An Improved Noise Reduction Modelling Approach For Wire Screens Applied To Aircraft Landing Gears

Dr. Patrick .N. Okolo, Dr. Eleonora Neri & Dr. Cristina Paduano
CFD Modelling Specialist Consultants, B-Fluid:
Buildings Fluid Dynamics Ltd, Dublin 2, Ireland

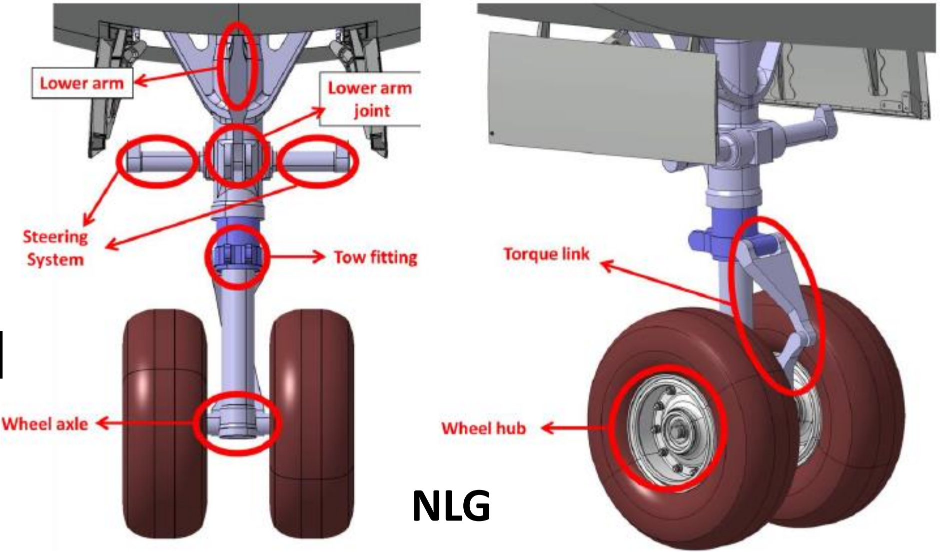
Prof. Gareth. J .Bennett
Fluids, Vibrations and Acoustics Group, Dept of Mechanical and Manufacturing Engr, University of Dublin, Trinity College.

INTRODUCTION

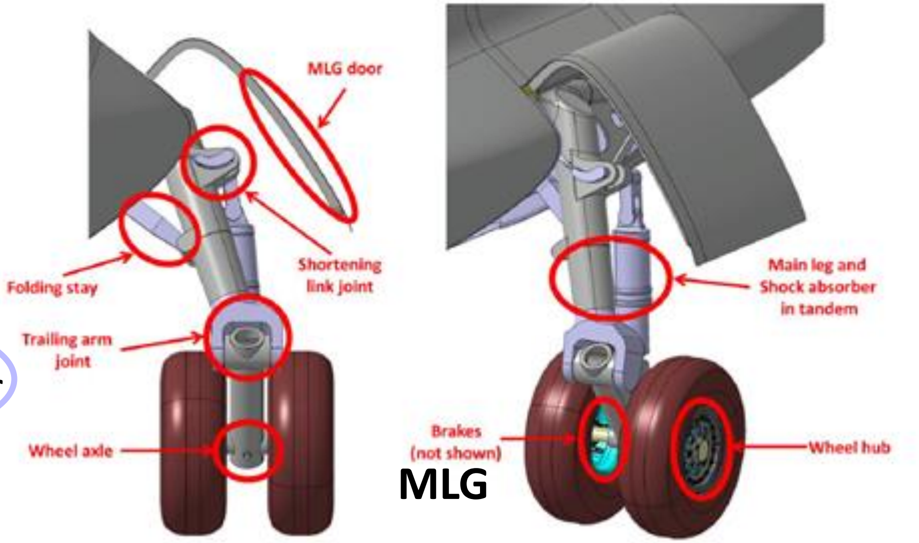
Aircraft Noise

Aircraft noise sources

- ENGINE NOISE
- AIRFRAME NOISE
  - High Lift devices (flaps/slats)
  - Landing Gear



NLG



MLG

INTRODUCTION

Aircraft Noise

- Airframe noise is dominated by landing gear noise during approach phases.

- These elevated noise levels yield negative consequences such as*;

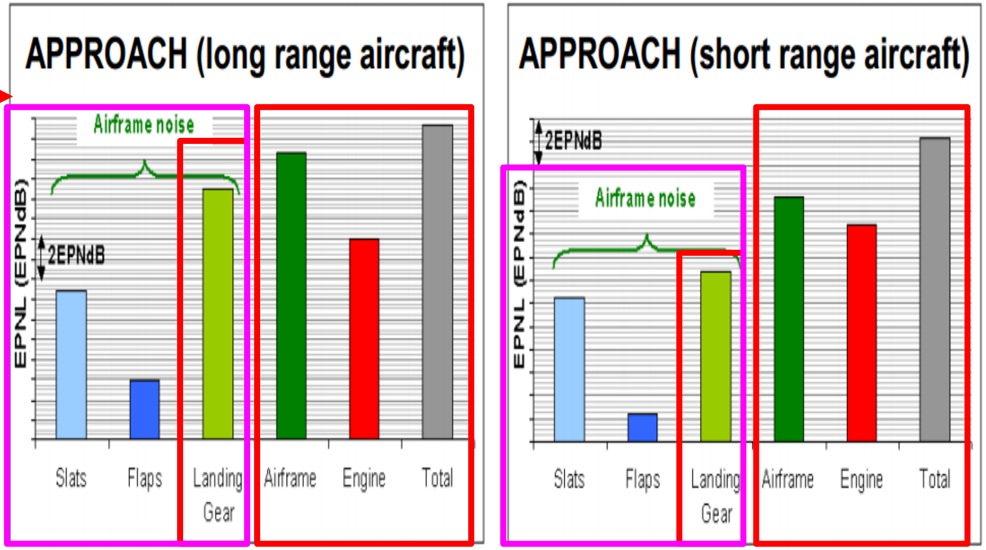
✓Sleep disturbance

✓Arterial hypertension

✓Hearing Impairment

✓Learning difficulties, e.t.c

- Therefore, landing gear noise reduction is a major research and industry concern



W. Dobrzynski, “Almost 40 years of airframe noise research: What did we achieve" Journal of aircraft, vol. 47, no. 2, pp. 353-367, 2010.

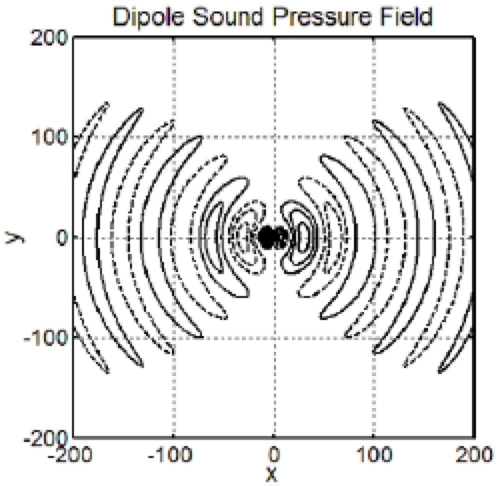
*U. Rosenhall, K. Pedersen, and A. Svanborg, “Presbycusis and noise-induced hearing loss," Ear and hearing, vol. 11, no. 4, pp. 257-263, 1990.

