RGC Ref.:
A_PolyU503/15

The Research Grants Council of Hong Kong
ANR/RGC Joint Research Scheme
<u>Completion Report</u>

(Please attach a copy of the completion report submitted to the ANR by the French researcher)

<u>Part A: The Project and Investigator(s)</u>

1. Project Title (ANR Acronym)

Experimental and Numerical Studies of Innovative Acoustical Material Technology for Industrial and Urban Low-Frequency Noise Mitigation

2. Investigator(s) and Academic Department/Units Involved

	Hong Kong Team	French Team
Name of Principal Investigator *(with title)*	Dr Randolph Chi Kin LEUNG	Prof Yves AUREGAN
Post	Associate Professor	Senior Researcher CNRS
Unit / Department / Institution	Department of Mechanical Engineering / The Hong Kong Polytechnic University	Laboratoire d'Acoustique (LAUM) / Université du Maine (UMR CNRS 6613)
Contact Information	mmrleung@polyu.edu.hk	yves.auregan@univ-lemans.fr
Co-investigator(s) *(with title and institution)*	N.A.	Dr Wenping BI Dr Alain LE DUFF

3. Project Duration

	Original	Revised	Date of RGC/ Institution Approval *(must be quoted)*
Project Start date	01/03/2016		
Project Completion date	29/02/2020	31/10/2020	08/08/2019
Duration *(in month)*	48	56	08/08/2019
Deadline for Submission of Completion Report	28/02/2021	31/10/2021	08/08/2019

Part B: The Completion Report

5. Project Objectives

5.1 Objectives as per original application

1. The first objective aims to go further inside the understanding of the physical mechanisms that appear in the interaction between sound and flow in the boundary layer just above an acoustical material. This will be done by comparing, on classical and innovative liners, the experimental results with analytical results and numerical results based on direct aeroacoustic simulation (DAS) approach. The output of this comparison will be guidelines to code users to see when it is relevant to use non-viscous codes and when the effect of viscosity and turbulence is important. It is a crucial issue for industrial users performing very large calculations (like in the aeronautical sector) because the calculation times are very different if the viscosity and turbulence are taken into account or not.

2. The second parallel objective of the current project is to develop innovative acoustic solutions involving specialized materials as key noise absorbers which are able to cope with the spatial constraints arising from real applications (from turbo-prop engines to ventilation in high-rise buildings). The underlying acoustic absorption mechanisms of the new acoustic solutions and their performance in the presence of parallel and grazing flows are studied using a combined analytical, experimental and numerical approach. It is expected that the outcomes of the project would produce a complete understanding of the innovative acoustic solutions as well as guidelines for their design and modelling for practical uses.

5.2. Revised Objectives

Not applicable.

6. Research Outcome

. Major findings and research outcome
(maximum 1 page; please make reference to Part C where necessary)

Study of generic liner design

After discussions between the French team at LAUM and Hong Kong team at PolyU, it was decided to compare the experimental results with a generic liner design, made of metallic porous material at LAUM, and the results of numerical calculations carried out in Hong Kong. To achieve this the PolyU team extended their time-domain DAS to account for the aeroacoustics of flow through porous material by integrating the Brinkman penalization method and the extended Brinkman-Forcheimer-Darcy model. All observed acoustic characteristics in experiments including self-noise induced by developing flow-instability over material interface were faithfully reproduced [J16,C8]. The LAUM team showed that in the presence of grazing flow the same acoustics were not obtained by modeling the liner as a periodic system or a homogeneous system with prescribed impedance [J1,C2]. A new impedance model was therefore developed to take into account the effects of the flow on the propagation near the acoustic liner [J3]. With consideration of longitudinal stresses acting on the liner, this new model effectively extended the applicability of conventional Ingard-Myers condition in the presence of grazing flow. In addition surface modes and wavenumbers riding on liner interface were proven an important consideration in devising correct impedance with grazing flow [J7,J8,C6,C7].

Study of innovative material concepts

The LAUM and PolyU teams developed two calculation methods for modeling of membrane-type liners with grazing flow, namely multi-modal method (MMM) [J2,C1] and a time-domain direct aeroacoustic-structural interaction simulation (DAASIS) [J4]. The LAUM team designed an ultra-thin low-frequency acoustic absorber of mass-membrane-cavity combination that perfectly absorbs 107Hz frequency for 16mm thickness. This represents the current world record for the absorber with the greatest wavelength-to-thickness ratio [J6]. They attempted works on a liner using an embedded plate surrounded by micro-slits using MMM and frequency-domain numerical calculations and MMM [J9, C5]. Their combined acoustic and laser doppler velocimetry (LDA) measurement results on this new type of innovative liner with showed that the liner performance is sensitive to upstream grazing flow condition and this will be carefully studied both analytically and numerically.

