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THE PROBLEM OF NOISE IN CIVIL AIRCRAFT AND THE POSSIBILITIES OF ITS ELIMINATION

By W. S. Tucker

PART I

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PART I

When the complete history of the present period comes to be written, it should surely be described as the age of noise, for it is inconceivable that so serious a menace to our comfort can be allowed to grow or even continue at a time when our standards of comfort are rising in all other directions. We have noise in the street, in the factory, in the office - and through lack of satisfactory building material from the acoustical point of view, noise in the home, and lack of that privacy which the more substantial building of the past has more or less assured, noise everywhere and no serious effort to reduce it. As one mechanical invention succeeds another a new contribution is made to the orchestra of sounds. Reduction of noise almost inevitably involves additional expense. So, in these days of cheap production, noise must be tolerated. We are supposed to get accustomed to these nuisances, even to tolerate them, and in some cases people claim to be unhappy without them. It has been stated that our London troops during the late war were able to endure gunfire with greater equanimity because of their normal conditions of living in a perpetual noise. Dead silence is

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(To be followed by T.M. No. 473, Part II.)

known to be oppressive - in the habitable places of the earth it seldom if ever occurs in nature - but how shall we estimate the evils of perpetual and harassing noise?

The subject of this lecture - the problem of noise in the cabins of civil aircraft - is of great importance at the present time, as it is generally acknowledged as a hindrance to commercial development.

Perhaps undue prominence is given to this feature of civil aviation - much has been done to enhance the comfort of passengers, and those who habitually make journeys by air are not discouraged by their experiences in view of the many advantages which rapid journeys afford. Nevertheless, there is room for great improvement and certain obvious remedies should be tried.

Of all problems in sound this is probably the most difficult to solve, and to appreciate it fully we must first consider the airplane as a source of sound.

Bear in mind, first of all, that we have to travel in closest proximity to a great engine, or it may be two or three engines developing from 600 HP. to 1300 HP. - that these engines convert chemical to mechanical energy by a series of rapid explosions, say 4000 to 5000 per minute - that these engines are rigidly connected to the structure of the airplane and cabin by materials of highly sound-conducting character, that the wings, stay-wires and cabin walls are all of good resonant materials, that the cabin itself serves as a sound box resounding and reverberating in response to every contribution of sound which gains admittance either through walls, ventilators or open windows. You will then appreciate the nature of the problem to be solved.

The airplane as a source of sound is of peculiar interest, and is of highly composite character. This is indicated by a microphone record obtained from an airplane in flight, taken at short range as shown in Figure 1. Similar records showing complexity of sound were obtained by Waetzmann.* The most prominent of all the sounds is the engine exhaust, and from the point of view of sound it is probably immaterial as to whether the engine is radial or whether the cylinders are in parallel or V-shaped banks. Nor does the number of cylinders necessarily affect the result - what is important is the number of explosions per second and their intensity. The former determines the frequency of the sound, or more correctly the frequencies, since the fundamental note of the explosion hum is enriched by a long train of harmonics. It is not unusual to find the lowest note of the engine exhaust as F on the musical scale more than an octave below middle C of the piano, and we can, by suitable means, identify in the same sound the octave above the fundamental, also middle C, the F above that and so on. The relative prominences of these constituents give the sound its characteristic quality. Again the nature of the sound is still fur-

*E. Waetzmann, Zeits. Tech. Physik., No. 6, p. 171.

ther affected by the air path by which the explosions reach the ear. The air path is determined first by the exhaust manifold - the metal pipes into which the exhaust gases are expelled. If the engine consists of two banks of cylinders, each bank is connected in general to a common exhaust pipe whose opening is generally situated on either side of the cabin in single-engine airplanes. For two-engine airplanes the exhaust pipes are arranged on either side of each engine - the engines being mounted on the lower wing. The explosions are so timed that these pipes receive them alternatively. Each engine, therefore, gives a pair of explosion sources out of phase by 180 degrees, and with three such engines there are six of these sources placed in six different positions relative to the fuselage. In so far as these are at varying distances from the observer, their relative contributions must vary through wide limits.

Other types of exhaust manifold produce even greater complications - for example, the Salmson ring exhaust receives all explosive contributions by vents disposed round a ring-shaped pipe and these escape to the outer air by three or four vents symmetrically or unsymmetrically placed. Each type of exhaust produces its own type of sound and from casual observations it does not appear that any considerations of sound reduction have entered into the problem of design.