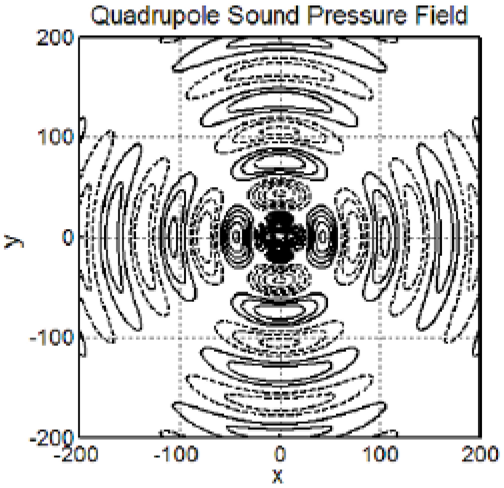
INTRODUCTION

Aerodynamic Noise Generation Theories

Sound Intensity | Acoustic Power

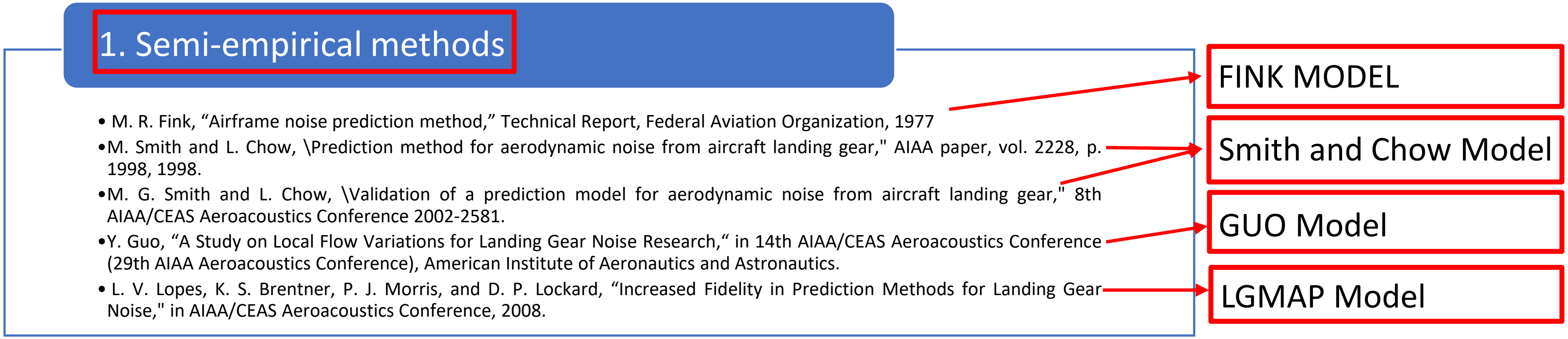
- Lighthill's Theory for Unbounded Flows → $I(x) \propto \rho_0 \boxed{U^8} a_0^{-5} (\frac{l}{x})^2$ $P \propto \rho_0 \boxed{U^8} a_0^{-5} l^2$ **Quadrupoles !**
- Curle's Theory For Solid Bounded Flows → $I_D(x) \propto \rho_0 \boxed{U^6} a_0^{-3} f(x-y)$ $P \propto \rho_0 \boxed{U^6} a_0^{-3} l^2$ **Dipoles !!**
- Ffowcs Williams & Hawkings (FW-H) Theory for Solids in arbitrary motion ← Couple CFD to FWH Analogy





INTRODUCTION

Aircraft Landing Gears Noise: Predictions



1. Semi-empirical methods

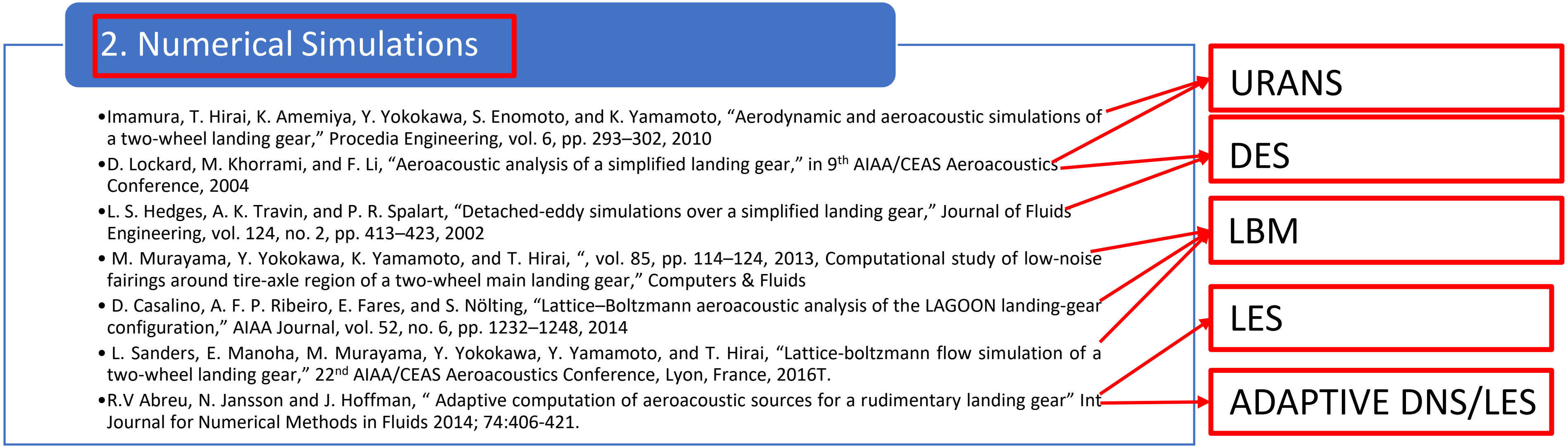
- M. R. Fink, “Airframe noise prediction method,” Technical Report, Federal Aviation Organization, 1977
- M. Smith and L. Chow, \Prediction method for aerodynamic noise from aircraft landing gear," AIAA paper, vol. 2228, p. 1998, 1998.
- M. G. Smith and L. Chow, \Validation of a prediction model for aerodynamic noise from aircraft landing gear," 8th AIAA/CEAS Aeroacoustics Conference 2002-2581.
- Y. Guo, “A Study on Local Flow Variations for Landing Gear Noise Research,“ in 14th AIAA/CEAS Aeroacoustics Conference (29th AIAA Aeroacoustics Conference), American Institute of Aeronautics and Astronautics.
- L. V. Lopes, K. S. Brentner, P. J. Morris, and D. P. Lockard, “Increased Fidelity in Prediction Methods for Landing Gear Noise," in AIAA/CEAS Aeroacoustics Conference, 2008.

FINK MODEL

Smith and Chow Model

GUO Model

LGMAP Model



2. Numerical Simulations

- Imamura, T. Hirai, K. Amemiya, Y. Yokokawa, S. Enomoto, and K. Yamamoto, “Aerodynamic and aeroacoustic simulations of a two-wheel landing gear,” Procedia Engineering, vol. 6, pp. 293–302, 2010
- D. Lockard, M. Khorrami, and F. Li, “Aeroacoustic analysis of a simplified landing gear,” in 9th AIAA/CEAS Aeroacoustics Conference, 2004
- L. S. Hedges, A. K. Travin, and P. R. Spalart, “Detached-eddy simulations over a simplified landing gear,” Journal of Fluids Engineering, vol. 124, no. 2, pp. 413–423, 2002
- M. Murayama, Y. Yokokawa, K. Yamamoto, and T. Hirai, “, vol. 85, pp. 114–124, 2013, Computational study of low-noise fairings around tire-axle region of a two-wheel main landing gear,” Computers & Fluids
- D. Casalino, A. F. P. Ribeiro, E. Fares, and S. Nölting, “Lattice–Boltzmann aeroacoustic analysis of the LAGOON landing-gear configuration,” AIAA Journal, vol. 52, no. 6, pp. 1232–1248, 2014
- L. Sanders, E. Manoha, M. Murayama, Y. Yokokawa, Y. Yamamoto, and T. Hirai, “Lattice-boltzmann flow simulation of a two-wheel landing gear,” 22nd AIAA/CEAS Aeroacoustics Conference, Lyon, France, 2016T.
- R.V Abreu, N. Jansson and J. Hoffman, “ Adaptive computation of aeroacoustic sources for a rudimentary landing gear” Int Journal for Numerical Methods in Fluids 2014; 74:406-421.

URANS

DES

LBM

LES

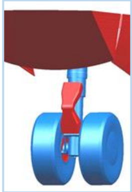
ADAPTIVE DNS/LES

INTRODUCTION

Landing Gears Noise Reduction Treatments

Fairings

K. Boorsma, X. Zhang, and N. Molin, “Landing gear noise control using perforated fairings,” Acta Mechanica Sinica, vol. 26, no. 2, pp. 159–174, 2009

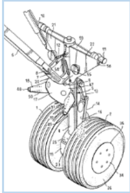


Ramp Spoilers

W. Dobrzynski, B. Schöning, L.C. Chow, Ch. Wood, M. Smith, Ch. Seror, Design and testing of low noise landing gears, AIAA/CEAS Paper 2005-3008, Monterey/USA, 2005

Bay Treatments

K. Takeda, H. Nishiwaki, and S. Fujii, “The reduction of cavity noise at subsonic speeds,” in National Aerospace Laboratory, 1990

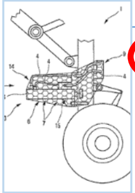


Wheel Hub Caps

L. Chow, D. Foot, and C. Wood, “Aircraft noise reduction apparatus,” US Patent US6619587 B1, 2003

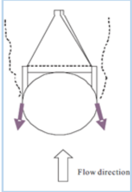
Hole Covring

W. Dobrzynski, “Almost 40 years of airframe noise research: What did we achieve?,” Journal of Aircraft, vol. 47, no. 2, pp. 353–367, 2010



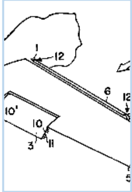
Meshes

S. Oerlemans, C. Sandu, N. Molin, and J.-F. Piet, “Reduction of landing gear noise using meshes,” 16th AIAA/CEAS Aeroacoustics Conference, 2010



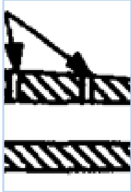
Plasma Actuators

F. O. Thomas, A. Kozlov, T. C. Corke, “Plasma actuators for cylinder flow control and noise reduction”, AIAA Journal 46 (8) 1921–1931, 2008.



