**МІНІСТЕРСТВО ОСВІТИ ТА НАУКИ УКРАЇНИ**
НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ
КАФЕДРА КОНСТРУКЦІЇ ЛІТАЛЬНИХ АПАРАТІВ

**ДОПУСТИТИ ДО ЗАХИСТУ**
Завідувач кафедри, д.т.н., проф.
___________ Сергій ІГНАТОВИЧ
«_____» ___________ 2021 р.

**ДИПЛОМНА РОБОТА**
ВИПУСКНИКА ОСВІТНЬОГО СТУПЕНЯ МАГІСТРА
ЗІ СПЕЦІАЛЬНОСТІ
«АВІАЦІЙНА ТА РАКЕТНО-КОСМІЧНА ТЕХНІКА»

**Тема: «Конструктивні підходи щодо зменшення рівня шуму літака»**

**Виконавець:** __________ **Ліньфен ЛІ**

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**Консультанти з окремих розділів**
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**Київ 2021**

**MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE**
**NATIONAL AVIATION UNIVERSITY**
DEPARTMENT OF AIRCRAFT DESIGN

**PERMISSION TO DEFEND**
Head of the department,
Professor, Dr. of Sc.
_________Sergiy IGNATOVYCH
«___» _______________ 2021

**MASTER DEGREE THESIS**
ON SPECIALITY
”AVIATION AND ROCKET-SPACE ENGINEERING”

**Topic: «Aircraft Noise Reduction Design Approaches»**

**Fulfilled by:** ______________ **Linfeng LI**

**Supervisor:**
**PhD, associate professor** ______________ **Sviatoslav YUTSKEVYCH**

**Labor protection advisor:**
**PhD, associate professor** ______________ **Victoria KOVALENKO**
**Environmental protection adviser:**
**Ph.D. associate professor** ______________ **Tamara DUDAR**

**Standards inspector**
**Ph.D. associate professor** ______________ **Sergiy KHIZNYAK**

**Kyiv 2021**

**НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ**

Аерокосмічний факультет
Кафедра конструкції літальних апаратів
Освітній ступінь «Магістр»
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Освітньо-професійна програма «Обладнання повітряних суден»

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Завідувач кафедри, д. т. н, проф.
__________ Сергій ІГНАТОВИЧ
«_____» ______________ 2021 р.

**ЗАВДАННЯ**

**на виконання дипломної роботи студента**

Лі ЛІНЬФЕН

1. Тема роботи: «Конструктивні підходи щодо зменшення рівня шуму літака», затверджена наказом ректора від 8 жовтня 2021 року № 2173/ст.

2. Термін виконання роботи: з 11 жовтня 2021 р. по 31 грудня 2021 р.

3. Вихідні дані до роботи: стільникова конструкція алюмінієвої мікроперфорованої панелі, коефіцієнт звукопоглинання мікроперфорованої панелі, коефіцієнт звукопоглинання мікроперфорованої панелі стільникової структури.

4. Зміст пояснювальної записки: дослідження методів шумопоглинання літаків, вивчення структурних параметрів стільникової конструкції мікроперфорованої панелі, проектування низькочастотної звукопоглинаючої тонкої мікроперфорованої панелі.

5. Перелік обов’язкового графічного (ілюстративного) матеріалу: презентація у power point, ілюстрації та графіки.

6. Календарний план-графік

| № | Завдання | Термін виконання | Відмітка про виконання |
|---|---|---|---|
| 1 | Аналіз літературних джерел щодо підходів до зменшення авіаційного шуму. | 11.10.2021–15.10.2021 | |
| 2 | Аналіз акустичної теорії та виведення формулу розрахунку коефіцієнта звукопоглинання. | 16.10.2021–20.10.2021 | |
| 3 | Аналіз доцільності низькочастотного звукопоглинання мікроперфорованої стільникової конструкції. | 21.10.2021–26.10.2021 | |
| 4 | Дослідження впливу конструкційних параметрів мікроперфорованих сот на коефіцієнт звукопоглинання. | 27.10.2021–31.10.2021 | |
| 5 | Розробка нового типу мікроперфорованої панелі стільникової структури. | 1.11.2021–15.11.2021 | |
| 6 | Виконання частин, присвячених охороні навколишнього середовища та охорони праці. | 16.11.2021–30.11.2021 | |
| 7 | Оформлення та редагування роботи | 1.12.2021–31.12.2021 | |

7. Консультанти з окремих розділів:

| Розділ | Консультант | Дата, підпис | |
|---|---|---|---|
| | | Завдання видав | Завдання прийняв |
| Охорона праці | к. біол. н., доцент Вікторія КОВАЛЕНКО | | |
| Охорона навколишнього середовища | к. т. н, доцент Тамара ДУДАР | | |

8. Дата видачі завдання: 8 жовтня 2021 року.

Керівник дипломної роботи ____________ Ліньфен ЛІ

Завдання прийняв до виконання ____________ Святослав ЮЦКЕВИЧ

**NATIONAL AVIATION UNIVERSITY**

Aerospace Faculty
Department of Aircraft Design
Educational Degree «Master»
Specialty 134 «Aviation and Rocket – Space Engineering»
Educational Professional Program «Aircraft Equipment»

**APPROVED BY**
Head of Department,
Dr. Sc., professor
________Sergiy IGNATOVYCH
«___» ________________ 2021

# TASK

## for the master degree thesis

Linfeng LI

1. Topic: «Aircraft noise reduction design approaches», approved by the Rector's order № 2173/ст from 8 October 2021 year.

2. Period of work: from 11 October 2021 year to 31 December 2021 year.

3. Initial data: aluminum micro-perforated panel honeycomb structure, the sound absorption coefficient of micro-perforated panel, the sound absorption coefficient of micro-perforated panel honeycomb structure

4. Content: research on aircraft noise reduction methods, study on structural parameters of micro-perforated panel honeycomb structure, design on low-frequency sound absorbing thin micro-perforated panel honeycomb structure.

5. Required material: power point presentation, drawings and diagrams.

6. Thesis schedule:

| № | Task | Time limits | Done |
|---|---|---|---|
| 1 | Research literature on aviation noise reduction approaches. | 11.10.2021–15.10.2021 | |
| 2 | Learn acoustic theory and derive the calculation formula of sound absorption coefficient. | 16.10.2021–20.10.2021 | |
| 3 | Feasibility analysis of low-frequency sound absorption of micro-perforated honeycomb structure. | 21.10.2021–26.10.2021 | |
| 4 | Study the influence of the structural parameters of the micro-perforated honeycomb on the sound absorption coefficient. | 27.10.2021–31.10.2021 | |
| 5 | Development of a new type of micro-perforated panel honeycomb structure. | 1.11.2021–15.11.2021 | |
| 6 | Implementation of the parts, devoted to environmental and labor protection. | 16.11.2021–30.11.2021 | |
| 7 | Edit and correct the draft, modify the format. | 1.12.2021–31.12.2021 | |

7. Special chapter advisers:

| Chapter | Adviser | Date, signature | |
|---|---|---|---|
| | | Task issued | Task received |
| Labor protection | PhD, associate professor Victoria KOVALENKO | | |
| Environmental protection | PhD, associate professor Tamara DUDAR | | |

8. Date of issue of the task: 8 October 2021 year.

Supervisor: ____________ Sviatoslav YUTSKEVYCH

Student: ____________ Linfeng LI

# РЕФЕРАТ


Пояснювальна записка дипломної роботи магістра «Конструктивні підходи щодо зменшення рівня шуму літака»:

71 с., 25 рис., 1 табл., 69 джерел

Ця магістерська робота присвячена дослідженню методу контролю та зменшення шуму на етапі проектування літального апарату та покращенню характеристик низькочастотного звукопоглинання мікроперфорованої панелі стільникової сендвіч-конструкції в зовнішнього контуру.

Методологія розробки базується на принципах аероакустики, теорії мікроперфорованої панелі, автоматизованого проектування та скінченно-елементного аналізу.

Практичною цінністю роботи є підвищення ефективності шумозаглушення літака на основі застосування мікроперфорованої панелі сотової сендвіч-конструкції.

Матеріали диплома магістра можуть бути використані в авіаційній промисловості та в навчальному процесі, пов’язаному зі зниженням шуму літаків.



**Авіаційний шум, шумозаглушення, мікроперфорована панель, стільникова сендвіч-конструкція**

## ABSTRACT

Master degree thesis " Aircraft Noise Reduction Design Approaches "

71 pages, 25 figures, 1 table, 69 references

This master thesis is dedicated to research of the noise control and reduction method in the aircraft design process and improving low frequency sound absorption performance of the micro-perforated panel honeycomb sandwich structure within space-coiling.

The design methodology is based on the principles of aeroacoustics, the theory of micro-perforated panel, computer-aided design, and finite element analysis.

Practical value of the work is improving the aircraft noise reduction performance on the base of the micro-perforated panel honeycomb sandwich structure application.

The materials of the master's diploma can be used in the aviation industry and in the educational process related to aircraft noise reduction.



**Aircraft noise, noise reduction, micro-perforated panel, honeycomb sandwich structure**

# CONTENT

# ABBREVIATIONS

ICAO – International Civil Aviation Organization

EASA – European Union Aviation Safety Agency

CAAC – Civil Aviation Administration of China

FAA – Federal Aviation Administration

FXLMS – Filter-x MeanSquares

WECPNL – Weighted Equivalent Continuous Perceived Noise Level

MPP – Micro-perforated panel

CDA – Continuous Descent Approach

APU – Auxiliary Power Unit

ACI – Airport Council International

MTOM – Maximum Take-off Mass

# INTRODUCTION

With the increasing requirements of modern aircraft for ride comfort, more stringent requirements have been put forward on the noise environment of the airplane cabin, and the problem of cabin noise has attracted the attention of scholars from all over the world.

The noise in the cabin will firstly affect the ride comfort seriously. Long-term exposure to high noise and strong vibration will cause fatigue and irritability, rapid heartbeat, high blood pressure and other discomfort, which will not only cause great harm to the health of the passenger, but also make pilots distracted, affecting the safety of aircraft operation. At the same time, radiated noise will shorten the life of control instruments and mechanical equipment, control failure, and even break down, which will have an adverse impact on the safety and reliability of aircraft. In addition, cabin noise may cover up the command and alarm sounds during flight, which may affect the execution of flight tasks or cause serious safety accidents. Therefore, regulations on noise airworthiness standards of the International Civil Aviation Organization (ICAO) and the European Union Aviation Safety Agency (EASA) are improving. And Civil Aviation Administration of China (CAAC) follow up.

In conclusion, excessive cabin noise will obviously restrict the comfort, operability and safety of aircraft, and cabin noise reduction design has become one of the key technical problems to be solved in the development of modern aircraft.

With the widespread application of composite materials in the aviation field, honeycomb sandwich structures are used in aircraft doors, bulkheads, floors and other structures with their excellent mechanical properties. In recent years, acoustic metamaterials have been rapidly developed, which are artificially designed and manufactured periodic composite structural materials. Generally, the wavelength of sound waves is much larger than the size of their unit structure, so their extraordinary acoustic properties are not available in any natural material. The composite honeycomb sandwich structure combining honeycomb core and acoustic metamaterials makes it possible to reduce low-frequency noise while maintaining a small size. [1]

The main structure of this work is divided into research status of aircraft noise reduction design approach, acoustic theory and sound absorption coefficient, study on sound absorption coefficient of micro-perforated panel honeycomb structure, new type micro-perforated plate honeycomb structure design, labor protection and environmental protection, general conclusions, and references.

In this work, the micro-perforated honeycomb structure and space-coiling structure are combined, and a new honeycomb sandwich structure is proposed for the first time. And verified that this structure can effectively absorb low-frequency noise with 20 mm thickness by the simulation method.

# 1. STATE OF THE ART LITERATURE REVIEW

## 1. 1 The main sources of aircraft noise

Aircraft noise is the sum of sound radiation of various sound sources during aircraft flight (Figure. 1.1). It is mainly divided into two main categories: propulsion system noise and airframe noise. Typically, propulsion system noise include: jet noise, core noise, inlet and aft fan noise, and turbine noise. Figure 1.2 shows the noise sources in a turbofan engine. Airframe noise is the result of the interaction of multiple components such as wings, horizontal and vertical tails, slats, flaps, landing gear, landing gear covers, and the airfoil-tip vortex [2]. Table 1 shows the main noise source classification of different types of aircraft.

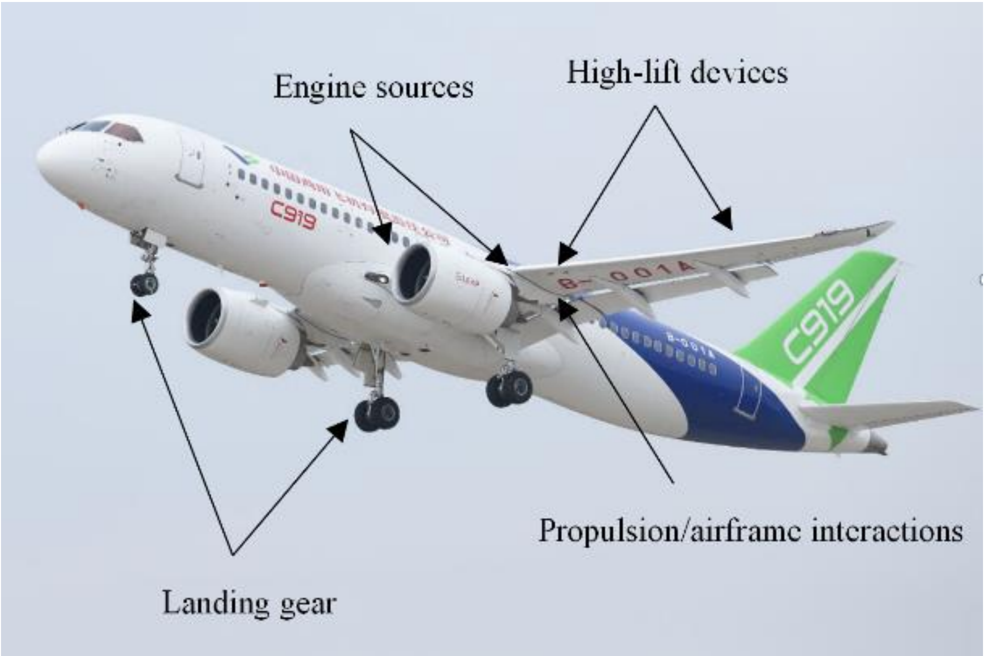


Figure 1.1 Aircraft noise source

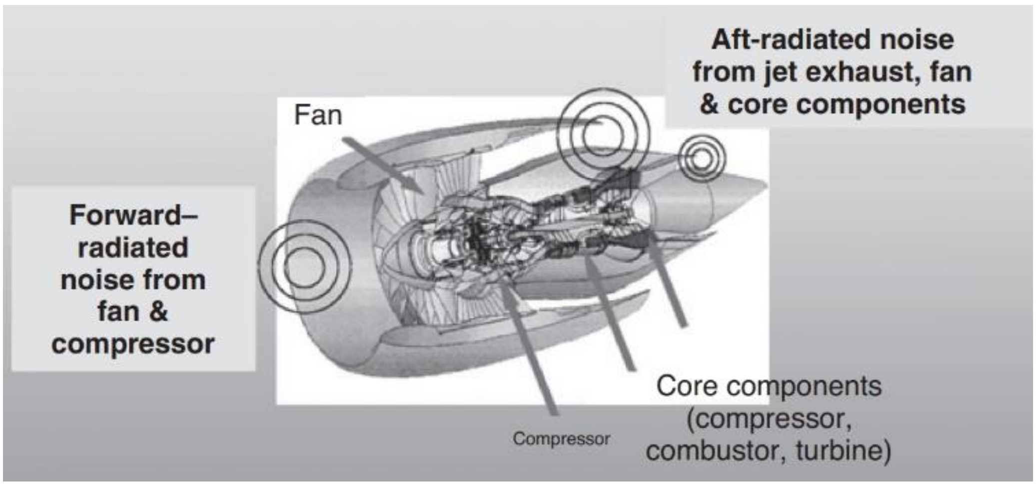


Figure1.2 Turbofan engine noise

| *Aircraft class* | *Main sources of noise* | | |
|---|---|---|---|
| | | Power-unit | Airframe |
| *Aircraft – ordinary takeoff and landing* | Turbojet | Jet, fan, core noise | Flap and wing trailing edges, flap side edges, slats, gear, fuselage and wing turbulent boundary layers |
| | Turboprop | Propeller, propfan, engine exhaust | |
| *Aircraft – short takeoff and landing* | Turbojet | Fan, engine exhaust | Interaction jet with flap |
| | Turboprop | Propeller | |
| *Supersonic aircraft* | | Jet | Interaction of flow with frame |
| *Helicopters* | | Blades of main rotor, engine exhaust | Not important |
| *Aircraft of general aviation* | Turbojet | Jet, fan | Not important |
| | Turboprop | Propeller, engine exhaust | |

