The Investigation on Calculating and Measuring the Flow Noise from Underwater Jets

Yongwei LIU, Dejiang SHANG, Qi LI, Dajing SHANG, Yan XIAO
Acoustic Science and Technology Laboratory
Harbin Engineering University
Harbin, China
liuyongwei3000@hrbeu.edu.cn

College of Underwater Acoustic Engineering
Harbin Engineering University
Harbin, China
Shangdejiang@hrbeu.edu.cn

Abstract*—Based on the combination of large eddy simulation theory and Lighthill's acoustic analogy equation, numerical simulation of underwater flow noise is investigated. The calculation model of nozzle and fluid is built up by finite element software, ANSYS. The property of fluid field is calculated by the software, Fluent, which is in the ANSYS. The fluid property changing with time is gotten and dealt with by FFT, then, introduced into ACTRAN. Therefore, sound field of flow noise can be calculated. The flow noise of a circular nozzle is carefully investigated. The diameter of the nozzle is 20 *mm*, and the velocity of the fluid is 10 *m/s*. The frequency is in the range from 20 to 5000 Hz. The results demonstrate that sound radiation from flow noise is mainly in transition area. The distance between the nozzle and transition area is in the range from 8 to 10 D. Here, D is maximum dimension of the nozzle. Meanwhile, the directivity of radiated noise in transition area is fourth polar. Based on the principle of reverberation method, a measurement system of underwater flow noise is built up. One kind of nozzle is a steel pipe, and inner diameter is 200 *mm*. The pipe is placed in a reverberation water pool. In the pool, there are two parts: one part is flow area; the other part is test area. In test area, there are 32 hydrophones, which are disposed at different depth. The other kind of nozzle is a circular nozzle with coverage formation. The diameter of the nozzles is 10 *mm*, 20 *mm*, 30 *mm*, respectively. The nozzle is placed in a reverberation water tank, which is made by steel plates and supported by separated points at the bottom. In the top, there are three ducts. The ducts can hinder sound propagation from the tank to the outside, and vice versa. The tank is also separated into two parts: one part is flow area; the other part is test area. In test area, there are four hydrophones, which are treated as a line array to receive the signal caused by the flow. All the designs can protect hydrophones from the knock by the flow. The flow noise source is a tank in high place. And the flow is generated by the gravity. The total level of sound radiation power from flow noise is proportional to the eighth power of the velocity. The results demonstrate that total level of flow noise from the nozzle of uniform type is only decided by the pressure of flow noise source, and not related to the section area of nozzle. The results are coincided with the simulation.

Keywords*—*flow noise; large eddy simulation; lighthill's acoustic analogy; experimental investigation

I. INTRODUCTION

In recent years, flow noise can be found in the propulsion system, such as water pump, new type of torpedo, underwater navigator, submarine, and so on. With the development of high speed jet equipment, the property of flow noise has drawn much attention.

Ruprecht [1] had investigated the flow in an elbow draft tube under part load conditions. He analyzed the unsteady behavior of the vortex rope by means of CFD. Bensow [2] had investigated the viscous flow around submarine hulls through the method of large eddy simulation. Zhangtao [3] has analyzed the effect of near-wall treatments on the numerical computation of turbulent flow. His study shows that Spalart-Allmaras model agrees best with the experimental data. Stanley [4] had firstly computed spatially evolving three-dimensional planar turbulent jets utilizing direct numerical simulation. Fanquanlin [5] had summarized experiments and numerical work on coherent structures in round turbulent jets. Niklas [6] had investigated two compressible jets' configuration by large eddy simulation. The two jets are an iso-thermal jet and a jet with a higher temperature than the quiescent surrounding air. Li [7] had developed a three-dimensional computational aero-acoustic procedure to simulate the screech phenomenon from a supersonic circular jet. Groschel [8] had numerically analyzed flow field and acoustic field of various realistic coaxial jet configurations. Wangxing [9] had applied second order upwind scheme Roe and Smagorinsky subgrid model to address jet noise problem. Yanghongtao [10] had acquired sound signal eigenvalues of target material and physical dimension to extract different eigenvalues of high pressure water. Yuyanfang [11] had analyzed entrainment characteristic of five different shape nozzles by using ANASYS Fluent6.3 and gotten the jet axial velocity and stream-wise velocity. Tangbin [12] had investigated flow filed structures of a round jet controlled by acoustic excitation. He performed large eddy simulation to calculate a round jet under phase-locked global acoustic excitation.