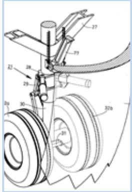
Vortex Disintegrators

I. Borchers, R. Drobietz, M. Gruenewald, K. Mau, J. Reichenberger, Noise reducing vortex generators on aircraft wing control surfaces, US Patent 6,491,260 (Dec. 2002)



Boundary Layer Suction

P. M. Rose, A. A. Mikolajczak, “Turbofan duct with noise suppression and boundary layer control”, US Patent 4,749,150, 1988



Air Curtains

S. Oerlemans and A. de Bruin, “Reduction of Landing Gear Noise Using an Air Curtain,” 15th AIAA/CEAS Aeroacoustics Conference, 2009

AIRBUS PATENT

- Weight and Acoustic gains
- Application (attachment issues)

INTRODUCTION

Landing Gears Noise: Coordinated Studies

1998-2002 **RAIN**

- W. Dobrzynski, L. C. Chow, P. Guion, and D. Shiells, “A european study on landing gear airframe noise sources,” 6th AIAA/CEAS Aeroacoustics Conference, 2000

- L. Chow, K. Mau, and H. Remy, “Landing Gears and High Lift Devices Airframe Noise Research,” 8th AIAA/CEAS Aeroacoustics Conference, 2002

SILENCER *2001-2006*

- W. Dobrzynski, B. Schöning;, L. C. Chow, C. Wood, M. Smith, and C. Seror, “Design and testing of low noise landing gears,” International Journal of Aeroacoustics, vol. 5, no. 3, pp. 233–262, 2006

2005-2006 **QTD2**

- Herkes, W. H., Olsen, R. F., and Uellenberg, S., “The Quiet Technology Demonstrator Program: Flight Validation of Airplane Noise-Reduction Concepts,” AIAA Paper 2006-2720, 2006.

TIMPAN *2006-2009*

- L. C. C. Werner Dobrzynski, “Experimental assessment of low noise landing gear component design,” International Journal of Aeroacoustics, vol. 9, no. 6, pp. 763–786, 2010

2009-2014 **OPENAIR**

- E. Kors and D. Collin, “Optimisation for low environmental noise impact aircraft-openair,” InterNoise, 2014.

ALLEGRA *2013-2014*

- E. Neri, J. Kennedy and G. J. Bennett, Bay Cavity Noise for Full-Scale Nose Landing Gear: a comparison between experimental and numerical results, *Aerospace Science and Technology*, 72, 2017, p278 - 291.

Since 2006 **LAGOON**

- L. Sanders, E. Manoha, S. B. Khelil, and C. Francois, “LAGOON: New Mach landing gear noise computation and further analysis of the CAA process,” in 18th AIAA/CEAS Aeroacoustics Conference, 2012

WP4.1 *Since 2009*

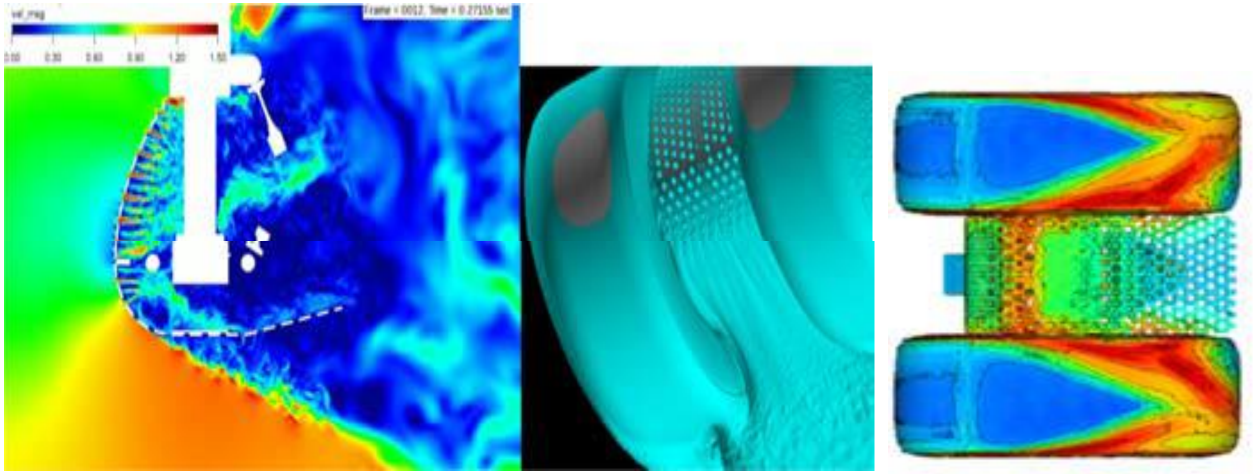
- M. Smith, L. C. Chow, and N. Molin, “Control of landing gear noise using meshes," in 16th AIAA/CEAS Aeroacoustics Conference, 2010-3974.

CURRENT CHALLENGES

Numerical Approach For Wire Mesh Effect on Landing Gear Noise

- **DNS, LES** or Lattice Boltzmann method (**LBM**) → Computational Intensive

- Numerically Resolving mesh screens as low noise treatments for Landing gears is an expensive computational task, which is often unrealistic due to tiny length scales involved.



M. Murayama, Y. Yokokawa, K. Yamamoto, and T. Hirai, “, vol. 85, pp. 114–124, 2013, Computational study of low-noise fairings around tire-axle region of a two-wheel main landing gear,” Computers & Fluids

CURRENT CHALLENGES

Numerical Approach For Wire Mesh Effect on Landing Gear Noise

- Therefore, an alternative approach is proposed here. This alternative approach should account for the major effects of a woven wire mesh screen (pressure drop, velocity change, turbulence effect and self noise).

- Volume-Averaged Method **(VAM)**

A modified Navier-Stokes equation is used to describe flow within a **porous zone**

Momentum Source Term →

$$S_i = -\left(\sum_{j=1}^{3} D_{ij}\mu v_j + \sum_{j=1}^{3} C_{ij}\frac{1}{2}\rho|v|v_j\right)$$

Viscous loss term

inertial loss term

POROUS ZONE MODELLING APPROACH

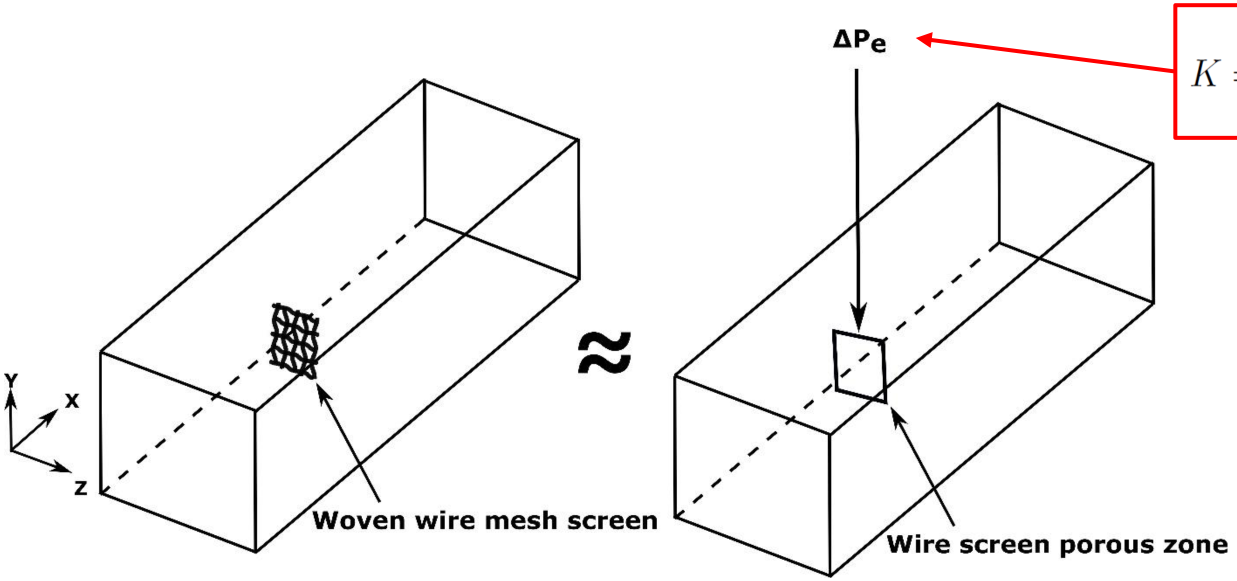
- Porous Modelling utilizing a Brinkman-Forchheimer modified Navier Stokes equation within a porous zone, accounts for modified pressure drop and velocity reduction characteristics