Table 1 A classification of main sources of noise on aircraft

### 1.1.1 Noise generated by fans

When a large amount of turbulent airflow rushes into the engine intake, the fan blades will meet the uneven axial airflow. When the blades rotate, because of the change of the attack angle, uneven flow causes an unstable load of the blades. Fan rotor blades hit the trail leaves the group generated downstream unsteady pressure fluctuation, which is the main source of noise fan noise. The random impulse which amplitude and phase of these unsteady loads also could produce wide-band noise. The intensity of noise is related to fan blade tip velocity. When the design of the second generation of the turbofan engine, there is no guide blade and choose the number of rotor and stator vane. This purpose is to minimize the amplitude of frequency sound through subsonic rotor blades. And if there is space between the rotor and stator vane, fan noise could be reduced [3].

### 1.1.2 Noise generated by jet

When an airplane lands and climbs, the turbulence of the nozzle outlet flows into atmosphere and produces jet noise. research of jet noise originates from England in the

1950s. Many researchers used turbulence density and velocity fluctuation to describe jet noise. And nowadays the method is basic of research of jet noise. Jet noise is a dominant part of noise when the airplane lands. so it is important to reduce engine jet noise when the airplane lands. V nozzle amendment is usually adapted to suppress jet noise, which can reduce the amplitude of jet noise and minimize engine performance loss. when airplane steeply climbs and aileron drawbacks, the velocity of engine nozzle jet outlet is 200~400m/s and blowing aileron, mixer nozzle, and outlet nozzle with acoustic line grain are available to reduce blow air flap noise and jet noise [4].

### 1.1.3 Noise generated by turbine

The most important part of turbine noise is the high-frequency noise generated by high-pressure turbine blades. In addition to the frequency sound frequencies through the vicinity have also focused on broadband noise. This broadband noise is due to fluctuating pressure turbine blade passing frequency of the sound-related exhaust jet stream interaction with the environment atmospheric boundary layer turbulence generated [5].

### 1.1.4 Noise generated by airframe

Airframe noise also named no power noise is a major source of noise when aircraft approach. It is derived from the turbulent boundary layer, expands the landing gear, landing gear doors, and covers around streams, expands the ailerons and flaps resistance plate flow around the wings and fuselage wake fuselage and engine installation and mutual interference. When the aircraft adopts a streamlined design, the main noise source is the interaction between the wing and the turbulent surface of the wing wake. When large-scale turbulence in the surface of the entire wing lift drag pulsating, low-frequency noise is generated; during turbulent scale can be compared with the wing chord length, and the high frequency noise appearanced due to small-range pressure fluctuation at the trailing edge,. When the landing gear, flaps, and resistance board expand, the main source of noise is a prominent part of the local flow.

No power airframe noise is the main obstacle for civil aircraft to meet noise standards. The Federal Aviation Administration of the United States has made strict regulations on the noise certification standards of civil aircraft and stipulated the maximum noise emission level of various aircraft. These standards adopt "stages" to indicate changes in the maximum noise level requirements. For jet and large turboprop aircraft, the noise standards of the FAA applicable to new type certifications is Stage 4, which is closely analogous to the ICAO Annex 16, Volume 1 Chapter 4 standards[6].

No power noise prediction can use the component method to predict the noise generated by each component of the aircraft such as wings, ailerons, struts, landing gear, pylons, and engine compartments, and then combine the noise of each component to obtain the overall no power noise of the aircraft[3].

Another prediction method called "drag element method", Revell conceived no power noise is caused due to mechanical resistance energy dissipation byproduct of the landing of aircraft noise is mainly wing profile drag and induced drag wing noise. Trailing edge noise generation mechanism is dipole distribution of aircraft components, airframe components drag coefficient of radiation into the far field noise associated with the component[7].

### 1.2 Methods of aircraft noise reduction

When an aircraft is flying, it produces friction and turbulence which generates sound waves. Generally speaking, the faster the flight speed of the aircraft, the greater the turbulence and frictional resistance generated by the aircraft. When the aircraft uses flaps and landing gear, the frictional resistance increases, and the noise generated by the aircraft also increases accordingly. The noise emitted by aircraft may be related to its flight status. In order to analyze the noise in the cabin, it is necessary to fully study the characteristics of various sound sources, including the sound pressure amplitude, phase, and their frequency and spatial distribution on the surface. These indicators determine the total sound wave of the fuselage area and the efficiency of the response by airframe structure which has a great influence on the noise in the cabin.

The study of aircraft cabin noise mainly focuses on the external noise source, the transmission of fuselage structure noise and the comfort of passengers in the cabin and control Cabin internal noise to achieve a satisfactory passenger riding environment.

Noise reduction in the cabin is a complicated project. It is necessary to take measures from the three aspects of noise source, noise transmission path and noise receiver at the same time to achieve good results, but the premise is that the characteristics of the sound source and the transmission path must be deeply understood. Noise reduction can generally be divided into active noise reduction and passive noise reduction according to the principle of noise reduction. Generally in the mainstream approach, passive noise reduction is to increase the transmission loss by modifying the transmission path. Active noise reduction is to eliminate the interference of the noise source by setting a secondary sound source or vibration source. This solution does not need to change the fuselage structure or increase the weight of the fuselage. Compared with the substantial modification of the fuselage structure, the lower cost, but more complicated due to involves adaptive algorithm design, secondary sound source selection, and layout optimization [8].

### 1.2.1 Passive noise reduction

The noise in the cabin is mainly formed by the external noise source entering the cabin through the transmission path, so reducing the sound pressure level of the noise source is the most fundamental method. At present, many scholars have done a lot of work in this area. In 1952, Lighthill proposed the classic eighth power law of noise intensity and speed [4]. On this basis, Powell pointed out the influence of jet velocity changes on radiation noise, and for the first time proposed that auxiliary flow technology can be used to change jet velocity distribution, thereby reducing jet aerodynamic noise [9]. In order to reduce the dynamic response of the airframe due to engine vibration, Kumar used excellent damping buffers on the engine support to attenuate the vibration [10]. The University of Florida has developed a sound-absorbing liner with a simple structure [11]. Papamoschou believes that the end of the core flow of the inner culvert nozzle is the main noise source, and the noise reduction of the jet noise can be achieved by increasing the length of the core area of the outer culvert nozzle.[12] Figure 1.3 shows the Boeing 777 airliner with chevron nozzles. Bridges and Brown [13] considered that the chevron nozzles are a better method to suppress jet noise. They studied the influence of different parameters such as chevron count, penetration, length, and chevron symmetry on jet noise. Within a European financed research project called SILENCER ("Significantly Lower Community Exposure to Aircraft Noise") a study in "advanced low noise landing gear design" was performed to develop operational landing gears that take into account aeroacoustic constraints early in the design stage[14,15]. Boeing adds "Tobobogan" fairing to the landing gear of Boeing 777-300ER, (see figure 1.4)[16]. Aiming at the attenuation of sound waves on their propagation path between the slat cove and the wing leading edge, Ma and Zhang propose slat cove and wing leading-edge liners [17].


Figure 1.3 Boeing 777 chevron nozzle


a) b)

Figure 1.4 'Toboggan' fairing (a) fairing before installation (b) fairing installed[16]

The optimized noise transmission path can achieve good noise reduction effects for both airborne sound transmission and structural sound transmission. However, external noise sources are usually distributed in a large area of the fuselage, and passive noise reduction is mainly concentrated locally, so the noise reduction effect of airborne sound is relatively poor. The noise reduction of the vibration source of the structure that is concentrated and easy to define is relatively good. The common fuselage structure is composed of fuselage skin, porous material, frame, stringers, trim panel, and etc., as shown in Figure 1.5

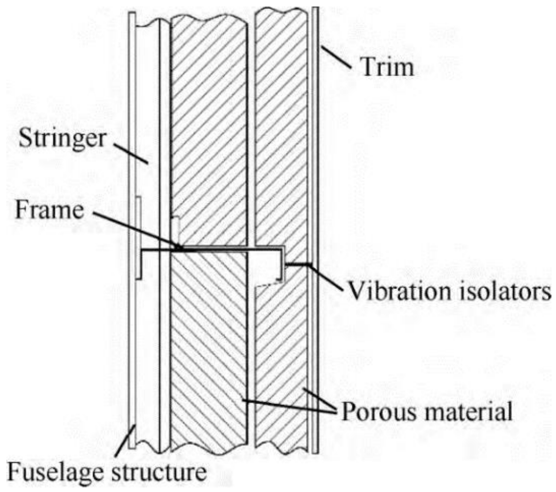


Figure 1.5 Cross-section of typical fuselage structure

In order to balance transmission loss and weight, sound-absorbing porous materials often use glass fiber mat with a density of about 7kg/m3. The glass fiber mat is wrapped with an impermeable material to prevent moisture from affecting its sound absorption performance. Both the fuselage skin and trim panels are installed on the fuselage frame. In order to effectively prevent structural sound transmission, dynamic vibration absorbers [18] or dampers [19,20] are often placed between the trim panels and the fuselage frame. The former has obvious damping effect only in a narrow frequency band, while the damping effect of the latter is related to the damping application structure. At present, the most commonly used form is constrained damping structure. For this kind of damping structure, one of the most important indicators is the shear parameter of damping material. If the shear parameter deviates from the optimal value, the structure loss factor may be only a few percent of the maximum value of damping material loss factor. The fuselage skin can generally obtain great damping effect in this way (Figure 1.6) [21], But the main limitation lies in the natural frequency of the fuselage skin. The use of damping materials on the fuselage frame and stringer, as shown in Figure 1.7, can extend the vibration damping performance to the low frequency range [22]. The use of damping structures on the floor, doors and trim surface can also achieve good vibration and noise reduction effects.

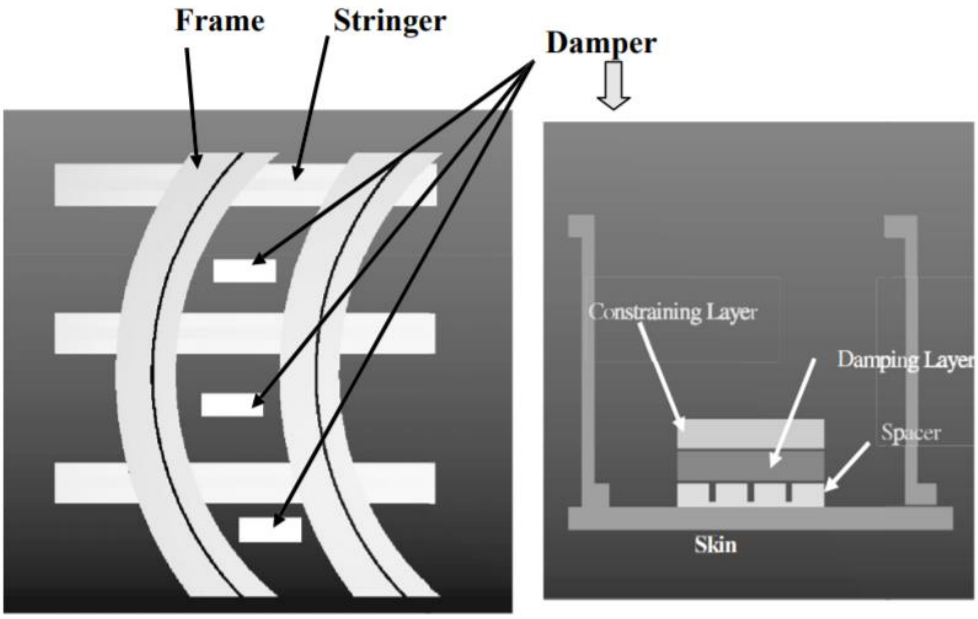


Figure1.6 Diagram of stand-off dampers used in fuselage skin[21]