So far we have dealt only with the acoustical effect of a single engine. The combination of two and even three such engines produces further complications. If the frequencies of the engine exhausts are not precisely alike, beats will be produced. This familiar phenomenon is due to the mutual interference of two trains of sound waves of nearly the same frequency, the effect of which is to produce a surging of sound of frequency equal to the difference of those frequencies. It must be remembered also that beating occurs not only between the fundamental notes, but also between the corresponding harmonics, until their difference is such that the ear can distinguish each of the beating sources as a different note. It need hardly be pointed out that such a serious difference in engine speeds, corresponding to this note interval, would not be consistent with conditions of safety. Beats would undoubtedly add to the distress of the passenger, although he would be unable to estimate to what degree. It is more probable that variation of beats produces an even greater effect, such variation coming into evidence when the airplane alters either its height or its course.

The next source of sound to be considered is the airplane propeller. Without taking into account the translation of the airplane through the air, the instantaneous disturbances produced by the propeller must be repeated in their entirety in a periodic fashion with a frequency equal to that with which each successive blade passes through any given point. A disturbance of this definite frequency is thus produced at every point affected by the propeller, and their sum total will therefore be a disturbance of the same frequency and will not, in general, be of zero amplitude, since the distance between some of the points in question will not be small compared with the wave-length of the disturbance. Now if we combine with this the motion of the airplane with its propeller source through the air, and with all the complications of moving medium due to slip stream and to the various local obstructions, the disturbances at a given point in the neighborhood of the cabin are very complicated. As in the case of the sound from the exhaust, the propeller sound is extremely rich in harmonics, giving a complete series. This again can be discovered by appropriate instruments. Furthermore, the blades suffer from flexural vibrations in a somewhat complicated mode - a type of disturbance which can be overcome to some extent by increasing the rigidity of the propeller.* Such a condition might be realized by substituting metal for wood.

By way of illustration, we may take an engine giving 1,707 revolutions per minute, such an engine giving the fundamental and train of harmonics for its exhaust sound of pitches above quoted. A common gearing ratio for engine and propeller not directly coupled is about .6, so that the propeller revolutions would be 1,024 and the note frequency for the fundamental of the two-bladed propeller is about 34 vibrations per second. This note will be almost too low to distinguish by ear, but the fundamental and train of harmonics will be represented by the lowest C of the piano, C below middle C, G and C respectively.

*A. Fage, Proc. Roy. Soc., Vol. CVII, p. 451 (1925).

We thus get two series of notes which, when represented by the Helmholtz notation, would come in the following order:

Propeller	...	...	C_1
"	...	...	C
Exhaust	...	...	F
Propeller	...	...	G
"	...	...	c
"	...	...	f
Exhaust	...	...	f
Propeller	...	...	g
"	...	...	b
Exhaust	...	...	c^1
Propeller	...	...	c^1

It will be seen, therefore, that the higher harmonics give discords which, if the ear were capable of distinguishing pitch in the general din of airplane sound, would add a further contribution to the unpleasant effect.

When the airplane has a single propeller located in front of the fuselage the propeller sound is relatively less important owing to its greater distance from the passengers. When, however, two wing-engines are employed, a considerable volume of sound is projected on the walls of the cabin. As with the exhaust sounds, beats are produced by the propellers of the engines which are a little out of tune - beats between fundamental notes, beats of twice the frequency between first harmonics and so on. Figure 3 shows a microphone record of propeller beats between the two propellers of a Vickers-Vimy. The intervals between the two records in each diagram are respectively two minutes and three minutes, and it will be noted what a big variation in acoustical effect is indicated. When the engines are most nearly in tune the quality of the resulting sound shows most variation.

Of the other sounds, relatively unimportant but possibly noticeable because of their different quality, the following types may be mentioned.

As described by Dr. Richardson in his paper before the Society on March 31, 1927, the vortices produced by the stay-wires produce vibrations in directions perpendicular to the direction of travel. In service airplanes this is very noticeable, but with the modern civil aircraft, carrying several passengers, the stays are of such magnitude as to suffer only small displacements. Nevertheless, the anchorages of these wires, being so rigidly connected to the wings and fuselage, form a good means of conveying their vibrations to the cabin and the passengers inside.

Other audible disturbances are the medleys of impulsive sounds due to the tappets of the engine and the gearing, and there are also generated at every sharp edge, such as the pilot's wind screen and other projections, a hissing and a roaring noise to which it is difficult to assign any definite frequency.

This formidable collection of sounds, audible and sub-audible, must be further supplemented by including low frequency structural vibrations due to any out-of-balance condition of engine and propeller systems, and to vibrations set up in the cabin by shock excitation. The whole structure, subject to so little constraint, undoubtedly has natural frequencies of its own which would make for discomfort when in resonance with the above sources. In this matter magnitude and disposition of load as affecting cabin frequency is a consideration.

