A STUDY OF DAMAR MINYAK AND SERAYA AS MATERIAL FOR GAMBUS JOHOR SOUNDBOARD

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ABSTRACT

Wood is the best material for chordophones instrument's soundboard, and among all wood species, European Spruce is of the highest quality in terms of acoustical properties according to western scholars and most musical instrument makers. Although spruce does not exist in Malaysia, there are several softwoods in Malaysia having physical and mechanical properties that are similar to the European spruce and one of them is the *damar minyak*. In addition to this, according to local *gambus* makers, *seraya* has been identified as one of the best and most preferable wood (material) for soundboard. Therefore, *damar minyak* and *seraya* have been selected as study material in the production of the *gambus Johor* soundboard.

The primary purpose of this study is to apply a scientific approach in identifying the acoustical properties of *damar minyak* and *seraya* according to its physical and mechanical properties. The approach was focused on the speed of sound through wood, characteristic impedance and sound radiation coefficient. The data complied from these elements were used to compute the acoustic formula which objectively aims to identify the potential of wood without using the trial and error method. Then, two *gambus* instruments were constructed with selected *damar minyak* and *seraya* for each soundboard. The *gambus* production process was also documented to serve as future reference and guideline in the production of *gambus*. Finally, the two *gambus* were played (demonstrated) and questionnaires were distributed to the ethnomusicologist, *gambus* makers, *gambus* players and *gambus* students in order to analyse and prove the acoustical quality and sound characteristic of *damar minyak* and *seraya* as *gambus Johor's* soundboards.

ABSTRAK

Kayu adalah bahan terbaik untuk papan suara alat muzik kordofon, dan di antara semua spesies kayu, *Spruce* Eropah adalah berkualiti tinggi dari aspek akustik menurut sarjana barat dan pembuat instrumen alat muzik. Walaupun *spruce* tidak wujud di Malaysia, kita masih mempunyai beberapa kayu kategori kayu lembut di Malaysia yang sifat-sifat fizikal dan mekanikalnya adalah sangat hampir sama dengan *spruce* Eropah dan salah satu daripadanya adalah damar minyak. Menurut kebanyakan pembuat gambus tempatan, seraya adalah salah satu kayu yang terbaik untuk dijadikan papan suara. Oleh itu, damar minyak dan seraya akan dikaji sebagai bahan untuk papan suara gambus Johor.

Tujuan utama kajian ini adalah untuk menjalankan pendekatan saintifik dalam mengenal pasti ciri-ciri akustik yang ada pada damar minyak dan seraya berdasarkan sifat-sifat fizikal dan mekanikal. Pendekatan ini memberi tumpuan kepada kadar kelajuan bunyi melalui kayu, ciri galangan dan pekali radiasi bunyi. Semua data ini digunakan dalam pengiraan formula akustik yang objektifnya untuk mengenal pasti potensi kayu tanpa menggunakan kaedah 'cuba jaya'. Kemudian, dua gambus dibuat menggunakan damar minyak dan seraya pada bahagian papan suaranya. Semua proses pembuatan didokumentasikan untuk rujukan masa depan sebagai satu garisan panduan dalam proses pembuatan gambus. Akhirnya, kedua-dua gambus dimainkan (demonstrasi) dan soal selidik diedarkan kepada ethnomuzikologi, pembuat gambus, pemain gambus dan pelajar gambus dan hasilnya dianalisa untuk membuktikan kualiti akustik damar minyak dan seraya sebagai papan suara gambus Johor.

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CHAPTER 1: INTRODUCTION

1.1 Introduction

The *gambus* is a traditional musical instrument of Malaysia. Generally, there are two types of *gambus* that exist among the Malays since the 15th century, namely *gambus Melayu* and *gambus Hadhramaut* (Anis, 1993). It is believed that the *gambus* was brought into *Tanah Melayu* by Arabs during the Islamisation of Malacca (Ibid.). Since then, both of these *gambus* have been used in *Zapin* and *Ghazal* music. Generation after generation, local people began to make their own *gambus* using local timbers (Malaysian wood) such as *seraya*, *jati*, *halban*, *koko* and *durian*. However, *gambus* makers never used a standard method in making *gambus* and always depended on 'trial and error' for materials (wood) selection. Most of the time, the quality of the *gambus* sound was affected by this 'by heart' method.

As a *gambus* maker himself, the researcher realised that the materials (Malaysian timbers), the method of making *gambus* and sound quality of *gambus* have never been studied before hence seeking to answer three questions: 1) do local timbers have great potential as *gambus* material in terms of acoustical quality? Second, what is the process of making *gambus* that should be followed by local *gambus* makers as a standard method in order to achieve and produce a better quality *gambus*? Lastly, what is the sound quality and sound characteristic that can be produced by the *gambus* made from Malaysian wood? It is important to state that the research focus is only on *gambus Johor.* The purpose of this chapter is to present an outline of the thesis and the approach to answering the questions. The chapter proceeds by giving some background necessary to build an understanding of the issues that will be discussed.

1.2 Background to the Study

The purpose of this thesis is to perform a study on the materials (Malaysian wood) specifically on the *gambus Johor's* soundboard. Identification on several aspects of the material will be conducted followed by full construction of *gambus Johor*. Finally, a playing demonstration of the *gambus* will be carried out in order to identify the tone quality and sound characteristic

Therefore, as a background to this study, some related topics that will be discussed include *gambus* and the diversity of Malaysian woods.

1.2.1 Gambus

The '*gambus'* or *'qanbus'*, an Arabic word is believed to get its name from the Turkic long-neck lute, *kopuz* (Sachs, 1940). It shows that *gambus* originated from the Arab world and was brought by the Arabs to the *Alam Melayu* in the 15th century (Anis, 1993). In Malaysia, there are we two types of *gambus* namely, *gambus Melayu* and *gambus Hadhramaut.*

1.2.1.1 Gambus Melayu

Gambus Melayu also goes by other names according to the local Malays such as *seludang, perahu, biawak, hijaz and gambus Palembang* (Hilarian, 2005). The *gambus Melayu* is probably a musical instrument that can only be found in Sumatra, the Riau islands, Kalimantan, Sulawesi of Indonesia, Brunei, Singapore, Johor in Peninsula Malaysia and the coastal areas of Sabah and Sarawak (Hilarian, 2005). The term 'M*elayu'* means ethnic Malays that live in the area which include the Malay Peninsula, the coastal areas of Sumatera, southern Thailand, south coast of Burma, Singapore, coastal areas of Borneo and the smaller islands between these areas (Milner, 2010; Benjamin & Chou, 2002). Hilarian also stated that the *gambus Melayu* is skin-bellied, lesser strings, pear-shaped, slimmer and smaller compared to the *gambus Hadhramaut* or *gambus Johor* (2005).

1.2.1.2 Gambus Johor

Gambus Hadhramaut is also known by the local people as *gambus Johor.* It was named *gambus Johor* because it was made by a local luthier in Johor and it has always been used in *zapin* and *ghazal* music of Johor. Anis (2005) states that g*ambus Hadhramaut* originates from the valley of Hadhramaut which is known nowadays as Yemen. It has a bowl-back body, a fingerboard, short neck, back-bent peg-box and the physical structure is similar to the classical Arabian lute called '*al-ud*' (Hilarian, 2005). Figure 1.1 shows the exterior design of *gambus* Johor.

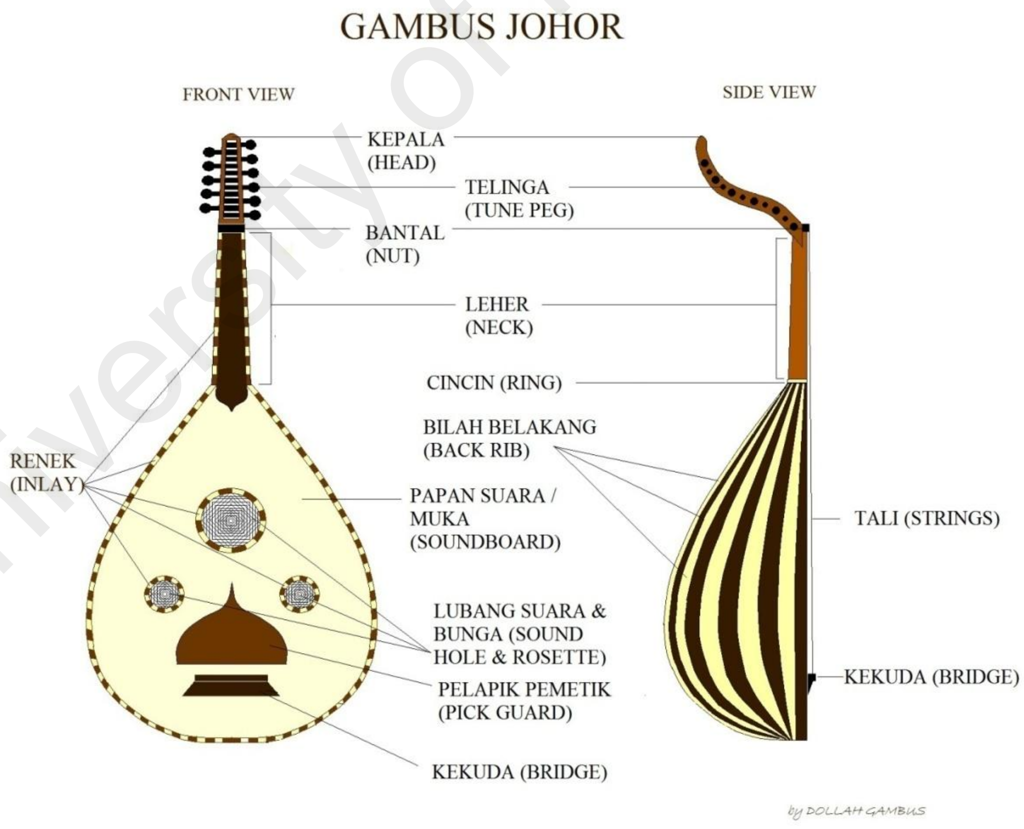


Figure 1.1: Font and side view of *gambus Johor*

Gambus Melayu and *gambus Johor* are very important in the culture of Malaysia especially in Johor. They both play the role as main instruments in *zapin* and *ghazal,* but has never been played together in the same ensemble. In *zapin, gambus* is the lead instrument which means it is the most important musical instrument on the ensemble. Now, some *gambus* makers still make *gambus Johor* because it is still used by local musicians. They tend to play *gambus Johor* instead of *gambus Melayu* because it has a louder sound and has more strings. *Gambus Melayu* on the other hand is approaching extinction because it is hard to find anyone that makes it or plays it anymore. Recently, *gambus Johor* has been used in orchestras and popular cultural music performances in Malaysia. This phenomenon describes that the *gambus Johor* has not only survived rather it has managed to blend with popular music compared to *gambus Melayu.* The chapter proceeds with some information on Malaysian wood which were used as materials to make the *gambus Johor.*

1.2.2 Malaysian wood

Gambus Johor is made from Malaysian wood. Some of the reviews collated on Malaysian wood from several journals, books and websites state that Malaysian wood are divided into four categories; heavy hardwood, medium hardwood, light hardwood and softwood. Hardwood trees have broad leaves and are deciduous as they lose their leaves at the end of the season. While the softwood trees are conifers (evergreens), have needles and are not deciduous. In Malaysia, there are more hardwoods compared to softwoods.