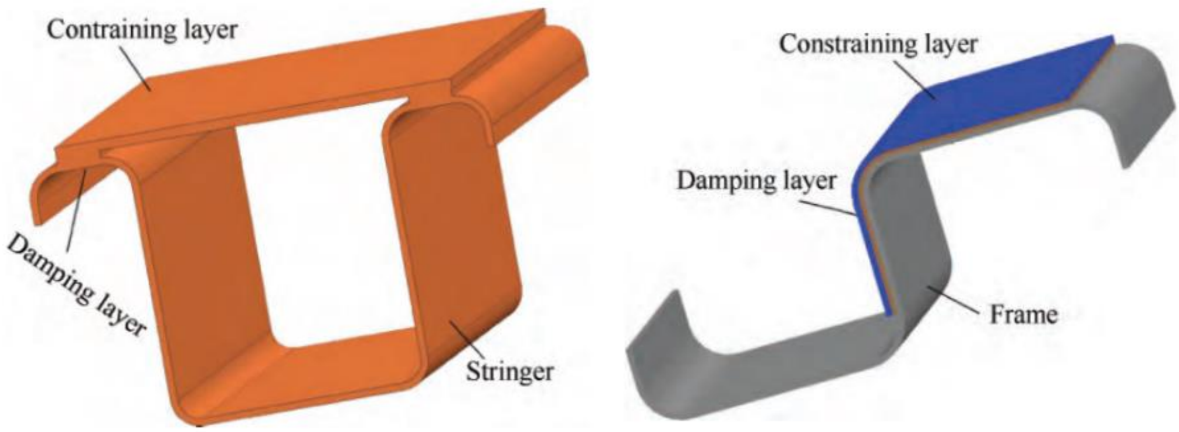


Figure1.7 Fuselage stringer damper and frame samper

### 1.2.2 Active noise reduction

Due to strict restrictions on aircraft weight requirements, passive noise reduction methods often require larger sizes and weights, so their application in engineering practice is limited, especially in the low frequency noise reduction field [23,24]. A common passive noise reduction method is to arrange passive coordinated vibration dampers on the fuselage to increase the dynamic stiffness of the fuselage, which can achieve a better vibration reduction effect at the resonance frequency of the fuselage [25]. However, this method is only effective in a certain frequency range, and the vibration reduction characteristics cannot be changed with the change of the noise source characteristics. Active noise reduction has attracted attention because of this characteristic. In the 1930s, Lueg proposed that the speed of sound in air was much smaller than that of an electrical pulse[26], meaning that when a sound wave travels from the point where it is detected to the point where it is controlled, there is enough time to process the sound signal and drive the control unit in an electronic circuit. In the early stage, analog circuit was mainly used to realize it, which was only suitable for the constant stable field, but not suitable for the unstable field of sound field. In the decades that followed, research on active control methods stagnated, not because of a lack of theory, but because of a lack of technical support, because to achieve the desired precision of the control system, the controller must precisely adapt to changes in the surrounding sound field. Until the 1980s, the theory proposed adaptive filtering and digital signal processing devices, only to active noise control to obtain rapid development [27]. The method of actively controlling the noise in the cabin is to control the sound modal in the cabin by arranging instruments and equipment such as microphones, vibration exciters, and error microphones in the cabin to generate signals with the opposite phase and the same amplitude. In 1990, university of Southampton carried out a series of active noise control work on propeller aircraft cabin, and obtained the relationship between noise reduction effect and sound field characteristics, secondary sound sources and error sensor arrangement [28]. Fuller et al. [29] studied the vibration acoustic radiation and transmission of structures by using the active structural control method, and the research results show that the active structural control method can effectively improve the vibration acoustic radiation characteristics. Griffin et al. [30] studied the attenuation of low-frequency noise on the acoustic test platform of Boeing767 fuselage section by using active noise reduction method, and determined the position of error sensor and exciter on the basis of modal analysis. And the FXLMS algorithm is adopted to achieve a noise reduction effect of 8 ~ 11dB in the cabin. Zhu et al. proposed a method of active sound absorption using piezoelectric material, which is used as the absorbing material in the active sound absorption system [31].

### 1.3 Honeycomb sandwich structure within acoustic metamaterials

Passive noise reduction technology mainly rely on the structure optimization design, additional or dynamic vibration absorber which is used to laying method such as damping materials, the advantages of stable performance, low cost, and easy to implement, but limited to the added mass and installation space, often can't satisfy the requirement of the low frequency and broadband vibration noise reduction, there are some limitations. Active noise reduction technology mainly uses the principle of acoustic interference or active vibration suppression to achieve the purpose of vibration reduction and noise reduction . Its low-frequency control effect is better than passive noise reduction technology, but it has disadvantages such as poor stability, poor environmental tolerance and high maintenance cost. Therefore, it is urgent to further develop new noise control technology to achieve better performance of low frequency and broadband vibration and noise reduction.

In the past few years, acoustic metamaterials [32] and the development of related research have provided new ideas for solving the problems of low-frequency vibration and acoustic radiation control of engineering structures. Acoustic metamaterials are specially designed artificial acoustic microstructure units periodically arranged, which can obtain extraordinary physical properties that non-artificial materials do not have, such as negative mass density, negative refraction, negative modulus, etc.

The concept of acoustic metamaterials was first proposed in the journal Science by Liu [33] in 2000, which evolved on the basis of local resonance phononic crystals. They adopted periodic embedding in epoxy resin. A lead ball covered by a soft material constructs a local resonance type phononic crystal (as shown in Figure 1.8), and a new band gap mechanism of local resonance band gap is put forward for the first time. Subsequently, Liu [34] and others further found that close proximity to the resonance frequency, the local resonance phononic crystal has the negative equivalent mass density characteristics that traditional materials do not have.

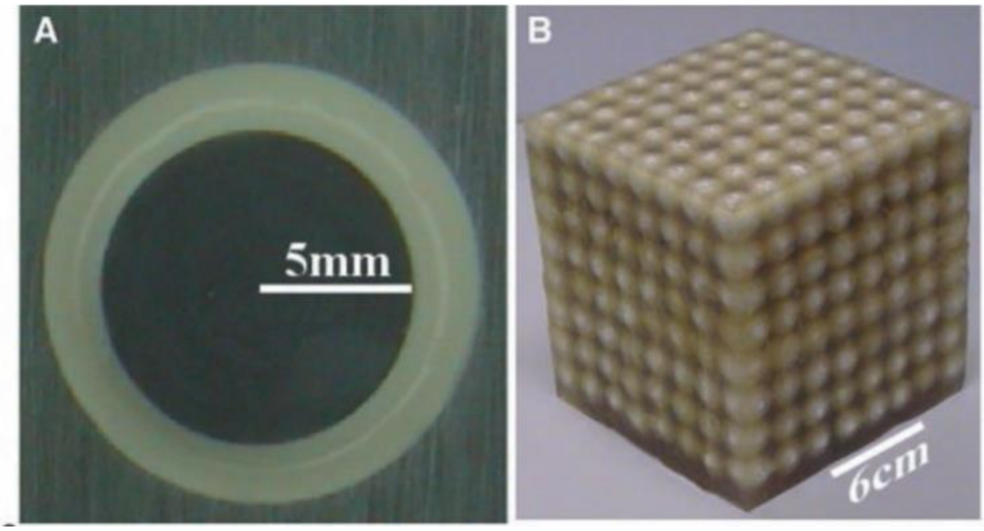


Figure 1.8 Locally resonant sonic crystals

Due to the breakthrough discovery of Liu et al., the concept of local resonance phononic crystals quickly attracted the research interest of more and more scholars. In 2004, Li et al. [35] conducted a study on a local resonance phononic crystal composed of a silicone rubber scatterer embedded in a water matrix and found that it has both negative equivalent mass density and negative mass density within a certain frequency range. Equivalent elastic modulus characteristics, they are analogous to electromagnetic metamaterials, and clearly put forward the concept of "acoustic metamaterials" for the first time.

In 2006, Fang [36] of the University of California, et al. proposed a new type of acoustic metamaterial composed of periodic arrays of water-filled Helmholtz resonators in the journal Nature Materials (as shown in Figure 1.9), which proves by experiment that it has a negative equivalent modulus in the band gap range.

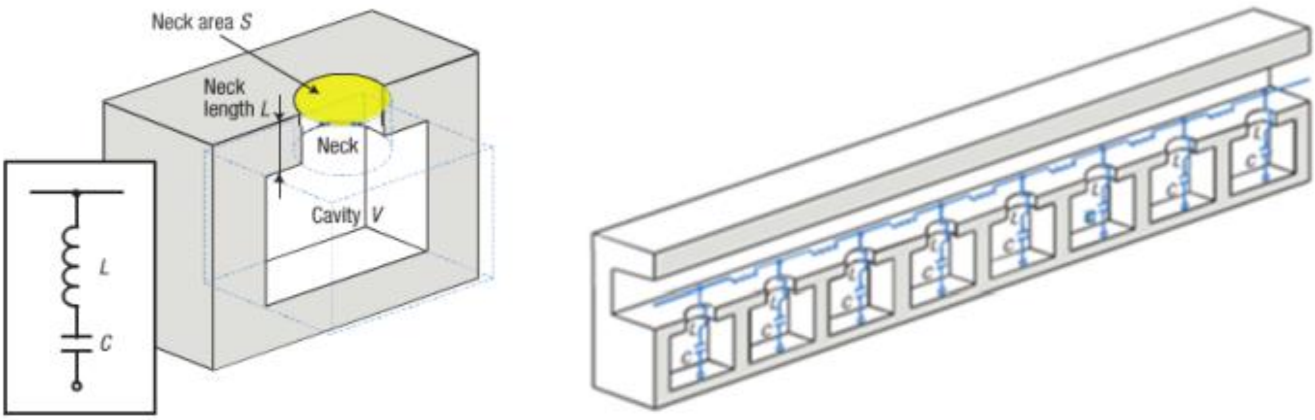


Figure 1.9 Helmholtz resonator acoustic metamaterials

The construction of acoustic metamaterials usually adopts periodically arranged local resonance units. Currently, the main forms of local resonance units that have been proposed are: scatterers with coating layers [37,38], ring oscillators [39], cylindrical oscillators] [40,41] Cantilever beam vibrator [42,43] thin film acoustic metamaterials [44-47], Helmholtz resonator [48], piezoelectric shunt vibrator [48-50] and space coiling structure [52,534].

In 2014, Li et al. [54] designed a multilayer-split-tube structure(see Figure 1.10)to product a lower low-frequency band gap, and analyzed the parameters affecting its band gap by using the acoustic and electrical analogy method.

In 2017, Jiang et al. [55] designed a Helmholtz periodic structure with double-opening inner and outer cavities to obtain a narrow band gap near 100 Hz. By designing and adjusting the arc length of the inner cavity, the band gap can be moved to achieve the sound insulation effect of a specific low-frequency band, but its attenuation loss is still concentrated in the middle and high frequency of 2000 Hz.

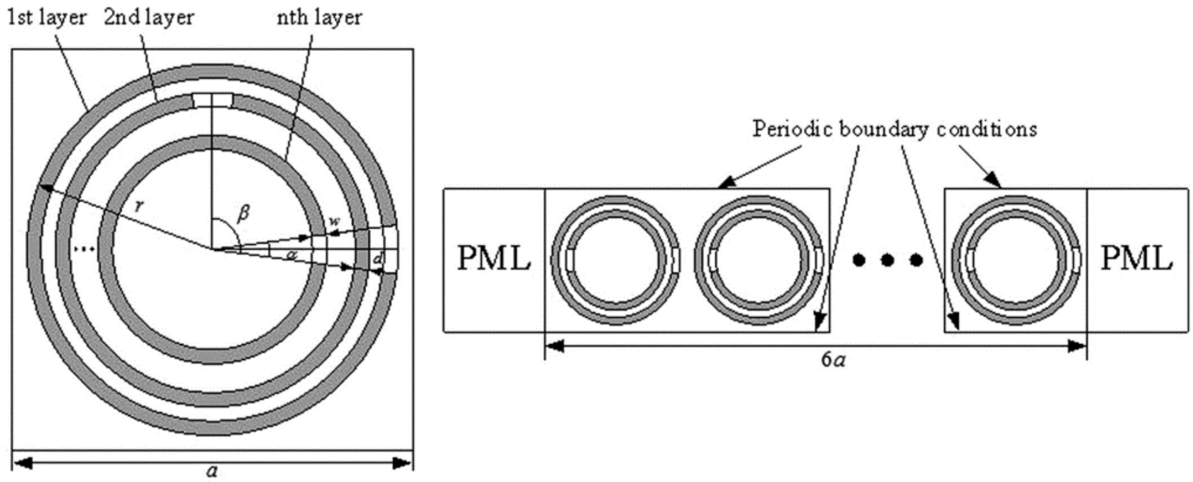


Figure 1.10 Schematic diagram of the multilayer-split-tube resonators[54]

In 2019, Wu et al. [56] proposed an acoustic material that can sub-perfectly absorb low-frequency noise. The material is composed of three-layer split tubes with opposite opening directions. The sound absorption performance of the absorber has been studied through simulation and experiments. This study has shown that the maximum sound absorption coefficient exceeds 0.9, and the sound absorption frequency and bandwidth can be effectively adjusted by changing the structural parameters of the absorber. But the influence of opening angle on sound absorption performance is not considered.

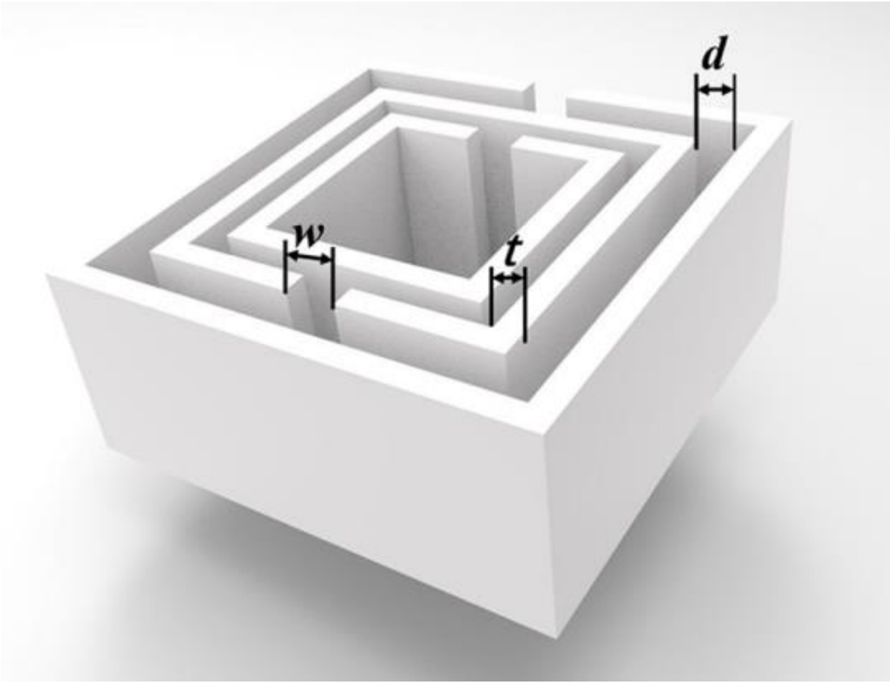


Figure 1.11 The schematic diagram of split-tube absorber[56]

Wang et al. [57]studied the influence of structural parameters on the acoustic performance of two-layer Nomex honeycomb acoustic metamaterials by experimental tests and theoretical models, and optimized the sandwich structure with genetic algorithm.

**Conclusion**

This chapter introduces the main aircraft noise sources, modern aircraft noise reduction methods and the research status of acoustic metamaterials. The emergence of acoustic metamaterials provides new possibilities for low-frequency noise reduction, broaden the material selection of aviation noise reduction and provides new theories and methods for low-frequency noise reduction in engineering applications. After a large number of studies and investigations by scholars from all over the world,the existing theoretical and experimental studies show that metamaterial structures have better low frequency noise reduction performance than traditional structures, and other unconventional properties, such as negative elastic modulus However, it remains to be further studied to combine the acoustic metamaterial principle with honeycomb sandwich structure for the noise reduction design of fuseli structure.

