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Session 2pAAb: Dah-You Maa: His Contributions and Life in Acoustics

2pAAb2. Prof. Dah-You Maa’s Contribution to Acoustics

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In his life-long career pursuing, Prof. Dah-You Maa contributed greatly in many areas of acoustics, not only in acoustical research and development, but also in the promotion of acoustical education, application and legislation. Prof. Maa presented a simplified method for calculation of normal modes for room acoustics, invented micro-perforated panel absorbers and micro-perforation jet mufflers, gave a formula of jet noise power via air pressure, and acoustically designed the first and biggest Congress Hall, built the first set of acoustical laboratories, established the acoustical standard system in China. He also supervised tens of postgraduate students working in environmental acoustics, building acoustics, speech signal processing, nonlinear acoustics, and active noise control. In this paper, the main contribution of Prof. Maa is introduced. Several of his typical research works, such as normal mode distribution in room acoustics and micro-perforated panel absorbers, are explained in detail, from which we can well appreciate the physical insights and theoretical skills of Prof. Maa.

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1. INTRODUCTION [1]

Born in 1915, Dah-You Maa grew up in a turbulent era in China. He obtained his Bachelor of Science from Peking (now Beijing) University in 1936. Then he got a Tsinghua Grant for postgraduate studies in the United States in an extremely competitive exam. After a one-year preparation in acoustics, Dah-You Maa began his graduate study with Prof. Vern O. Knudsen at the University of California, Los Angeles (UCLA) in 1937. He continued his research with Prof. Frederick V. Hunt at Harvard University, when Prof. Knudsen was on sabbatical leave.

During the first two years in US, Maa's research resulted in two journal publications: “Distribution of Eigentones in a Rectangular Chamber at Low Frequency Range” co-authored with Prof. Knudsen, and “Analysis of Sound Decay in Rectangular Rooms” co-authored with Prof. Hunt and his fellow classmate Leo Beranek. Both published in JASA in 1939, and established a new chapter in the development of fundamental theories of room acoustics[2,3].

Maa obtained his Ph.D. degree from Harvard University in June 1940, and soon came back to China. He served as an associate professor and then a professor at Southwest United University in Kunming in those very difficult days during World War II. Maa returned to Beijing as a professor in Tsinghua University after the war, and in 1948 at his age of 33, he founded and became the first Dean of the Engineering School at Peking University. In 1952, Prof. Maa was appointed as the Dean of Harbin Institute of Technology. He was elected as a Member (Academician) of the Chinese Academy of Sciences (CAS) in 1955 and joined the Institute of Physics, CAS, the same year. Since then on, he had worked in CAS until he left us on July 17, 2012. He founded the Institute of Electronics in 1956, and then the Institute of Acoustics in 1964. In 1978, he was appointed as the Head of Physics Department and the Executive Dean of Graduate School, CAS, where he served for seven years. During his lifelong career in education, he had taught courses in physics, electronics, electrical engineering, and acoustics.

Prof. Maa had worked in many areas of acoustical research. His early work was mainly on room acoustics, then speech signal processing, infrasound, high-intensity sound sources and acoustical fatigue tests, noise control and sound absorptive materials, especially the theory and application of micro-perforated absorbers (MPA). Since late 1970s, he paid more attention to environmental acoustics and jet noise control. In his last two decades, Prof. Maa was more interested in nonlinear acoustics and active noise control. In his research life of more than 70 years, he published more than 100 technical papers and 20 books, established the acoustical standard system for China with more than 140 standards.

2. NORMAL MODE DISTRIBUTION IN ROOM ACOUSTICS

In UCLA, R. H. Bolt was another Ph.D. student supervised by Prof. V.O. Knudsen when Dah-You Maa was there. Bolt was going to finish his doctoral thesis. He extended the Rayleigh's formula of normal mode number in a rectangular room to low frequency or small room and succeeded. Maa thought that the rules in nature should be simpler. Therefore he blazed a new trail to further simplify the Bolt's result and to make clearer physical insights. The formula he gave to describe the distribution of normal modes in a rectangular chamber at low frequency range is as follows[2],

\[
N_c = \frac{4\pi V f^3}{3c^3} + \frac{\pi S f^2}{4c^2} + \frac{L f}{8c}
\]

where \( S \) is the surface area, \( L \) the sum of the three dimensions, \( V \) the volume of the chamber and \( c \) the velocity of the sound. Maa also predicted that the formula was not limited to rectangular rooms but applicable to any other shapes. His prediction was later proved to be correct by P. M. Morse. The formula became one of the basic relations in acoustics and was cited in many acoustic text books. This work, together with the paper on the process of sound decay in rectangular rooms, co-authored with Prof. H. V. Hunt and Leo L. Beranek[3], set a milestone in the development of room Acoustics.

