A Generalised Ffowcs-Williams and Hawkings Formulation Applied to Flow Simulations with Vortical Outflow

Sam Sinayoko, M. Wright, R. D. Sandberg

UNIVERSITY OF Southampton
Institute of Sound and Vibration Research

ROYAL COMMISSION EXHIBITION OF 1851

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Outline

1. The Generalised Ffowcs-Williams and Hawkings analogy
    - Classical FW-H analogy
    - Vortical outflow problem
    - Generalised FW-H analogy
2. Validation
3. Application to a convecting vortex
    - Divergence-free Gaussian vortex
4. Conclusions

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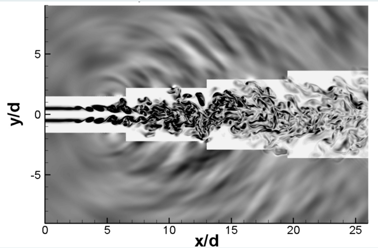
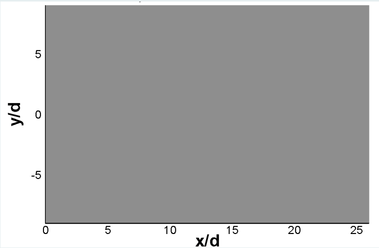
Classical FW-H analogy

Turbulent flow



Quiescent medium



Classical FW-H analogy

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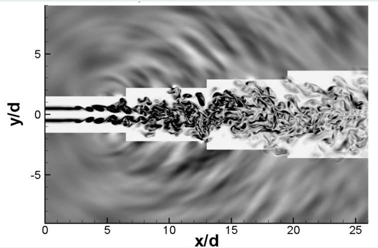

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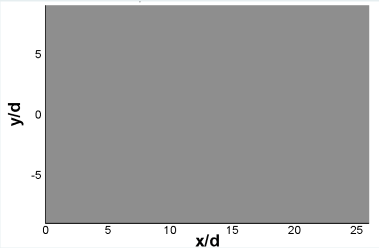
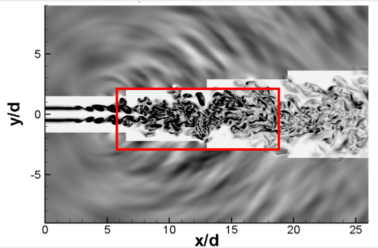


$\Rightarrow$ What are the equivalent sound sources?

Classical FW-H analogy

Turbulent flow



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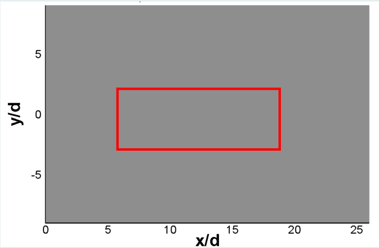

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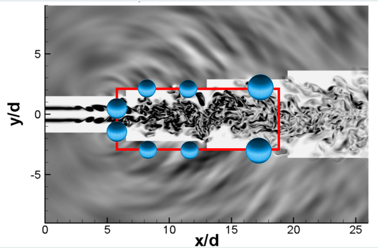

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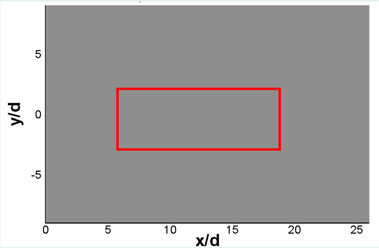

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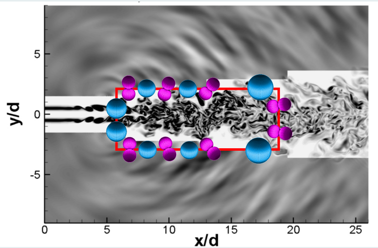
 Monopoles

Classical FW-H analogy

Turbulent flow



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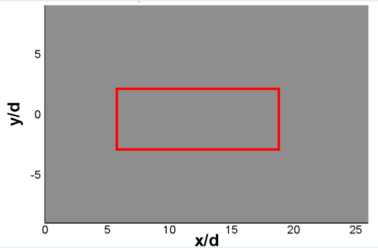
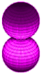
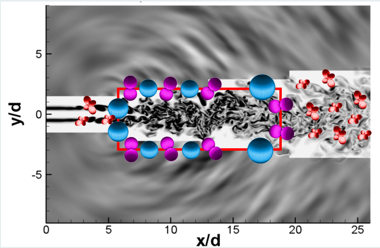


⇒ What are the equivalent sound sources?