# 2. METHODOLOGY

## 2.1 Theoretical derivation of honeycomb-microperforated panel acoustic absorber

The concept and theory of micro-perforated panel was first put forward in 1975 by the Chinese physicist Maa[58,59]. Micro-perforated absorbers consist of a micro-perforated panel(MPP), air cavity, and a non-perforated rigid backing. The honeycomb-microperforated panel structure is a lightweight sound-absorbing structure with excellent mechanical properties, as shown in Figure 2.1. The honeycomb-microperforated panel structure is composed of an upper layer MPP, honeycomb cores, and a rigid backing panel.

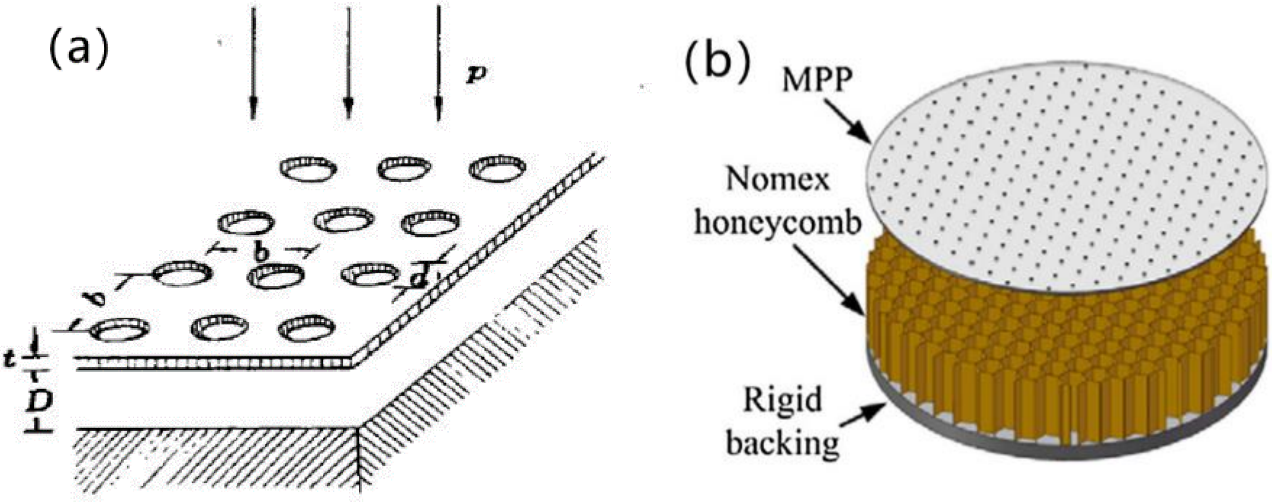


Figure 2.1 The schematic diagram of (a) Micro-perforated sound absorber structure and (b) Honeycomb-MPP structure

The calculation formula of the sound absorption coefficient of the micro-perforated panel is derived from the pipe acoustics theory. This section mainly discusses the detailed derivation process. In pipeline acoustics, when the diameter of the pipeline is relatively large or the sound frequency in the pipeline is relatively low, the coal quality in the pipeline is assumed to be an ideal coal quality, and no thermal viscosity loss will occur with the pipe wall. However, when the diameter of the pipe is small or the frequency of the sound wave is high, the pipe wall will interfere with the movement of the particles of the propagation medium, and this interference will affect the size of the thermal viscosity loss during the propagation of the sound wave.

Assuming that the air in a circular pipe is divided into many very thin coaxial cylindrical layers, the elastic and viscous forces of the medium in the pipe will affect the axial movement of each layer. Divide the tube into many ring elements along the radial direction, and take one of them, as shown in Figure 2.2.

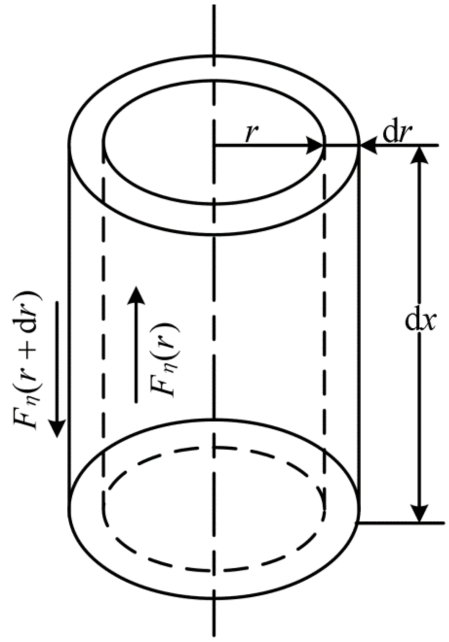


Figure 2.2 Coaxial cylindrical layer

The inner surface area of the ring element is $d\sigma = 2\pi r dx$, and the volume of the ring element is $dV = 2\pi r\, dr\, dx$, $F\eta$ is the viscous force received by the medium point. After derivation, the motion equation of the propagation medium in the pipeline can be obtained as

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial v}{\partial r}\right) - \frac{\rho_0}{\eta}\frac{\partial v}{\partial t} = \frac{1}{\eta}\frac{\partial p}{\partial x} \tag{2.1}$$

Where r is radius of media layer, v is the velocity of the coal particles, $\rho_0$ is the air density, η is the viscosity coefficient of the air, p is the sound pressure, t is the time, and the sound wave propagates along the x direction. It can be seen from this equation that the medium particle velocity is a function of the axial coordinate x and the radial coordinate r. First, fix x to determine the relationship between the particle velocity v and the radial coordinate r. Let $p = p_a(x)e^{j\omega t}$、 $v = v_a(x,r)e^{j\omega t}$ into the formula (2.1), we get:

$$\left(\frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r} + K^2\right)v_a = \frac{1}{\eta}\frac{\partial p_a}{\partial x} \tag{2.2}$$

Where $K = (1-j)\sqrt{\frac{\rho_{0\omega}}{2\eta}}$, The special solution of the equation is: $v_{a_1} = \frac{1}{\eta k^2}\frac{\partial p_a}{\partial x}$ Perform variable transformation, set $Z = Kr$, then the corresponding homogeneous equation can be transformed into a standard form of zeroth order Bessel equation, the solution is known, so the general solution of equation (2.2) can be obtained as:

$$V_a = AJ_0(Kr) + BN_0(K_r) + \frac{1}{\eta K^2}\frac{\partial P_a}{\partial x} \tag{2.3}$$

Because the speed is limited at $r = 0$, and the Neumann function is divergent at this point, set $B = 0$, and then consider the boundary conditions of the rigid wall, that is, when $r = a$, $v_a = 0$ can be obtained as:

$$A = \frac{1}{\eta K^2}\frac{\partial p_a}{\partial x}\left[-\frac{1}{J_0(Ka)}\right] \tag{2.4}$$

Then the formula (2.3) can be simplified as::

$$A = \frac{1}{\eta K^2}\frac{\partial p_a}{\partial x}\left[1 - \frac{J_0(Kr)}{J_0(Ka)}\right] \tag{2.5}$$

Where $J_0$ is the zero-order Bessel function; the equation (2.5) is averaged over the entire cross section to obtain:

$$\bar{v}_a = \frac{1}{\pi a^2}\int_0^a 2\pi r v_a\, dr = \frac{1}{\eta K^2}\frac{\partial p_a}{\partial x}\left[1 - \frac{2J_1(Ka)}{KaJ_0(Ka)}\right] \tag{2.6}$$

Where $J_1$ is a first-order Bessel function; introduce effective density $\rho_e$, $\rho_e\frac{\partial \bar{v}_a}{\partial_t} = -\frac{\partial p}{\partial x}$, considering the viscous effect of the pipe wall, the sound wave in the pipe can be set as a plane wave. At this time, the sound wave vibration speed is represented by $\bar{v}$. If the effective density $\rho_e$ is replaced by the air density $\rho_0$, the effective density in the pipe is given by the following formula:

$$\rho_e = \frac{1}{\rho_0}\left[1 - \frac{2J_1(ka)}{kaJ_0(ka)}\right] \tag{2.7}$$

The argument $ka$ of $J_0$,$J_1$ is a complex number, and k can be written as $k = (1-j)/\sigma$,where $\sigma = \sqrt{\frac{2\eta}{\rho_0\omega}}$ is the thickness of the viscous boundary layer, which indicates the range of the viscous force around the boundary.

Using Rayleigh [60]'s research results on sound waves, and then Crandall [61] for further derivation, the final calculation formula for the acoustic impedance ratio of sound waves in the small tube is shown in the following equation.

$$z_s = \frac{-\dfrac{\partial p_a}{\partial x}}{\bar{v}_a} = j\omega\rho_0 t\left[-\frac{2}{x\sqrt{-j}}\cdot\frac{J_1\left(k\sqrt{-j}\right)}{J_0\left(k\sqrt{-j}\right)}\right]^{-1} \tag{2.8}$$

Where $k = d\sqrt{\frac{\omega\rho_0}{4\eta}} is$ perforation constant, $w = 2\pi f$ is the sound wave angular frequency, $t$ is the length of the small tube, same as the thickness of the perforated panel, and $\rho_0$ is the air density.

When 1<k<10 is considered, it is the condition that the micro-perforated panel is established, and the acoustic impedance rate of the microperforated tube is approximately expressed as the following formula:

$$z_s \approx \frac{32\rho_0\mu t}{d^2}\sqrt{1+\frac{x^2}{32}} + j\omega p_0 t\left(1+\frac{1}{\sqrt{9+\frac{x^2}{2}}}\right) \tag{2.9}$$

Where $\mu = \eta/\rho_0$ is aerodynamic viscosity coefficient, the value usually is $1.79 \times 10^{-5}\ Pa\cdot s$.

However, the difference between the plate thickness t and the pore diameter d is not very large, and end correction is required. Due to the sound radiation at the end, the end correction value of the sound quality is required, which is equivalent to the thickness of the panel increased by 0.85d. Add the corresponding end correction term and divide by the air characteristic impedance $\rho_0 c$ on both sides of the equation, and the modified relative acoustic impedance ratio calculation formula of the micro-perforated panel is shown in the following formula

$$z = r + j\omega m \tag{2.10}$$

$$r = \frac{32\mu t}{\rho_0 p d^2}\left(\sqrt{1+\frac{x^2}{32}} + \frac{\sqrt{2}k}{8}\frac{d}{t}\right) \tag{2.11}$$

$$m = \frac{t}{pc}\left(1 + \frac{1}{\sqrt{9 + \frac{x^2}{2}}} + 0.85\frac{d}{t}\right) \tag{2.12}$$

Where r is the relative acoustic resistance of MPP; m is the relative acoustic resistance of MPP; d is the pore diameter of MPP; p is the perforation rate of MPP.

The cavity behind the micro-perforated panel has a large size relative to the micro-holes, and the cavity is equivalent to an acoustic volume. The relative acoustic impedance of the corresponding cavity is as follows:

$$z_D = -j\,cot\left(\frac{\omega D}{C}\right) \tag{2.13}$$

For the honeycomb-microperforated panel sound absorber, the relative acoustic impedance of the sound absorber can be obtained by adding the relative acoustic impedance of the micro-perforated panel and the cavity,as shown in the following formula:

$$z_0 = r + j\omega m + z_D \tag{2.14}$$

Considering the situation of vertical incidence, the sound absorption coefficient of the honeycomb-microperforated panel at vertical incidence can be written as

$$\alpha = \frac{4Re(z_0)}{[1 + Re(z_0)]^2 + [Im(z_0)]^2} \tag{2.15}$$

### 2.2 COMSOL finite element simulation process

COMSOL Multiphysics is an advanced numerical simulation platform based on the finite element method, which covers all steps in the modeling workflow. COMSOL Multiphysics can assist users in solving partial differential equations to simulate various physical phenomena in real or virtual scenes such as acoustics, fluid mechanics, and electrochemical scenes. Contains a wealth of physics modules, and the rich and colorful post-processing methods included in the software make the presentation of the simulation results clearer. The calculation process is the same as the traditional finite element method. When performing simulation solution, it also needs to go through the process of modeling, meshing, physics setting, material setting, solving, data post-processing, etc.

For the structure of the micro-perforated sound-absorbing body, the pressure acoustic module built in the software is used to establish a three-dimensional model as shown in Figure 2.3.

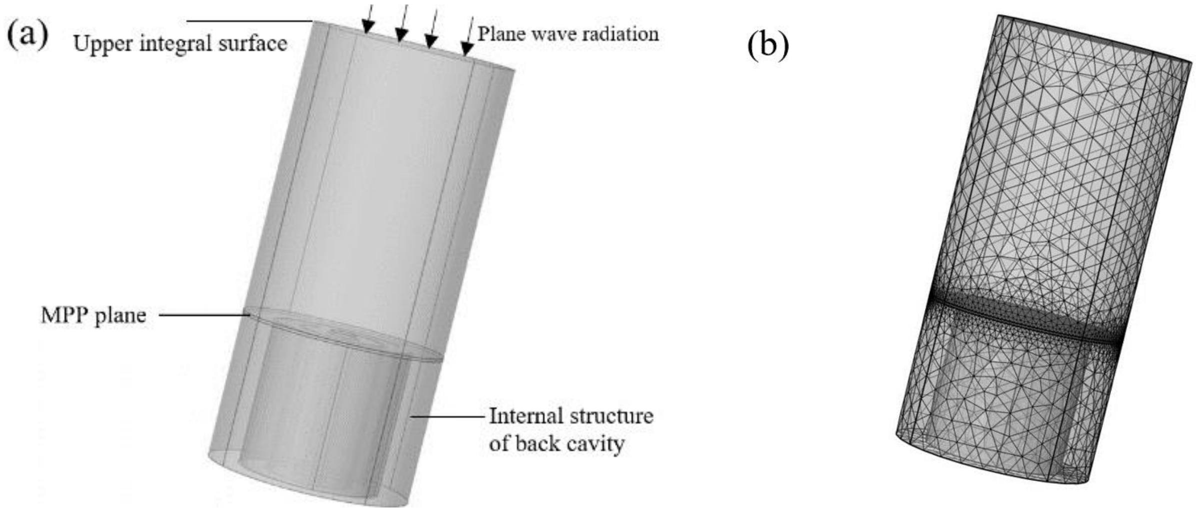


Figure 2.3 Schematic diagram of MPP simulation (a) modeling and (b) meshing

The cylinder above it is the background cavity, and plane wave radiation is set on the top surface of the background cavity to generate plane wave excitation; the upper surface is selected as the integration surface, instead of probe integration to obtain the incident sound power; the background field is set and the plane wave vector and size are set; and For the micro-perforated panel, if only consider the uniform distribution of the micro-perforated panel, can directly use the built-in perforated panel physical field built in COMSOL, select the micro-perforated panel plane and set the parameter values of the pore diameter d, the plate thickness t, and the perforation rate p; The parameters of cavity D can be obtained by modeling from the height of the back cavity.

For the meshing required for the simulation of the sound absorption coefficient of the rigid micro-perforated panel, the free tetrahedral meshing built in the software can be used directly, and the physics control can be selected or in order to save computing power, the meshing control parameters can be set.