Table 1.1 – Table 1.4 show the common names, botanical names and density at 15% moisture content for all 100 Malaysian woods, grouped into four categories which are heavy hardwoods, medium hardwoods, light hardwoods and softwoods (Malaysian

Timber Industry Board [MTIB], 2008). These 100 woods are the common commercial timbers of Malaysia.

Table 1.1: Common names, botanical names and density of Malaysian heavy hardwoods

No.	Common Names	Botanical Names	Density
1	Balau / Selangan Batu	*Shorea spp*	860
2	Balau, Red / Selangan	*Shorea spp*	810
3	Belian	*Eusiderroxylon zwageri*	845
4	Bitis	*Madhuca spp. and Palaquium spp.*	830
5	Chengal	*Neobalanocarpus heimii*	925
6	Giam	*Hopea spp.*	875
7	Kekatong	*Cynometra spp.*	1155
8	Keranji	*Dialium spp.*	765
9	Malangangai	*Eusideroxylon malangangai*	535
10	Merbau	*Intsia spp.*	800
11	Penaga	*Mesua ferrea*	955
12	Penyau	*Upuna borneesis*	1005
13	Resak	*Vatica spp. and Cotylelobium*	665
14	Tembusu	*Fagraea spp.*	650

Malaysian Timber Industry Board [MTIB], 2008

Table 1.2: Common names, botanical names and density of Malaysian medium hardwoods

No.	Common Names	Botanical Names	Density
1	Alan Batu	*Shorea albida*	850
2	Bekak	*Amoora spp.*	770
3	Derum	*Cratoxylum spp.*	715
4	Entapuloh	*Teijsmanniodendron spp.*	756
5	Geriting / Teruntum	*Lumnitzera spp.*	755
6	Kandis	*Garcinia spp.*	700
7	Kapur	*Dryobalanops spp.*	585
8	Kasai	*Pometia spp.*	745
9	Kayu Malam	*Diospyros spp.*	605
10	Kedang Belum / Tulang	*Milletia spp.*	815
11	Kelat	*Eugenia spp.*	505
12	Keledang	*Artocarpus spp.*	785
13	Kempas	*Koompassia malaccensis*	890
14	Keruing	*Dipterocarpus spp.*	690
15	Keruntum	*Combretocarpus rotundatus*	645
16	Kulim	*Scorodocarpus borneesis*	655
17	Mata Ulat	*Kokoona spp.*	905
18	Mempening	*Lithocarpus spp. and Quercus spp.*	1010

19	Mengkulang / Kembang	*Heritiera spp.*	635
20	Meransi	*Caralia spp.*	680
21	Merawan / Gagil	*Hopea spp.*	497
22	Merbatu	*Parinari spp. and Maranthes*	695
23	Merpauh	*Swintonia spp.*	675
24	Mertas	*Ctenolophon parvilfolius*	805
25	Nyalin	*Xanthophyllum spp.*	610
26	Pauh Kijang	*Irvingia malayana*	940
27	Perah	*Elateriospermum tapos*	1235
28	Petaling	*Ochanostachys amentacea*	897
29	Punah	*Tetramerisia glabra*	625
30	Ranggu	*Koordersiodendron pinnatum*	705
31	Rengas	*Gluta spp. and Melanochyla spp.*	720
32	Semayur	*Shorea inaequilateralis*	794
33	Senumpul	*Hydnocarpus spp.*	778
34	Simpoh	*Dillena spp.*	685
35	Tampoi	*Baccaurea spp.*	640
36	Tualang	*Koompassia excelsa*	820

Malaysian Timber Industry Board [MTIB], 2008

Table 1.3: Common names, botanical names and density of Malaysian light hardwoods

No.	Common Names	Botanical Names	Density (kg/m3)
1	Alan Bunga	*Shore albida*	575
2	Ara	*Ficus spp.*	360
3	Babai	*Saraca spp.*	515
4	Bayur	*Pterospermum spp.*	395
5	Berangan	*Castanopsis spp.*	620
6	Bintangor	*Calophyllum spp.*	475
7	Binuang	*Octomeles sumatrana*	280
8	Dedali	*Strombosia javanica*	590
9	Durian	*Coelostegia, Durio spp. and Neesia spp.*	430
10	Geronggang / Serungan	*Cratoxylum spp.*	350
11	Gerutu	*Parashorea*	725
12	Jelutong	*Dyera spp.*	425
13	Jongkong	*Dactylocladus stenostachys*	600
14	Kedondong	*Species of Burseraceae*	518
15	Kelumpang	*Sterculia spp.*	570
16	Kembang Semangkuk	*Scaphium spp.*	560
17	Ketapang	*Terminalia spp.*	385
18	Kungkur	*Pethecellobium spp.*	465
19	Larang	*Anthocephalus spp.*	300
20	Machang	*Mangifera spp.*	555
21	Mahang	*Macaranga spp.*	495
22	Medang	*Species of Lauraceae*	355
23	Melantai / Kawang	*Shorea spp.*	415

24	Melunak	*Pentace spp.*	540
25	Mempisang	*Species of Annonaceae*	380
26	Meranti Bakau	*Shorea uliginosa*	750
27	Meranti, Dark Red / Obar Suluk	*Shorea spp.*	565
28	Meranti, Light Red / Red Seraya	*Shorea spp.*	626
29	Meranti, White / Melapi	*Shorea spp.*	500
30	Meranti, Yellow / Yellow Seraya	*Shorea spp.*	595
31	Merbulan	*Blumeodendron spp.*	670
32	Mersawa	*Anisoptera spp.*	520
33	Nyatoh	*Species of Sapotaceae*	410
34	Pelajau	*Pentaspadon spp.*	490
35	Penarahan	*Species of Myristiceae*	382
36	Perupok	*Lapopethalum spp.*	480
37	Petai	*Parkia*	686
38	Pulai	*Alstonia spp.*	370
39	Ramin	*Gonystylus spp.*	530
40	Rubberwood	*Hevea brasiliensis*	615
41	Sengkuang	*Dracontomelum dao*	510
42	Sentang	*Azadirachta excels*	676
43	Sepetir	*Sindora spp. and Capaifera palustris*	532
44	Sesendok	*Endrospermum spp.*	315
45	Terap	*Artocarpus spp., Paratocarpus spp. and Antiaris toxicaria*	400
46	Terentang	*Campnosperma spp.*	330
47	White Seraya	*Parashorea spp.*	420

Malaysian Timber Industry Board [MTIB], 2008

Table 1.4: Common names, botanical names and density of Malaysian softwoods

No.	Common Names	Botanical Names	Density (kg/m3)
1	Damar Minyak	*Agathis borneensis*	510
2	Podo	*Podocarpus spp.*	650
3	Sempilor	*Dacrydium spp. and Phyllocladus spp.*	445

Malaysian Timber Industry Board [MTIB], 2008

Malaysian wood are used in many sectors such as heavy, medium and light construction, heavy duty flooring, plywood manufacture, railways sleepers, furniture, roof truss, door, window frame, paneling, carving, toys and charcoal manufacture, beams, lorry and truck bodies, bridges and harbor works (Gan & Lim, 2004). Malaysian rainforests have been recognised as one of the most productive types of forests in the world because of the diversity of the wood species. Although they are not well-known as material for musical instruments but surely they have the great potential that have not been highlighted.

The data on Malaysian wood is gathered for the reason to explore the capability of Malaysian wood as material for musical instruments. In order to do that, we need to know what makes some wood better than others in terms of their quality as musical instrument material. This will be discussed in greater detail in chapter two's literature review.

1.3 Problem of Statement

Malaysian wood have been used as the material of *gambus Johor* since the first time it was made in Johor by a local *gambus* maker. Many types of wood have been used such as *seraya, jati, durian, halban, meranti, koko, pulai,* and *nangka.* However, there is no documentation of which wood is better in terms of acoustical quality. The wood selection is still based on the experience of the makers who basically select the easy to get wood as the material. However, some fussy *gambus* makers emphasise on the aesthetic value more than the acoustical value. Till now, there is no literature that can be used as a guideline in selecting Malaysian wood in terms of the acoustical quality for the *gambus Johor.*

As one of the *gambus Johor* makers, the researcher admits that the *gambus Johor* has its own uniqueness and beautiful sound that has always been heard in z*apin* and *ghazal* music. However, *gambus Johor* has never reached an equally standardised quality of sound. The differences of sound quality of *gambus Johor* are always huge although they were made by the same maker. The size, shape and design of each *gambus Johor* are also different from each other which really affects the sound quality of the *gambus*. This phenomenon basically occurred as a result of the materials used in making this musical instrument and some errors made by the makers in the aspect of design, size and technique.

In the chordophone musical instrument such as *gambus Johor*, soundboard is the most important part which contributes to the quality of sound and sound characteristic of the instrument. Therefore, in order to improve the quality of *gambus Johor*, this research includes the topics of the materials selection for soundboard, the documentation on *gambus Johor* making process and identification of the sound quality and sound characteristic of Malaysian wood as *gambus Johor's* soundboard.

1.4 Objectives

1. To discuss the suitability of *seraya* and *damar minyak* capability as the material for *gambus Johor's* soundboard by determining its acoustical properties using calculation of acoustical formulas.

2. To document the full process in making two *gambus Johor* with different soundboard materials.

3. To analyse the sound quality and sound characteristic of each *gambus Johor* according to the wood used as the soundboard.

