EXTENDING OPENFOAM COMPUTATIONAL AEROACOUSTICS CAPABILITIES

CAA in OpenFOAM

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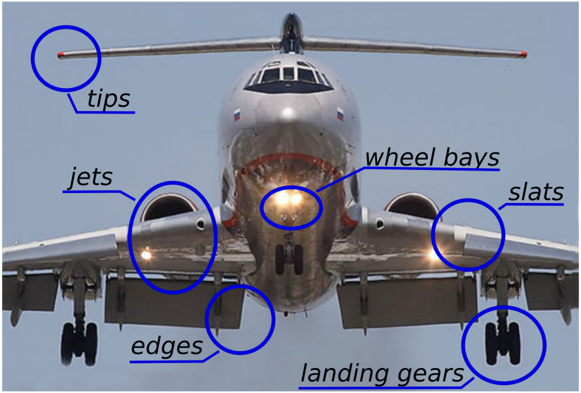
11th OpenFOAM Workshop, Guimarães, Portugal

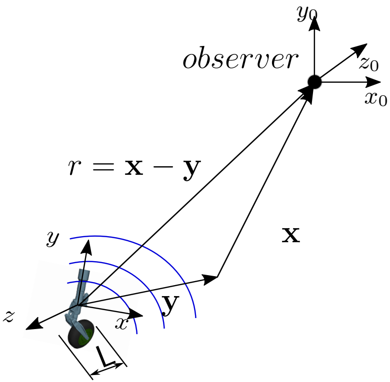
26th – 30th of June, 2016

Intro



Roland Ewert, Aircraft noise simulation at DLR, CEAA, Svetlogorsk, Russia. 2012.

libAcoustics::Curle

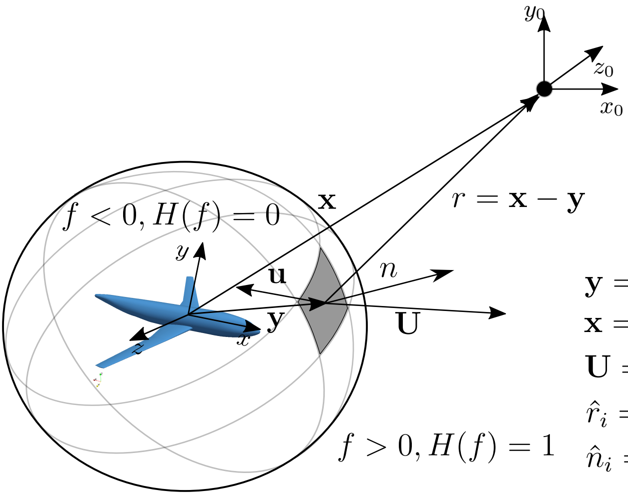


- Low-speed incompressible flow
- The surface assuming non-deforming and stationary
- The non-linear effects are excluded

Curle analogy formulation (with near-field term):

$$p' = \frac{1}{4\pi c_0} \frac{x_i}{r^2} \left(\frac{\partial F_i(t)}{\partial t} + \frac{c_0 \cdot F_i(t)}{r^2} \right)$$

libAcoustics::FWH



permeable surface, S

$$\mathbf{y} = \mathbf{y}_0 + \int_0^t \mathbf{U}(t')dt'$$

$$\mathbf{x} = \mathbf{x}_0 + \int_0^t \mathbf{U}(t')dt'$$

$$\mathbf{U} = -\mathbf{U}_{\text{inf}}$$

$$\hat{r}_i = \mathbf{r}/|\mathbf{r}|$$

$$\hat{n}_i = \mathbf{n}/|\mathbf{n}|$$

libAcoustics::FWH

- High-speed compressible flow, supersonic flows could be considered
- Icludes several approaches: noise of moving surface, permeable surface
- The non-linear effects are excluded

FfowcsWilliams-Hawkings equation

Permeable surface formulation

Source: Crighton, D. G.; Dowling, A. P.; Ffowes Williams, J. E.; Heckl, M.; Leppington, F. G., Modern Methods in Analytical Acoustics. Lecture Notes.

Equation without quadruple term:

$$4\pi|\mathbf{x}|p'(\mathbf{x},t) =$$

$$\frac{x_i}{c|\mathbf{x}|}\frac{\partial}{\partial t}\int_{f=0}\left[\frac{p'n_i + \rho u_i(u_j + U_j)n_j}{|1 - M_r|}\right]_{ret} dS + \frac{\partial}{\partial t}\int_{f=0}\left[\frac{\rho_0 u_i + \rho'(u_i - U_i)}{|1 - M_r|}\right]_{ret} dS.$$

- The permeable surface could move with velocity U.
- *ret* – retarded time (source time) evaluations.
- In similar formulations we avoid spatial differentiation (and evaluate time defferentiation) for acoustic source terms.