The solution part is based on the completion of the physical field setting. This work uses the pressure acoustics and frequency domain modules, which only consider the air domain and the inner walls of the structure are rigid walls. Run the software after setting the starting point, step length and ending point in the frequency domain to be solved.

In the post-processing part of the results, this work chooses to export the data after the sound absorption coefficient curve is obtained by the simulation software. The drawing and analysis operations are carried out in Originlab, which has richer data visualization and analysis operations. Some complex structural diagrams drawed by CATIA V5 software.

**Conclusion**

This chapter principally expounds on the basic theories of acoustics, research methods, and software of modeling, simulation, and drawing used in this work. The calculation formula of acoustic impedance ratio and theoretical calculation of sound absorption coefficient of the MPP sound absorber is mainly introduced and deduced. The theoretical model shows that the sound absorption coefficient of the micro-perforated panel sound absorption structure depends on its structure parameters of pore diameter, perforated rate, plate thickness, and cavity depth. it lays a theoretical foundation for the subsequent research on the optimization design of sub-wavelength and low-frequency sound absorption structure and honeycomb micro-perforated panel structure.

# 3. RESULTS AND DISCUSSION

The previous chapter introduces the structural parameters of the MPP. This chapter starts with four structural parameters affecting the sound absorption coefficient of MPP sound absorption structure: pore diameter d, thickness t, cavity depth D, and perforation rate p, and using the control variable method to study the influence of the four parameters on the sound absorption coefficient by COMSOL Multiphysics simulation software. Furthermore, the micro-perforated panel and the honeycomb sandwich structure are combined. On this basis, the internal structure of the honeycomb core is improved, and a new MPP-honeycomb structure is designed for the first time, which verifies its effective absorption of low-frequency noise by simulation.

## 3.1 The relationship between pore diameter d and sound absorption coefficient

For the single-layer rigid micro-perforated panel, structural parameters t = 1mm, D = 20mm, and p =3% remain fixed, and only the value of pore diameter d is changed, ranging from 0.1mm-1mm. Calculated in COMSOL Multiphysics, the absorption coefficient curve with only changing pore diameter parameters is shown as Figure 3.1.

Figure 3.1 reveals that under the condition of controlling other parameters unchanged, as the pore diameter d of MPP decreases, the sound absorption frequency band and the maximum sound absorption coefficient gradually increase. The frequency corresponding to the maximum sound absorption coefficient slightly rise with the decrease of pore diameter, indicating that the increase of pore diameter of MPP reduces its resonance frequency. Therefore, the sound absorption performance of the micro-perforated panel can be increased by appropriately reducing the pore diameter.

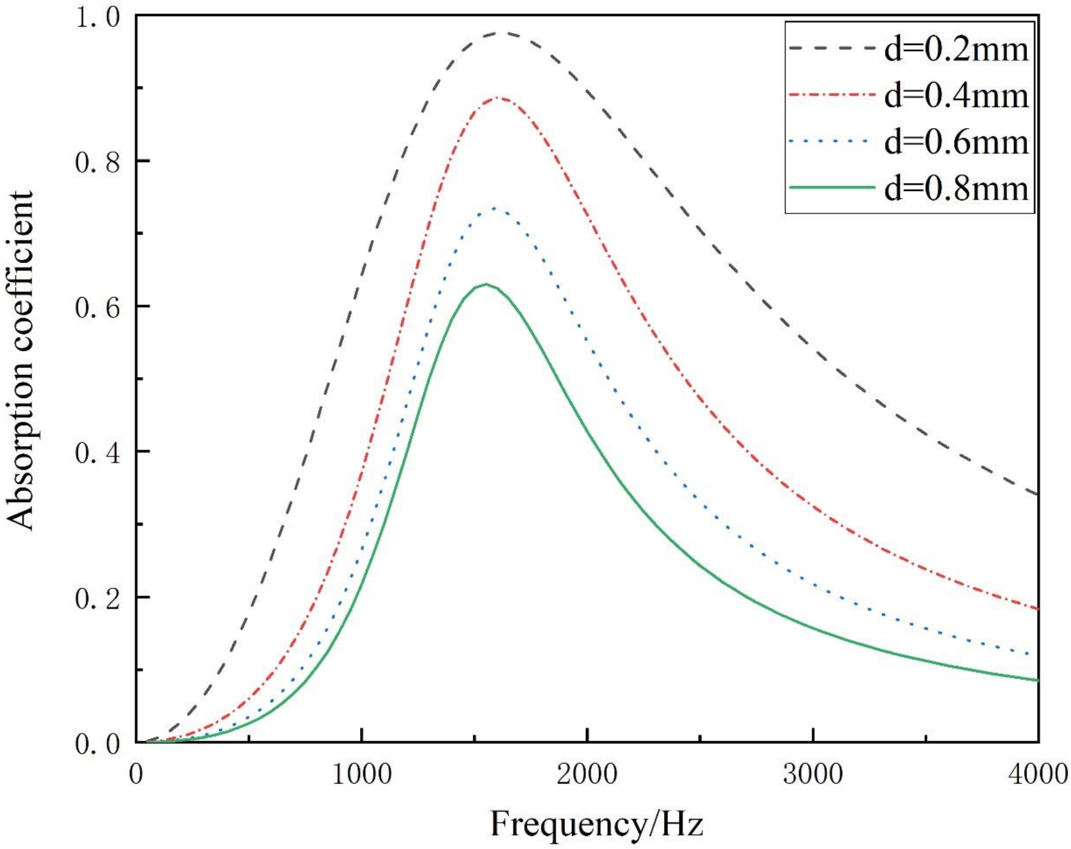


Figure 3.1 Absorption coefficients with different pore diameter of MPP

### 3.2 The relationship between cavity depth D and sound absorption coefficient

For single-layer rigid micro-perforated panel, structural parameters t = 1mm, d = 0.2mm and p =3% remain fixed, and only the value of cavity depth D is changed, ranging from 10mm-40mm.Calculated in COMSOL Multiphysics, the absorption coefficient curve with only changing cavity depth parameters is shown as Figuer 3.2.

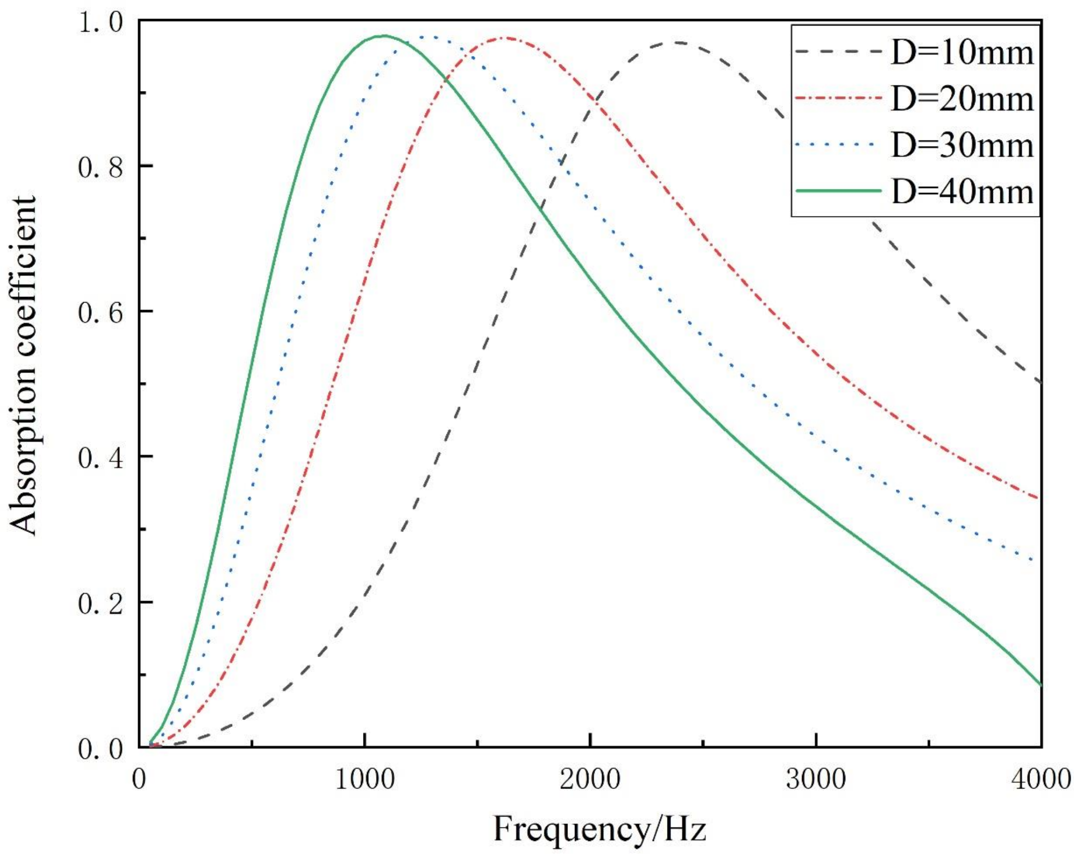


Figure 3.2 Absorption coefficients with different cavity depth of MPP

It can be seen from Figure 3.2 that only considering the effect of cavity depth D on the sound absorption performance of the microperforated panel, it can be seen that as the cavity depth D increases, the maximum sound absorption coefficient increases, the change is not obvious, and the frequency band becomes narrower. Furthermore, increases cavity depth of the MPP and correspondingly the sound absorption coefficien curve shifts to a lower frequency, and the moving range is more obvious than other parameters. This study has identified that the back cavity has a major effect on the sound absorption frequency and has special significance in changing the sound absorption performance.

### 3.3 The relationship between perforation rate p and sound absorption coefficient

For single-layer rigid micro-perforated panel, structural parameters t=0.5mm, d= 0.3mm and D=20mm remain fixed, and only the value of perforation rate p is changed, ranging from 10mm-40mm.Calculated in COMSOL Multiphysics, the absorption coefficient curve with only changing perforation rate parameters is shown as Figuer 3.3.

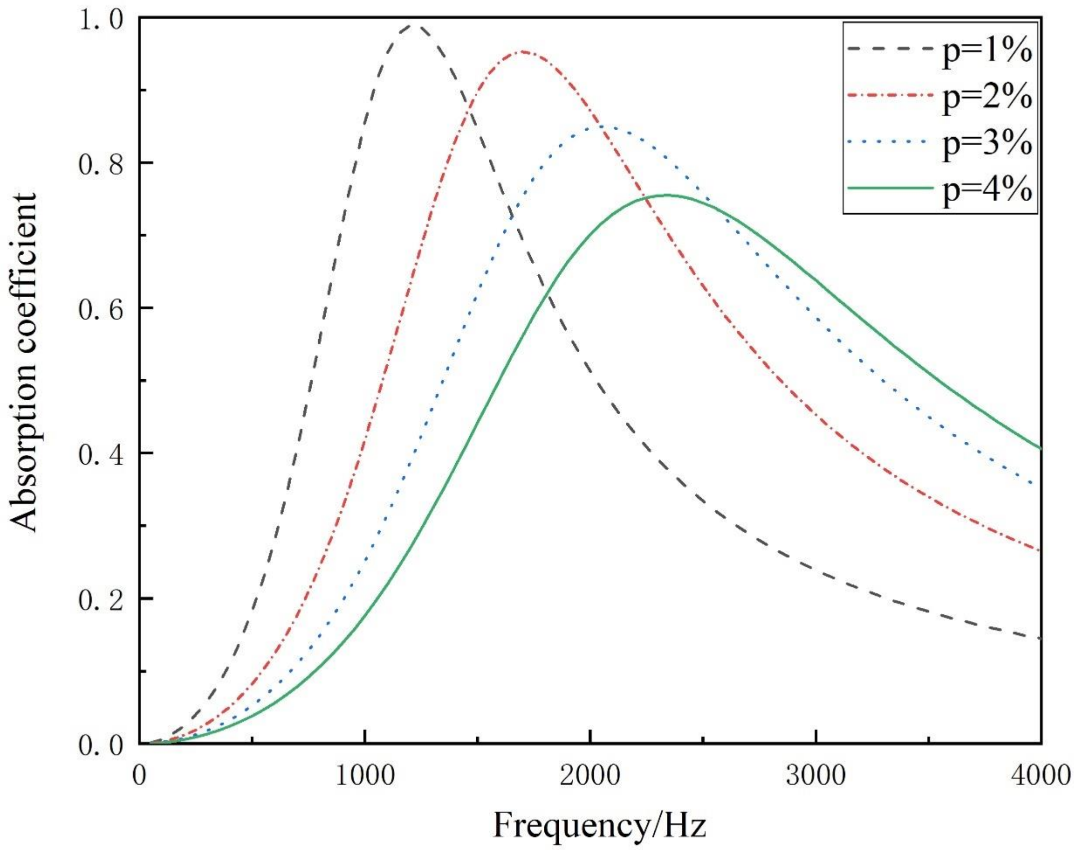


Figure 3.3 Absorption coefficients with different perforation rates of MPP

From Figure 3.3 above we can see that the frequency corresponding to the peak of sound absorption coefficient curves reduces with the diminution of perforation rate. In addition, it can be concluded that the sound absorption band becomes wider as the perforation rate increases by studying the bandwidth of the sound absorption coefficient curve, but the maximum sound absorption coefficient decreases. Therefore, on the premise of meeting the requirements of sound absorption performance, appropriately reduce the maximum sound absorption coefficient to increase the bandwidth.

### 3.4 The relationship between plate thickness t and sound absorption coefficient

For single-layer rigid micro-perforated panel, structural parameters D=20mm, d= 0.2mm and p=3% remain fixed, and only the value of plate thickness t is changed, ranging from 0.4mm-1mm.Calculated in COMSOL Multiphysics, the absorption coefficient curve with only changing plate thickness parameters is shown as Figuer 3.4.