Momentum Source Term →

$$S_i = -\left(\boxed{\sum_{j=1}^{3} D_{ij}\mu v_j} + \boxed{\sum_{j=1}^{3} C_{ij}\frac{1}{2}\rho|v|v_j}\right)$$

Viscous loss term

inertial loss term

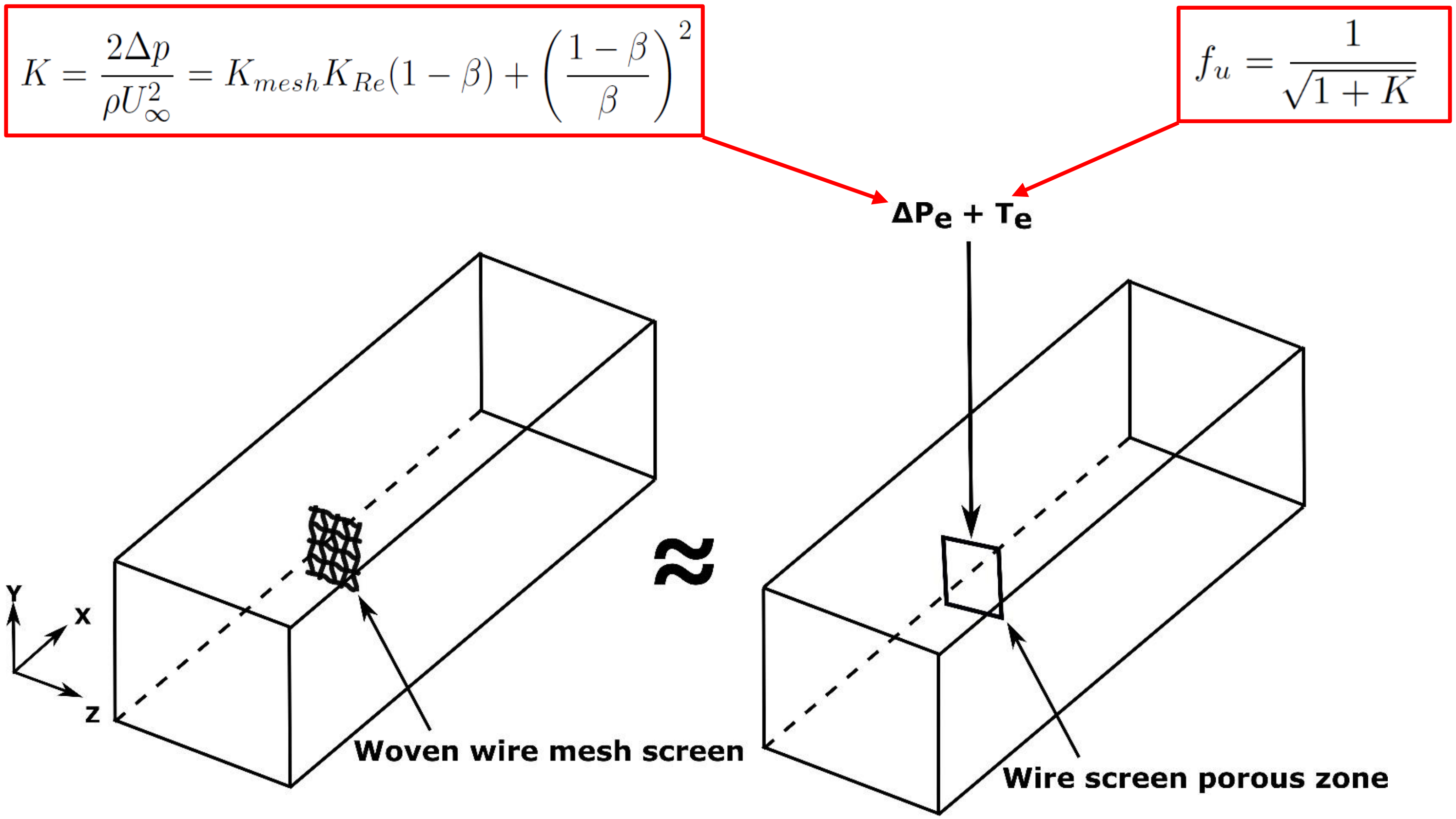


$$\boxed{K = \frac{2\Delta p}{\rho U_{\infty}^{2}} = K_{mesh}K_{Re}(1-\beta) + \left(\frac{1-\beta}{\beta}\right)^{2}}$$

Wire screens loss coefficient

POROUS ZONE MODELLING APPROACH

- Previous approach does not account for turbulence effect of wire screens!!!



$$K = \frac{2\Delta p}{\rho U_\infty^2} = K_{mesh} K_{Re}(1-\beta) + \left(\frac{1-\beta}{\beta}\right)^2$$

$$f_u = \frac{1}{\sqrt{1+K}}$$

$\Delta P_e + T_e$

Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

B-Fluid
Buildings Fluid Dynamics

RESEARCH AIMS

- To propose and implement an alternative approach of modelling woven wire mesh screens for low noise treatment applications within a CFD domain in a non-computational expensive manner.

- To implement woven wire screens pressure drop and turbulence reduction into a modified Volume Averaged Method (VAM).

- To test the modified VAM modelling approach on a realistic representation of an aircraft main landing gear (MLG).

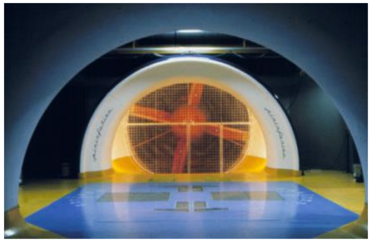
- To show that the implementation of this approach represents a good alternative to more expensive means of fully resolving the effect of wire screens upstream or wrapped around landing gear models within a CFD domain.

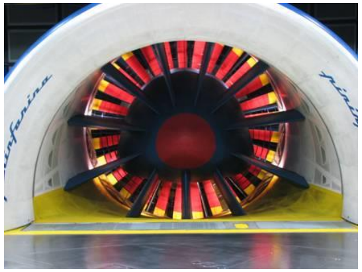
- To validate CFD numerical acoustics results against experimental campaign tests of ALLEGRA project.

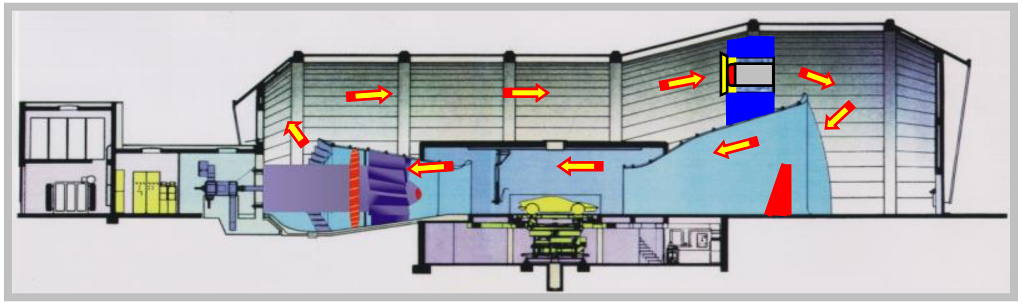
ALLEGRA EXPERIMENTAL SETUP

Pininfarina Wind Tunnel features:

- Jet section: 11 m^2 (semi-circular)
- Max speed: 260 km/h (empty test section)
- BNL: 68 dBA at V = 100 km/h
- Turbulence intensity: 0.3%
- Test Section: 8m x 9,6m x 4,2m







ALLEGRA specifications:

- **Full representation** of the landing gear detail and associated structures (e.g. bay cavity, bay doors, belly fuselage etc.) are included and addressed at a realistic scale.
- The Nose Landing Gear is designed at full scale and the Main Landing Gear at half scale.
- Implementation of low-noise technologies.