1.5 Research Questions

1) To identify Malaysian wood capability as the material for *gambus Johor* soundboard by determining its acoustical properties using calculation of acoustical formulas.
    - What types of wood can be used as a material for *gambus Johor's* soundboard?
    - How to choose the right wood as material of *gambus Johor's* soundboard?
    - What makes some woods better than others as a material for *gambus Johor's* soundboard?
    - How to identify the acoustical value of Malaysian wood?
2) To document the full process in making two *gambus Johor* with different soundboard materials but very similar in size, design and materials used for all other components.
    - How to construct several *gambus Johor* with a similarity in the aspect of size, shape and design?
    - What new idea or inovation can be done as a future guideline in making *gambus*?
3) To analyse the sound quality and sound characteristic of each *gambus Johor* according to the wood used as the soundboard.
    - How good is the sound quality of *seraya* and *damar minyak* when used as *gambus Johor's* soundboard?
    - What are the sound characteristic of *seraya* and *damar minyak* as a *gambus Johor's* soundboard?
    - Which wood produces better sound quality for *gambus Johor's* soundboard?

1.6 Significance of the study

This section will provide a brief description on the various significances of the study given the two categories Reference and Educational, and Economic.

1.6.1 Reference and Educational

This research serves as reference or guide to *gambus* makers in choosing a good acoustic wood as material for *gambus Johor's* soundboard. It will also help *gambus* makers constructing *gambus Johor* with a better technique that can assure the *gambus* consistency in design, shape and size aspects. Moreover, this research will also identify the characteristic and sound quality of several Malaysian woods which can be a good reference for musical instrument makers and also the musicians especially *gambus Johor* players. The proposed study will also benefit and help the future researchers as a guideline. The study can also open opportunities of further development or research. Therefore, it can be used as a reference syllabus for the Musical Instrument Technology subject which is offered in some universities.

1.6.2 Economy

This research identifies the acoustic capability and analyses the sound quality and characteristic of Malaysian wood as a soundboard for gambus Johor. The result proved that some Malaysian wood can be superior material for musical instrument's soundboard. This phenomenon will raise the value of the particular wood which then can also increase the economy of the timber industry. In future, Malaysia also can be the main supplier of this wood for the musical instrument industry of the world.

1.7 Limitation of Study

This research covers topics of *gambus Johor* or *gambus Hadhramaut* and several Malaysian timbers as the material of *gambus Johor's* soundboard. Two types of Malaysian timbers were chosen for experimental-analysis research based on a few aspects. It also focused on the acoustical value, sound quality and sound characteristic of each *gambus Johor* with a different type of soundboard. The demonstration of making the *gambus* is just a documentation of a technique to construct several *gambus* similar in size, shape and design. It is not meant to demonstrate the best size, shape or design for the *gambus Johor*.

1.8 Conclusion

This study will be presented in a five-chapter format with the aid of illustrations in the form of pictures, figures and tables. Chapter 1 will define the background of the study, the problem statement, objectives, research questions, the significance of the study, the scope and limitations and the summary of this thesis. Chapter 2 will show a review of the literature related to *gambus Johor*, wood for soundboard of chordophones, and acoustical properties of wood used as soundboard. Chapter 3 will evaluate and describe the methodology used within the research. It will state what materials, techniques, samples, data and approaches were used in the study. Chapter 4 will present the findings and discussion of the research by dividing it into two sections. The first section is the documentation of the whole process in making the *gambus* including the wood selection according to popular and alternative choice, mechanical properties of the wood measured by Non-destructive Modulus of Elasticity Evaluator, acoustical properties of the selected wood, and the making process of the *gambus.* The second part of Chapter 4 will discuss the result of the sound quality and characteristic of the *gambus*. Chapter 5 will conclude the study and will provide some recommendations based on the findings of the study.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This literature review is based on several researches and studies from journals, books, encyclopedias and professional websites which are related to the research topic. This research is made on Malaysian wood in the perspective of *gambus Johor,* so firstly it is necessary to present previous studies about *gambus Johor* and related topics. Then, the diversity species of Malaysian wood will be presented in the next topic. It will be followed by the properties that make some wood more superior as musical instrument material with three subtopics; physical properties, mechanical properties and acoustical properties. Then the type of wood that have been used in the construction of chordophone instruments from different places in the world with a sub-topic on spruce. Additionally, this chapter will present the gap or the lack in previous studies which leads to the topic of my research that studies the acoustical properties and sound characteristic of Malaysian wood in the perspective of *gambus Johor's* soundboard.

2.2 Gambus Johor

Anis (1993) stated that g*ambus Johor* was brought in by the Arabs since the 15th century while Hilarian (2005) was believed to be brought in by the Persian since the 9th century. There are three parts in *gambus Johor* which comprise of: the arched-back body (generally constructed from 17 – 21 strips of wood), the belly (soundboard) and the neck (Francis, 2005). Several wood are used as materials for gambus Johor such as *Leban, Seraya, Jati, Durian Belanda Cengal, Pokok Pinang, Merawan* and *Meranti* (Ibid.). Most of the previous documentations on *gambus Johor* were about the history of *gambus* existence and development, role in local culture, playing technique and physical structure of *gambus Johor*. However, till today there is no documentation on the making process of *gambus Johor* or the sound quality and sound characteristic of *gambus Johor*. The main focus of this research is on the material used for making *gambus* and its effect to the produced sound, therefore wood for musical instrument will be discussed in the next chapter.

2.3 Wood for Musical Instrument

This review is about the wood used in many places for construction of chordophone instruments. Some wood are better than the others as a material for musical instrument because of the capability to produce a very fine quality of sound. Somogyi (2010) said, wood used for soundboards need to be densities-different than wood for backs, to ensure the instrument produces the best sound. He also said that softwood be used for soundboard and hardwood be used for back and side (Ibid.). Wegst (2006), he said that the softwoods with straight grain are commonly used for soundboard. All the previous studies agreed that softwood is the material for soundboard and hardwood is more suitable for back and side. This method on selecting different wood for back and soundboard was also applied by local *gambus* makers. The popular wood used for the back of the *gambus Johor* are *koko, durian, meranti, seraya* and *sepetir* while for the soundboard, wood used include *jati, pulai, ara, jelutung,* dark red *meranti* and *medang.*

According to Wong, teak (*Tectona grandis) or jati* its local name, can be used for making musical instruments (1982). Hilarian also stated that *jati* wood was used in making the soundboard or belly of *gambus Hadhramaut / gambus Johor* (2005). Across the globe, Arabian *'al-ud'* makers agree that the wood must be thin, light and well-seasoned although they have different opinions about preferable wood for making *'al-ud'* such as beech, elm or walnut (Villoteau, 1809). While in the Renaissance and the

Baroque, Hellwig stated that the belly (soundboard) is the most important part as it affects the sound quality of the lute and is commonly made of spruce or fir (1974).

In another journal, Usher said, pine or spruce for soundboards and hardwoods such as walnut, rosewood, mahogany, maple, sycamore and satinwood for back and ribs are used for the best Spanish guitars today were actually used in the 18th century (1956). It means that in the 18th century, European or Western makers knew what types of wood were best for their musical instruments. This is also supported by the story of a legendary violin maker, Antonio Stradivari who makes extraordinarily-good sound violins during the 17th and 18th century called Stradivarius, using spruce as the soundboard (Pollens, 1992). Norway spruce and Sitka spruce are softwood species which were preferred as superior materials for violins and pianos (Muller, 2000). Somogyi said, softwood such as spruce or cedar is the best materials for high quality guitar faces or soundboard (2010).

It seems like spruce is the best wood used for soundboard of chordophones instrument because most of the previous studies stated that spruce is the choice of musical instrument makers. However, spruce does not exist in Malaysia, so the properties of spruce need to be studied in order to search and identify alternative Malaysian wood that can be as good as or even better than spruce. Before we discuss the properties of spruce, it is imperative to know the reason why some wood used as soundboard are better than others in term of the sound produced. Hence, the next topic will discuss wood properties.

2.4 Wood Properties

The quality of sound produced by the wood depends on the acoustical value of the wood. However, acoustical value of wood is dependant on the physical and mechanical properties. It is very important to know the physical and mechanical properties of the wood in order to define the capability of its acoustical value. Every type of wood are different according to its physical and mechanical properties, therefore, the acoustical value of each wood is also different from each other. This research will be the first of its kind using a scientific approach to identify the acoustical properties of several Malaysian timbers. The next sub-topic will review the physical, mechanical and acoustical properties of wood in more detail.

2.4.1 Physical Properties – Density

The amount of wood substance for a given volume determines *density.* Woods with more weight for a given volume have higher density than woods with less weight. Wood density is the physical property of wood which ranges from about 100 kg/m3 for balsa to about 1400 kg/m3 for lignum vitae and snakewood (Wegst, 2006). Both weight and volume of wood are affected by the amount of moisture it contains (Mullins, 1981). Wegst (2006) also stated that wood's moisture content is also important in ensuring the acoustical performance of a wood. Therefore, when specifying density it is important to also state moisture conditions. For example, the density for air-dried *damar minyak* is 465. This means it weight is 465kg per meter cube at 12 percent moisture content - a standard for strength testing and density measurement.

Density is an excellent indicator of wood strength; the higher the density the stronger the wood. However, a wood with a density of 600 may not be twice as strong as one with a density of 300. It depends on the strength properties (mechanical properties) being discussed (Jessome, 1977). For soundboard, density of the wood is not required to be high in order to achieve a good quality acoustical value. It is best if the density of the wood is low while the stiffness (elasticity) value is high. We will discuss about the wood stiffness in this next sub-topic.

2.4.2 Mechanical Properties – Modulus of Elasticity (MOE)

Acoustical properties of a material can be determined mostly with Modulus of Elasticity (MOE) and wood density (Wegst, 2006). MOE is a measure of the stiffness of wood which means the amount of deflection of wood in response to a load. MOE unit is mega-pascals. Somogyi stated that wood with high stiffness to weight (density) ratio is good as material for soundboards (2010). Wegst stated, in soundboard design, the one that radiates the loudest sound also is the stiffest per unit mass (2006). That is why some instrument use very thin soundboard plate which typically measures around 2-3 mm thickness and can still support the load of the strings with minimal deflection. The wood stiffness test is shown in figure 2.1 below.