From the analysis of listed references, it can be found that the method of investigating flow noise is mature, especially numerical method. However, most of results are related to high speed flows, which are placed in the air. Only a little of underwater flow noise has been mentioned. Meanwhile, underwater measurement environment is more complicated

978-0-933957-43-5 ©2015 MTS

This is a DRAFT. As such it may not be cited in other works.
The citable Proceedings of the Conference will be published in
IEEE Xplore shortly after the conclusion of the conference.

than that of air environment. Therefore, experimental investigation is difficult to be carried out. This has hindered the validation of underwater flow noise.

II. NUMERICAL SIMULATION OF UNDERWATER FLOW NOISE

Based on the combination of large eddy simulation (LES) [13] and Lighthill's acoustic analogy equation [14], numerical calculation of underwater flow noise has been carried out. The basic technological process is shown in Fig.1. A circular jet is investigated. The inner diameter of the jet is D, which is equal to 20 *mm*. The thickness of the jet is 0.1D. The length of the jet is 5D. The area of fluid field is 30D×50D. The total number of mesh is 2690,000.

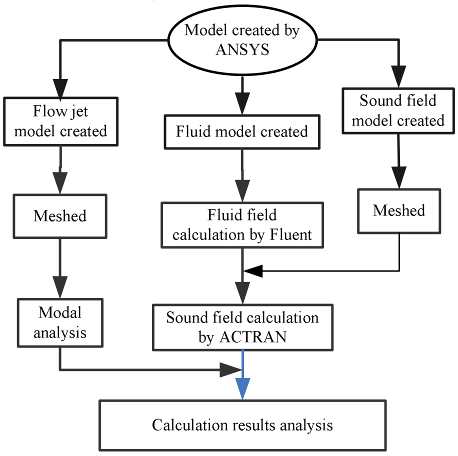
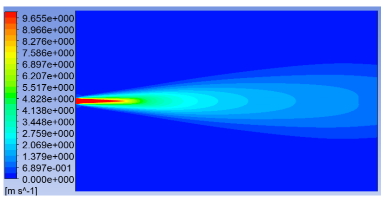
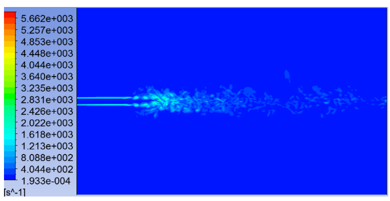


Fig.1 Diagram of numerical simulation

After many trials, we find that initial condition of large eddy simulation can be obtained through steady-state calculation of turbulent model. After 1,600 steps, the calculation of steady-state becomes convergence. Then, the transient flow field calculation of large eddy simulation is carried out. The step of the time is 0.00001 *s*. After 0 and 20,000 steps, the results are shown in Fig.2. By inspection, fluid velocity of the points in flow field does not change with the numbers of iteration. It indicates that the calculation of flow field attains convergence.



(1) 0 *s*



(2) 2 *s*

Fig.2 Velocity contour at different time

The data of fluid property are dealt with by FFT, fluid velocity distribution of each frequency can be extracted by the software, ACTRAN. After the process of Lighthill's acoustic analogy, sound field distribution and sound radiation power of the flow can be gotten.

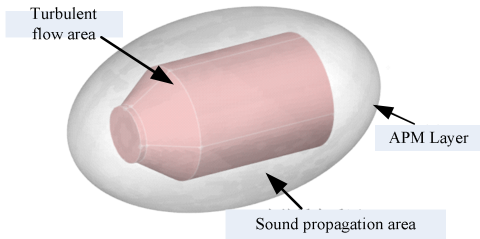
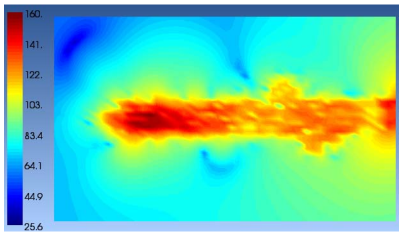
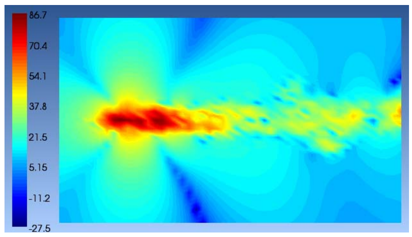


