{n=1}^{N} A_n.\cos(2\pi nF\,t + \phi_n)$



Control parameters of the simulations (virtual embouchure) [2]

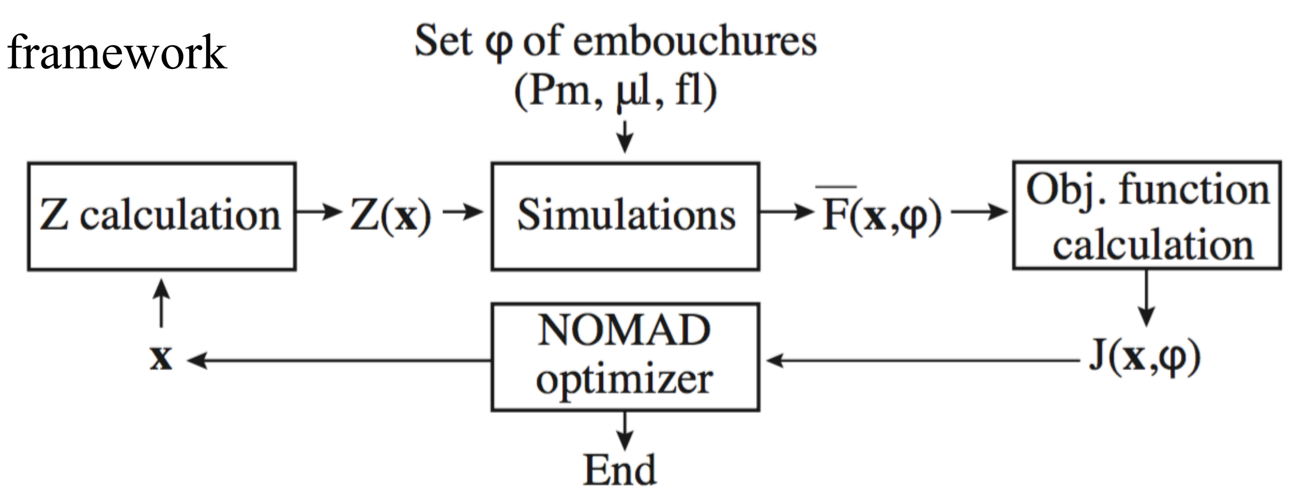
Definition	Notation	Value
Resonance frequency of the lips	f_l (Hz)	130 to 480
Mass per area of the lips	μ_l (kg/m^2)	1 to 6
Pressure in the mouth	P_m (kPa)	6 to 9
Width of the lips	b (mm)	10
Rest value of the opening height	H_0 (mm)	0.1
Quality factor of the resonance	Q_l	3

3. Problem formulation: minimization of an objective function *J*

$$\min_x J(x,\varphi)$$

x: design variables (bore of the resonator)
φ: set of embouchures (virtual musician)

Optimization framework



Example of objective function J (representative of the intonation)

$$J(x,\varphi) = \frac{\sum_{i \in notes} |ETD(x,i,\varphi)|}{P-1}$$

ETD: Equal Tempered Deviation (cent)

$$ETD(x,i,\varphi) = \alpha_{ref \to i} - 1200.\log_2\left(\frac{\overline{F}_i(x,\varphi)}{\overline{F}_{ref}(x,\varphi)}\right)$$

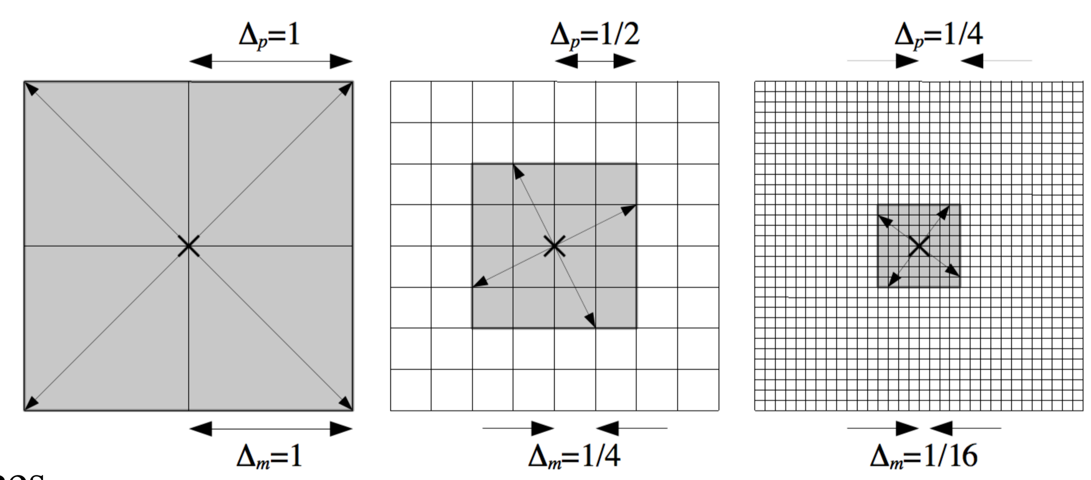
4. Optimization method

The objective function J(x,φ):

- Potentially heavy calculation time
- Derivative not available (J(x,φ) is stochastic due to random sampling of the set of embouchures φ)

Surrogate-assisted derivative-free optimization (NOMAD software)

Mesh Adaptative Direct Search (MADS)