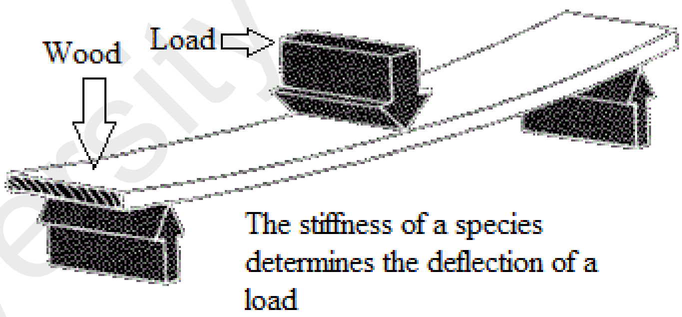


Figure 2.1: The wood stiffness test (destructive test).

2.4.3 Acoustical Properties

"The word 'acoustic' is derived from a Greek word *akoustikos* meaning 'for hearing' (Knopoff, 1969). The physical and mechanical properties of the wood determine the acoustical properties which are the volume, quality and color of the sound of soundboards because the material itself vibrates to produce sound (Wegst, 2006). The most important acoustical properties of woods are the speed of sound through the wood, the characteristic impedance and the sound radiation coefficient (Ibid.). These three values are the main focus of this research in order to identify the capability of the wood for soundboard.

2.4.3.1 Speed of Sound

The speed of sound is directly related to the density and modulus of elasticity. It is independent of wood species, but only varies with grain direction. Generally, the speed of sound value will increase when modulus of elasticity is higher and the density is lower. As we can see in Equation 2.1: $\boldsymbol{c = \sqrt{(E/\rho)}}$.

The speed $\boldsymbol{c}$, is defined as the root of the material's Young's modulus, $\boldsymbol{E}$, divided by material's density, $\boldsymbol{\rho}$. The speed of sound decreases, with an increase in temperature or moisture content. It also decreases slightly with increasing frequency and amplitude of vibration (Wegst, 2006).

2.4.3.2 Characteristic Impedance

Characteristic impedance is also directly related to the modulus of elasticity and density as shown on Equation 2.2: $\boldsymbol{z = c\rho = \sqrt{E\rho}}$.

The impedance, $\boldsymbol{z}$, of a material, is defined as the product of the material's speed of sound, $\boldsymbol{c}$, and its density, $\boldsymbol{\rho}$. This quantity is really important when vibratory energy is transmitted from one medium. Any medium that vibrates, has its own impedance value. Soundboard-quality woods are not only the best sound radiators of all, but they also have low characteristic impedance. Low impedance is beneficial for sound transmission into the air. However, the soundboard's impedance is proportional not only to the characteristic impedance on the material from which it is made, but also to the square of the soundboards thickness (Wegst, 2006). As an example, soundboard with considerable thickness like pianos, have impedance larger than that of the strings. For the chordophone instrument, the impedance of the soundboard and the strings must be controlled very carefully in order to achieve a great sound quality (Benade, 1990). Although the characteristic impedance is depending on both strings and soundboard, but it still can be a guideline or important feature in wood selection for soundboard which stated before that low characteristic impedance wood is good for sound transmission into air.

2.4.3.3 Sound Radiation Coefficient

The sound radiation coefficient describes how much the vibration of a body is damped due to sound radiation. The sound radiation coefficient, $\boldsymbol{R}$, of a wood, is defined as the ratio of the wood's speed of sound, $\boldsymbol{c}$, to its density, $\boldsymbol{\rho}$:

Equation 2.3: $\boldsymbol{R} = c/\boldsymbol{\rho} = \sqrt{\boldsymbol{E}/\boldsymbol{\rho}^3}$.

Wood for soundboard has both exceptionally high speed of sound value and remarkably high sound radiation coefficient. (Wegst, 2006). If we wish to maximise the average loudness of the *gambus* for a given density and prescribed soundboard dimensions, we need to maximise the combination of material properties earlier defined as the sound radiation coefficient, $\boldsymbol{R} = \sqrt{\boldsymbol{E}/\boldsymbol{\rho}^3}$. In other words, if we wish to produce a loud sound *gambus*, a large sound radiation coefficient of the material (soundboard) is desirable.

2.5 Spruce

As been discussed before, spruce is well-known as the superior wood for musical instrument's soundboard. However, it does not exist in Malaysia, therefore, the properties of the spruce need to be identified in order to find alternative Malaysian wood that can be used for *gambus* soundboard.

According to the United State Department of Agriculture, Forest Service [USDA], spruces are softwood, fine and even textured, straight grain and absent of vessel (1974). Table 5, shows the average density and Modulus of Elasticity at air-dry condition of several spruces which maybe the secret or reason why spruce is a superior material for soundboard.

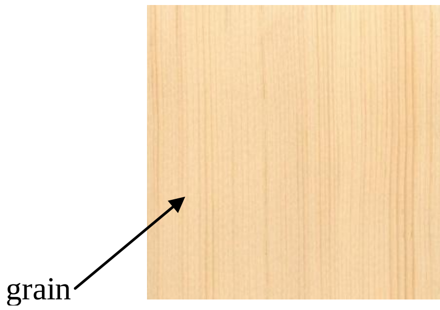
Table 2.1: Average density and Modulus of Elasticity of Spruce tested on air-dry condition

Common Names	Botanical Names	Average Density (kg/m3)	Modulus of Elasticity (Mpa)
Norway / common spruce	*Picea abies*	460	11,900
Sitka spruce	*Picea sitchensis*	430	11,200
Black spruce	*Picea mariana*	420	11,100
Red spruce	*Picea rubens*	404	11,438
White spruce	*Picea glauca*	361	9852
Engelmann spruce	*Picea engelmannii*	420	10,700

United State Department of Agriculture, Forest Service (USDA, 1974)

Figure 2.2 below, shows the spruce tree (a) and the spruce wood (b) (The Hiker's Notebook, 2010). We can see that spruce is a conifer tree and has a very straight grain (vertical lines).


(a) Spruce tree



(b) spruce wood

Figure 2.2: Spruce tree (a) and Spruce wood (b)

Physical and mechanical properties of spruce will be the guide line to search an alternative Malaysian wood. The identification and comparison of selected Malaysian wood with spruce will be discussed in Chapter 4.

2.6 **Conclusion**

From this review, I realise that spruce is the most common wood used for chordophones instrument soundboard. Ironically, *gambus Johor*'*s* soundboard is made from local woods by the instrument maker with high aesthetic value without concern about the wood's acoustical properties. As the result, the quality of our traditional music instrument will remain the same because the materials used are not suitable for soundboard. Still, we know that spruce is not a Malaysian wood so it is unfavorable if we use imported wood for our local traditional instrument. Hence, we need to identify local wood as an alternative for the high quality wood such as spruce. As a result, the scientific approach based on acoustical properties calculation will be conducted on Malaysian wood in order to find a high acoustical value wood. However, as mentioned before, no documentation has been made on *gambus Johor* making process such as specific details on the techniques, designs, measurements and materials used during the process. Therefore, all the process of *gambus* making will be demonstrated and documented in detail systematically. The next chapter shall evaluate and describe the methodology used within the research. It will state the research design, area of study, instruments for data collection, method of data collection, method of data analysis and approaches that were used in the study.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

The purpose of this study is to determine the sound quality of two Malaysian woods used as materials for *gambus Johor's* soundboard. The two types of Malaysian woods have been selected are *seraya* and *damar minyak.* The selection is based on the previous studies related to this case study. It is also based on the empirical experiences of *gambus Johor* makers.

In this chapter I will discuss the research design of this study, explain the sample selection, procedure used in designing the instrument, method of data collection and statistical procedures used to analyse the data.

3.2 Research Design

3.2.1 Experimental

Experimental research design was used for this study. An "experiment" is a set of various conditions which allowed measurement of the effects of a particular treatment (Seigel, 2000). The researcher manipulates independent variables (e.g., type of wood as soundboard) and measures dependent variables (acoustical value) in order to establish cause-and-effect relationships between them. Notice, the independent variable is controlled or set by the researcher and the dependent variable is measured by the researcher. The main function of the experimental research design is to control variance (differences).

Therefore, the researcher attempts to maximise the difference in the dependent variable (acoustical value) caused by maximising or altering the differences in the independent variables (type of wood as soundboard). Then, control the variance of unwanted variables that may have an effect on the experimental outcomes such as the size, shape, design and materials for other parts of *gambus Johor*. Therefore, all these aspects must be similar in every set to assure that only the differences of soundboard material (independent variable) will cause the differences in the acoustical value (dependent variable). Finally, to minimise the error or random variance avoid unreliable measurement instruments which have high errors of measurement.

3.2.2 Survey

A survey research design was also used for this study. The term 'survey' is commonly applied to a research methodology designed to collect data from a specific population, or a sample from that population, and typically utilises a questionnaire or an interview as the survey instrument (Robson, 1993). The researcher chose survey research design because it can gather information which is not available from other sources, unbiased representation of popular population of interests, same information collected from every respondent and compliment existing data from secondary sources (Linda, 2002). Social scientists rarely draw conclusions without disaggregating the sample population into various sub-groups. For example, the Gallup polls typically examine issues disaggregated by gender, ethnicity, education and region of the country (Rossi, Wright and Anderson, 1983).

According to Leary (1995), there are distinct advantages in using a questionnaire vs. an interview methodology: questionnaires are less expensive and easier to administer than personal interviews; they lend themselves to group administration; and, they allow confidentiality to be assured. Robson (1993) indicates that mailed surveys are extremely efficient at providing information in a relatively brief time period at low cost to the researcher.

3.3 Area of Study

For experimental research, all the measurements and calculations on the wood properties was done in Forest Research Institute Malaysia (FRIM) in Kepong, Kuala Lumpur. The making process of the *gambus* was held at the researcher's work lab in Kampung Linggi, Negeri Sembilan.

In the survey study, the researcher focuses only in two states which are Johor and Kuala Lumpur. Johor is the origin place of *gambus Johor* which produced a great number of *gambus* makers and players. The first maker in Johor is Hassan bin Osman who is the master *gambus* maker in Malaysia. Unfortunately, just before the researcher started this research, the master *gambus* maker passed away at the age of 87. He has a nephew who continued his work, Halidan bin Ithnin. Halidan who was interviewed as a primary data source for this study. Another *gambus* maker who was also a student of Hassan bin Osman is Mohd Diah bin Ariffin. He has been working with the Malaysian Handicraft Development Corporation as a *gambus* maker.

Kuala Lumpur become the solitary study area due to the existence of many great *gambus* players, traditional musicians, music students and lecturers of traditional music. Two great *gambus* players are Haji Md.Yassin bin Amin and Norihan bin Saif who both used to work in *Istana Budaya*, Kuala Lumpur. They are well known *gambus* players among local professional musicians.