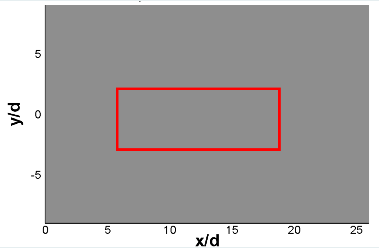
 Monopoles  Dipoles

Classical FW-H analogy

Turbulent flow



Quiescent medium



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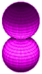
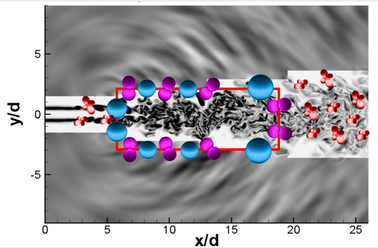

Dipoles

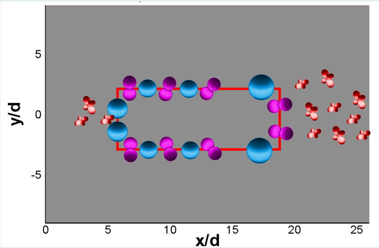

Quadrupoles

Classical FW-H analogy

Turbulent flow



Quiescent medium



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Classical FW-H analogy

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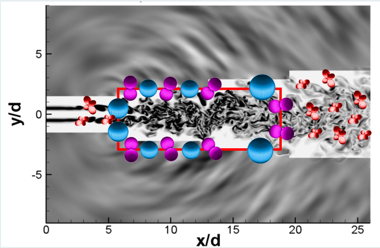

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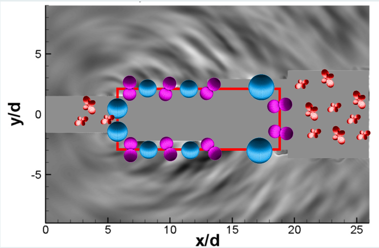

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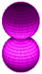
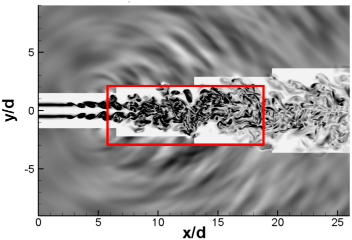
Monopoles


Dipoles

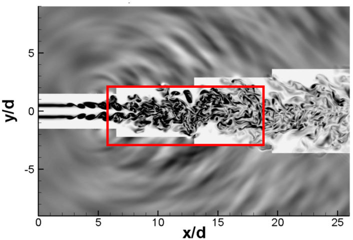

Quadrupoles

The problem with vortical outflows



Neglecting quadrupole sources generates spurious noise!