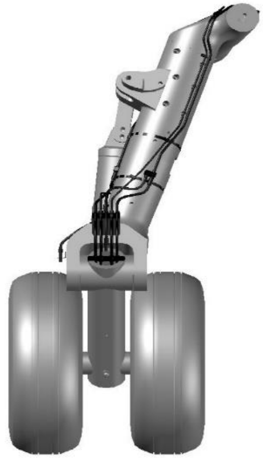
$\beta = 65\%$

Wire mesh

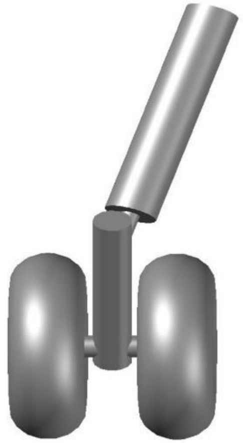
-5dB

4000 Hz

NUMERICAL SETUP & MODEL MODIFICATIONS

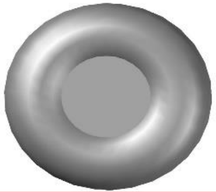


(a) Original MLG



(b) Remodeled MLG

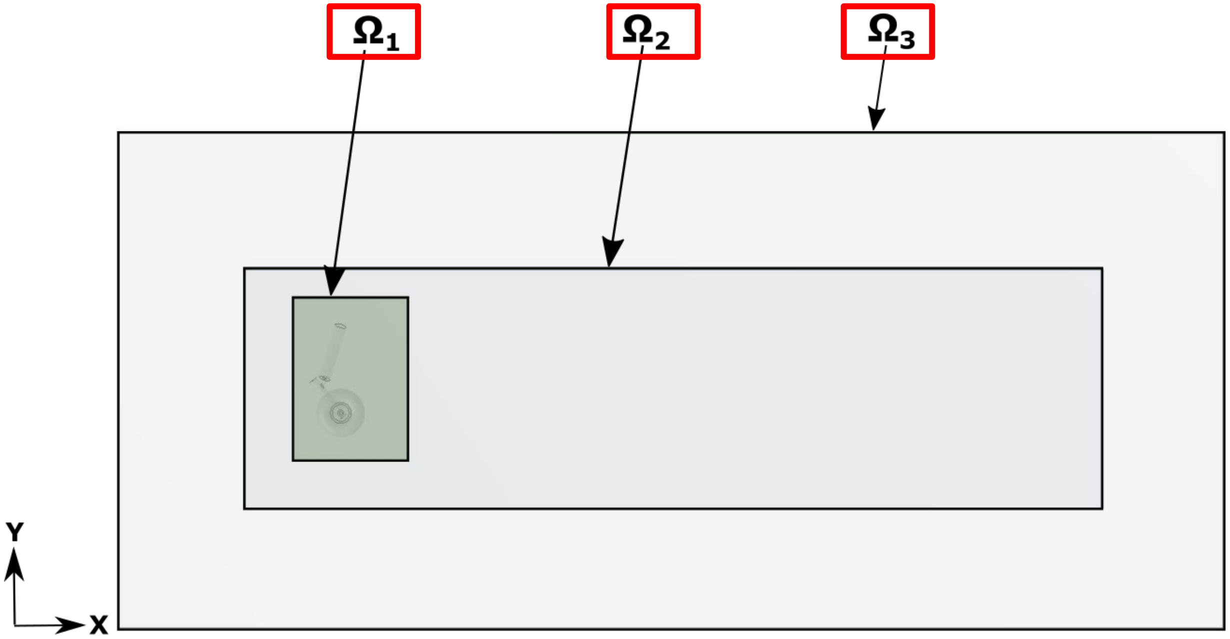
(a) Original Wheel



(b) Remodeled Wheel

Domain	L_x	L_y	L_z	Max cell size (m)	Zone
Ω_1	$2.5D_w$	$4D_w$	$2.3D_w$	0.02	LES zone
Ω_2	$18.5D_w$	$5D_w$	$5D_w$	0.10	LES/URANS zone
Ω_3	$23D_w$	$8D_w$	$8D_w$	0.17	URANS zone

MLG Numerical Domain Dimensions



Nomenclature

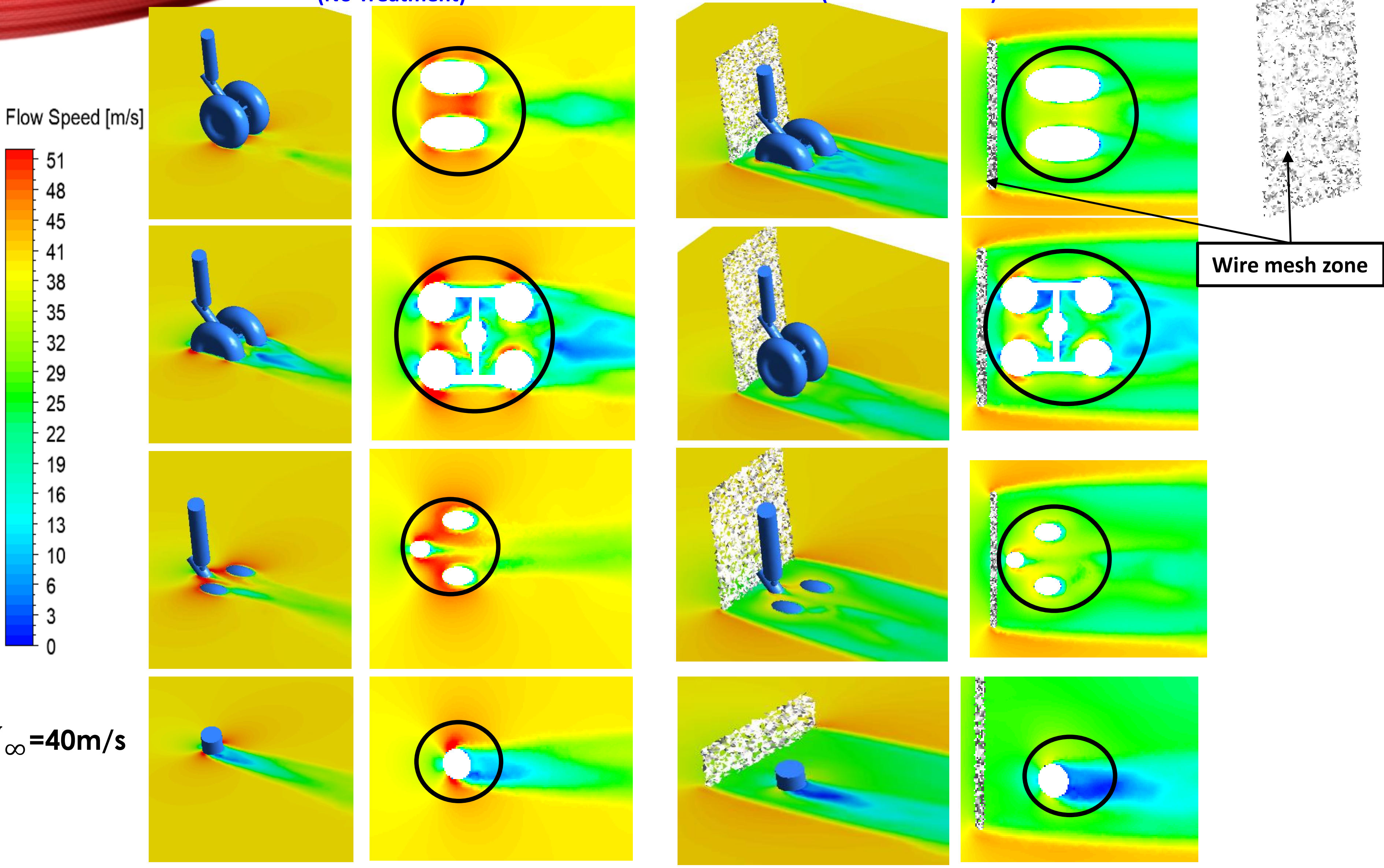
MLG-1	MLG-No Treatment
MLG-2	MLG-Mesh Treatment

$\beta = 65\%$

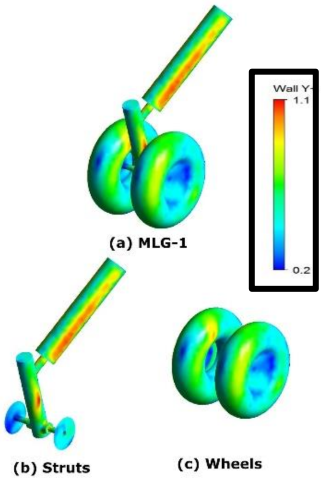
STEADY VELOCITY RESULTS

MLG-1
(No Treatment)

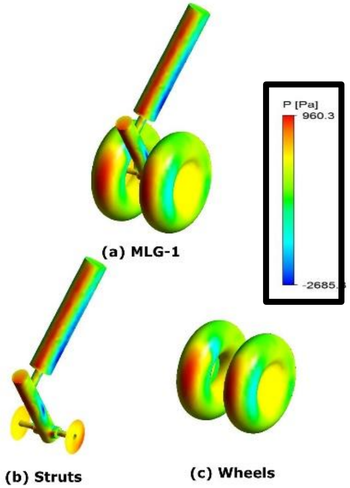
MLG-2
(Mesh Treatment)