Maa did not stop there. He extended the acoustical boundary condition to non-uniform in his doctoral thesis[4]. An exact solution is derived for the behaviour of sound in a rectangular room with non-uniformly distributed acoustic materials on the walls.

The research on sound field characteristics was never stopped in Prof. Maa's life. He reviewed the steady state sound field in a room both theoretically and experimentally during 1990s. At last, he suggested that the sound field could be expressed as the sum of a direct sound and a reverberation part physically[5].
Prof. MAA firstly presented the possibility of Active Noise Control (ANC) in rooms based on the suppression of normal modes. An ANC system consisting of an error microphone and the canceling loudspeaker is proposed\cite{6}. The ANC system is schematically shown in FIGURE 1.

![FIGURE 1. Principal diagram of an active noise control system for sound field in a room](image)

A general formula of possible noise reduction of such system is derived. The maximum noise reduction attainable for mode n is given by\cite{7}

\[
NR_n = \lim \left| \frac{p_n(r|r_0)}{p_n(r)} \right|^2 = 1 + K_n^2 + 2\sqrt{K_n}\sin\left(\frac{\omega_0d}{c}\right)
\]  

(2)

where \(K_n\) is a decaying constant of the nth mode dependent mainly on the room absorption and frequency, \(d\) is the distance between the secondary source and the error microphone.

The proposed corner ANC system is most suitable for low-frequency noise reduction. A reduction of 8dB was realized for a band noise centering at 100Hz. The proposed ANC system is independent of shape, size, and contents of the room. Prof. Maa also studied the transit process in a room with the corner ANC system, especially the growth and decay of noise field\cite{8}. All these pioneer work exploited the physical mechanism of active mode control which inspired further research and wider applications.

In 1959, Prof. Maa got a chance to use his expertise in room acoustics in an important application. The Chinese government needed to built a great People's Congress Hall\cite{9}. Maa was appointed as the chief acoustical architect. The Hall took roughly the shape of oblate eclipse, and had a capacity of 10,000 seats and a volume of 91,000 m\(^3\). It was the biggest at the time and intended to be used for both meetings and musical performances.

Acoustic treatments and appropriate parameters in existing halls offered little help in such a huge and stately hall. Prof. Maa solved the problem through an integral consideration of acoustical treatments and electroacoustical systems. Cavity resonators with plywood panel facing were used for low frequency absorption in combination with absorptive materials. Based on extensive analysis and predictions a distributed sound system consisting of more than 8000 direct-radiating loudspeakers was chosen for speech amplification. A three channel connected stereophonic system was devised for music amplification. The connected stereophonic system could operate in two different ways: either to provide uniform sound field in the system or to provide stereophonic effect in sound reproduction. Measurements in the completed hall suggested that the expected requirements were well fulfilled and the acoustical characteristics were completely accepted by listeners.

3. MICRO-PERFORATED PANEL ABSORBER (MPA)

Perforated panels as sound absorbing materials have been widely applied for many years. However, before the late 1960s their applicability had been limited to be protective covering materials due to the requirement of using them with conventional porous materials. Prof. Maa was the first who proposed the concept and calculation model for MPA prototypes which formed the basis for various applications, in which the acoustic resistance could be given by the micro-perforation.
In 1960’s, Prof. Maa got a research project on high-intensity blowing noise reduction in a severe environment of both high-speed airflow and high temperature. Conventional porous materials could not be applied effectively. Based on his physical concept and innovation consciousness, Prof. Maa presented MPA and established the approximate theory and gave a complete design method in 1975[10].

Based on the result of acoustic character of small orifices obtained by Rayleigh and U. Ingard[11-13], the formula for very narrow \((x < 1)\) and relative wide \((x > 10)\) tube can be obtained, and usually be used by Zwikker and Kosten. Where, \(x\) is \(\sqrt{2}\) times the ratio of radius to the thickness of viscous boundary layer. In Maa’s approximate theory of MPA, the formula

\[
z_{MPP} = \frac{32 \mu \rho u}{d^2} \sqrt{1 + \frac{x^2}{32}} + j\omega pt \left(1 + \frac{1}{\sqrt{3x^2 + x^2}}\right)
\]

is valid for any value of \(x\). MPA can be designed so that \(x\) lies between 1 and 10 and relatively wide frequency band results without additional porous materials. The coefficient of absorption at normal incidence is given by

\[
\alpha = \frac{4r}{(1 + r)^2 + (\omega m - c\omega g(\omega D / c))^2}
\]

And he also pointed out that according to the relationship of the acoustic resistance of micro-hole is inversely proportional to the diameter squared, if the diameter would be reduced to a certain extent, the acoustic resistance can be significantly increased, and the sound can be absorbed quite efficiently.