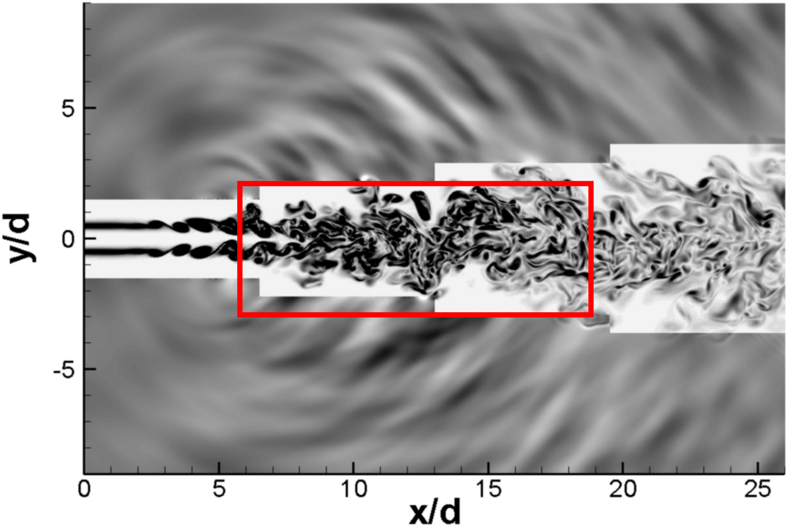
The problem with vortical outflows



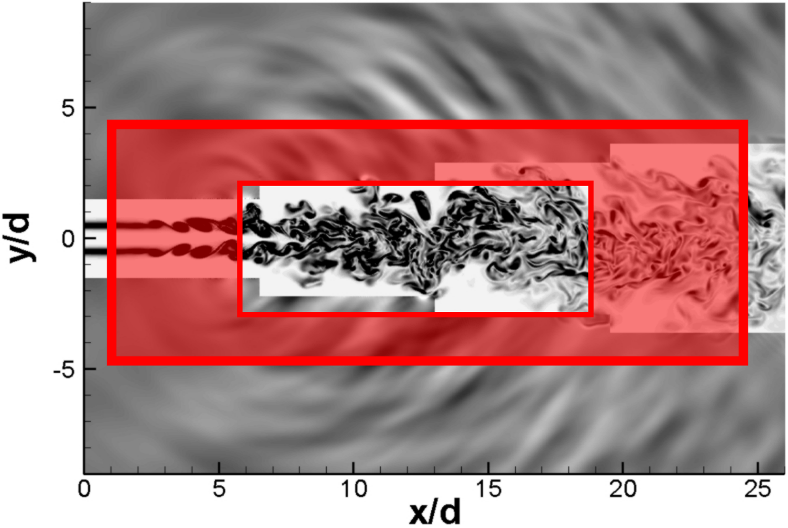
Neglecting quadrupole sources generates spurious noise!

- Vortex convecting subsonically is *physically* silent
- But vortex crossing FW-H boundary generates
  1. spurious dipole sources,
  2. spurious quadrupole sources,
  3. ... that cancel each other out!
- No cancellation when neglecting quadrupoles

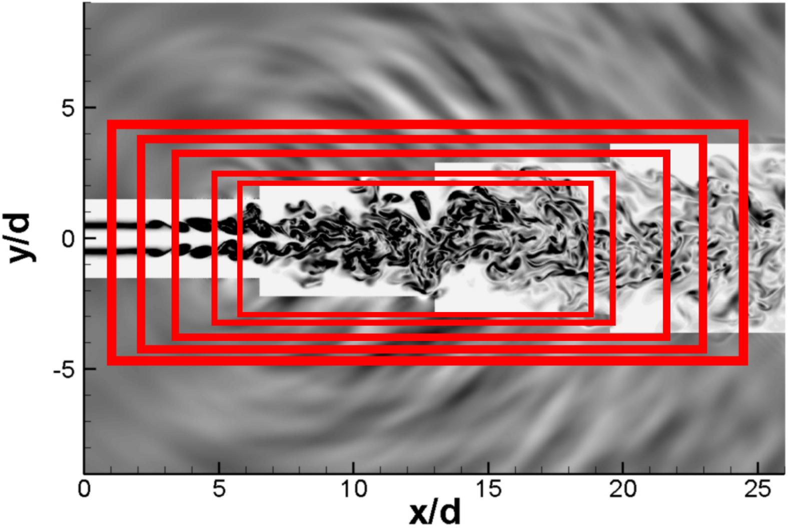
Classical FW-H: single surface



Generalised FW-H: bounded volume (Wright et al)



Generalised FW-H discretisation: multiple surfaces (Wright et al)



Previous work

- Shur (IJA 2005), Spalart and Shur (IJA 2009)
  Averaging over multiple surfaces
- Mendez, Shoeybi, Lele, and Moin (IJA 2013)
  Review and modelling of surface averaging for jet noise.
- Wright and Morfey (IJA 2015)
  Generalised averaging over multiple surfaces.
- Najafi-Yazdi, Bres and Mongeau (Proc. Roy. Soc A 2009)
  Acoustic analogy for moving sources in a uniform flow.
- Gregory, Sinayoko, Agarwal, Lasenby (arXiv:1403.7511 2015)
  An acoustic space-time and the Lorentz transformation in aeroacoustics