Here, then, is an impressive catalogue of nuisances from which it is necessary to protect the passenger.

Let us now consider what that protection is.

Here the practice varies somewhat. It must, of course, be understood that the walls of the cabin must be of light material, as weight is so important a factor in the economic running of the service. Some of the cabins have more substantial walls than others. An outer skin of light three-ply wood would appear to the casual observer as a more efficient obstacle for sound than the extremely light fabric walls of some of the airplanes employed in cross-Channel traffic. On the rigid framework of the cabin, in solid and rigid contact with all the above-enumerated sources of sound, there is an outer skin of doped airplane fabric - capable of reflecting, it is true, a large amount of sound, but constituting, by its flexible properties and its strained condition, an efficient secondary source of sound. The inner lining of regoid or some such material is scarcely less capable of transmitting disturbance, and it is obvious on inspection that apart from the more rigid floor of the cabin the most efficient obstacle to sound is the window, whether of glass or of some preparation of celluloid, such as celastoid. One very fruitful medium for transmitting vibration is the emergency exit. In the "Argosy" type of airplane two of these are provided. They consist of diaphragms of translucent paper or similar material stretched in such a way as to produce a good musical note when tapped. Such membranes recall the experiments of Regnault and others who employed the device for a sensitive detector of sound. Had they been placed in the walls of the cabin instead of the roof, they would have been still more effective for transmitting sound to the passenger. Further examination of the cabin shows that it bears in its framework, and in rigid contact with it, the exhaust pipes of the central engine, thereby ensuring the maximum conveyance, by conduction, of the explosion disturbance. Surrounding a portion of the exhaust pipe is a hollow jacket by which warm air is injected into the cabin. This air inlet, so fully excited by the exhaust explosions, constitutes a veritable organ pipe opening into the cabin. As a heating device it is simple and apparently highly efficient, but it certainly adds to the many disturbances which we wish to eliminate. Wherever an opening occurs, either by ventilator, open window or illfitting door, sound pours in. It would appear, therefore, that the modern cabin, showing wonderful economy in weight and in running costs, is very ill adapted for adding to the amenities of travel where noise is concerned.

A simple experiment can be shown to illustrate the sound-screening effect of various cabin walls. Three skeleton cubes of seasoned wood having two-foot edges are employed to make an enclosure by covering their faces with one of three materials:

(a) Glass.

(b) Three-ply wood.

(c) Airplane fabric as an outer layer and American cloth within.

One cube face is left open so that the cube, so produced, can be employed as a kind of bell jar, its open end capable of resting on sand in a large wooden tray. Underneath the cube, and resting on a felt pad in the middle of the tray, a ticking metronome is placed in order to form a source of sound. For the purposes of demonstration the conditions are a reversal of those given by the airplane cabin. The source of sound is here put inside the cabin, and the passengers outside it are the members of the audience. The very marked difference in behavior of these screening enclosures is obvious to the ear. Another simple experiment illustrates the opening of a window as an effective means of letting in sound. A cubical box made of mahogany 3/4 inch thick, supplied with a sliding window also of wood, constitutes the airplane cabin. The metronome is placed on a felt pad in the box and the window can be opened to allow the sound to get to the audience - as before the passengers in the model experiment. The very marked changes in audibility show themselves most when the box is just opened.

It is interesting to note that these experiments which are apparently convincing, are actually very misleading, but they have been shown by way of emphasizing an important principle. While it is true that for impulsive sounds, or sounds of limited duration such experiments are effective, for continuous sounds they cease to be valuable, nor can the relative positions of source of sound and passenger be safely interchanged to give a correct idea of what takes place. It must be remembered that the open window, an efficient inlet, is also an equally efficient outlet, and that the effectively screening three-ply is an equally effective reverberant material, so that sound trapped in such an enclosure will build up by reverberation until the energy conditions inside and outside work towards equality. In this argument one qualifying factor is assumed, that no acoustical energy is converted into heat within the substance of the walls of the cabin itself. In order to explain the phenomenon of sound within and around the airplane cabin, it may be fruitful to consider an analogy first propounded by Prevost in 1792 to explain the transmission and distribution of radiant heat. In his famous "Theory of Exchanges" he associated with every body above the absolute zero of temperature a power to radiate heat, which power was independent of the output of other bodies in its neighborhood. A flow of radiant heat was only supposed to pass from bodies at higher to those of lower temperature. Prevost* opened a Profit and Loss account, in which the actual transfer of heat was the balance between the two. Exchange of radiation would proceed until in any given region equilibrium of temperature occurred. This equalization of temperature would endow the surface of every radiating body with a power to return a quantity of heat to the radiating surfaces in its vicinity independent of the nature of the surface of that body. By way of illustration, a black surface is a 100 per cent radiator - a polished surface a 100 per cent reflector, and a perfectly diathermous surface a 100 per cent transmitter permitting those surfaces, behind which may be radiators or reflectors, to send back unobstructed their 100 per cent of radiation. Or we may endow these surfaces with capacities for radiating, reflecting and transmitting totaling to 100 per cent, so that all the radiation received is returned to the outer radiating surfaces. Thus a thermometer bulb, made of any material whatsoever, placed in an enclosure at constant temperature will take up the temperature of that enclosure. The walls of the thermometer may be poorly conducting and may be ample in their reflecting properties, but ultimately equilibrium will be realized, though some time may elapse before the operation is complete.