Prof. Maa continued his research on MPA in various directions. He invented double-layer panels with a much wider absorption band[14] and microslit panels[15] which are easier to produce, investigated the characteristics of MPA in high sound intensity environments[16] and at random incidence[17,18], and gave the general theory and design for MPA[19, 20].

All those researches reveal that the acoustic resistance \(r\) and the perforation constant \(k\) are the determinants of sound absorption coefficient and frequency characteristics of this kind of absorbers. When \(r = 1\) and the coefficient of absorption is at the maximum, roughly in the range \(k < 1\), the MPA absorption width can approach the utmost when the cavity depth is nearly a quarter of the sound wave length. When \(k > 2\), shallow cavity will generally cause narrow absorption band. But there is a possibility to realize a relatively wide band with appropriate shallow cavity. For larger values of \(r\), the maximum absorption reduces and the values of \(\sqrt{r}k\) and \((1 + r)\) will determine the frequency characteristics. The greater the \(r\), results in the lower sound absorption and the wider absorption band, with the same value of \(k\). Multiple absorption band design can greatly improve the wide-band performance.

The investigation on statistical sound absorption in a randomly incidence sound field revealed that the absorption curves of MPA for random incidence and for normal incidence are similar, only the peak absorption is more and less reduced and the whole curve is shifted to higher frequencies with little change in shape. Therefore, the behavior of MPA in normal incidence sound field can be used in forecasting the sound absorptive characteristics of MPA in a diffused sound field.

A complete theory for the microslit absorber (MSA) presented that MSA had essentially the same formulae as the MPA, except that the numerical coefficient of the resistance was smaller and the end correction for the mass reactance was larger for the MSA, resulting in a performance inferior to that of MPA if similar structure parameters are used. Remedies were proposed to compensate the end correction by using a thicker panel, and to compensate the smaller resistance coefficient with narrower slits, neither introduces any difficulty for the MSA.

The theory and application of MPA established by Prof. Maa promoted the development of fibre-free broadband sound absorptive materials[22]. More and more engineers and enterprises have been involved in the development and applications of MPA, mainly in building acoustics and noise control in the last 20 years. Almost every year, you could find related papers published in Inter-Noise and other international conferences. At the same time, various technologies and methods for manufacturing MPA are also developed, such as laser drilling, hot-needle, powder metallurgy, welded meshing and electro-etching to form micrometer order holes. A large number of MPA modules and surface elements have evolved from Prof. Maa’s creative pioneer work, such as flexible tube bundle, thin film MPA, multi-layer structures and so on[23].
One of the notable applications of MPP was conducted in 1993. The Fraunhofer Institute of Bauphysics used a well designed and fabricated MPP in the plenum of the Deutscher Bundestag in Bonn. The congress hall was designed and built with a totally transparent and round glass wall, which brought a disaster in the room acoustics and audio engineering. The MPA technique cancelled the echoes from the wall without any influence of the transparency and the shape. The Germans thought that it was Prof. Maa's theory helped them to present and complete the solution, and gave a Gold Medal of the Fraunhofer Society of Germany to Prof. Maa in 1997[21].

4. PROF. MAA'S CAREER CONTINUES AFTER HIS LEAVING

Prof. Maa joined the Acoustical Society of America in 1940. He was elected as an ASA Fellow in 1943. On May 16th, 2012, ASA selected Prof. Maa as its 19th honorary fellow at the first joint meeting of ASA and ASC held in Hong Kong. I accepted the honor for Prof. Maa because he could not come to Hong Kong to join us for the bad health. Two months later, on July 17, 2012, Prof. Maa left us forever. But his career continues in the Institute of Acoustics, CAS, in the Acoustical Society of China, in the Acta Acustica Journal, in the Acoustical Standard Committee of China, and in all those acoustical careers he started, in as well as the friendship he established among the acousticians in China and all over the world, and this memorial session.

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