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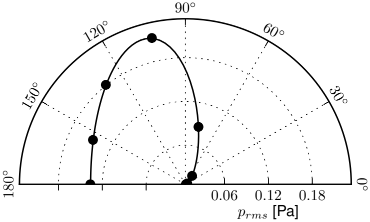
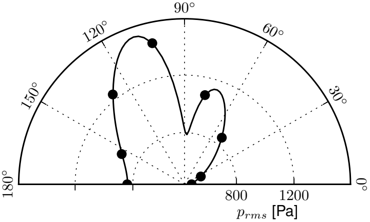
Parameter	Physical effect
Mach number	
M	Controls convection speed
Observer distance	
$\bar{r}_o = r_o/\lambda$	Near/Far field
Cube edge	
$\bar{r}_s = r_s/\lambda$	FW-H surface compactness
Cube Cell size	
$\Delta r_s = r_s/m$	Cube cell compactness
He $\equiv k\Delta r_s/\beta = 1$	
$m \geqslant 8$	

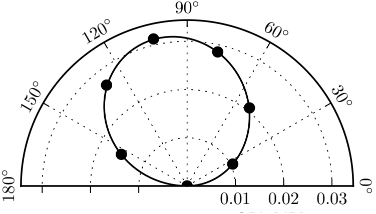
$M = 0.9,\ \bar{r}_o = 100,\ \bar{r}_s = 0.01$



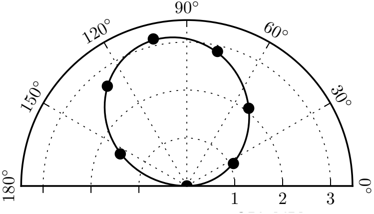
$M = 0.9,\ \bar{r}_o = 0.02,\ \bar{r}_s = 0.01$



$M = 0.2,\ \bar{r}_o = 100,\ \bar{r}_s = 1.0$



$M = 0.2,\ \bar{r}_o = 1.01,\ \bar{r}_s = 1.0$



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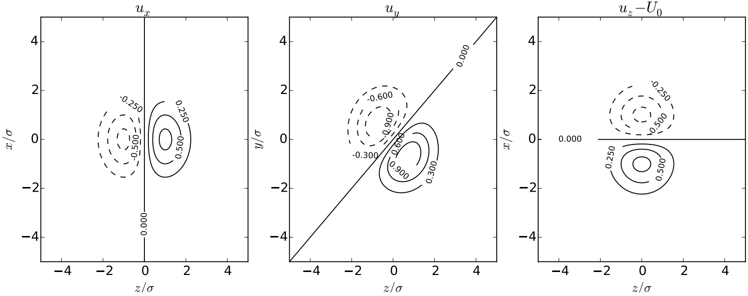
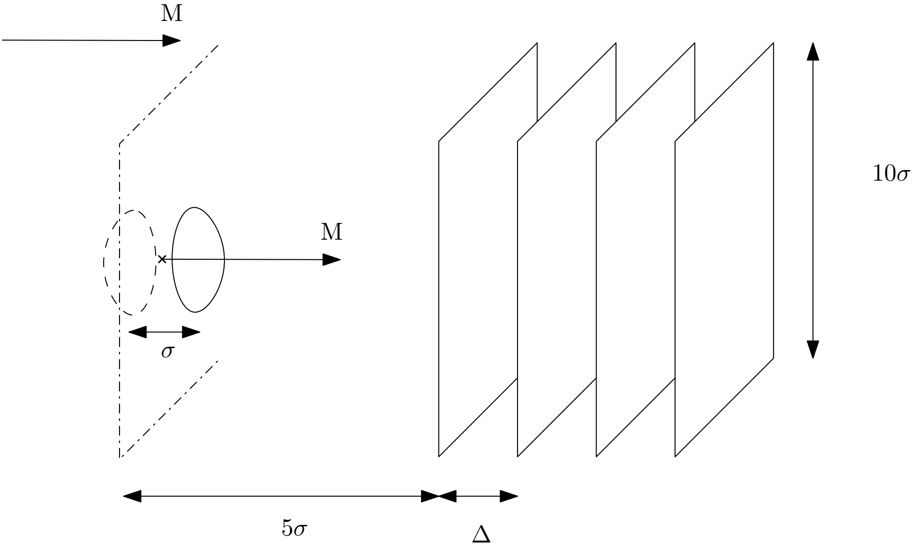
Divergence-free Gaussian vortex