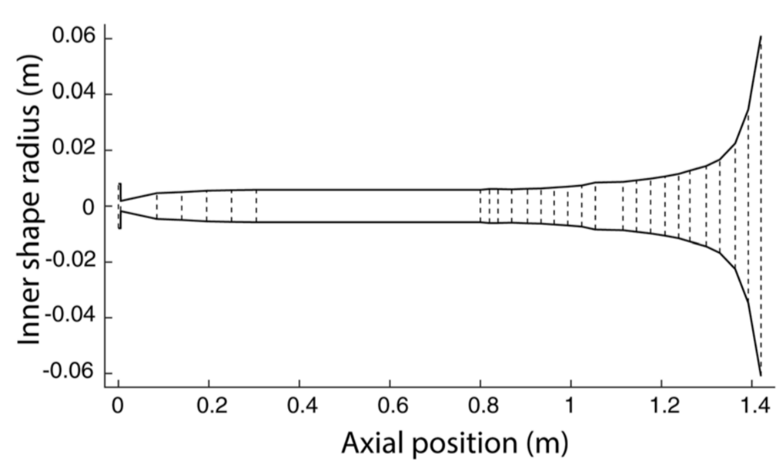
Different Surrogate models:

- Polynomial response surfaces
- Kernel Smoothing
- Radial Basis Functions

RESULTS

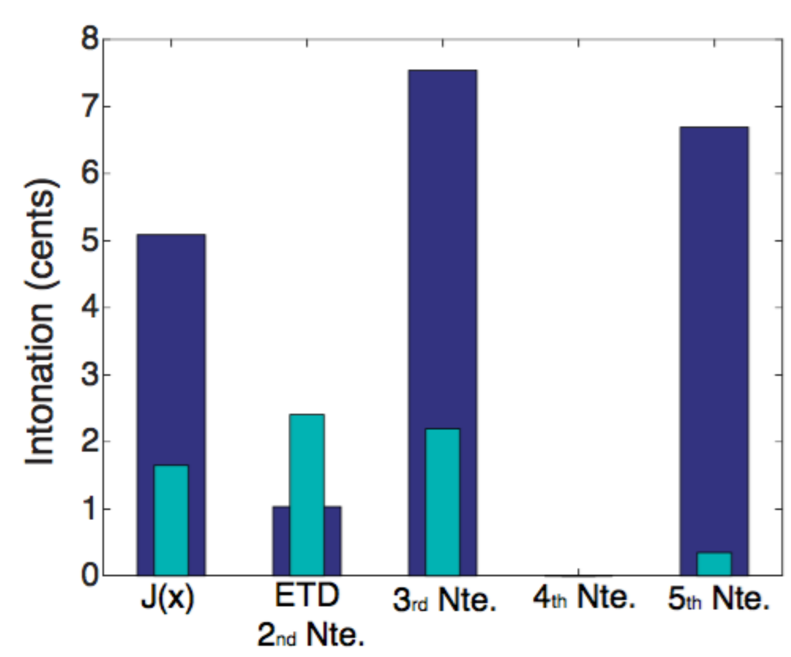
Optimization of the leadpipe of a trumpet

Objective function: intonation of the regimes 2, 3, 4, 5 (notes)

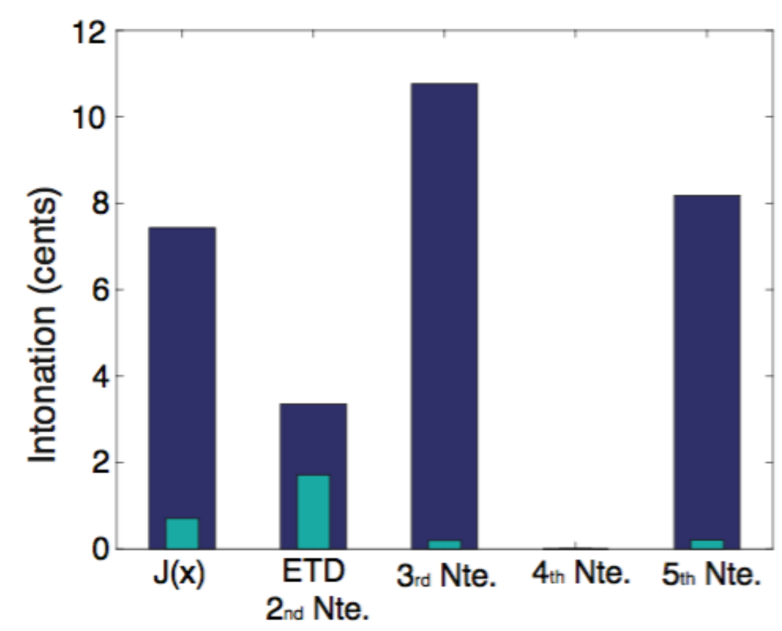


Two cases:

- 2-d problem (2 diameters in the leadpipe)
- 5-d problem (4 diameters in the leadpipe+ mouthpiece depth)

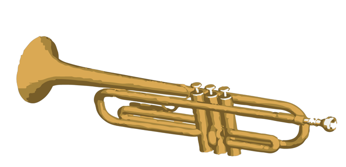


Results of J and ETD for the 2-d problem



Results of J and ETD for the 5-d problem

CONCLUSIONS



- Alternative to an optimization based on the input impedance [2]
- Improvements of the intonation of trumpets based on simulations [3], with a reasonable computation time
- Possibility to define objective functions based on the spectrum of the sounds
- Possibility to optimize the spectrum of sounds subjected to constraints on the intonation

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REFERENCES

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