Both teams conducted an extensive study with innovative material design with cavity fully covered by a membrane. Having validated their DAASIS model [J4], the PolyU team studied the aeroacoustic-structural responses of the innovative material design exposed to grazing boundary layer flow and confirmed its feasibility of aeroacoustic instability suppression [J10,J11,C4]. Both teams went on to study the variations of the cavity and membrane designs and showed that the cavity geometry plays an important role in determining the transmission loss of duct flow [J5,J12,J13]. The designs were shown to provide strong stopbands of transmission loss covering wider a low frequency range than existing generic liners of same overall dimensions. An addition of dissipation to the enclosed cavity was shown able to combine all stopbands into a truly wide band of transmission loss starting at a much lower frequency. The PolyU also team attempted preliminary studies for two possible methods for enhancing the performance of proposed design. The first one showed the adoption of membranes in tandem [J14,C3,C9] along the duct gave a transmission loss increase by more than 8 dB in same frequency range as isolated one. The second one illustrated the addition of a small mass on membrane was able to give a richer stopband distribution in low frequency range as a result of local resonant dynamics of the mass-membrane system [J15,C10]. All these ideas for liner performance enhancement will be carefully studied.

. Potential for further development of the research and the proposed course of action
(maximum half a page)

The outcomes of the project show that addition of dissipation to the enclosed cavity of innovative material liner design may provide a truly wide-band low frequency noise suppression with a starting frequency much lower than existing generic liners [J14]. The adoption of multiple cavity-backed membranes and small mass on membrane may further enhance noise suppression [J15]. The Hong Kong team is poised to apply for funding for a new project from such sources as the Innovative and Technology Fund of HKSAR Government, Central Research Grant of PolyU, etc. for further study of these ideas with prototype building and experimental verification. For the former idea they propose to introduce dissipation to cavity by introducing porous fibrous materials or the concept the French team introduces in [J6]. It is envisaged that this proposed project, if funded, would provide a clearer physical picture and design guidelines for innovative material concepts.

7. The Layman's Summary

(describe in layman's language the nature, significance and value of the research project, in no more than 200 words)

This project advances the physical understanding and technological know-how of innovative acoustical material technology for low frequency flow noise mitigation required in industrial and domestic/urban arenas. Such technology is highly demanded due to the increasing needs of superb mitigation effectiveness within tightening spatial constraints encountered in vast modern engineering applications (e.g. aeroengines, automotive systems, ventilation systems in high-rise buildings, etc.). The aim of this project is to create the knowledge base that supports the design and implementation of new acoustic material technologies reducing noise pollution in modern buildings and transportation. The noise produced by different air circulation systems is responsible for a significant part of low frequency noise problems in transport and buildings, which are still very difficult to tackle. The French-Hong Kong team collaborates to delineate the fundamental noise suppression physics of innovative acoustic materials taking the inherent coupling of sound, flow, material and structure into account, and devises innovative material technology concepts with the new physics uncovered. A particular focus is put on innovative concepts comprising elastic structures such as vibrating membranes or a deformable plate with micro-slits. These concepts are proven particularly effective at low frequencies and able to improve the acoustic quality of the environment.

Part C: Research Output

8. Peer-reviewed journal publication(s) arising directly from this research project

(Please attach a copy of each publication and/or the letter of acceptance if not yet submitted in the previous progress report(s). All listed publications must acknowledge RGC's funding support by quoting the specific grant reference.)