*Dictionary of Applied Physics, Volume IV, p. 567.

Now let us suppose an ideal case in which the region surrounding the cabin of the airplane is so uniform in acoustic radiation that, to the ear or other competent instrument, the intensity of the sound appears to be uniform. One can imagine a property of sound analogous to temperature and can formulate a principle that this property, a kind of acoustical potential* - is such that sound will pass from a region of higher to one of lower acoustical potential until such potentials are equalized. The walls of the airplane cabin receiving intense disturbance on all its surfaces in equal measure will arrive at a state in which they will return an equal amount of radiation to that received. If the walls are non-reflecting and non-absorbent, they will transmit all radiation and will equally transmit back all radiation received by surfaces within the cabin. If the walls are capable of being set in vibration they will, again, if non-absorbent, act like lampblack in the heat radiation case and radiate back the energy they have received. So far the analogy seems to be satisfactory. In Prevost's presentation of the theory, however, it was assumed that the surfaces were such that no changes occurred other than thermal - for instance, no chemical change occurred as the result of thermal radiation, so that heat energy might be continuously absorbed and stored up as chemical energy. Even so, chemical changes would ultimately become complete, when Prevost's theory would ultimately hold. In the acoustical problem, however, the ultimate form of energy

*Not to be confused with "velocity potential."

as the result of viscous forces damping out vibration, will be heat - which can itself continuously radiate away. For this reason the above qualifications are made, that the materials exposed to the sound should be non-absorbent. Thus within an airplane cabin lined with sound-absorbent material the acoustical potential would always be lower owing to this conversion into heat which takes place within the material.

Now let us illustrate this principle by some numerical examples. We will make an assumption at the outset that the material of the walls of the airplane cabin can be expressed as being equivalent to a certain proportion of open window, which is a perfect transmitter of sound, and a certain proportion of perfectly reflecting material. If sound absorption is negligible these two proportions should add up to the whole of the material employed.

Thus as a first approximation three-ply reflects 97 per cent and transmits about 3 per cent of sound with negligible absorption - it would have 3 per cent of open window equivalent. Special measurements of the properties of airplane fabric and American cloth combined (as in the airplane cabin of the "Argosy") give reflecting power of 51 per cent and, neglecting absorption, transmitting power of 49 per cent - so that it would have an open window equivalent of 49 per cent.

We will suppose the windows of the cabin to be of glass - this has an open window equivalent of 1.5 per cent. All these values are obtained for a frequency of 512, which is a good average frequency for audible sound.

Suppose the cabin to be of dimensions of the "Argosy" type of airplane, and for the sake of simplicity, suppose the floor and ends to be non-transmitting, as they nearly are.

The area of the flexible walls of the cabin, supposed to be of the nature above described amounts to about 485 sq.ft. This has an open window equivalent of 238 sq.ft.

The area of glass window is 70 sq.ft. and the open window equivalent for the whole of this is 1 sq.ft.

Hence the total open window equivalent is 239 sq.ft. If Q, therefore, is the amount of radiation per second entering 1 sq.ft. of open window, the amount of sound entering the cabin is 239 Q.

Now imagine the flexible walls to be replaced by three-ply wood. Under the same conditions with an area of 485 sq.ft. there is now an open window equivalent of 14.5 sq.ft., and the glass windows remaining as before we get a total of 15.5 sq.ft. open window, and the sound admitted is now only 15.5 Q.

Hence the flexible walls admit 15.4 times the sound admitted by the more rigid three-ply walls. But this does not represent the acoustical conditions inside the cabin.

It has been shown by Sabine that the sound admitted into such an enclosure will produce reverberations which will build up to a maximum, and an expression has been obtained by Jäger* for the rate of growth of sound within such an enclosure.