Fig.3 Diagram of radiated noise calculation

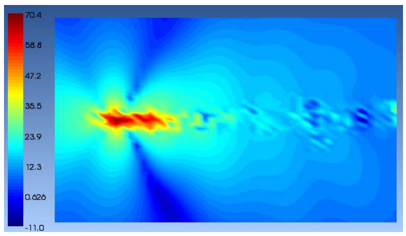
The diagram of calculating flow noise from underwater jets is shown in Fig.3. The velocity of the fluid is 10 *m/s*, sound field distribution at different frequencies from the flow is shown in Fig.4.



(1) 80 kHz



(2) 2 kHz



(3) 5 kHz

Fig.5 Sound field distribution at different frequencies

The conclusions are as follows: firstly, sound radiation from underwater flow is mainly in transition area. The distance between the jet and transition area is in the range from 8 to 10 D. This result is different from that in the air [15]. Secondly, the directivity of flow noise from underwater jets is equivalent to a fourth-polar point source. Lastly, sound of low frequency is generated by large-scale vortex, nevertheless, sound of high frequency is generated by small-scale vortex. The vortex in transition area generates and extinguishes more frequently than other area. With the increase of the frequency, there exists a ‘diffusion’ phenomenon in sound field.

The sound radiation power of underwater flow noise from circular jet is shown in Fig.5.

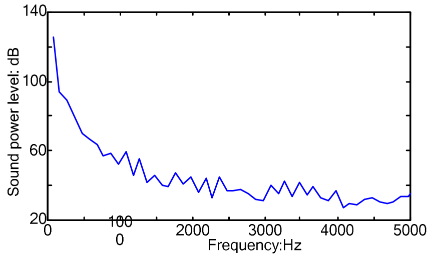


Fig.5 Radiated sound power curve of a circular nozzle

III. Experimental Investigation

Nowadays, in order to achieve good results, the measured frequency of the pool is not below 1 kHz. Meanwhile, the measurement method is not like that in the air, in which sound pressure is measured perpendicular to the jet [16]. Therefore, the reflected sound from the wall can not be neglected. If the hydrophone is placed close to the jet, the received signal contains turbulent, which contaminates the real signal. Based on present conditions, a reverberation method has been developed to measure underwater flow noise [17].

In order to eliminate pressure pulsation due to the pump [18], flow source is a water tank in high place. The flow is generated by the pressure due to gravity. Two types of jets are tested in the experiment. One is a steel pipe. The other is a nozzle with the formation of convergence. The inner diameter of steel pipe is 200 *mm* and the pipe is placed in a reverberation pool. In order to eliminate the effect of propulsion to the hydrophone, the pool is separated into two parts, one part is flow area, the other part is test area. In test area, 32 hydrophones are disposed at different positions, as is shown in Fig.6.

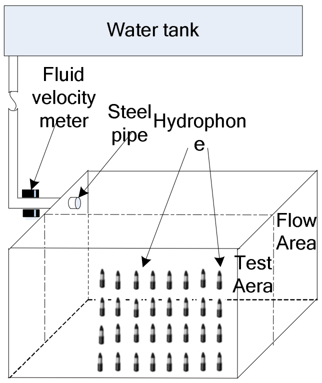


Fig.6 Diagram of flow noise from steel pipe

There exist slots in the pool. This technique can make the water volume unchanged in test process. The results are shown in Fig.7 and Fig.8.