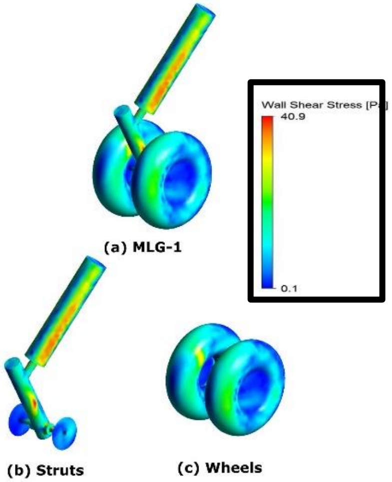
SURFACE SHEAR STRESS RESULTS



(a) MLG-1 Wall y+

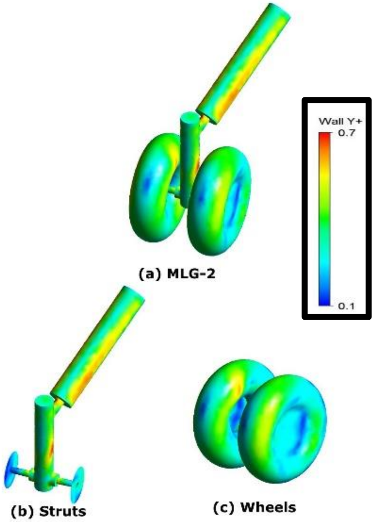


(b) MLG-1 Surface Pressure

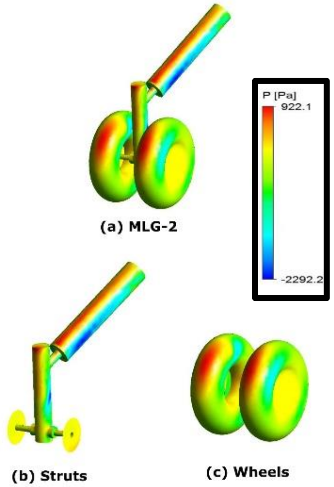


(c) MLG-1 Wall Shear Stress

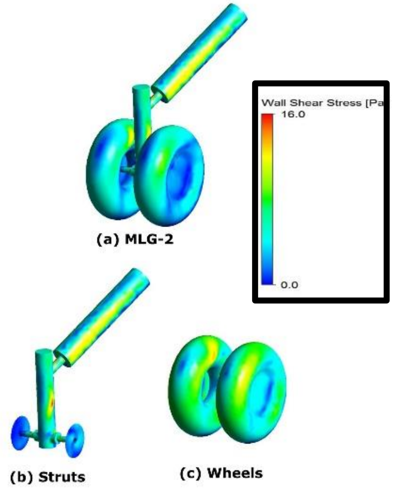
MLG-1
(No Treatment)



(a) MLG-2 Wall y+



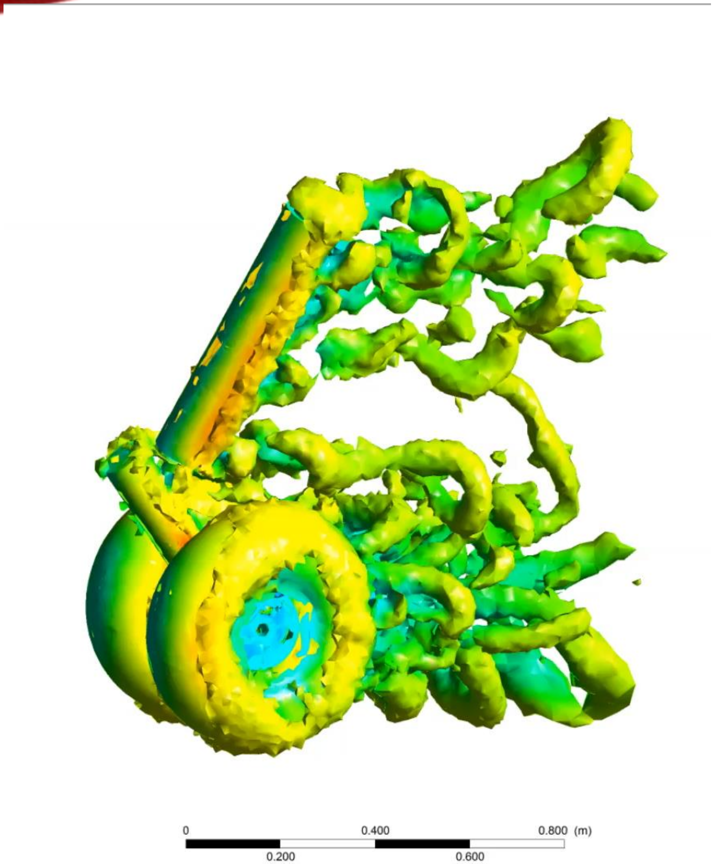
(b) MLG-2 Surface Pressure



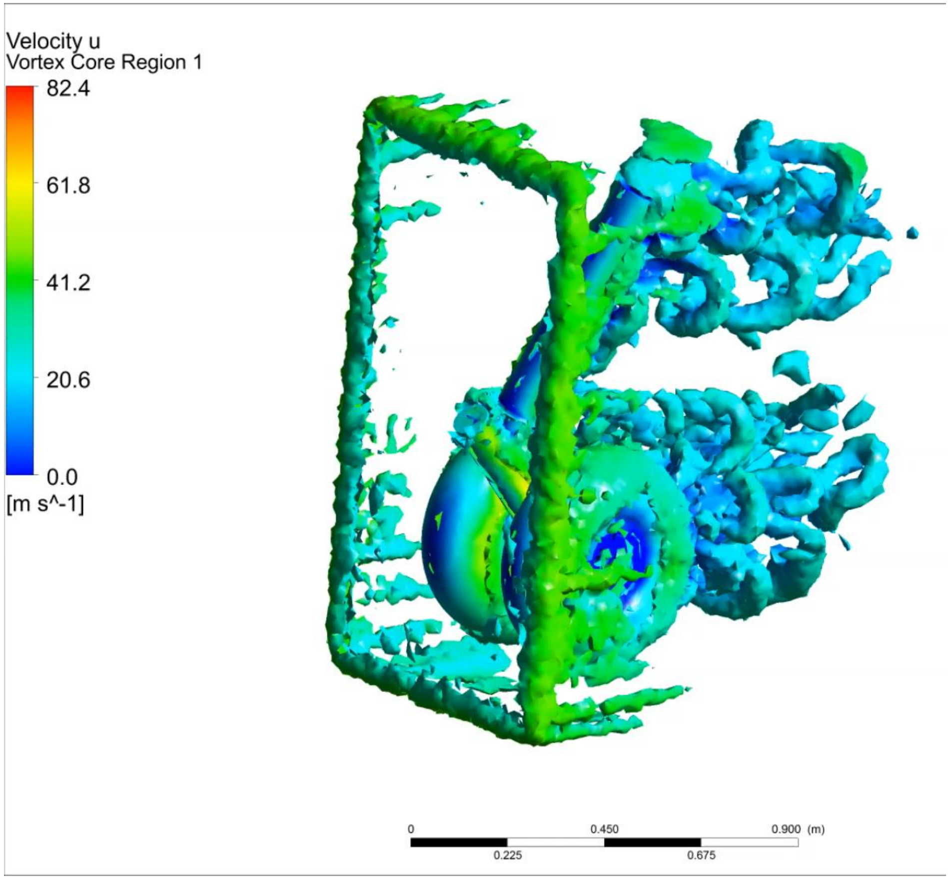
(c) MLG-2 Wall Shear Stress

MLG-2
(Mesh Treatment)

UNSTEADY VELOCITY RESULTS



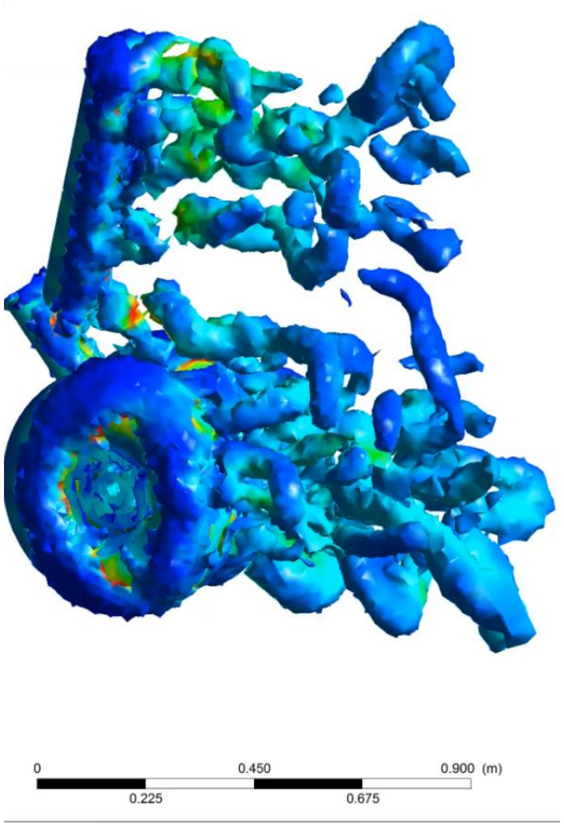
MLG-1
(No Treatment)