3.4 Population of the Study

The target population in this study are people related to the *gambus Johor* which includes *gambus* makers, *gambus* players and *gambus* students. They are all important in this study on account of their knowledge and experience in *gambus* especially in sound quality and characteristics of the *gambus Johor*. Table 3.1 below depict the distribution of related people who are included in the population of the study.

Table 3.1: The population of the *gambus* makers, *gambus* players and *gambus* students in the area of study.

No.	People Related to *Gambus Johor* / Subjects	Numbers in Johor	Numbers in Kuala Lumpur	Total
1	*Gambus* maker	2	-	2
2	*Gambus* player	10	20	30
3	*Gambus* student	-	10	10
	Total	12	30	42

3.5 Sample of Population

Sample of population is a subset of subjects that is representative of the entire *population*. For this study, a total of 42 people comprising of three subject populations from two states, Johor and Kuala Lumpur were taken as population samples. The formula to evaluate the sample of population numbers by Krejcie and Morgan (1970) is:

$$ss = \frac{Z^2 * (p) * (1-p)}{c^2}$$

Where:

Z = Z value (e.g. 1.96 for 95% confidence level)

p = percentage picking a choice, expressed as decimal (.5 used for sample size needed)

c = confidence interval, expressed as decimal (e.g., .04 = ±4)

Table 3.2 below presents the sample population of the three subject populations. This is because 42 is the total of several different subjects, so we cannot simply use the formula using the total of 42 to obtain the sample population number. The researcher rather, used the formula on each subject population to obtain the sample population of each subject.

Table 3.2: Sample population of the three subject populations

No.	People Related to *Gambus Johor* / Subjects	Total Population (N) Johor + Kuala Lumpur	Sample of Population (s)
1	*Gambus* maker	2	2
2	*Gambus* player	30	29
3	*Gambus* student	10	10
	Total	42	41

In Table 3.2, calculations using the *Creative Research System* website calculator on the sample size shows a total of 41 sample population. As the difference in total is not too great from the full population of 42, the researcher decided to use the full population of 42 people for this study.

3.6 Instrument for Data Collection

3.6.1 Non-Destructive Modulus of Elasticity Evaluator

Non-Destructive Modulus of Elasticity Evaluator (Non-Destructive Test –NDT) is a system to measure the density and elasticity of wood. This measurement system was developed by Dr. Mohamad Omar bin Mohamad Khaidzir from Forest Research Institute Malaysia (FRIM) in 2002 through several versions. NDT is capable to generate signals in the form of sine wave, arbitrary wave, triangular wave, pink noise and white noise. It is also able to transform sound signal from time domain to frequency domain by the use of Fast Fourier Transform (FFT). NDT is also able to portray the output signal or frequency response (natural frequency) of sound after passing through the material such as wood. Finally, the most important function of the NDT is that it determines the density and modulus of elasticity (MOE) of wood.

The NDT uses several equipments such as high quality of condenser microphone, small hammer, a computer with a Digital Signal Analyser programme (Time domain – FFT frequency domain / DSA) and two stands. The test was done by putting the wood on the stands with a microphone positioned at the end side (end grain). Then, knocking with medium force at the front side of the wood (the other side of the end grain) and the microphone which has been connected to the computer using the software will capture the sound or frequency through the wood. The DSA will process the data and came out with the density and MOE values.

3.6.2 Calculation on Acoustical Value of the Wood

The properties on which the acoustical performance of wood depends upon are density and Young's modulus of Elasticity (MOE). All the density and MOE of the wood have been measured by NDT as discussed in the previous sub topic. The most important acoustical properties in selecting woods for soundboard of musical instruments are speed of sound within the wood, the characteristic impedance and the sound radiation coefficient. Therefore, calculation by acoustical formula using these mechanical values of the wood can show the acoustical value of the particular wood. This acoustical value is used as a guide in choosing wood to construct a good soundboard for *gambus Johor.*

3.6.3 Construction of two *gambus Johor*

Two *gambus Johor* with different soundboards were constructed by the researcher. *Seraya* and *damar minyak* were respectively selected as the soundboard for each *gambus.* The other parts of the *gambus* are similar to each other in the aspects of size, shape, design and materials. The entire process of making the *gambus Johor* was documented to be used as future reference and to assure consistency in all aspects of *gambus Johor*.

3.6.4 New Innovation Floating Bridge

A floating bridge was never been used on gambus Johor. It became popular due to the fact of Oud players (Middle East) using it in the 50's such as Munir Bashir and Fadel Shamma. Floating bridge tends to produce more crisp sound, while a fixed bridge produces more mellow sounds usually associated with traditional playing. From the author's self-reflexive account, floating bridge causes less energy dissipation than a fixed bridge. Because of better transmission of vibration and more efficiency, a floating bridge should be more responsive to subtle changes in playing. Floating bridge is more convenient and practical to control external elements than fixed bridge on both gambus soundboard. A single floating bridge can be used for both gambus in this study. Therefore, the results will be more precise on the soundboard.

Five important things that should be considered in making floating bridge are the length, thickness, height, material and position. Most makers will make floating bridges around 15centimeters. Longer bridge gives better bass, sustain and a far better echo, while shorter bridge gives a great crisp sound, clearer tone (less overtone) and less echo.

Thicknesses of the floating bridge also play an important role to the sound. Thicker bridge gives better bass response while thinner gives clearer and crispier sound. Ideal thickness is around 4mm to 5mm but still depends on the sound characteristic desired by the maker.

Another important thing is height of the floating bridge in order to get an optimum vibration transmission from the strings through floating bridge into the soundboard. The higher the bride, the more pressure to the soundboard and the more acute the breaking angle of the string. Acute angle of strings and too high pressure to the soundboard will kill the vibration. While lower bridge gives better vibration transmission but less action or strings tension. Too low strings tension will result bad buzzing sound.

Material of the floating bridge is very important. The capability to transmit wave or vibration is the main factor in selecting the material of floating bridge. Most makers use Indian Rosewood, Madgascar Rosewood, Padauk and Spruce.

Lastly, the position of the floating bridge is crucial in order to get the best gambus sound. However, its position is not similar in every gambus. It is based on the size of the soundboard and the arrangement of the bracing (*tetulang*). Most makers positioning it by distance measurement but the researcher has found new technique in determining the right position of the floating bridge. This technique will be discussed on chapter 4.

3.6.5 Interview

Interview is one of the instruments used by the researcher for data collection. The researcher interviewed several people as a primary source of data such as a *gambus* maker, a *gambus* player and an ethnomusicologist from Akademi Seni Budaya dan Warisan Kebangsaan (ASWARA).

The interviews were aimed at the previous sound characteristic and sound quality of *gambus* Johor based on their experiences. They opinion on the selection of wood as the material for the *gambus* soundboard was also sought. The interview questions are attached as appendices for reference.

3.6.6 Questionnaire with Live Performance Demonstration

The questionnaire (Appendix 1) designed by the researcher entitled "Sound of *Gambus* Johor" was also used in the study. The purpose of the questionnaire is to determine the *gambus* with better sound quality and why it is better. All questions are closed type questions. This questionnaire's result will define which wood has greater acoustical quality as a *gambus* soundboard. It will then be compared to the acoustical calculation result.

The questionnaire is made up of three sections. The first section collects personal data of the respondents. The second section contains questions about the sound quality and characteristic of both *gambus*. The third section requires respondents to choose the *gambus* with better sound quality and state the main reason for choosing so.

3.6.6.1 Validation of the Questionnaire

The questionnaire and research question copies were given to some ethnomusicologist as the validation process of this study. After these ethnomusicologists compared the questionnaire and research questions, they suggested several corrections.

David (2014) said, questionnaire problems can be avoid by pretesting the survey to a small sample of respondents. He also stated, pretesting questionnaire can indentify confusing items, respondents problem, researcher mistake, potential biases and uninformative questions (Ibid.). Then, the pilot test was carried out for the questionnaire with live performance by the researcher himself using 10 *gambus* students. This was done in order to see:

- the reaction of the respondents to the questionnaire and the live performance;
- whether the questions are clear enough and easy to understand;
- whether the live performance of each *gambus* is clear and easy to analyse;
- whether the respondents can stay focused during the live performance;

- whether some of the respondents did not respond to some of the questions; and
- to determine the effectiveness of the instrument for the method of data analysis in the study.

According to the pilot test, the researcher was able to understand that some items needed to be improved. However, the most important thing that the researcher discovered from the pilot test is that the language used in the questionnaire needed to be changed from English to *Bahasa Melayu*. As most of the respondents lack proficiency in English the researcher used *Bahasa Melayu* (Attachment 2) to ensure the questionnaire can be understood easily.

3.7 Method of Data Collection

For the experimental research**,** all the data are gathered in a laptop, note book and video. All the processes are easily collected as it was done by the researcher himself. The two *gambus* constructed are the most valuable data in the safekeeping of the researcher.

The survey (corrected a few times), pilot testing, questionnaire and live performance sessions were done several times. The 1st session with the *gambus* students from Kuala Lumpur, was conducted at UITM Shah Alam in August 2016. Ten (10) copies of questionnaires have been given out and successfully completed on time. Theerafter, many sessions were done in different places according to the respondents who are *gambus* players and *gambus* makers. All respondent were given a questionnaire during the survey and *gambus* playing demonstration. As the questionnaire must be completed by the respondents within a specific period of time, it easy for the researcher to collect the questionnaires.

3.8 Method of Data Analysis

The data collected from the experiments, interviews and questionnaires were analysed. For the experiments, all the data were analysed by the researcher. The experiment's data has defined the acoustical potential of *damar miyak* and *seraya* as a soundboard. The researcher has also summarised the audio-recorded interviews. From the questionnaires, the researcher determined the chosen *gambus* by most of the respondents and analysed the reason why they chose so.

3.9 Summary

The main purpose of this research design is to define which wood between *damar minyak* and *seraya* has better sound quality as a *gambus Johor's* soundboard according to theoretical acoustic calculation and the opinion of the respondents who are considered related and experts in *gambus*. The findings are stated in Chapter 4.

CHAPTER 4: DATA ANALYSIS REPORT

4.1 Introduction

This chapter presents the data gathered from the instruments used in the study, and analysed according to the research questions (see Chapter 1). This chapter is organised in the following sequence; beginning with a report of the collected data from the field; an analysis on the acoustical properties of the selected woods; discussion concerning suitable materials for each of the *gambus Johor's* soundboard based on the acoustical properties result; a detailed report on *gambus*-making using the selected materials and feedback from 42 respondents (including experts, musicians and students) regarding the sound quality of the instrument made for this research purpose.