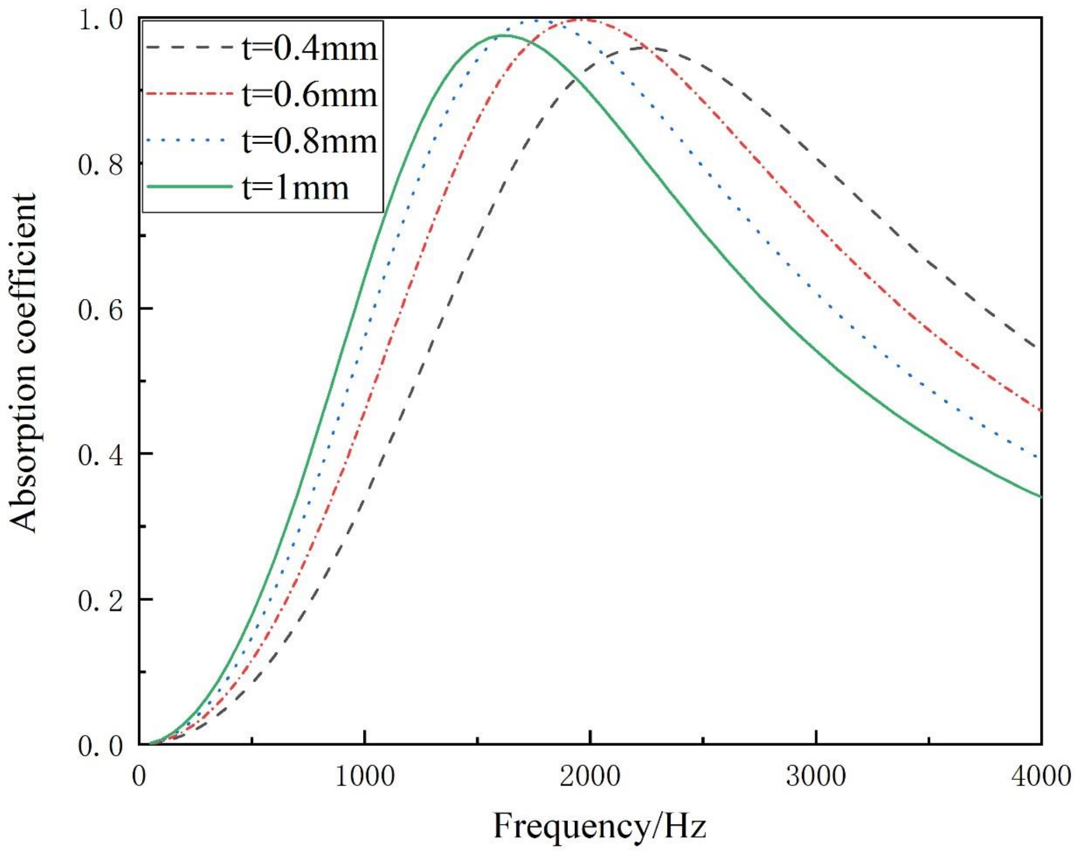


Figure 3.4 Absorption coefficients with different plate thickness of MPP

As shown in Figure 3.4, as the plate thickness increases, the maximum sound absorption coefficient increases correspondingly, and the frequency band becomes narrower. The increasing the plate thickness of the MPP and correspondingly the sound absorption coefficient curve and resonance frequency shift to a lower frequency.

The micro-perforated panel sound absorber is periodically arranged to form a hexagonally packed circular honeycomb-microperforated panel composite structure, as show in Figure 3.5,so that it has good noise reduction performance and mechanical properties, and can be widely used in the engineering field.

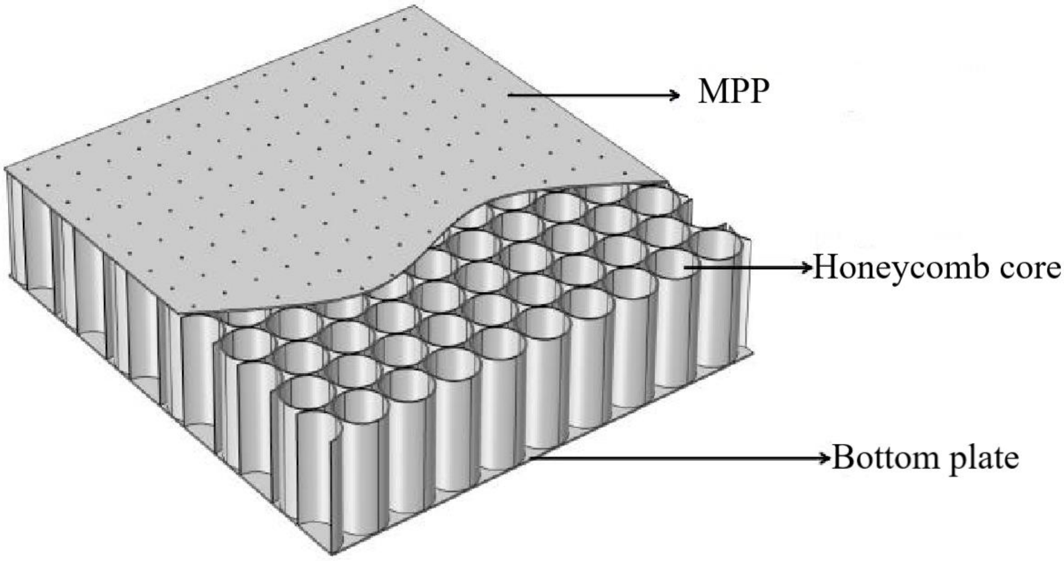


Figure 3.5 Hexagonally packed circular honeycomb-MPP composite structure

In order to solve the size limitation of low frequency sound absorption performance, a space-coiling structure similar to split ring resonator is designed inside the honeycomb core, as shown in Figure 3.6. The structure is composed of a micro-perforated panel, a honeycomb core sandwich within space-coiling and a bottom panel.

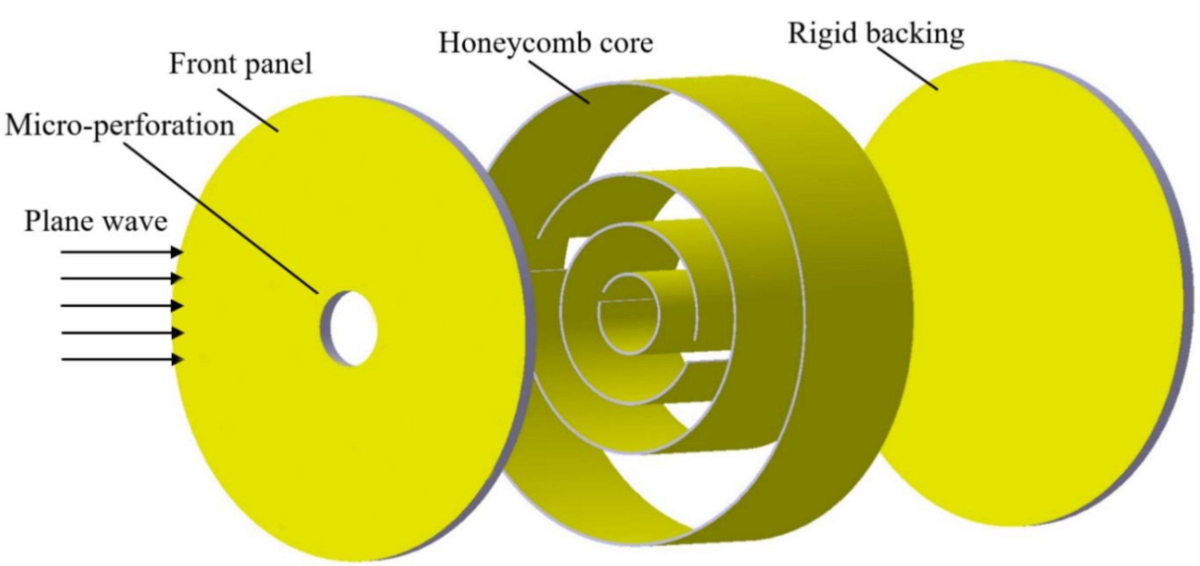


Figure 3.6 Schematic of cell of honeycomb-MPP structure within space-coiling

In order to study the sound absorption performance of the honeycomb-MPP structure within space-coiling, simulation calculation were performed in COMSOL Multiphysics, and adopted the module “Pressure Acoustics, Frequency Domain”. The node “Narrow Region Acoustics” was used to simulate the thermal dissipation caused by micro-perforation. The speed of sound in air was set as 340 m/s. Set the incident plane wave to radiate the object of simulation from the -z direction, and set its amplitude to 1 Pa.The micro-perforated front panel's parameters were set as pore diameter d=0.6mm, thickness t=0.5mm and perforation rate p=0.15%. The height of the honeycomb core is set to 20mm, the diameter is 28mm, the opening angle of the split rings is 40 degrees, the wall thickness is 2mm, and ther number of rings is three. structure The comparison of the sound absorption coefficient of the honeycomb-MPP structure within space-coiling and ordinary honeycomb-MPP structure is shown in Figure 3.7.

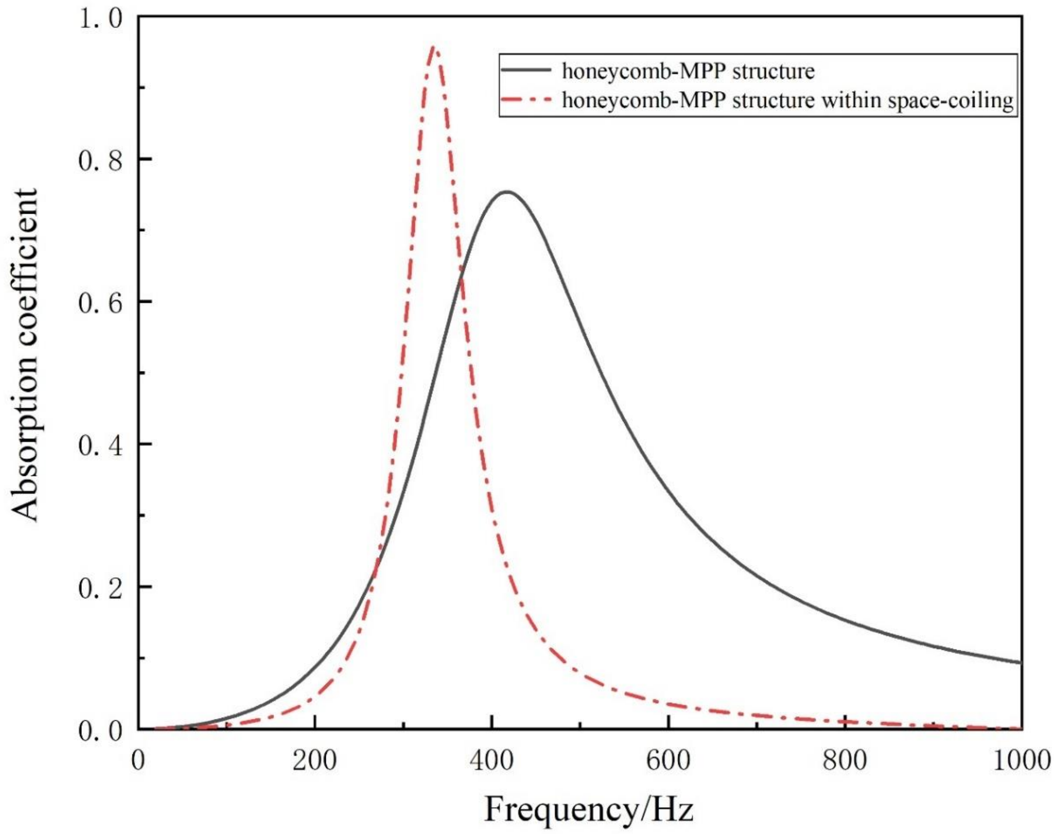


Figure 3.7. Comparison of absorption coefficient curves

It can be seen from the above figure that the maximum absorption coefficient of the new type micro-perforated plate honeycomb structure reaches 0.96 when the structural parameters of the micro-perforated plate are the same, which is significantly improved compared to the maximum sound absorption coefficient of the ordinary micro-perforated plate honeycomb. And the sound absorption coefficient curve of new type micro-perforated plate honeycomb structure shift to a lower frequency, where the resonance frequency is 335Hz.But the the frequency band of  sound absorption becomes narrower.

In general, the honeycomb-MPP structure within space-coiling achieves the design expectations, and is close to perfect sound absorption for low-frequency noise at 335Hz. It satisfies the effective control of low-frequency noise while keeping small thickness. The periodic arrangement of unit cells can form a new type of honeycomb sandwich panel, which can be used in aircraft structure manufacturing to greatly reduce cabin low-frequency noise and improve ride comfort.

**Conclusion**

This chapter first takes the micro-perforated panel absorber as an example, uses COMSOL Multiphysics to simulate and calculates the influence of different parameters on the sound absorption performance of the micro-perforated plate sound absorber, and draws the following conclusions:

1. Only reduce the pore diameter d, the resonance frequency of the micro-perforated plate sound absorber will shift to high frequency, and the sound absorption bandwidth and maximum sound absorption coefficient will increase significantly.

2. Only increase the cavity depth D, the resonance frequency of the micro-perforated plate sound absorber will greatly shift to low frequency, while the sound absorption bandwidth and maximum sound absorption coefficient have not changed significantly.

3. Only increase the perforation rate p, the resonance frequency of the micro-perforated plate sound absorber will shift to high frequency significantly, and the bandwidth will increase significantly when the sound absorption coefficient is greater than 0.5, but the maximum sound absorption coefficient will decrease to a certain extent.

4. Only increase the plate thickness t, the resonance frequency of the micro-perforated plate sound absorber will shift to low frequencies, and the sound absorption bandwidth will be significantly reduced. At this time, the maximum sound absorption coefficient can be maintained at a higher level.

Introduce a space-coling structure into the back cavity of the MPP sound absorber to form honeycomb-MPP sandwich structure. With a thickness of 20 mm, it close to perfect sound absorption (0.96) for low-frequency noise at 335 Hz. Compared with the ordinary micro-perforated plate honeycomb structure, both the sound absorption frequency and the maximum sound absorption coefficient have been significantly improved, and reach the expected design goal.

# 4. LABOR PROTECTION

With the improvement of laws and regulations, public safety awareness continues to increase, strengthening labor protection, improving working conditions, and safeguarding labor rights have become key issues of concern. This work is based on theoretical research and computer simulation. The workplace is located in the laboratory of the National Aviation University. All research and investigations must be carried out under safe conditions. This chapter will consider the safe operation of the laboratory and the labor protection of the operators under this condition.

## 4.1 Analysis of workplace conditions

According to the Hygienic standards of GN 08.04.2014 № 248 «Hygienic classification of labor (according to indicators of harmfulness and danger of factors of the production environment, severity and intensity of the labor process) »， Working conditions are divided into four classes according to working environment, labor intensity and risk:[62]

Class 1 is optimal working conditions. Under such working conditions, not only the health of workers can be protected, but also conditions are created for workers to maintain high efficiency. The best health standards for production factors are set for the microclimate and labor process factors.

Class 2 is allowable working conditions. The characteristics of this working condition are that the factors of the production environment and the labor process do not exceed the established health standards, and the potential changes in the worker's physical function are restored after regular breaks, and it will not adversely affect the health of workers and their offspring in the short and long term.

Class 3 is harmful working conditions. Under this working condition, the level of harmful production factors exceeds the health standard, which may adversely affect the health of workers and even their offspring. Harmful working conditions can be divided into 4 levels according to the degree of exceeding the health standard and the severity of possible changes in the worker's body.

Class 4 is dangerous working conditions. Its characteristic is that the level of harmful factors in the production environment and labor process is quite high. The dangerous factors and adverse effects in the workplace pose a serious threat to the lives of workers during shifts, and has a huge risk of occupational injury.

The laboratory where is the workplace completed this work is shown in Figure 4.1. For the area of the workplace is approximately $40m^2$ and volume of the workplace is 120 $m^3$. The laboratory consists of computer workstations, meeting rooms, laser projectors, teaching equipment for aircraft parts and fire test chambers.