	The Latest Status of Publications				Author(s) *(**bold** the authors belonging to the project teams and denote the corresponding author with an asterisk*)*	Title and Journal/Book *(with the volume, pages and other necessary publishing details specified)*	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this report *(Yes or No)*	Acknowledged the support of this Joint Research Scheme *(Yes or No)*	Accessible from the institutional repository at PolyU *(Yes or No)*
	Year of publication	Year of Acceptance *(For paper accepted but not yet published)*	Under Review	Under Preparation *(optional)*						
J1	2016				Dai, X., & Aurégan, Y.*	"Acoustic of a perforated liner with grazing flow: Floquet-Bloch periodical approach versus impedance continuous approach," *The Journal of the Acoustical Society of America*, 140(3), 2047–2055	2018	No	Yes	No
J2	2017				Dai, X., & Aurégan, Y.*	"Flexural instability and sound amplification of a membrane-cavity configuration in shear flow," *The Journal of the Acoustical Society of America*, 142(3), 1934–1942	2018	No	Yes	No
J3	2018				Aurégan, Y.*	"On the use of a Stress–Impedance Model to describe sound propagation in a lined duct with grazing flow," *The Journal of the Acoustical Society of America*, 143(5), 1934–1942	2018	No	Yes	No
J4	2018				Fan, H. K. H., Leung, R. C. K.*, Lam, G. C. Y., Aurégan, Y., & Dai, X.	"Numerical coupling strategy for resolving aeroacoustic-structural of in-duct elastic panel," *AIAA Journal*, 56(12), 5033–5040	No	Yes	Yes	Yes
J5	2018				Dai, X., & Aurégan, Y.*	"A cavity-by-cavity description of the aeroacoustic instability over a liner with a grazing flow," *Journal of Fluid Mechanics*, 852, 126–145	No	Yes	Yes	No
J6	2018				Aurégan, Y.*	"Ultra-thin low frequency perfect sound absorber with high ratio of active area," *Applied Physics Letters*, 113(20), Paper No. 201904.	No	Yes	Yes	No
J7	2018				Farooqui, M., Aurégan,	"Explicit approximation of the wavenumber for lined ducts," *The Journal of the*	No	Yes	Yes	No

					Y.* & Pagneux, V.	*Acoustical Society of America*, 144(3), EL191–EL195.				
J8	2018				Farooqui, M., Aurégan, Y.* & Pagneux, V.	"Using liner surface modes in acoustic ducts to make obstacles reflectionless," *Scientific Reports*, 9, Paper No. 6981.	No	Yes	Yes	No
J9	2018				Aurégan, Y.* & Farooqui, M.	"In-parallel resonators to increase the absorption of subwavelength acoustic absorbers in the mid-frequency range," *Scientific reports*, 9, Paper No. 11140.	No	Yes	Yes	No
J10	2020				Arif, I., Wu, D., Lam, G. C. Y., & Leung, R. C. K.*	"Exploring airfoil tonal noise reduction with elastic panel using perturbation evolution method," *AIAA Journal*, 58(11), 4958–4968	No	Yes	Yes	Yes
J11	2020				Arif, I., Lam, G. C. Y., D. Wu, & Leung, R. C. K.*	"Passive airfoil tonal noise reduction by localized flow-induced vibration of an elastic panel," *Aerospace Science and Technology*, 107, Paper No. 106319	No	Yes	Yes	Yes
J12	2020				Fan, H. K. H., Lam, G. C. Y., & Leung, R. C. K.*	"Spatio-temporal aeroacoustic–structural responses of cavity-backed elastic panel liner exposed to grazing duct flow," Journal of Fluids and Structures, 102, Paper No. 103228	No	Yes	Yes	Yes
J13	2020				Lam, G. C. Y., Fan, H. K. H., Leung, R. C. K.* & Aurégan, Y.	"Effect of back cavity configuration on performance of elastic panel acoustic liner with grazing flow," Journal of Sound and Vibration, 492, Paper No. 115847	No	Yes	Yes	Yes
J14	2021				Shen, C.,Yang, S., Fan, H. K. H., & Leung, R. C. K.	"Investigation on a duct noise control method through membranes in tandem," *Shock and Vibration*, 2021, Paper No. 5533228,	No	Yes	Yes	Yes
J15	2021		Yes		Li, J., Zuo, H., Shen, C.* & Leung, R. C. K.	"Low frequency noise control in duct based on locally resonant membrane-type metamaterial," *Journal of Vibration and Control* (under review)	No	Yes	Yes	No
J16	2021			Yes	Hou, G. R., Lam, G. C. Y., & Leung, R. C. K.*	"Time domain modeling of aeroacoustics of porous duct liner exposed to grazing flow," *Journal of the Acoustical Society of America* (in preparation)	No	Yes	Yes	No

9. Recognized international conference(s) in which paper(s) related to this research project was/were delivered *(Please attach a copy of each delivered paper. All listed papers must acknowledge RGC's funding support by quoting the specific grant reference.)*