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libAcoustics::FWH

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FWH formulations

permeable

- sampling on `triSurface`
- getting values using `faceSet`

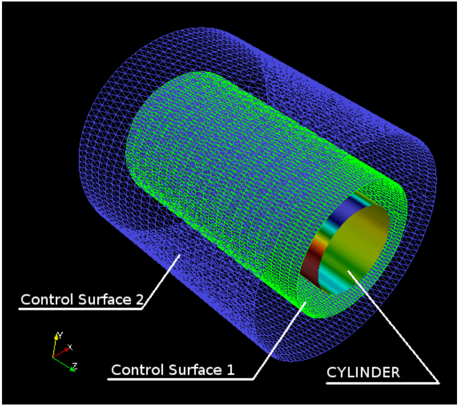
moving surface

- sampling on `patch`
- operating using `fvMesh` and `objectRegistry` (implemented in `Curle`)

libAcoustics::FWH

sampledSurfaces class:

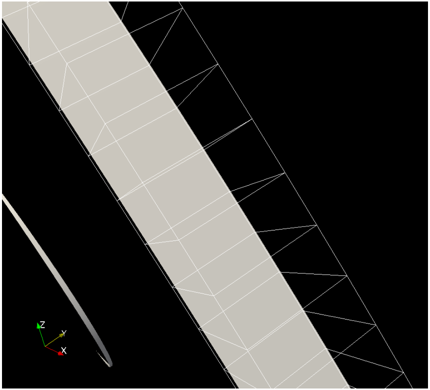
- PtrList of sampledSurface
- sampledSurface could be:
  - patch
  - triSurface
  - isoSurface
  - ...



libAcoustics::FWH

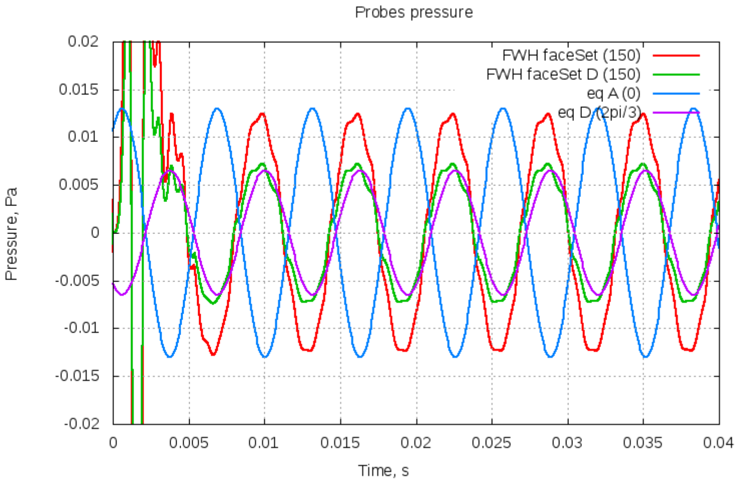
Using faceSet:

- The FWH constrol surface is uncluded in mesh
- faceSet should be provided by:
  - snappyHexMesh
  - topoSet



Validation of the `libAcoustics::FWH`

`faceSet`, far-Field, compact source – trembling sphere



The issues we are currently working on

- Improvement of 2D simulations, excluding coefficient `dRef`
- Resolving oscillations of the `FWH` solution using `sampledSurfaces`
- Implementation of the source-time dominant algorithm
- Implementation of the different formulations in `libAcoustics::FWH` to handle moving and permeable surfaces
- Including quadruple source-terms

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CAA experiments options

- CAA Workshop
  - Tandem cylinders
  - Cavity
- BANC Workshop
  - Landing gear
  - 3-section wing
- Cylinder-foil
- Cylinder aeolian tones
- Wedge tones