If E is the energy of sound per unit volume in the cabin,

A the sound energy emitted per second by the source,

V the volume of the enclosure,

v the velocity of sound,

a the average absorption coefficient,

and s the area of the walls,

then the maximum value of sound energy per unit volume being E_o, the value of E after time becomes

$$E = E_o (1 - e^{-avst/4v})$$

and that under these conditions

$$E_o = 4Q/avs$$

the sound admitted into the cabin will be trapped, so to speak, and will take time to die away - in the meantime sound is pouring in at a steady rate, so that the actual sound within the cabin, when in a steady state, is the sum of that entering, and those contributions from the sound entering earlier, which as time proceeds get fainter and fainter at a rate depending upon the transmitting power of the cabin walls. (It must be borne in mind that the illustration does not assume absorption in the walls.)

Now we get an expression for the ultimate energy of the sound within the cabin E_o in the two cases.

*Akad. Wiss. Wien. Ber., 120, 613, 1911.

Case I.- Cabin with flexible walls:

$$E_o = 4 \times 239\ Q/as\ v$$

as is the open window equivalent since

a, the absorbing power of open window is considered unity.

$$E_o = 956\ Q/239\ \ v = 4Q/v$$

Case II.- Cabin with three-ply walls:

$$E_o = 4 \times 15.5\ Q/15.5\ \ v = 4Q/v$$

From this illustration therefore under the ideal conditions quoted in the problem, no advantage is gained by substituting three-ply for the flexible material if the cabin is

(a) empty,

(b) non-absorbent,

(c) in a region of uniform sound intensity.

Now we will assume that we fill the cabin with 18 passengers. Sabine has obtained by experiment the average absorbing power of individuals in an audience. His values were for a frequency of 512 which has been taken as an average frequency throughout this illustration. He found that each person produced a sound absorption equivalent to 5.35 sq.ft. of open window, making a total of open window equivalent of 96.3 sq.ft. The amount of sound absorbed by the passenger is lost and is converted into heat causing a reduction within the cabin of acoustical potential.

If $E_{(f)}$ is the sound energy inside the cabin of flexible walls,

$$E_{(f)} = 956\ Q/(239 + 96)\ v = 2.85\ Q/v$$

If $E_{(r)}$ is the value for the more rigid three-ply walls

$$E_{(r)} = 62\ Q/(16.5 + 96)\ v = 0.556\ Q/v$$

hence under these conditions

$$E_{(r)} = 0.19\ E_f \text{ (about 1/5)}$$

Here, then, is the very marked advantage resulting from using a cabin of three-ply.

Let us suppose further that we line the two cabins with Balsam wool, a very light, but highly absorbent material, whose coefficient has been found to be .48 of open window.

We have an area of surface including all that occupied by the flexible material (ignoring the emergency windows) amounting to 239 × .48 sq.ft. of open window = 115 sq.ft. Substituting in the above expressions

E_f becomes $956\ Q/(239 + 96 + 115)\ v = 2.13\ Q/v$

and E_r becomes $62\ Q/(15.5 + 96 + 115)\ v = 0.274\ Q/v$

so that $E_r = 0.13\ E_f$ (about 1/8).

It will be noted that in lining the cabin with Balsam wool no allowance has been made for thereby decreasing the transmitting power of the walls. No data are as yet available for this, but it may be noted that this quantity would reduce the numerator in the expression $E = 4A/asv$ so that the value above quoted is a superior limit of the sound in the cabin, and this quantity must be multiplied by the factor expressed as a fraction of unity, corresponding to the transmitting power of the material used.

Additional advantage may also be obtained by covering the floor of the cabin with a carpet. One of medium weight with a good pile would have an open window equivalent of 25 per cent. The floor area is about 150 sq.ft., so that the open window equivalent is 37.5 sq.ft. and the values of the acoustical energies with this additional provision becomes $E_f = 1.96\ Q/v$ and $E_r = 0.22\ Q/v$.

A further advantage is therefore shown by the rigid cabin, the sound being now 1/9 that in the one of flexible walls.

The final condition therefore is that the sound within the cabin has been reduced by sound absorption to 1/19 its value for an empty non-absorbent cabin.

The effects of lagging the two types of cabin is clearly brought out by the diagram (Fig. 4). Here it will be seen how the two empty cabins, supposed empty and non-absorbent, start with equal acoustical properties and how by lagging with different sound absorbents advantage lies with the cabin having poorly transmitting walls.