	Month/ Year/ Place	Title	Conference Name	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this report *(Yes or No)*	Acknowledged the support of this Joint Research Scheme *(Yes or No)*	Accessible from the institutional (PolyU) repository *(Yes or No)*
C1	05/ 2016/ Lyon	Influence of shear flow on liner impedance computed by multimodal method	*22[nd] AIAA/CEAS Aeroacoustics Conference*	2018	No	Yes	No
C2	09/ 2016/ Southampton	Impedance of perforated and micro-perforated liners with grazing shear flow: Does the impedance make sense with flow?	*20[th] workshop of the Aeroacoustics Specialists committee of the CEAS*	2018	No	Yes	No
C3	11/	Duct flow noise control by	*17[th] Asian Pacific*	2018	Yes	Yes	Yes

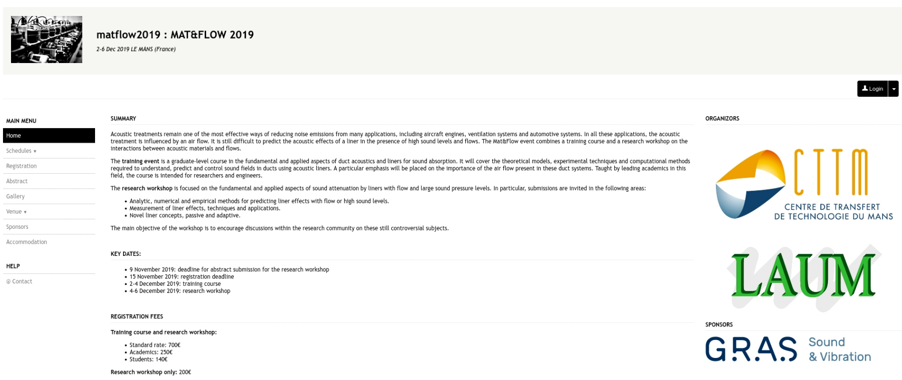
	2017/ Nanjing	excited vibrating membranes	*Vibration Conference*				
C4	04/ 2017/ College Park	Numerical study of nonlinear fluid–structure interaction of an excited panel in viscous flow	*Flinovia – Flow Induced Noise and Vibration Issues and Aspects II*	No	Yes	Yes	Yes
C5	06/ 2018/ Atlanta	Compact beam liners for low frequency noise	*24th AIAA/CEAS Aeroacoustics Conference*	2018	No	Yes	No
C6	09/ 2018/ Espoo	Manipulating acoustic waves radiation direction using liner surface modes	*12th International Congress on Artificial Materials for Novel Wave Phenomena (Metamaterials)*	2018	No	Yes	No
C7	05/ 2018/ *Heraklion*	Guiding acoustic waves over obstacles using linear surface modes	*Euronoise 2018*	2018	No	Yes	No
C8	12/ 2018/ Adelaide	Modeling of porous liner using CE/SE method with application to duct aeroacoustics	*21st Australasian Fluid Mechanics Conference*	2018	Yes	Yes	Yes
C9	08/ 2018/ Chicago	Duct aeroacoustic control by multiple flexible panels	Internoise 2018	No	Yes	Yes	Yes
C10	08/ 2020/ Seoul	Experimental study of acoustic metamaterial duct silencer carrying low speed flows	Internoise 2020	No	Yes	Yes	Yes

10. Student(s) trained *(Please attach a copy of the title page of the thesis.)*

	Name	Degree registered for	Date of registration	Date of thesis submission/ graduation
1	HOU Ruoyang George	MPhil	January 16, 2017	May 19, 2020 (graduation with full support from the present project)
2	NG Ming To	PhD	January 15, 2018	January 2020 (withdrawn due to personal reasons)
3	LAM Ka Hei	PhD	January 26, 2015	May 25, 2021 (graduation with partial support from the present project)

11. Other impact *(e.g. award of patents or prizes, collaboration with other research institutions, technology transfer, etc.)*

An international technology transfer (MAT & FLOW 2019) workshop was organized during December 2– 6, 2019 in Le Mans, France. It brought together world specialists working in areas of sound-flow-materials interactions (NASA, DLR, TU Delft, Shanghai Jiao Tong University, etc.) and industrialists (AIRBUS, Snecma) around researchers from Le Mans and Hong Kong Polytechnic University. The workshop was well received.



12. Statistics on Research Outputs *(Please ensure the summary statistics below are consistent with the information presented in other parts of this report.)*

	Peer-reviewed journal publications	Conference papers	Scholarly books, monographs and chapters	Patents awarded	Other research outputs (Please specify)
No. of outputs arising directly from this research project	16	10	0	0	0