4.2 Material Selection for Gambus Johor Soundboard

The following section is a report on the preliminary work carried out in search of a suitable material to build a *gambus Johor* soundboard. Informants such as Hasan bin Osman and Halidan Ithnin were interviewed. This section explored into different materials and their acoustical quality in forming decisions to build a soundboard using wood other than the commonly used: *seraya* (Shorea spp.), *jati* (Tectona grandis), *mahang* (Macaranga spp.) and *durian belanda* (Annona muricata).

4.2.1 Commonly Used Materials for *Gambus Johor* Soundboard

Wood commonly used for *gambus* soundboard-making are *seraya /* dark red meranti, *jati, mahang and durian belanda*. According to Osman (Personal Communication, *Bengkel Industri Budaya,* Johor, Aug 22, 2009), or more commonly known among the Malaysian *gambus* circle as *'Wak Misan'* (Uncle Misan), this is also because these wood types are easily assessable. However, the two most popular ones for *gambus* soundboard according to the late Pak Hassan were *seraya* (dark red meranti) and *jati*.

Hasan bin Osman, is the pioneer maker of *gambus Johor* who contributed half of his life making this instrument. Most of the *gambus* makers in Malaysia especially those residing in Johor (including the present author), studied from him. His hand-made *gambus* can be defined as the pure *gambus Johor* of Malaysia in the perspective of design, size and materials. His nephew, Halidan Ithnin, continues his work and is still constructing the *gambus Johor* using the traditional design and method. According to Halidan Ithnin (Interview, Kuala Lumpur, Mar 26, 2012), wood selection for *gambus* is based on the experience of the maker. Ithnin recalled what he learned from his uncle during wood selection, that is, by observation of the visual aspect of a particular part of a wood log.

Citing a report from the Malaysian Timber Industry Board (MTIB, 2008), the following Table 4.1 shows the physical and mechanical properties of *seraya* and *jati*. Figure 4.1 displays the (a) texture and (b) grain of the *seraya* (dark red meranti) and *jati*.

Table 4.1: Physical and Mechanical properties of *seraya* and *jati*.

MOE (Mpa)	Grain	Texture	Density (kg/m3)	Timber Classification	Botanical Names	Common Name
13,900	Interlocked or wavy	Coarse but even	625	Light hardwood	*Shorea spp.*	*Seraya* (Dark Red Meranti)
11,720	Straight but occasionally wavy	Coarse with open pores	590	Light hardwood	*Tectona grandis*	*Jati*

Timber Industry Board (MTIB, 2008)
*MOE is Modulus of Elasticity *Density and MOE show average value on air-dry condition

SERAYA ***JATI***

(a) texture (b) grain (a) texture (b) grain

Figure 4.1: Texture (a) and grain (b) of *seraya* and *jati* (MTIB, 2008)

4.2.2 Selection of Malaysian woods for Acoustical Properties Test

According to Halidan bin Ithnin, *seraya* was believed to be more popular compared to the *jati* in term of *gambus* soundboard material. Therefore, *seraya* is included in the experiment of acoustical properties. In comparison with spruce, the Malaysian softwood *damar minyak* (*Agathis* borneensis) was chosen as the material in question in this study with a hypothetical assumption that this may be a suitable and less costly type of wood for *gambus* soundboard. This is based on the preliminary findings showing similarity of physical properties between them. Table 4.2 shows the comparison on physical and mechanical properties of *damar minyak* and *spruce.*

Table 4.2: Physical and mechanical properties of *damar minyak* and spruce.

Wood	Common Spruce	*Damar minyak*
Classification	Softwood	Softwood
Texture	Fine and even	Fine and even
Grain	Straight	Straight
Vessel	Absent	Absent
*Density (kg/m3)	460	510
*Modulus of Elasticity (Mpa)	11, 900 (average)	12,000 (average)

**Average value on air-dry condition*

According to Table 4.2, we can see the similar physical properties of the *damar minyak* and spruce. Results reveal that there may be a possibility that the acoustical properties of *damar minyak* may be close to that of the spruce, which generates good sound quality when it is used to build a musical instrument. Therefore, two types of wood: *seraya* and *damar minyak* were chosen in this study as I posit that they may be suitable alternatives to the more costly spruce. Table 4.3 shows the two selected Malaysian woods for *gambus Johor's* soundboard and common spruce as a comparison.

Table 4.3: Physical and mechanical properties of *seraya, damar minyak* and common spruce.

Common spruce	*Damar minyak*	*Seraya* (Dark Red Meranti)	Property
Softwood	Softwood	Light hardwood	Classification
Fine and even	Fine and even	Coarse but even	Texture
Straight	Straight	Interlocked or wavy	Grain
Absent	Absent	Moderately large, mostly solitary	Vessels
460	510	625	*Density (kg/m3)
11,900	12,000	13,900	*MOE (Mpa)
			Picture of wood

*MOE is Modulus of Elasticity
*Density and MOE are on air-dry condition
*Pictures of wood are taken from MTIB, 2008.

Table 11, shows the similarity and the differences between our two local woods with the superior wood, spruce. However, we still do not know how these similarities and differences can affect the sound quality of each wood. So, I will present those aspects in this next topic.

4.2.2.1 Mechanical Properties by Non-Destructive Modulus of Elasticity Evaluator

The purpose of this test is to measure the density, natural frequency and Modulus of Elasticity of the wood. The test is carried out at Forest Research Institute Malaysia or Institut Penyelidikan Perhutanan Malaysia (FRIM) under the supervision of Dr. Md. Omar bin Md. Khaidzir. Eight samples for each wood (dark red meranti / *seraya* and *damar minyak*) as shown in figure 4.2 have been measured during this test. Table 4.4 and 4.5 show the result of the test.

Figure 4.2: Non-Destructive Modulus of Elasticity Evaluator

Table 4.4: Non-Destructive Modulus of Elasticity Evaluator Test on *damar minyak.*

MOE (N/mm^2)	Natural Frequency (hz)	Density (kg/m^3)	Mass (kg)	Dimension (mm)	Sample No.
13937	3006	458	0.701	83.42 × 19.99 × 917	DM 1
14716	3118	446	0.697	83.63 × 20.28 × 921	DM 2
12780	2919	443	0.803	86.64 × 22.73 × 919	DM 3
12201	2850	443	0.766	83.98 × 22.36 × 920	DM 4
16773	3171	496	0.765	81.19 × 20.70 × 916	DM 5
13658	2720	551	0.899	86.38 × 20.64 × 915	DM 6
13523	2862	491	0.754	83.10 × 20.16 × 917	DM 7
14349	3092	442	0.646	82.68 × 19.22 × 920	DM 8

Table 4.5: Non-Destructive Modulus of Elasticity Evaluator Test on *seraya* (dark red meranti)

MOE (N/mm^2)	Natural Frequency (hz)	Density (kg/m^3)	Mass (kg)	Dimension (mm)	Sample No.
10164	2157	606	0.810	84.65× 16.63 × 949	DRM 1
10848	2392	562	0.737	84.45 × 16.91 × 919	DRM 2
12304	2556	580	0.737	82.42 × 17.11 × 901	DRM 3
9484	2242	562	0.721	81.77 × 17.12 × 916	DRM 4
9326	2138	638	0.739	81.58 × 15.88 × 894	DRM 5
11614	2476	566	0.768	82.27 × 18.04 × 915	DRM 6
9623	2242	588	0.724	82.14 × 16.61 × 902	DRM 7
10051	2242	620	0.755	83.85 × 16.17 × 898	DRM 8

The MOE value of each sample (*damar minyak* and *seraya*) can be used to determine their acoustical properties. The next topic will discuss the acoustical properties of each sample.

4.2.2.2 Acoustical properties of selected woods by calculation

The acoustical properties of wood, such as volume, quality and color of sound are determined by the mechanical properties of the wood because the sound is produced by vibration of the wood/soundboard itself. The properties on which the acoustical performance of a wood depends upon are density and Young's modulus of Elasticity. The most important acoustical properties for selecting woods for soundboard of musical instruments are speed of sound within the wood, the characteristic impedance and the sound radiation coefficient.

The speed, *c*, sound travels through a wood, is defined as the root of the wood's modulus of elasticity, *E* (in N/m2), divided by the wood density (in kg/m3), *p:*

Equation 4.1

$$c = \sqrt{E/p} = \sqrt{\frac{N/m^2}{kg/m^3}} = \sqrt{\frac{(kg*m/sec^2)/m^2}{kg/m^3}} = \sqrt{\frac{m^2}{sec^2}} = \frac{m}{s}$$

According to Eq.1, the speed of sound (*c*) is directly related to the modulus of elasticity (*E)* and density (*p*). The equation shows the unit of the speed of sound is m/s (meter/second).

The impedance, *z,* is defined as the product of the wood's speed of sound, *c,* and its density, *p:*

Equation 4.2 $z = cp = \sqrt{Ep}$

The characteristic impedance (z) is also directly related to the modulus of elasticity (*E*) and density (p) of the wood. Soundboard-quality woods are not only the best sound radiators of all, but they also have low characteristic impedance. Low impedance is beneficial for sound transmission into the air. However, for chordophone instrument; the impedances of the strings and the soundboard must be controlled very carefully in order to achieve a high sound quality (Benade, 1990).

The sound radiation coefficient describes how much the vibration of a body is damped due to sound radiation (Wegst, 2006). The sound radiation coefficient, *R*, of a wood, is defined as the ratio of the wood's speed of sound, *c*, to its density, *p:*

Equation 4.3 $R = c/p = \sqrt{E/p3}$

A large sound radiation coefficient is desirable if we wish to produce a loud sound of a soundboard. In soundboard design, this means that the one that produces the loudest sound is also the stiffest per unit mass that can support the 70 to 90 N load of the strings with minimal deflection (Wegst, 2006).

The three most important acoustical properties of wood are determined by calculation using the above formula. Table 4.6 and Table 4.7 show the speed of sound, characteristic impedance and sound radiation coefficient of each sample of *damar minyak* and *seraya.* The tables also include the ranking of each sample according to spesific properties and potential indication numbers (lowest is the best).