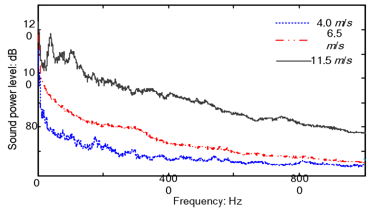


Fig.7 Measurement result of different fluid velocity

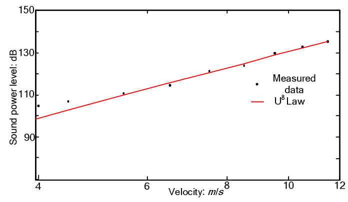
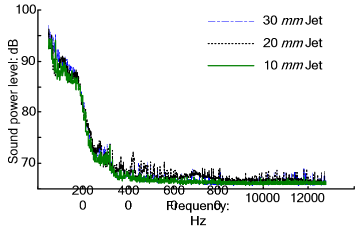


Fig.8 Relationship between sound radiation power and fluid velocity

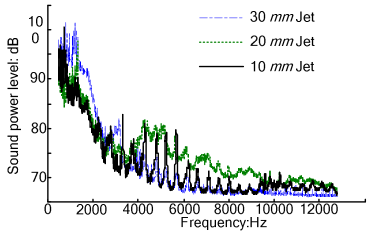
The flow noise spectrum increases with fluid velocity. At a certain velocity, flow noise spectrum decreases with the frequency, this coincides with the simulation. The total level of sound radiation power is proportional to the eighth power of fluid velocity, this coincides with the U^8 law, as is in the air flow research. The result also indicates that underwater flow noise can be measured by the reverberation method.

In the water tank, a pressure adjuster valve is mounted. Then, the water is transported into a rectifier. At the end of the rectifier, a jet with convergence formation is installed. The diameter of the jet at the nozzles is 10 *mm*, 20 *mm*. 30 *mm*, respectively. The jets are placed in a rectangle reverberation steel tank. The tank is supported by steel beams at the bottom. In the reverberation steel tank, there are also two parts. One part is flow area, the other part is test area. In test area, there is a line array consisting of four hydrophones to receive sound signal. The flow noise is collected by spatial averaging method. Meanwhile, there are three slots in test area, in order to maintain water volume to be unchanged. Due to sound wave-guide design with soft-boundary and the limitation of cut-off frequency, flow noise in the reverberation tank can not propagate into the outside through the wave-guide. After a number of simulation and experiment tests, we find that the flow from the jet can not achieve the opposite wall in reverberation tank. This also indicates that the wall can not be excited by the flow, and no extra noise is generated.

The flow noise spectrum of circular jets with different diameters is shown in Fig.9. At the pressure of 0.1 MPa, the total level of sound radiation power is 117.4dB, 118.1dB, 119.0dB, respectively. At the pressure of 0.2 MPa, the total level of sound radiation power is 122.4dB, 119.8dB, 123.0dB, respectively. This indicates that the total level of sound radiation power is only decided by the pressure, even if fluid velocity of circular jets is different. The bigger difference between the lowest and highest fluid velocity may be over 20 *m*/*s*. A number of experimental results indicate that the total level of sound radiation power from the jets of uniform types is only decided by the pressure, not the section area.



（1）0.1MPa



（2）0.2MPa

Fig.10 Flow noise of circular nozzle with three types under different pressure

IV. CONCLUSIONS

By the method of combining large eddy simulation and Lighthill's acoustic analogy theory, numerical simulation of flow noise from a circular jet has been carried out. The results indicate that flow noise from underwater jets is mainly generated by transition area. This is different from that in the air. The directivity of flow noise is equivalent to a fourth polar point source. The sound of high frequency is generated by small-scale vortex. The sound of low frequency is generated by large-scale vortex.

A method of measuring flow noise from underwater jets has been developed on the basis of reverberation method. A reverberation tank is carefully designed. The effects are reliably eliminated by over-flow slots. The flow noise can not propagate through the slots. Also the tank is divided into two parts, and this technique has protected the hydrophones from the knock by the flow. The experimental results of flow noise from steel pipe and circular jets with convergence formation are listed. It can be found that total level of sound radiation power from flow noise is proportional to the eighth power of fluid velocity. If the jets of uniform types, the total level of sound radiation power is only decided by the pressure of flow source, and not related to the section area of the jets.

It is believed that some references may be provided for underwater flow propulsion design, the test of flow noise, and so on.