Divergence-free 3D Gaussian convecting vortex (Sescu and Hixon (2013))

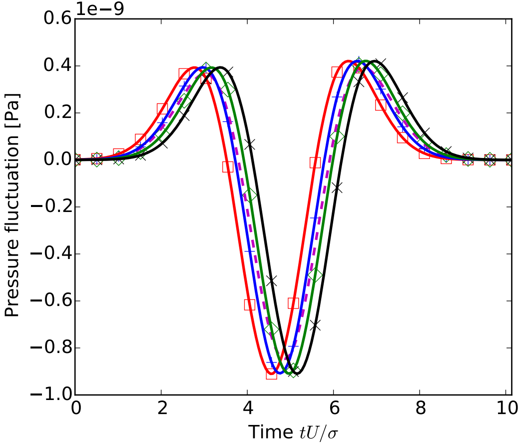


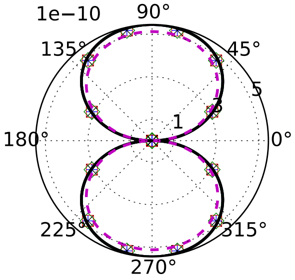
FW-H surfaces



Results

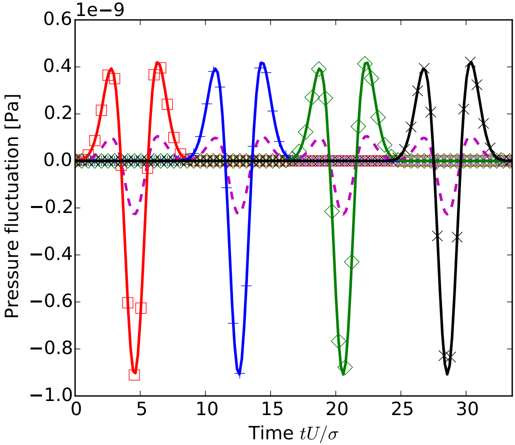
Closely spaced surfaces $\Delta = 0.2\sigma$

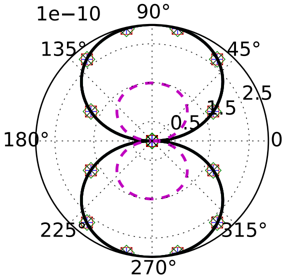




Results

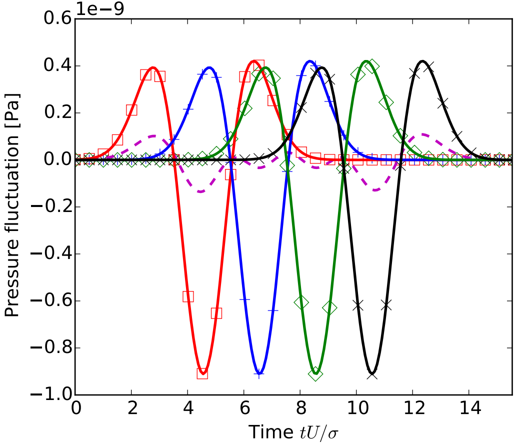
Widely spaced surfaces $\Delta = 8\sigma$

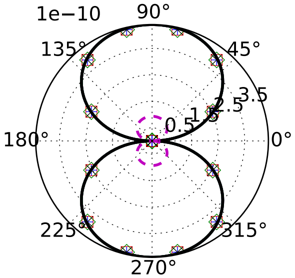




Results

Optimal spacing $\Delta = 2\sigma$





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Conclusions

Achievements

1. Validated FW-H implementation for formulation 1C
2. Tested Generalized FW-H analogy for convecting vortex
3. Averaging technique of Schur et al is near optimal

Future work

- Test generalized FW-H for synthetic turbulence
- Test generalized FW-H for wavepackets
- Apply FW-H to Jet DNS of Sandberg et al

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Further information

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s.sinayoko@soton.ac.uk

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