Table 4.6: Acoustical properties of *damar minyak*

Sound Radiation Coefficient [R = c/p]	Characteristic Impedance (10*3) [z = cp]	Speed of Sound (m/s) [C = $\sqrt{E/p}$]	Sample no. ( ) = (R)+(z)+(C)
12.044 (4)	2526.488 (4)	5516.351 (4)	DM 1 (12)
12.879 (2)	2561.9 (5)	5744.172 (2)	DM 2 (9)
12.124 (3)	2379.399 (2)	5371.104 (5)	DM 3 (10)
11.846 (5)	2324.874 (1)	5248.024 (6)	DM 4 (12)
11.71 (6)	2880.897 (8)	5808.26 (1)	DM 5 (15)
9.035 (8)	2743.275 (7)	4978.72 (8)	DM 6 (23)
10.688 (7)	2576.779 (6)	5248.023 (7)	DM 7 (20)
12.890 (1)	2518.384 (3)	5697.701 (3)	DM 8 (7)

E = MOE in N/m², p = Density in kg/m³, C = Speed of Sound,
z = Characteristic Impedance, R = Sound Radiation Coefficient, ( ) = ranking

Table 4.7: Acoustical properties of dark red meranti / *seraya.*

Sound Radiation Coefficient [R = c/p]	Characteristic Impedance (10*3) [z = cp]	Speed of Sound (m/s) [C = $\sqrt{E/p}$]	Sample no. ( ) = (R)+(z)+(C)
6.758 (6)	2481.81 (5)	4095.397 (5)	DRM 1 (16)
7.817 (3)	2469.124 (4)	4393.46 (3)	DRM 2 (9)
7.941 (2)	2671.389 (8)	4605.843 (1)	DRM 3 (11)
7.309 (4)	2308.681 (1)	4107.973 (4)	DRM 4 (9)
5.992 (8)	2439.259 (3)	3823.291 (8)	DRM 5 (19)
8.147 (1)	2563.888 (7)	4529.838 (2)	DRM 6 (10)
6.88 (5)	2378.723 (2)	4045.447 (6)	DRM 7 (13)
6.494 (7)	2496.321 (6)	4026.324 (7)	DRM 8 (20)

E = MOE in N/m², p = Density in kg/m³, C = Speed of Sound,
z = Characteristic Impedance, R = Sound Radiation Coefficient,
( ) = ranking and potential indication numbers

According to the result in Table 4.6 and Table 4.7, the acoustical properties of each *damar minyak* and *seraya* samples were reported. Based on this result, each samples acoustical capability as a soundboard of a *gambus* was analysed. The sample with the lowest number in bracket has the best potential for soundboard material. With this, the absolute 'trial and error' method in the wood selection for *gambus* soundboard that is both costly and time-consuming is avoided. Via this research, this scientific calculation provides a new approach and an important source of information for *gambus* maker in selecting the best wood or sample as a material of *gambus Johor's* soundboard instead of the conventional qualitative observation. Though, the preliminary finding from this quantitative result may still need further assessment. Building a *gambus* using the selected wood based on the data analysed, needs to be tested by *gambus* making experts and players for further qualitative assessment of sound quality. Subsequently, a *gambus* making report using the selected material is discussed.

4.3 Gambus Making Process

The process of *gambus* making was observed from the late Pak Hassan bin Othman, Halidan bin Ithnin and Haji Mohd Diah bin Aripin for a period of 8 years from 2007 to present. Each session of observation lasted approximately a month to six months. The process is divided into six phases: Template-making, wood selection and shaping, wood treatment and storing, body mould-making, parts construction, and finishing touch. Each phase is interrelated but sometimes a particular sequence can be altered according to the makers. The following report reveals the six-phase *gambus* making process by the author, forming a synthesised making-process with reference to data collected from the late Pak Hassan bin Othman, Halidan bin Ithnin and Haji Mohd Diah bin Aripin and the author's new entry on acoustical analysis in wood selection.

4.3.1 Templates Making

Template-making for each *gambus* part forms the first phase of the process. Template means a shaped piece or drafting used as a pattern for the next wood processes such as shaping, cutting, sawing or drilling. The template must be accurate in measurement and design according to the specification. This is to ensure the measurement and design of *gambus* parts will be precise and accurate with the specification (Appendix 2). Eight main templates were made:

1. *Chetak* (Body Mould)
2. *Kepala* (Head)
3. *Leher* (Neck)
4. *Bahu* (Shoulder)
5. *Tampuk Dalam* (Inner Holder)
6. *Kekuda* (Bridge)

7. *Bunga* (Rosette)
8. *Muka* (Soundboard)

From the *gambus*-maker masters, it is gathered that templates are usually made of paperboard and sometimes from plywood. However, template for *bunga* (rosette) was made from plain paper because it will ease the sawing process. Figure 4.3 below shows the example of templates for *kepala* (head), *leher* (neck), *bahu* (shoulder), *chetak* (body mould) and *tampuk dalam* (inner holder) from the author's participant-observation process in October 2014. Figure 4.4 shows the template for *bunga* (rosette).

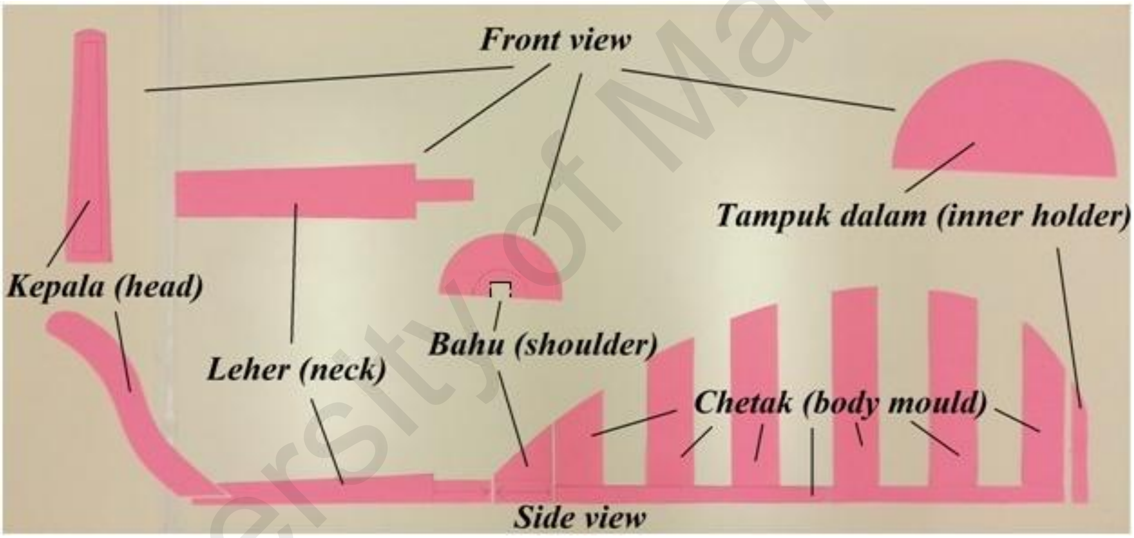


Figure 4.3: Templates of *gambus* parts.

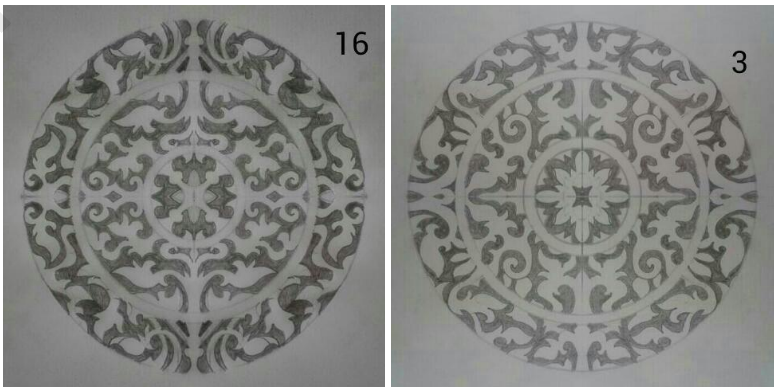


Figure 4.4: Templates for *bunga* (rosette)

4.3.2 Wood Selection and Shaping

The completion of template-making proceeds to wood selection. Acoustical calculation (see Chapter 3) was used in this study instead of the conventional visual observation approach led by the masters. Therefore, selection was based on the results of acoustical properties from Table 4.6 and Table 4.7 above as discussed earlier. The woods for the other parts are *merpauh, penaga, akasia, buey, angsana* and *halban*. These woods were selected based on their hardness and suitability for specific parts.

Decision of wood selection led to the next process of shaping raw materials (wood) on the designed template according to the music instrument requirement. The shaping is accurately done by cutting and trimming referring to templates using hand tools and equipment. Several techniques have been used in shaping the wood such as sawing, planning, sculpting and sanding. The raw woods were shaped for the parts such as *kepala* (head), *leher* (neck), *bahu* (shoulder), *tampuk dalam* (inner holder), *bilah badan* (body strip) and *papan suara* (soundboard). Figure 4.5 shows the example of raw part shaping which is the *leher* (neck). The purpose of this process is to make it easy for the wood treatment process and to store the wood according to the parts which are the next process of *gambus* making.

Figure 4.5: *Leher* (neck) Raw Part Shaping

4.3.3 Wood Treatment and Storing

The wood treatment phase proceeds by treating all the raw parts with oil (tung oil) to ensure zero contamination such as dry rot and wet rot fungi, termites, woodworm (beetle larvae), molds and mildew. Then, after the raw parts have been treated with oil treatment, the parts were then dried naturally at room temperature (or moderate temperature). The drying process is referred to as 'storing process.' Storing process is to make sure the woods are always in the right condition during the drying process. The important aspects that should be observed on the storage are moisture content, temperature and insects. After the storage location was identified, all raw parts were labeled and stored for drying process. The natural drying process usually takes time depending on the species, size and density of the wood. Figure 4.6 shows an example of wood storage for drying process.

Figure 4.6: Wood storage for drying process

4.3.4 Body Mould-making

Body mould is the most important equipment that needs to be constructed in order to make the *gambus* body. The body mould functions to ensure accuracy of the shape, size and design of the *gambus*. According to professional makers interviewed, a *gambus* body is one of the major factors that affect the tone color and sound characteristic. This phase commences with material (light wood or plywood) cutting according to templates. The measurement, shape and design of the mould can be reffered at the Appendix 2 (Body Mould). From my own participant-observation, the cutting process is not a trivial undertaking, because any error of angle or measurement will cause real problem in the process of body making. After the cutting process was done, all the mould parts were merged with fixtures and fitting such as wood glue, screw and nails. Finishing the mould with sanding technique can be done properly with sand paper or sanding machine. Figure 4.7 shows the new inovation body mould developed in this study by the researcher.