Further qualification must be given to the above results in so far as the acoustical conditions surrounding the cabin are not uniform, and it is certain that the roof of the cabin would receive less acoustical radiation than the walls. Here again the numerator would be reduced without affecting the denominator and the above conditions of screening give rather higher values for the intensity of sound within the cabin than actually would occur. It must also be stated that transmitting and absorbing powers are quoted for a frequency of 512 vibrations per second - a frequency for which all the coefficients are known. The values for the lower frequency hums which are so prominent should be reduced for transmission in wood, and would also be reduced for absorbing power, but in a less degree. These again tend to give a lower value for the amount of sound in the sound-lagged cabin. In all these approximations quoted, therefore, the ultimate state of the cabin treated in the above manner and indicating a reduction in sound over the non-absorbent cabin as 1/19 is a minimum reduction. A value of about (1/20) is a reasonable one to work on. In order to convert the "Argosy" cabin from its present condition to one giving this reduction of sound involves an extra weight in three-ply of about 280 pounds and with its lining of Balsam wool, an extra 120 pounds, making 400 pounds extra weight in all.

A further consideration in adopting a three-ply wall rather than fabric is derived from the work of Sabine who showed that the time taken for a sound to build up in a room was inversely proportional to its total absorbing power, i.e., its open window equivalent. Taking the empty and non-absorbent cabins of flexible walls and three-ply walls respectively - the sound takes

239/15.5 = 15.4 times as long for a three-ply cabin to build up to its maximum as for a cabin with flexible walls - hence momentary impulsive sounds only produce a small effect.

This explains why, in a reverberant office, closing a window will give relief from short period harassing noises.

Lagging a cabin for sound absorption will reduce reverberation, and sound will build up to its maximum more quickly. The ear will get a more truthful reproduction of any change in an external source, but the observed intensity will also be reduced in the lagging to so great an extent that it will cease to be a nuisance to the observer inside.

Now let us consider the passenger as the receiver of this disturbance. It may be stated at the outset that the amount of sound his ears will receive will give him a sense of discomfort. The well-known curve of Harvey Fletcher* showing the limit of auditory sensation and the sensation of feeling - "the discomfort line," so to speak, anticipates sounds of such magnitude that exposure to them is painful. It is difficult to say what proportion of all the constituent sounds above referred to come in this category. The passenger tends to lose sense of pitch, but is probably most conscious of the very low frequency hums of the propeller and the lower notes of the exhaust. According to Mayer** these low notes will exert a masking effect on the

*Journal of the Franklin Institute, 193, p.720, 1922; and 196, p.289, 1923. Journal of the Royal Aeronautical Society, 28, p.504, 1924.

**Phil. Mag., Vol. II, p.500, 1876.

higher frequency sounds, and although Wegel and Lane* do not support Mayer's theory for the weaker sounds, they admit that such masking does occur for sounds of great intensity. That the high frequency sounds are not absent is abundantly shown by a very simple experiment. If the listener cups the palm of his hand over his ear, so that he makes an opening between one edge of his hand and his head he makes a resonator which he can tune by altering the size of the opening. Sounds of frequency from 250 to over 1000 vibrations per second can thus be amplified. As tested in the "Argosy" cabin, so great is the magnification produced that these higher frequency disturbances rise to a scream in the ear, and can themselves become deafening.

The masking effect of the low frequency is thus overcome. Variation of this resonating cavity does not reveal any sounds of predominant frequency, but it is evident that there is abundance of high frequency sound and that the general effect on the auditory nerves is compound of that of all the frequencies, so that it is difficult to say to what degree each is responsible for the general discomfort. My own impressions are those of discomfort from the low-pitched sounds coupled with that intermittency in loudness which is due to beats.

A very useful protection is afforded by the cotton wool plug supplied by the Imperial Airways Company. Here, the absorption is most definite in the high frequencies. A complete block-

*Wegel and Lane, Phys. Review, 23, Series 2, p.266, 1924.

ing of the ear passage can be produced by small spherical pellets made of ivoroid or similar material, by which all sounds should be reduced without reference to frequency, but there is not so much comfort, and objection might be made on hygienic grounds.