Cylinder aeolian tones

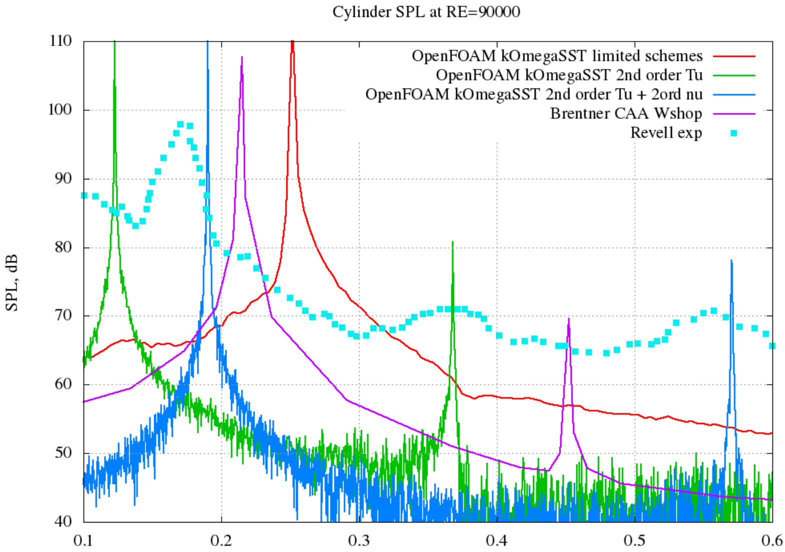
Experimental setup data

J.D. Revell, R.A. Prydz, and A.P. Hays, Experimental Study of Airframe vs. Drag Relationship for Circular Cylinders, Lockheed Report 28074, Final Report NASA Contract NAS1-14403, 1977.

- $Re = 90000$
- $D = 0.019$ m
- $M = 0.1, 0.2, 0.3, 0.35, 0.4, 0.45, 0.5$
- $Tu = 0.2 - 0.4\%$

Aeolian tones of cylinder

2D, RANS, `blockMesh`



Breathing sphere: linear acoustics

Source:

Yang-Hann Kim, Sound Propagation: An Impedance Based Approach. John Wiley & Sons, Asia (2010). 416 pp., ISBN:10:0470825839

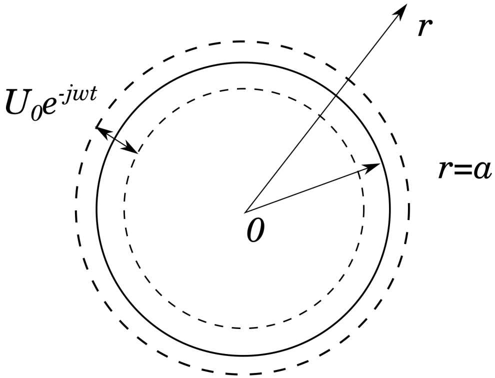


Figure: The breathing sphere. (The direction of vibration is r, velocity is $U_r = U_0 e^{-j\omega t}$

Breathing sphere: equations

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The pressure magnitude:

$$p = A \cdot \rho_0 \cdot c \frac{jkc}{r} \tag{1}$$

where,

$$A = \frac{U_0 \cdot a^2}{jka - 1} \exp^{-jka} \tag{2}$$

p – pressure magintude, Pa, ρ_0 – density, m/s, Θ – direction angle, k – wave number, r – distance, m.

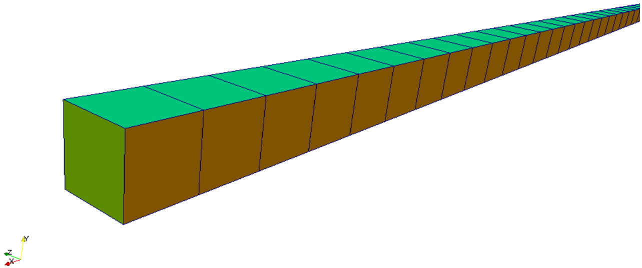
The 3 is evaluated using values

$$U = 5 \text{ m/s}; \ \rho_0 = 1.2922 \text{ m/s}; \ c = 330.7 \text{ m/s}; \ a = 0.1 \text{ m};$$
$$\omega = 1000 \text{ 1/s};$$

Breathing sphere: and OpenFOAM case

Features:

- Computational easy 1D-case.
- `blockMesh`.
- `pisoCentralFoam` without mesh moving/deformation.
- `gnuPlot` for graphs and `python` for analytical calculations.