Figure 4.1. Schematic diagram of workplace

### 4.2 Characteristics of dangerous and harmful factors

From the Hygienic standards of GN 08.04.2014 № 248, production factors can be divided into dangerous factors and harmful factors according to their impact on humans. Dangerous production factors refer to production factors that may cause injury or death of workers. Harmful production factors refer to the environment or labor process that contains such production factors. Under certain working intensity and working hours, it will cause occupational diseases, temporary or permanent decrease in efficiency, and increase the probability and risk of physical diseases.

The dangerous and harmful production factors can be roughly divided into the following four categories, physical factors, chemical factors, biological factors and factors in the labor process. According to the actual situation of the laboratory workplace, this chapter mainly considers the following 3 hazardous production factors which are non-ionizing electric radiation, insufficient lighting and electric injuries.

**Non-ionizing electric radiation**

Non-ionizing radiation is also called electromagnetic radiation. As the name implies, radiation that does not cause material ionization, such as electromagnetic waves with a frequency between 0 and 300 GHz. In the laboratory, the electromagnetic radiation generated by the electronic equipment, whether it is a computer, or laboratory equipment and lighting source, is non-ionizing radiation. Non-ionizing radiation accelerates the movement of molecules and produces a thermal effect, which heats up the object. But non-ionizing radiation will not kill cells or damage DNA. Under normal conditions, the radiation intensity of computer monitors and system units is extremely low, but attention should be paid to controlling the operating power, the duration of exposure to radiation, and the distance from the radiation source. It should also be noted that some non-ionizing electromagnetic radiation will induce currents in surrounding conductors, such as radio frequency radiation generated by computers and experimental equipment, which may cause other objects to generate such induced currents.

**Lighting limitations**

According to the form of light, it can be classified into artificial light or natural light, and according to the nature of light, it can be divided into direct light and scattered light. When natural light is insufficient, artificial light sources are required to re-light. If there is insufficient light, it is easy to mishandled it, resulting in more serious accidents. Glare, color rendering, color temperature and brightness will affect the physiological and psychological conditions of the staff, laboratory lighting to be uniform, horizontal illumination than vertical luminosity value is higher, to ensure that the eye's need for light. If the relative brightness of the work area is too strong, people's attention is easy not to concentrate, if the brightness is too weak, it is easy to cause visual fatigue, for the larger area of laboratory lighting, the brightness distribution is uneven, easy to cause visual fatigue, and the brightness is too uniform and appear to work environment rigid. Glare will affect people's vision, resulting in visual fatigue, thus affecting the work efficiency of workers, to avoid direct glare. Insufficient lighting, but also prone to negative emotions, lighting conditions will also affect the person's melatonin secretion, indirectly affecting the sleep quality of workers.

**Electric injuries**

Because there are many electrical equipments in the laboratory, the electric shock caused by accidental contact with the power supply should be considered. The human body has good conductivity, which means that the current can easily pass through the human body. Direct contact with electric current can be fatal. Although some electrical burns may seem small, there may still be serious internal injuries, especially to the heart, muscles, or brain.

Electricity can cause damage in four ways:

1. Electric current affects the heart and causes cardiac arrest;
2. The destruction of muscles, nerves, and tissues when the current passes through the human body;
3. Thermal burns caused by contact with the power supply;
4. Falling and injured after electric shock.

## 4.3 Measures to ensure safe working conditions

Pay attention to the arrangement of office electrical appliances in the laboratory, and do not place them in a centralized manner. Especially some electrical appliances that easily generate electromagnetic waves, such as computers, monitors, etc.. Pay attention to the time when using office appliances. All kinds of electrical equipment should try not to run for a long time, and avoid multiple electrical appliances from starting at the same time. It is best to install a computer anti-radiation screen made of lead glass.Keep the distance between the human body and electrical appliances. The distance of the fluorescent lamp should be 2-3 meters, and the distance of the computer should be more than 0.6m. When electrical appliances are not in use, it is best not to keep them in a standby state, because weak electromagnetic fields can be generated at this time, and radiation accumulation will also occur for a long time.

Routine laboratories should consider ensuring sufficient illuminance, and the general test area should not be less than 300Lx.The glare in the laboratory mainly comes from direct glare and reflected glare. For the light source in the field of view, some shading devices can be added to the lamp to achieve the purpose of anti-glare. Reflected glare is mainly caused by display screens, floor tiles, glass and other highly reflective materials. In order to avoid reflected glare, the relative positions of people, light sources and reflective surfaces should be considered in the indoor arrangement.In the experimental area, in addition to normal work lighting, emergency lighting should be considered. In order not to affect personal safety, emergency lighting should not be less than 50Lx, and the emergency time should not be less than 30min. Emergency lighting is easy to use decentralized emergency power supply, and emergency lighting with internal batteries and inverter modules can be used.

Keep away from power sockets, power cords, electrical appliances or exposed parts of wires, and try to avoid accidental contact.Electrical appliances should be used in strict accordance with the requirements of the instructions, and electrical equipment of qualified quality should be purchased.Turn off the switch when checking and repairing electrical appliances. If it is necessary to operate with electricity, special tools and professional operation are required.

### 4.4 Fire safety of the production facilities

In recent years, university laboratory fire accidents occur frequently, so it is of great practical significance to prevent fire, extinguishing fires in the correct way and escape in a correct way to reduce the loss of human life and property. The laboratory may cause a fire due to short circuit or overheating of computer. In DSTU EN 2: 2014 «Fire Classification», fires are divided into 4 classes according to different combustible materials[63]:

Class A - fires are accompanied by the burning of solid materials, usually of organic origin, during the combustion of which usually form embers;

Class B - fires are accompanied by the burning of liquids or solids that turn into a liquid state;

Class C - fires are accompanied by burning gases;

Class D - fires are accompanied by burning metals;

Class F - fires are accompanied by the burning of substances used for cooking (vegetable and animal oils and fats) and contained in kitchen appliances.

The main burning objects in my laboratory are computer workstations, so the fire types are class A and class D. Based on this situation, the laboratory should be equipped with dry powder fire extinguishers and carbon dioxide fire extinguishers. A 2kg dry powder fire extinguisher can cover an area of about 75 square meters. The placement of the fire extinguisher must be obvious, and there must be obvious signs, preferably fluorescent signs, etc. Of course, it cannot affect the evacuation channel. The fire extinguisher can be hung on the wall, but not hung too high, generally no more than 1.5 meters, or it can be placed in a extinguisher cabinet on the ground. The extinguisher cabinet should not be locked, but can be used immediately. Fire extinguishers need to be checked regularly by someone in the laboratory. It should be replaced immediately if expired.

The laboratory can choose electrical fire monitoring detectors, which have both monitoring and detection functions, integrating signal detection, operation display and sound and light alarms, and can communicate with the central monitoring host in real time. General installation principles of automatic alarms:

1. The horizontal distance between the detector and the wall and beam side should not be less than 0.5m.

2. There should be no obstructions within 0.5m of the horizontal distance around the detector.

3. The closest horizontal distance between the detector and the air outlet of the air conditioner should not be less than 1.5m.

4. The installation distance of point-type temperature-sensitive fire detectors should not exceed 10m. The installation distance of point-type smoke detectors should not exceed 15m.

5. The detector should be installed horizontally. When it is necessary to install it at an angle, the inclination angle should not be greater than 45°.

In addition to the proper use of fire extinguishers, there are also emergency escape routes familiar with the laboratory. When a fire breaks out, evacuate to the escape channel immediately. If there is an announcement, listen carefully and follow the evacuation route and precautions as directed by the announcement. If there is no broadcast or personnel guidance for evacuation, the nearest safe passage directly to the outside of the building should be selected for evacuation, so as to escape to the ground outside the burning building is the safest. The escape route of the laboratory is shown in Figure 4.2.


Figure 4.2. Emergency escape route from the laboratory

When the fire cannot be controlled and an emergency evacuation is required, the first thing to do is to maintain a good attitude. Under the abnormal circumstances of sudden fire, most people panic due to the emergence of smoke and fire, which is the most fatal weakness. Maintaining a calm mind is very important to prevent tragedies. In case of fire, maintaining psychological stability is an important prerequisite for escape. If you can stay calm in the face of danger, first observe the fire, then decide the escape method, and use the learned refuge knowledge to minimize the disaster loss. And then find the safety passage and evacuation passage to escape. After the fire, quickly find the fire passage and run downstairs (the elevator must have been blocked). If there is smoke spreading, you should lower your body position and move quickly. Never move upstairs, because most of the roof terraces are locked, increasing the difficulty of rescue. It is worth noting that after the fire starts to spread, do not open the doors and windows of the room casually, because when the doors and windows of the room are closed tightly, the air is not smooth and the indoor oxygen supply is insufficient. Therefore, the fire develops very slowly. Once the doors and windows were opened, fresh air poured in and the fire developed rapidly. At the same time, due to the convection of the air, the flame will burst out.

Experimental fire safety is a complex disaster prevention and control system that integrates prevention, management, publicity, exercises, and disposal. It needs the cooperation of supporting facilities and management personnel to maintain normal operation. In order to avoid the occurrence of catastrophic accidents caused by the laboratory, workers are required to have sufficient mental preparation and contingency measures to do pre-accident prevention work and post-accident remedial work to ensure the safe and stable operation of the laboratory. Once an accident occurs, it can be dealt with in a scientific and effective manner, effectively reducing and controlling the hazards of safety accidents, and minimizing losses.

Figure 4.3 shows the laboratory fire emergency evacuation plan diagram, the diagram can clearly see the exit, fire hydrant, fire extinguishers, and the location of the call, for in an emergency evacuation well prepared and plan, the figure also identifies the plane structure of the floor where the laboratory is located, planning the escape route and making the evacuation plan.


Figure 4.3 Fire emergency evacuation plan

### 4.5 Calculation of natural lighting office space

According to «Natural and artificial lighting» DBN B.2.5-28-2018., approximate calculation of the lamp area required by the laboratory[64].

The calculation formula for the side lighting of the room is as follows

$$S_v = \frac{D_H}{100m} \cdot \frac{K_z \eta_v K_b}{\tau_0 r_1}$$

The calculation formula for the top lighting of the room is as follows

$$S_l = \frac{D_H}{100m} \cdot \frac{K_z \eta_l}{\tau_0 r_2 K_l} \cdot S_P$$

Where $S_v$ and $S_l$ refers to the side and top light area, $S_P$ is construction area, m is the light climate index, $\eta_v$ and $\eta_l$ refers to coefficient of the light activity of the windows and lanterns, $K_l$ is lantern type coefficient, $\tau_0$ is the total light trasmittance.

**Conclusion**

This chapter mainly introduces labor protection in the workplace. Analyze the harmful and dangerous factors of workers in the workplace, improve the lighting, radiation, electric shock and other elements of the working environment, and ensure the safe operation of the laboratory and the health of the workers. It also evaluates and analyzes potential fire risks in the workplace, and determines fire-fighting measures and emergency escape routes.

# 5. ENVIRONMENTAL PROTECTION

## 5.1 ICAO requirements towards aircraft noise impact into environment

The International Civil Aviation Organization (ICAO), headquartered in Montreal, Canada, is a specialized and funding agency of the United Nations formally established in accordance with The International Civil Aviation Covenant in 1947. At present, ICAO has 193 member states and in charge of the governance and elaboration of worldwide civil aviation affairs. Its purpose is to formulate the principles and technologies of global navigation, promote the planning and improvement of international air transport, and assure the standardized and efficient operation of international civil aviation.

ICAO serves as a multilateral platform for cooperation on international aviation environmental protection. For many years, ICAO member states have concentrated their cooperation on aviation environmental protection in three core areas, where aircraft noise is the most important cause of adverse community reactions related to airport operations and expansion. It is expected that this situation will continue to be maintained in most parts of the world for a long time in the future. Therefore, the most important task of ICAO at present is to limit or reduce the number of people severely affected by aviation noise, which is also one of ICAO’s pivotal environmental goals. The Committee on Aviation Environmental Protection (CAEP) deals with the main environmental issues related to civil aviation, that is, the impact of aircraft noise and aircraft engine emissions. The guiding principles of its work are technically feasible, economical and reasonable, and beneficial to the environment. The ICAO's standards and recommended practices for environmental protection (SARPs) are listed in Annex 16 of the Convention on International Civil Aviation. For this purpose, aircraft noise provisions appear in Volume I of Annex 16 [65]. This document contains certification standards and recommended schemes for the qualification of the noise generated by aviation aircraft during operation. It is applicable to some specific aircraft classes used in international traffic to a certain extent. This document also contains two parts of international specifications, namely noise measurement during aircraft operation and corresponding noise assessment methods.

ICAO Annex 16 provides noise limits, measurement, and evaluation requirements for various types of aircraft. According to the different ages and types of aircraft production, different requirements for noise limits are given, and the noise limits for different stages of aircraft are compared with the noise of corresponding aircraft types. In addition to aircraft certification recommendations for noise and recommendations for measuring and monitoring noise, Annex 16 Volume 1 also provides detailed guidance on noise assessment during certification and detailed instructions for noise monitoring at airports and nearby aircraft in its appendices. Including various aircraft noise limits and measurement and assessment requirements, according to the age and type of aircraft production, different noise limit requirements are given, the aircraft noise limits at different stages and the noise comparison of corresponding models.

In the past 40 years, ICAO has been working hard to solve the problem of environmental pollution caused by aircraft noise. The aircraft and helicopters currently manufactured must comply with the noise certification standards adopted by the ICAO Council, which aims to reduce noise from noise sources level. These are included in ICAO Annex 16. The first-generation jet airplanes do not have to implement Annex 16, so they are called noise-free certified airplanes. The jet aircraft designed before 1977 is the Annex 16 chapter 2. After 1977, the requirements of Annex 16 chapter 3 aircraft must be met. In June 2001, on the basis of the recommendations made at the fifth meeting of the Aviation Environmental Protection Committee, the Security Council passed a new chapte 4 noise standard, which is more stringent than the chapte 3. From January 1, 2006, the new standard became applicable to newly certified aircraft and required recertification of chapte 4 aircraft. If an airworthiness certificate is applied for after January 1, 2006, such aircraft must also meet the chapter 4 noise requirements. Therefore, the ICAO mode is generally to issue noise certificates for aircraft. The issuance of certificates not only evaluates the acoustic characteristics of the aircraft at the stage of applying for a type certificate, but also checks the maintenance and modification records, so that the noise characteristics of the aircraft can be found to change during the entire course of use.

**Noise Standards for jet and large propeller airplanes**

In the 1969 meeting, the content of the "Special Meeting on Aircraft Noise Near Airports" was discussed and recommendations were made. In 1972, the draft international aircraft noise standards and recommended measures were formulated and put into application in major companies. These set standards define the three reference measurement points for noise certification, and the noise limit is also set as a direct function of the maximum take-off mass (MTOM). The acquisition of this function is also used to determine the Heavy-duty aircraft with transport capacity will produce more noise during operation than light-duty aircraft with low transport capacity. This is the Chapter 2 noise standard contained in Annex 16, Volume I.

High bypass ratio jet engines that can reduce engine noise were put into use, which made the ICAO noise standard more stringent in 1977. With the application of more advanced aviation noise reduction technologies, aircraft noise performance has been improved, which has resulted in more stringent of  the noise standards contained in Annex 16, Volume I, Chapter 4.