A very fruitful source of disquietude to the inexperienced traveler is the production of the beat and its variation (Fig. 2). Such a passenger, subject only to constant disturbance would, no doubt, gradually accustom himself or herself to the sense of being deafened, and would have no anxiety as to the movements of the airplane. But when the engines get out of step, so that they alter their beats from say, 1 in 5 seconds to 2 a second, the enormous change in the sound effect cannot but attract attention. If the engines could, by any means, be synchronized or be kept running constantly though at different speeds, that source of discomfort would be removed. We have, as yet, no experience of the effect on the nervous system of intense low frequency disturbance, and although the variation of beats may cause mental disquietude - it is conceivable that slow beats of uniform frequency may cause an effect also. Our own bodies with their systems of blood circulation, are subject to periodic disturbance due to heart action. The projection of the blood from the heart gives the body a definite periodicity, and it is conceivable that the vibrations due to intense beats of frequency, equal to, greater or less than that of the heart beat can exert an intensifying, an accelerating or a retarding influence on this operation. Investigations on these lines might be of interest to the physiologist or the pathologist.

One other effect must not be ignored. The whole structure of the airplane cabin is in a state of vibration of lower frequency, a vibration that can be felt but not heard. Such disturbance can be communicated to the brain via the feet, or by any part of the body in contact with the vibrating surfaces. The psychological effect of this continuous vibration must not be ignored. Tribute, however, can be paid to the cabin furnishers, whose seats are well designed to minimize this effect. The cushions in the "Argosy" are such as to reduce jarring and vibration to a minimum, although disturbance will be transmitted through the feet.

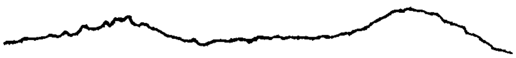
A few words must be said about the power of the listener to judge of any effect produced by silencing engine or cabin. It has been stated that auditory sensations can be expressed as logarithms to base 10 of the intensity values, so that regarding 10 units of intensity as 1, 1,000,000 units would be expressed by the number 6. In a former paper to this Society* I referred to the work which had been done on this subject. All that need be said in this connection is, that unless the effect of sound absorbents is very drastic, one is apt to be disappointed with the result.

*Journal of the Royal Aeronautical Society, 28, p.504, 1924.

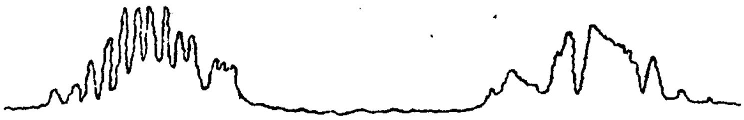
In the case above quoted, where cabin sounds could be reduced to 1/20 by sound lagging, it is of interest to compare by ear the relative intensities of sources which bear the ratio of 1 to 20. A loud-speaker can be set up, whose output can alternately be made of intensities 1 and 20 units, and it will convey some idea of the improvement to be expected. This experiment, carried out in a room, requires members of the audience to be still while these successive sounds are produced. The movement of any one member will alter the distribution of sound in the room to such an extent that no single individual can make a true aural comparison. The conduct of this experiment involves a new process of calibrating microphones due to Dr. E. T. Paris and by using microphone control a very accurate ratio can be given.

(To be followed by Technical Memorandum No. 473, Part II.)

Fig.1 Record of airplane sound range 600 ft.Taken in flight.



I.Engine revolutions differing by 60 per minute.



II.Engine revolutions differing by 12 revolutions falling to 1/2 revolutions per minute.

Fig.2 Records of beats produced by a Vickers Vimy airplane, equipped with two Eagle VIII Roll's-Royce engines.