Figure 4.7: Body mould for *gambus*

4.3.5 Parts Construction

The actual size of instrument parts are decided and confirmed based on specification of the *gambus.* The raw shape parts of the instrument are cut, trimmed, planed and sanded, according to templates. All the parts such as *kepala, leher, bahu, tampuk dalam, kekuda,* and *bunga* had gone through similar construction process according to their specification. All the specifications can be reffered to on Appendix 2.

4.3.5.1 Bowl-back Body

The bowl-back body of the *gambus* was constructed on the body mould that has been made earlier. Starting with one strip at the middle or centre of the body, each end of the wood strip was glued on the *bahu* and *tampuk dalam.* The process was continued with the next strip to each side of the first strip. Figure 4.8 shows the first strip glued to *tampuk dalam.* Figure 4.9 shows the neck, shoulder and bowl-back body.

Figure 4.8: First strip glued to *tampuk dalam*

Figure 4.9: Neck, shoulder and Bowl-back body

4.3.5.2 Soundboard and Bracing (tetulang)

Damar minyak and *seraya* were selected as the materials for the soundboards. Two soundboards were made based on the specifications. Measurement, design and shape were based on the plan shown at the Appendix 2 (soundboard and bracing). Figure 4.10 shows the soundboard making process.

Figure 4.10: Soundboard making process

After all the *gambus* parts were constructed, work sequence to assemble instrument parts are applied and followed. The instrument parts are fitted, glued and clamped based on specification. Sanding process was carried out on the instrument parts until it was smooth and clean according to specification.

Decoration on the *gambus* such as rosette, inlays and pick guard were constructed after the sanding process. Motive and design pattern was selected and applied to specific parts of the g*ambus*. Carving, painting, inlay and sanding applied to the decoration parts according to design pattern and requirement. Figure 4.11 shows some parts (body, neck, head, soundboard with bracing, rosette and bridge) of the *gambus*.

Figure 4.11: Parts of *gambus*

4.3.6 New Innovation - Floating Bridge

The bridge (*kekuda*) was made with 2 parts: the first part was fixed on the gambus bottom and made for tie the strings. The second part made from tusk was put on the soundboard and was not glued to it. This second part is the "floating bridge" which acts as a link between strings and soundboard. It allows a precise adjustment of the strings height and length.

The length of floating bridge was 11cm. It was shorter than average length done by most oud makers. The floating bridge thickness was 5mm, thicker than average thickness made by other makers. Height of the floating bridge was 11mm, considered low compared to Middle East Oud’s floating bridge. Another important about floating bridge was the position. The researcher found a new method on determining the position rather than using fix distance measurement. The researcher used tone tuning technique to determine floating bridge position. All strings were tune using a tuner device. To get the right position of the floating bridge, both sides of the strings (from floating bridge to the nut and from floating bridge to the fix/bottom bridge) must be tuned on the same note but differ in two octave range. Example on A string, from floating bridge to nut was tuned A 110Hz and from floating bridge to bottom bridge was note A 440Hz. The same note was achived by adjusting the floating bridge position.

4.3.7 Finishing Touch

All the tools for finishing such as clean cloth, sand paper, sanding machine, coating and finishing materials were prepared. Then, all the surface areas of the *gambus* were smoothed with fine sand paper before applying the coating and finishing materials. Polyurethane was used as the finishing coating. Figure 4.12 shows finishing materials and polished bowl-back result.

Figure 4.12: Finishing materials and polished bowl-back result

4.3.8 End Product

Both gambus were constructed similarly in materials used, shape, measurement and design except for soundboard materials which *seraya* and *damar minyak* were used. Figure 4.13 shows both *gambus* successfully made by researcher.

Front View **Back View**

Figure 4.13: *Gambus* made by researcher

4.4 Survey Questionnaire

There was no written benchmark or standard for what is considered a good gambus sound. It just defined by hearing and opinion from the experts. Therefore, the opinions of gambus experts were needed in this survey. 42 questionnaires were given to 42 respondents since July 2016. All the questionnaires have been analysed and the result is shown in Table 4.8 below.

Table 4.8: Result of questionnaires

No.	Question	Gambus A	Gambus B	Both
1.	Which one is more beautiful?	18	14	10
2.	Louder sound?	20	8	14
3.	Bright sound?	17	7	18
4.	Mellow sound?	4	20	18
5.	Sustain?	18	4	20
6.	Better tone clarity?	34	2	6
7.	Better reverb?	35	2	5
8.	Melodious?	26	11	5
9.	Respondent's choice?	36	6	-

From the result, it shows that the sound produced by *Gambus* A (*damar minyak*) was louder, has better tone clarity, more reverb and is more melodious than *Gambus* B (*seraya*). Most of the respondents (36 respondents) chose *gambus* A in terms of sound quality and they realised that these differences are due to the quality of the soundboard. One of the reasons why Gambus B has more mellow sound is because of *seraya* was lower in ratio of MOE (modulus of elasticity) to density compared to *damar minyak*. High ratio of MOE to density can lead to a good acoustic properties such as greater tone clarity, reverb and melodious.

4.5 Conclusion

Based on the findings, *damar minyak* was indeed a high quality wood on acoustical value and was proven to produce great sound as a *gambus* soundboard. The demostration and questionnaires have also proven that the calculation of acoustical formulas method for material samples selection is very succesful and time saving compared to the ‘trial and error’ method. To construct a great sounding *gambus*, the documentation of *gambus* making process and floating bridge innovation by the researcher can be used as a guideline or future study for any *gambus* maker and future generations.

CHAPTER 5: CONCLUSION

This chapter summarises the study by highlighting the research conducted on the topic. The conclusions given were drawn from the outcomes of the research and survey-demontration on sound quality of *seraya* and *damar minyak* as the *gambus* soundboard. Moreover, recommendations were base from the findings and conclusion of the study.

5.1 Overview

The main purposes of this study is to determine the acoustical properties of *seraya* and *damar minyak* by using acoustical formulas to document the gambus making process as a future guideline and to analyse the sound quality and sound characteristic of *seraya* and *damar minyak* as *gambus* Johor's soundboard.

In this study, *seraya* was selected because it was recomended by the master *gambus* maker and *damar minyak* was selected due to its physical and mechanical comparison with spruce. Then, wood sample selections to make the *gambus* soundboard were based on the result of acoustical formula calculation done on each sample. This was conducted under the suprervision of Dr. Md Omar bin Md Khaidzir at Forest Research Institute Malaysia (FRIM). Futhermore, the researcher has constructed two *gambus* similar in size, design and materials except for the soundboard materials and documentation has also been made throughout the *gambus* making process since 2014 in Linggi, Negeri Sembilan. Finally, the researcher has conducted a *gambus* demonstration-survey to 42 respondents in a several locations at different times as a methodology to prove the greatness of the acoustical quality of *damar minyak* as a *gambus* soundboard.

5.2 Implication of Research

5.2.1 New Method of Selecting Wood for Soundboard

Acoustical formula calculation is a better way of selecting wood for soundboard material compared to the 'trail and error' method. Acoustical properties of wood samples can be measured before *gambus* makers contruct their *gambus.* Therefore, this method developed by the researcher to ensure the high sound quality of *gambus* can be produced.

5.2.2 *Gambus* Making for Future Guideline

The documentation of the *gambus* making process will serve as a guideline and reference for future generations and other *gambus* makers. Moreover, when all local *gambus* makers follow this guideline, *gambus* will be standardised in design and be able to maintain the good quality of sound. It can also serve as a silibus in the higher education system such universities or college for Technology of Musical Instrument's Making.

5.2.3 Malaysian Wood in Musical Instrument Industry

Damar minyak is a very high acoustical quality wood and is suitable as a *gambus* soundboard. This study shows that Malaysian wood can also be as good as Europe's well-known wood such as *spruce.* Therefore, Malaysian wood can be commercialised to the musical instrument industry and perhaps after several years, *damar minyak* will be more popular than *spruce.*

5.3 Suggestion for Future Research

5.3.1 Futher Studies on Malaysian Hardwood for *Gambus* Body / Back Ribs.

Studies on the Malaysian wood as the soundboard of the *gambus* is just a starter. As we know, the sound quality and sound characteristic of the *gambus* are not only affected by soundboard but it also affected by the body / backribs. The *gambus* body is best constructed with hardwood and luckily Malaysian forests are rich with hardwood species. Therefore, the researcher suggests that in the future it would be great to futher this study on Malaysian hardwood as the material for *gambus* body.

5.3.2 Studies on the Bracing of *Gambus* Soundboard

Bracing is very important to support the strength of *gambus* soundboard. However, instead of supporting the strength, the bracing should not disturb the vibration capability of the soundboard. The researcher believes that the sound quality of the *gambus* is also affected by the bracing material, position and design. In fact, there is no proven theories on the *gambus* bracing yet. Therefore, is a great pleasure if the researcher can futher studies on this topic.

5.3.3 Studies on the Shape of *Gambus* Body (Bowl Back)

The bowl back body of the *gambus* is the main factor which will create the sound characteristic of any *gambus*. The researcher believes that the bowlback body is the reason why the sound of the *gambus* is really different form a guitar's sound. However, the bowlback shape has never been studied before and infact there is no theories on the shape of the *gambus* body. The uniqueness of the bowlback body really makes the researcher fall in love to futher study on this matter.

5.4 Conclusion

The researcher was able to arrive at these conclusions based on the findings of the study. The acoustical formula calculation method for selecting wood samples for making *gambus* soundboard developed by researcher is a really great method. This method shows the acoustical capability and the potential of any wood as the *gambus* soundboard according to the speed of sound through the wood, characteristic impedance and radiaton coefficient. Therefore, this calculation method is a better way in selecting the samples for *gambus* soundboard than the 'trial and error' method used before.

The documentation of the *gambus* making process is a detailed guideline for future reference. Other makers can use it and most importantly, the uniqueness of *gambus Johor* can be preserved for future generations. Improvement on the making process also can be made by any researcher by refering to this documentation.

Gambus with *damar minyak* as a soundboard produces better sound quality compared to the *seraya's* soundboard. It is not only based on acoustical formula calculation but it is also recognised through demonstration-survey done by the researcher. Moreover, the sound quality of the *damar minyak* soundboard *gambus* is better than several Ouds imported from middle east that used spruce as a soundboard.

As a conclusion, acoustical formula calculation method in selecting samples for gambus soundboard is proven, documentation on gambus making process is important for future reference and *damar minyak* is an excellent material for gambus soundboard which can produce very high quality sound.

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