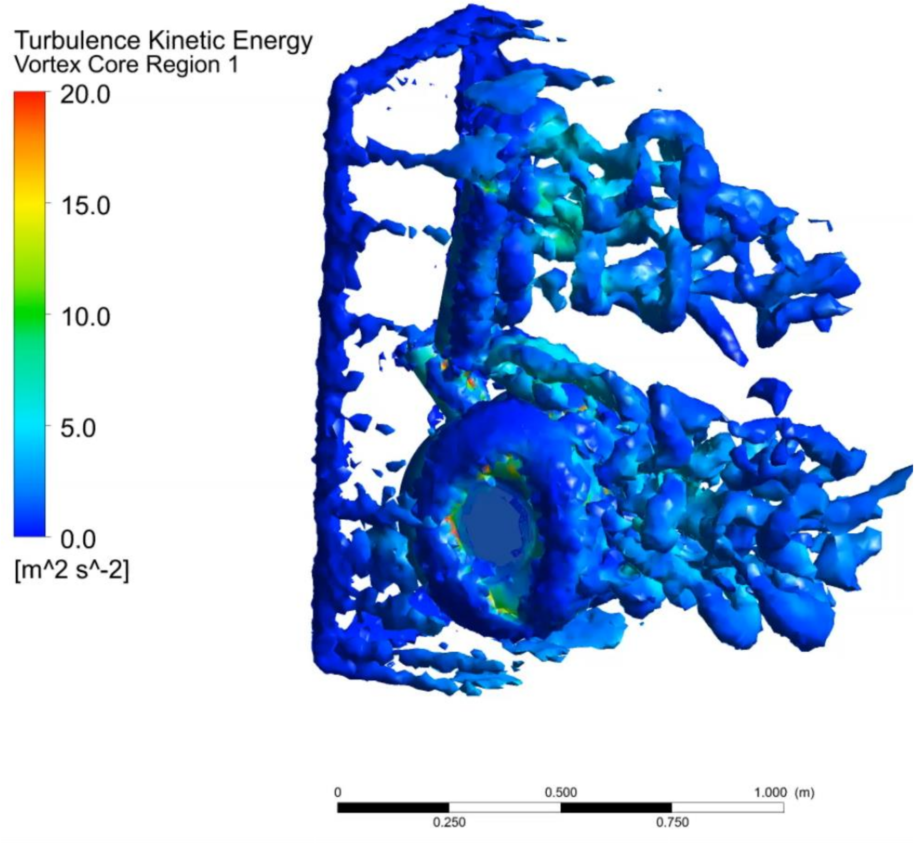
MLG-2
(Mesh Treatment)

Unsteady Results after 1.05secs
($\Delta t = 3.2 \times 10^{-6}$)

TURBULENT KINETIC ENERGY RESULTS



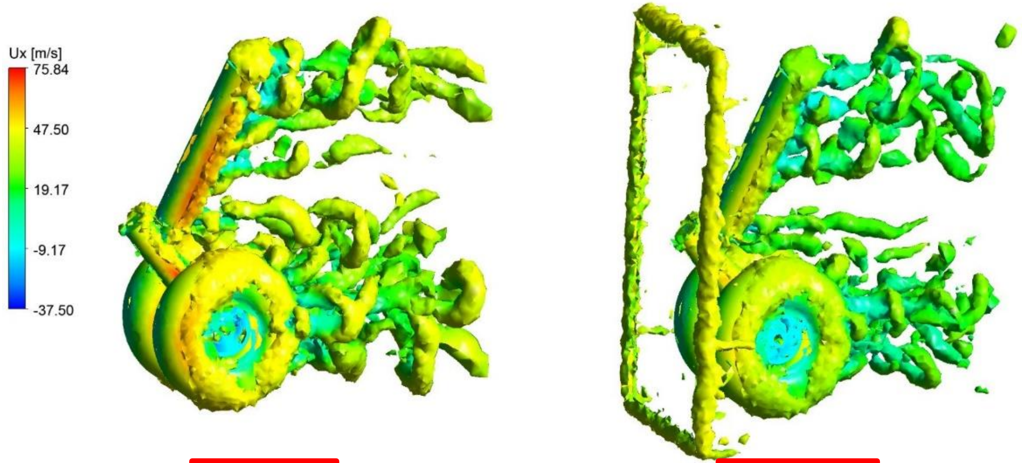
MLG-1
(No Treatment)



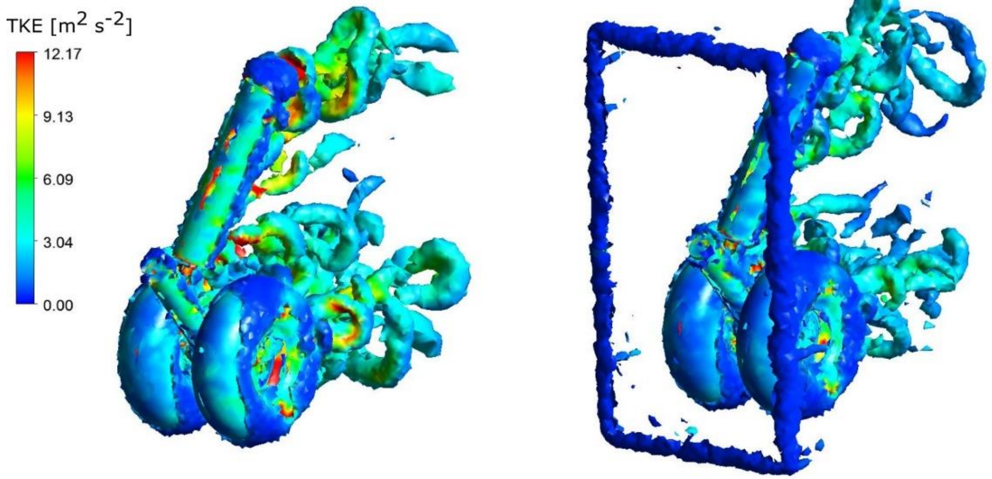
MLG-2
(Mesh Treatment)

Unsteady Results after 1.05secs
(Δt=3.2×10^{-6})