Breathing sphere: and OpenFOAM case

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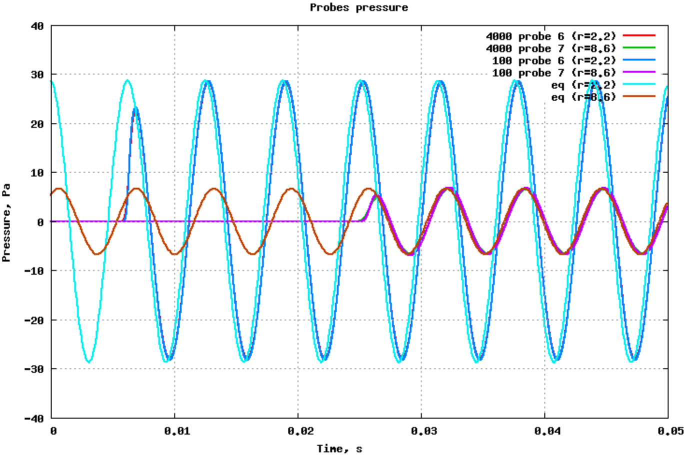

The breathing sphere results, `pisoCentralFoam` vs equation 1

Trembling sphere: linear acoustics

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Yang-Hann Kim, Sound Propagation: An Impedance Based Approach. John Wiley & Sons, Asia (2010). 416 pp., ISBN:10:0470825839

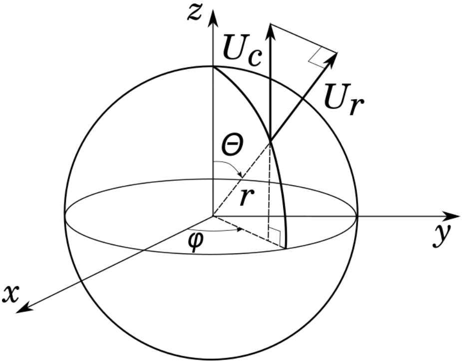

Figure: The trembling sphere. (The direction of vibration is Z, velocity is U_c, and U_r is velocity in r direction

Trembling sphere

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The pressure magnitude:

$$p = A \cdot \rho_0 \cdot c \cdot \cos\Theta \cdot \left(\frac{(jk)^2}{r} - \frac{jk}{r^2} \right) \quad (3)$$

where,

$$A = \frac{U_c \cdot a^3}{2 - (ka)^2 - 2jka} \exp^{-jka} \quad (4)$$

p – pressure magintude, Pa, ρ_0 – density, m/s, Θ – direction angle, k – wave number, r – distance, m.

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Trembling sphere and OpenFOAM case

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Features:

- `blockMesh`.
- `pisoCentralDyMFoam`.
- `faceSet` for `FWH` integral estimation.
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Trembling sphere and OpenFOAM case

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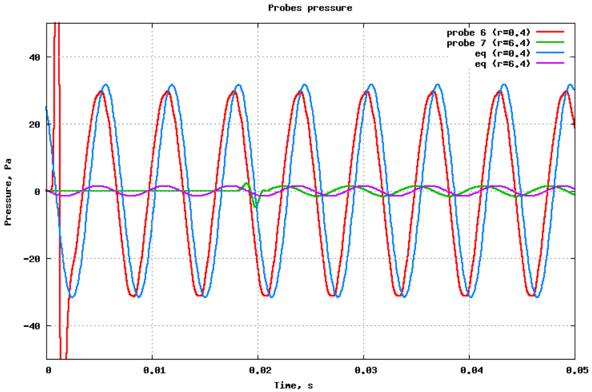

The trembling sphere results, `pisoCentralFoam` vs equation 1

Trembling sphere: far-field permeable FWH

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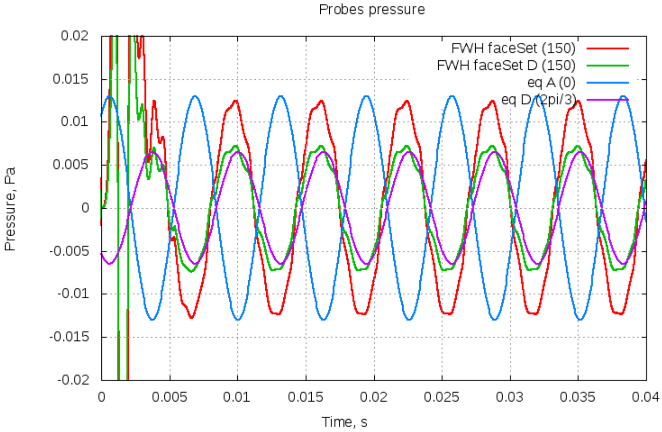

The trembling sphere results, *far field*, $r = 150$ m, `libAcoustics::FWH` vs equation 1

Thank you for your attention.
Questions?