ACKNOWLEDGMENT

The author would like to thank undergraduate Hao SONG, Bo ZHANG, and Qingming ZHANG for their assistance of data processing. The work has been supported by the Fundamental Research Funds for Central Unversities, No.HEUCF130511, HEUCF150506. The work has also been supported by the major project from Acoustic Science and Technology Laboratory, No. 9140C200104140C20003. The work has also been funded by the National Natural Science Foundation, No. 11274080, 11474074.

REFERENCES

[1] Ruprecht A, Helmrich T, Aschenbrennert, "Simulation of pressure surge in a hydro power plant caused by an elbow draft tube," IAHR WG 1 symposium. Trondheim, pp. 1-10, 2001

[2] Bensow R. E, "Large eddy simulation of the viscous flow around submarine hulls," 25th symposium on naval hydrodynamics. Canada, pp. 261-276,2004

[3] Zhang Tao, Zhu Xiaojun, Peng Fei, Min Shaosong, "Analysis of effect of near-wall treatments on numerical computation of turbulent flow, " Journal of Naval University of Engineering. Wuhan, vol.25, pp.104-108,2013

[4] Stanley,Sarkar, Mellado, "study of the flow-field evolution and mixing in a planar turbulent jet using direct numerical simulation, " J. Fluid Mech. Cambridge, vol. 450, pp. 377-407, 2002

[5] Fan Quanlin, Wang Xilin, Zhang Huiqiang, Guo Yincheng, Lin Wenyi. "Coherent structures in turbulent round jets," Advances in mechanics. Warsaw, vol. 32, pp. 109-118,2002

[6] Niklas Andersson,lars-erikisson,Lars Davidson. "A study of Mach 0.75 jets and their radiated sound using large-eddy simulation," 10th AIAA/CEAS Aeroacoustics conference. Manchester, pp. 1-24,2004

[7] Li X D, Gao J H. "Prediction and understanding of three dimensional screech phenomenon from a circular nozzle," 13th AIAA/CEAS Aeroacoustics conference. Rome,pp. 1-19,2007

[8] Groschel E, Renze P, Schroder W. "Towards Noise Reduction of Coaxial Jets," 13th AIAA/CEAS Aeroacoustics conference. Rome, pp.1-18,2007

[9] Wang Xing, Zheng Liu, Zhou Yuerong, Chen Zhimin. "Flow field structure and noise for different nozzles," Journal of propulsion technology. Beijing, vol. 32, pp.365-369,2011

[10] Yang Hongtao, Wang Congdong, Zhang Dongsu, Li Meng, Sun Yuling. "Research on feature extraction method of high pressure water-jet reflective sound signals," Chinese journal of mechanical engineering. Wuhan, vol. 21, pp.2434-2467,2010

[11] Yu Yanfang, Li Chunxiao, Meng Huibo, Wang Yanfen, Song Mingyan, Wu Jianhua. "Flow and entertainment characteristics of jet from different shape nozzles," The Chinese Journal of processing engineering.Beijing, vol. 14, pp.549-555,2014

[12] Tang Bin, Zhu Mingming, Liu Minghou, Ye Taohong, Chen Yiliang. "LES of flow structure control of a round jet by acoustic excitation," Journal of University of Science and Technology of China. Hefei, vol. 45, pp.59-167,2015

[13] Smagorinsky J. "General circulation experiments with the primitive equations (I): The basic experiment," Monthly Weather Review, Wikipedia, vol. 91, pp. 99-165,1963

[14] Lighthill, M.J. "On sound generated aerodynamically. Ⅱ. Turbulence as a source of sound," Proc.Roy.Soc. London, vol.1148, pp.1-32, 1954

[15] Goldstein. Aeroacoustics, Yanzaiyou translate, 1st ed., vol.1, Beijing: National defense industry press, 2014, pp.78

[16] Dah-You Maa. The basis of modern acoustic theory. 1st ed., vol.1, Beiing: Science press. 2004,pp. 305-310

[17] Shang Dajing, Li Qi, Shang Dejiang, Hou Benlong. "Measurement of the radiated power of sound sources in a reverberation pool, " Journal of Harbin engineering university. Harbin, vol. 31, pp. 938-944,2010

[18] Zhu Wangfang, Study on the characteristics of water jet noise based on piston pump source. Wuhan: Huazhong University of Science and Technology, 2012