In 2014, ICAO Council adopted a new Annex 16, Vol I, Chapter 14 noise standard for jet and propeller-driven aeroplanes, which involving an increase in stringency of 7 EPNdB (cumulative) relative to the last Chapter 4 levels. The International Civil Aviation Organization has issued band-new and stricter standards for the noise of subsonic jets and propeller aircraft. These standards will become the most important standards in the future.

**Noise Standards for light propeller airplanes**

In 1974, the standards for noise generated by light propeller aircraft were included in Annex 16 for the first time. So far, these regulations and standards have been added to Chapter 10 of Volume 1 of Annex 16. This noise standard is limited to the maximum certified takeoff mass not exceeding 8,618 kg.

**Noise Standards for helicopters and tiltrotors**

The standards and regulations for helicopter noise were listed in Annex 16 in 1981, which was the first time in history. Up to now, the standards for helicopter noise are in Chapters 8 and 11 of Volume I of Annex 16. The standards contained in Chapter 8 apply to all current types of helicopters; Chapter 11 provides an alternative and simplified certification procedure, but only applies to light helicopters with a maximum certified take-off mass of 3,175 kg or less.

### Noise Standards for Supersonics

At present, Annex 16 Volume I only includes the noise standards for supersonic aircraft for type certificate applications submitted before 46 years ago, but these supersonic aircraft have now all withdrawn from the civilian market. As Boom Supersonic's new-generation aircraft "overture" is about to be put into operation, work is ongoing in ICAO to develop new noise standards for supersonics. The Airport Council International (ACI) believes that it is indeed necessary to strengthen research on such aircraft and conduct aviation noise-related regulations.

### Noise Standards for UAVs

Unmanned aerial vehicles (UAVs) are one of the aviation sectors that have seen rapid growth in their utilization rate and concentrated expression of advanced technology in the near future. In the long run, UAVs have a wide range of applications. At present, the ICAO is still closely tracking the development of the industry and has not issued relevant regulations to restrict UAVs. However, due to inconsistent perceptions, the public and community's acceptance of this technology varies from person to person or to the use of UAVs. For UAVs used for public utilities, such as emergency rescue and disaster relief, the public generally expresses that they can tolerate their noise, while the noise generated by entertainment UAVs that are used for social benefits may not be acceptable. Generally, heavier and larger industrial UAVs will generate more noise, so it can be predicted that in the future, the public will pay more attention to the international noise standards when large passenger UAVs operate in urban areas.

## 5.2 The ways how to reduce noise impact in the vicinity of the airport

In September 2001, the ICAO submitted a "Balanced Approach" that can manage aircraft noise around airports, also known as Resolution A33-7. This Balanced Approach is defined as a plan to solve aircraft noise at the level of a single airport. The creators considered four key elements. These four elements are used to effectively reduce aircraft noise without affecting safety standards:

- Reduction of noise at source.

  This includes the use of quieter aircraft and the implementation of noise control measures on the propulsion system, wings and landing gear of existing aircraft fleets. ICAO Annex 16 stipulates that there are various aircraft noise limits and measurement and assessment requirements. According to the age and type of aircraft production, different noise limit requirements are given, the aircraft noise limits at different stages of aircraft are compared with the noise of corresponding aircraft types. Gradually eliminate high-noise aircraft in airport operations, and consider aircraft noise as an important indicator in the aircraft design and manufacturing stage. The development of new low-noise aircraft can reduce aircraft noise from the source and reduce the impact of aircraft noise on the surrounding environment.

- Land use planning and management.

  Land use planning is one of the effective measures to ensure that activities close to the airport meet aviation requirements. Its main purpose is to minimize the size of the population affected by aircraft noise by introducing land use zoning. Appropriate land use planning and management are also guaranteed by reducing the latest An extremely important means that the gains from the noise of a generation of aircraft are not offset by the further development of residential areas around the airport. Newly built or expanded airports should pass a systematic noise risk assessment. On the basis of the noise risk assessment framework, combined with land planning and urban planning, the impact of noise on the surrounding area should be reduced at the airport site selection stage. South Korea's Incheon International Airport divides the land around the airport into three levels, namely, the airport protection zone, the restricted construction zone, and the development and construction zone. Similarly, the Japanese government requires that the new airport should be built on the sea as much as possible, and it can also be built in the area around the airport where the land use control has been planned. Through the rational planning of land around the airport, the land planning of residence and school, which are incompatible with aircraft noise, should be far away from the area affected by aircraft noise, while the land use of heavy equipment manufacturing and bonded areas, which are compatible with aircraft noise, should be arranged around the airport. According to the relevant regulations of the state environmental protection administration of China, “the area around the airport where the aircraft noise is greater than 75dB (WECPNL) shall not be planned to build new houses, schools, kindergartens, hospitals and other noise-sensitive buildings.

- Noise abatement operational procedures.

Regarding the airport noise reduction operating procedures, there are mainly two methods, one is the technology of optimizing flight procedures, and the other is the adjustment of the airport's operating mechanism.

In an ideal situation, after the airplane climbs to the optimal cruising altitude, it will stay at that altitude as much as possible until it needs to land. But in reality, the aircraft must coordinate with ATC, which often interrupt climbing and descending with level-offs and turns, forcing them to spend more time at lower altitudes. When the flight altitude is low and accompanied by frequent thrust changes, the ground is severely affected by noise. Noise abatement operational procedures currently inculding take-off and approach phases. Using Continuous Descent Approach (CDA) begins to descend at the cruising altitude, the aircraft flies its respective best vertical profile to the entrance. Compared with other traditional descent systems, it can reduce fuel consumption and noise. These operations have been variously known as, Continuous Descent Arrivals, Optimized Profile Descents, Tailored Arrivals, 3D Path Arrival Managementand Continuous Descent Operations. [66]

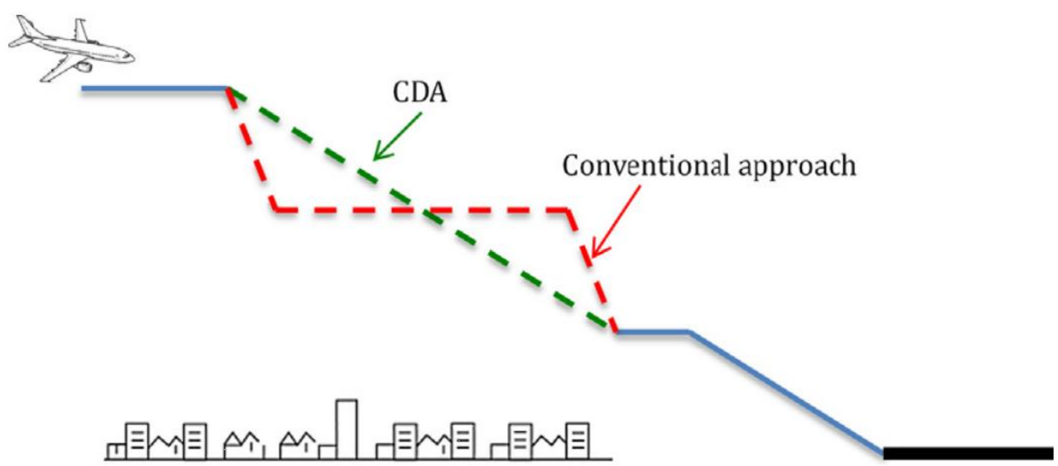


Figure.5.1. CDA vs. conventional approach[66]

CDA (see Figure.5.1) allows the aircraft allows a smooth, constant-angle descent and landing instead of in a staircase style. The noise abatement operational procedures also take into account the climb phase of the flight. Noise Abatement Departure Procedures (NADPs) can effectively reduce takeoff and landing noise, which are the ICAO noise abatement take-off climb procedures [67].

There are three main ways to adjust the airport's operating mechanism: Firstly, the adjustment of aircraft take-off and landing periods. Usually the impact of aircraft noise at night will reach the extreme, followed by the evening, and the smallest during the day. Secondly, optimize the runway utilization plan, alternate the use of various runways, and develop different runway use plans, each set for different goals, in order to reduce the frequency of use of specific runways and reduce the noise impact on specific areas. Finally, isolate the aircraft maintenance test site in the airport and use noise silencing devices to reduce noise. For example, MacArthur Airport has installed sound absorbing devices.

- Operating restrictions on aircraft.

  Operational restrictions refer to management measures such as restricting or prohibiting high-noise aircraft from taking off and landing at airports, restricting or prohibiting the use of runways with high noise impact, restrictions on aircraft operation periods, and flight restrictions (such as restrictions on the number of take-offs and landings within a day) to reduce aircraft nosie polution. There is a positive correlation between the number of aircraft takeoffs and landings and the impact of noise. Therefore, starting from the number of aircraft takeoffs and landings, some airports have strictly controlled the number of aircraft inbound and outbound flights. However, under normal circumstances, airports are unwilling to reduce the number of aircraft takeoffs and landings as a means to reduce the impact of noise, because considering their own economic interests, the airport hopes to increase the number of aircraft takeoffs and landings as much as possible with capacity permitting. Due to the difference in background sound, the noise at night is more obvious than during the day. It can be seen that the aviation noise at night has a significant impact on residents near the airport. Therefore, it is necessary to properly control the operation of aircraft at night, and even completely prohibit the airport from taking off and landing at night. The night curfew policy is operation on many airports in the world, but there are big differences in specific practices. In some airports, planes are completely forbidden to take off and land, and runways are closed; while in other airports, low-noise propeller planes are allowed to take off and land. Although curfew can effectively reduce noise interference at night, it also has side effects, for example, aircraft will queue for too long on the ground during peak hours, airlines choose other airport in the airport income decrease, because the time difference makes long-range flight departure time arrangement difficult.

According to “Balanced Approach”, More measures to alleviate the impact of airport noise have been put into practice, One further study found that different measures for noise reduction are used at different airports[68]:

1. Noise Abatement Procedures –including departure and arrival flight trajectories and optimized flight technology.
2. Preferential Runways – refers to when weather and safety conditions permit, try to take off and land from multiple runways instead of on the same runway, so as to reduce the impact on nearby residents.
3. Engine Operate Restrictions – refers to the restrictions on the engine testing on the ground and “reverse thrust” in landing.
4. Noise Charges – refers to the additional compensation for airlines whose aircraft exceed the acceptable noise level.
5. Noise Level Limits – refers to that exceeding a certain allowable appreciation of the noise monitoring system will result in additional fees being charged to the airline as a fine.
6. APU Restrictions – refers to restricting or prohibiting the use of Auxiliary Power Unit (APU) on the ground, implementing mobile Ground Power Units instead of APU.
7. Airport Curfews – refers to certain or all types of aircraft that are not allowed to take off or landing for a particular period of time (usually at night or on weekends)

8. Noise Budget Restrictions – the meaning is allowable amount of noise for each take-off and landing is allocated based on the total annual approved noise and the number of annual flight operations.
9. ICAO Annex 16 Chapter 3/Chapter 2 Restrictions –refers to the prohibition of taking off and landing on aircraft that comply with these Chapters certifications.
10. Buildings sound Insulation – refers the use of active or passive sound absorption and insulation methods (sound-absorbing cotton, sound insulation barriers, etc.) for buildings within the scope of airport noise influence to achieve the purpose of noise control.
11. Operating Quotas – refers to the number of commercial operations selected each year and the restrictions on flights in and out of ports during peak hours.
12. Laws Guarantee – There are many laws to protect the rights of airport operators and nearby residents, such as zoning laws, overflight easements property and disclosure laws etc..

## Conclusion

As seen from the above that ICAO has strict regulations and restrictions on aircraft noise, and with the advancement of technology and increased awareness of environmental protection, ICAO has a trend of further raising noise emission standards. At present, most of the mainstream noise reduction measures in the vicinity of the airports are based on the “Balanced Approach” proposed by ICAO. In actual airport operations, the combined use of various measures will produce better noise control effects.

# GENERAL CONCLUSION

Aircraft noise, as a problem that cannot be ignored, has always been an important focus of researchers from various countries. This work starts with aircraft noise sources and analyzes the main noise sources of aircraft and the corresponding noise reduction methods.

Among them, the honeycomb sandwich panel structure is not only widely used in aerospace fields such as fuselages, wings, fairings, etc., is also used as sound insulation components in sound insulation and noise reduction designs. In order to pursue a honeycomb sandwich structure with better acoustic performance, a honeycomb-MPP composite structure with sound absorption and sound insulation performance can be designed. However, most of the honeycomb-MPP structure needs a large thickness when dealing with low-frequency noise, and it is difficult to meet the strict size requirements and demanding weight requirements of the aircraft. Therefore, this work uses a thin honeycomb-MPP structure with low-frequency sound absorption capability. For the design goals, relevant researches were carried out from the aspects of structural design, theoretical derivation, and simulation analysis.

The main research contents and innovations of this work are as follows. First, the main noise sources of aircraft are systematically discussed. The noise reduction methods are mainly divided into automatic noise reduction and passive noise reduction. Through literature review, the international mainstream noise reduction methods are introduced in detail. Among them, the passive noise reduction technology The structure of the honeycomb micro-perforated plate has the characteristics of simple structure and lightweight. Acoustic metamaterials are the current research hotspot, and the combination of the two may provide an effective solution.

Secondly, the theoretical derivation and simulation of the structure of the micro-perforated panel are carried out, and the sound absorption coefficient of the micro-perforated panel is calculated using the acoustic-electric analogy. Using COMSOL Multiphysics to simulate and calculate the sound absorption coefficients of different structural parameters of the micro-perforated panel, through comparative analysis results, it is found that the low-frequency sound absorption performance can be effectively increased by changing the depth of the back cavity.

Finally, through the design of the honeycomb core of the honeycomb-MPP structure, split rings are introduced to form a space-coling structure, which effectively increases the depth of the back cavity. It is known from the simulation results that the honeycomb-MPP structure within space-coiling is close to perfect sound absorption for low-frequency noise at 335 Hz with thickness at 20mm, and satisfy the expected goal and realize the initial idea of the design.

This work mainly studies the thin and light honeycomb-microperforated plate structure with low-frequency sound absorption performance and has achieved some meaningful research results, but there is still a lot of work to continue in-depth research:

1. The structural parameters of split rings can be studied, such as the influence of changing the wall thickness, the distance between the rings, the number of layers, the radius, the opening angle, etc. on the sound absorption coefficient.

2. In view of the current narrow sound absorption bandwidth of the honeycomb-MPP structure within space-coiling, the opening direction of the split ring can be adjusted to make the sound wave transmission path inconsistent and broaden the sound absorption bandwidth.

3. The the honeycomb-MPP structure within space-coiling can further broaden the sound absorption bandwidth and increase the sound absorption performance by installing double-layer micro-perforated panels.

4. For the honeycomb-MPP structure, further experiments on its mechanical properties can be carried out. Compressive tests prove that it has excellent sound absorption performance with good mechanical properties, and can meet the structural strength used in the field of aircraft equipment.

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