UNSTEADY RESULTS



(a) MLG-1 **(b) MLG-2**



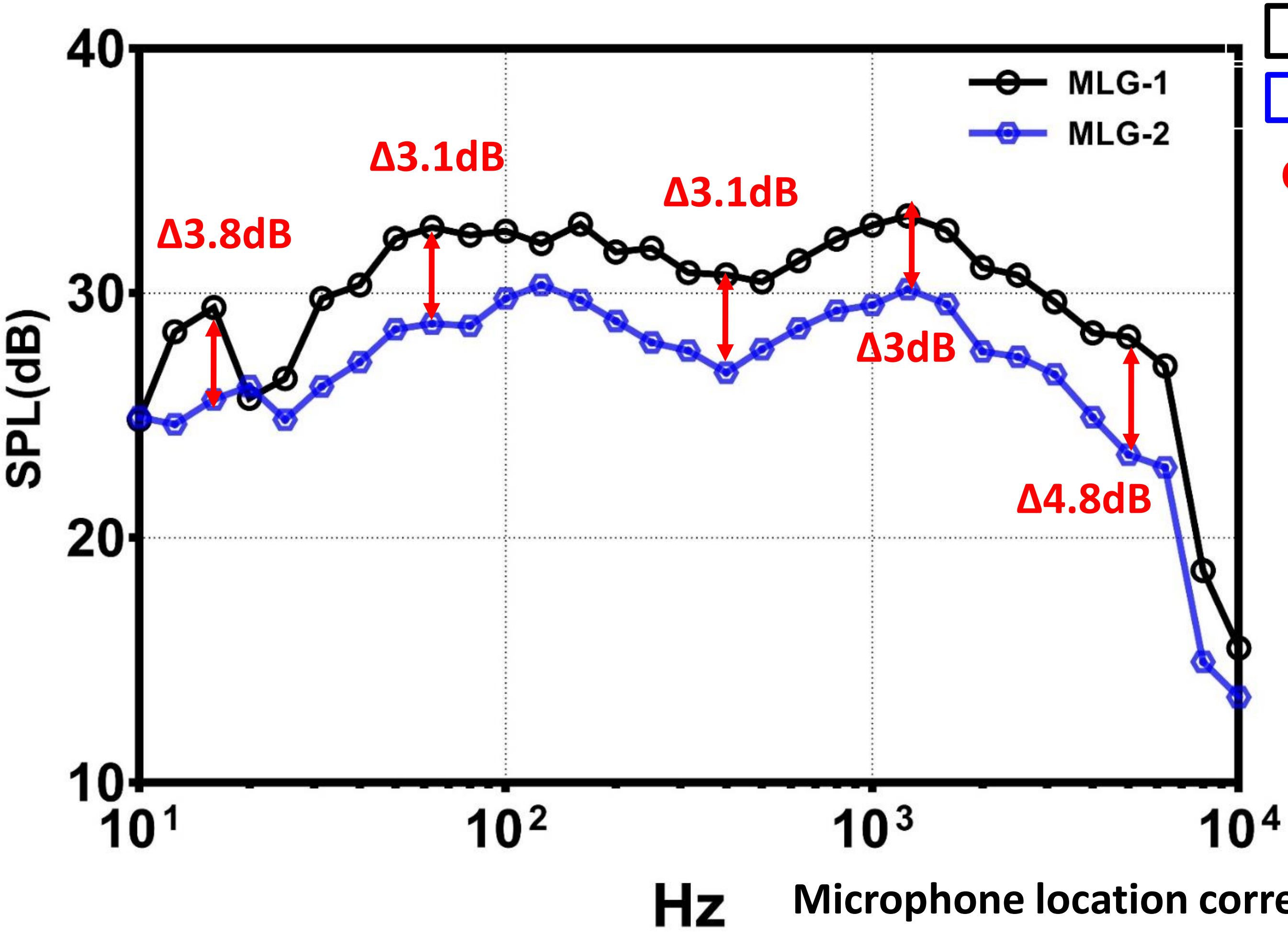
(a) MLG-1 **(b) MLG-2**

Reduced Flow speed

Unsteady Results at 1.05secs (Δt=3.2×10^{-6})

Reduced Turbulent Kinetic Energy

FAR-FIELD ACOUSTICS



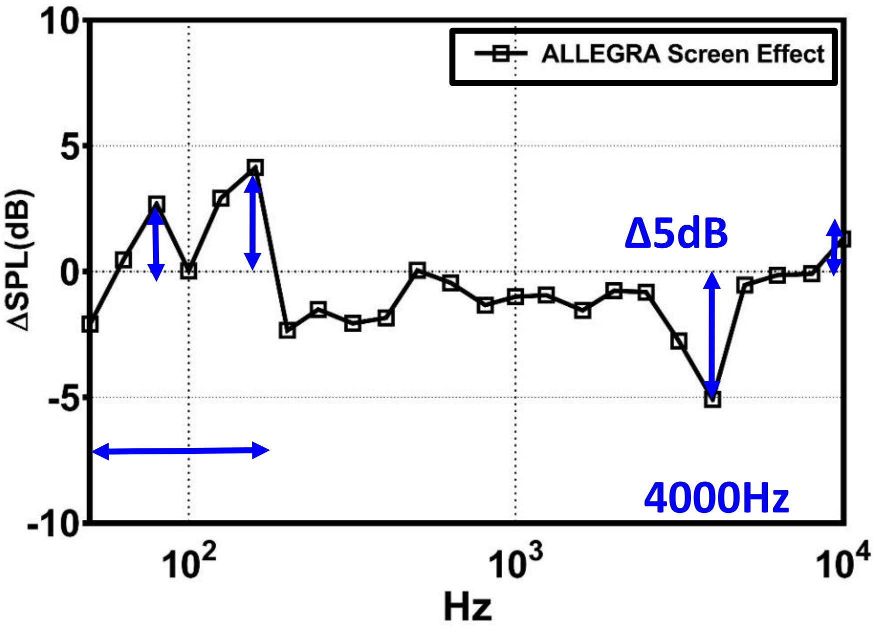
MLG-1 (No Treatment)

MLG-2 (Mesh Treatment)

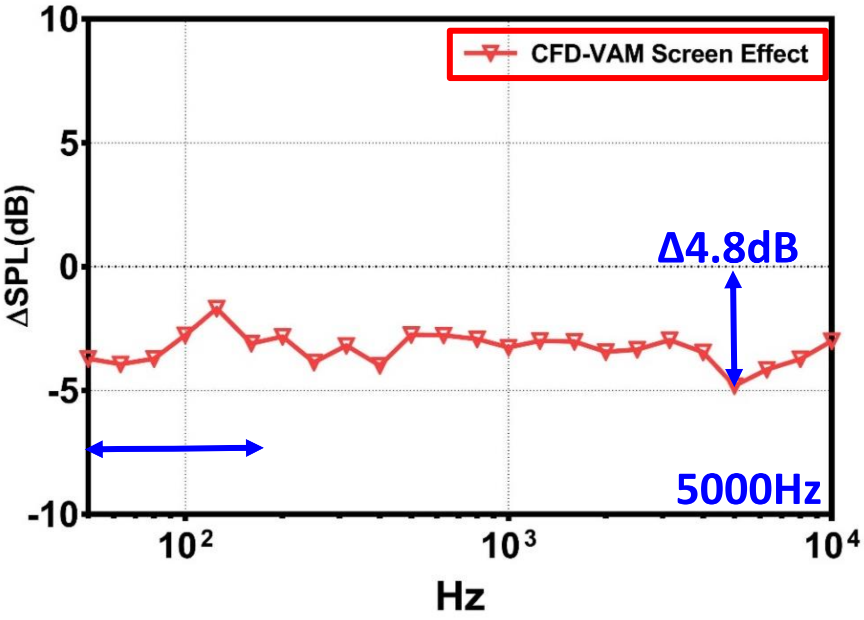
CFD Far-field Acoustics

Microphone location corresponds to 2.92m and 90^o
Linear array location used for ALLEGRA

FAR-FIELD ACOUSTICS



(a) ALLEGRA Wire Screen Noise Reduction



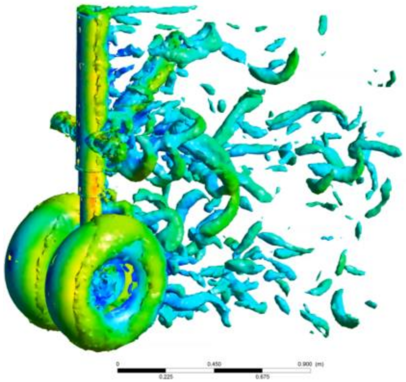
(b) CFD-VAM Wire Screen Noise Reduction

- ALLEGRA low frequency noise increase not detected by CFD-VAM
- ALLEGRA maximum noise reduction = 5dB at 4000Hz
- CFD-VAM maximum noise reduction = 4.8dB at 5000Hz
- High frequency noise increase is not detected by the CFD-VAM

CONCLUSIONS

- A potentially less computational intensive method of modelling and simulating the characteristics of mesh screens is proposed
- The proposed alternative CFD-VAM modelling approach for woven wire screens shows promising signs on a rudimentary level.
- This method helps to account for velocity drop, surface pressure reductions and turbulence kinetic energy reduction on aerodynamic shapes.
- This method does not detect low frequency noise increase, and consistently produces SPL decrease.
- High frequency noise increase is not detected by this approach (Increase Expected due to self-Noise of wire mesh)

Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin



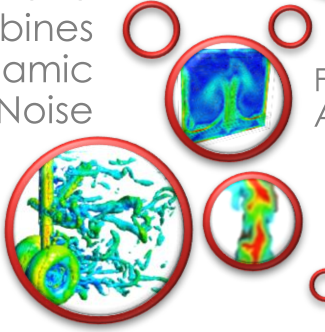
Thank you

Flow Testing

- Aeroacoustics Testing
- Wind Tunnel Tests
- On Site Smoke Testing

CFD and Multi-Physics Modelling

- Urban and Buildings Aeroacoustics
- HVAC Analysis
- Wind Impact study



- Aircraft and Wind Turbines Aerodynamic Noise
- Façade Thermal Analysis
- Fire and Smoke Modelling

B-Fluid Ltd | Buildings Fluid Dynamics Consultants

Block 4, Harcourt Centre, Harcourt Road, Dublin

T: +353 (0)1 477 3427 M:+353 (0)85 71 36 352

Email: info@b-fluid.com **Web:** www.b-fluid.com **LinkedIn:** linkedin.com/company/bfluid-ltd

B-Fluid
Buildings Fluid Dynamics