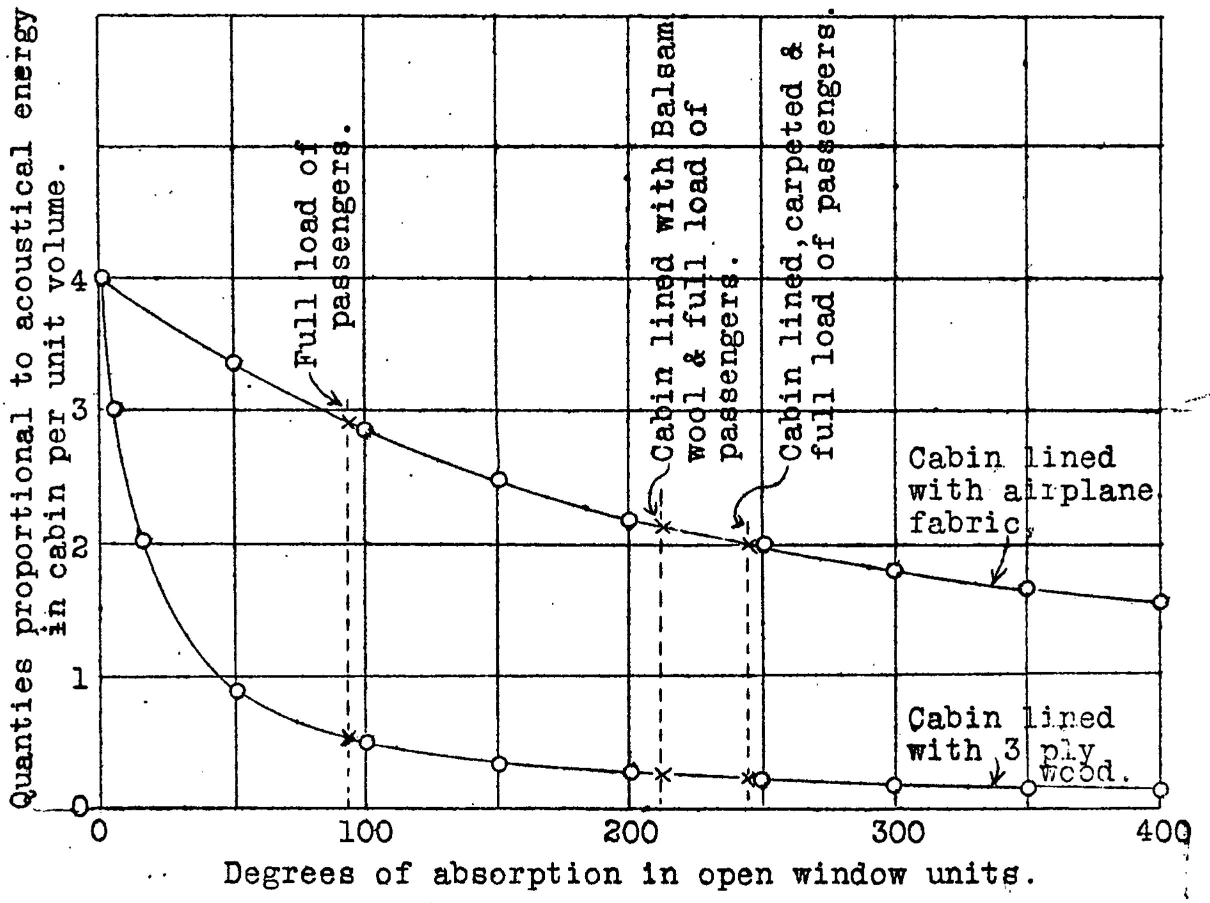


Fig.3 Acoustical conditions within an airplane cabin with dimensions of the Argosy type. Imperial Airways.

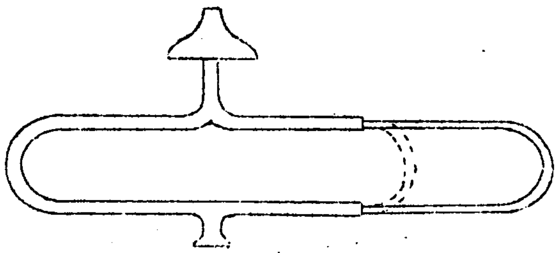


Fig. 4 Quincke's apparatus to illustrate principle of elimination of the odd harmonics in engine exhausts.

TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 473

THE PROBLEM OF NOISE IN CIVIL AIRCRAFT AND THE POSSIBILITIES OF ITS ELIMINATION

By W. S. Tucker

PART II

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL MEMORANDUM NO. 473

THE PROBLEM OF NOISE IN CIVIL AIRCRAFT AND THE POSSIBILITIES OF ITS ELIMINATION.*

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PART II

Silencing of Engines and Discussion

The silencing of engine exhaust for airplanes has had a certain amount of attention, but from my observations on the aircraft at Croydon and elsewhere, I have seen no serious attempt to employ anything effective. The problem is very difficult owing to the increase of weight involved, together with possible decrease in power. Only partial silencing can be realized with so complex an exhaust pipe system as that employed.

Two types of silencer may be described, although neither has come into effective use in aircraft. The first works on the principle of baffling the escaping gases so that pressure changes resulting from the escape of high pressure gases are made more gradual at the mouth of the exhaust pipe. This is accomplished by the introduction of baffles or by causing a succession of breaks in continuity in the cross section areas of the exhaust pipe system. An effective silencer for a marine engine of this type is described in Engineering, April, 1921, but its weight is quoted against its adoption for small craft.

*From The Journal of The Royal Aeronautical Society, March, 1928, Vol. XXXII, No. 207. For Part I, see N.A.C.A. Technical Memorandum No. 473, Part I.

How much more valid would such an objection be when applied to aircraft! A very simple one is, however, employed to a limited extent especially in airplanes employing "wireless." In this case the open end of the long straight exhaust pipe is sealed up, but the wall is perforated by small holes through a considerable proportion of its length giving in the aggregate a more than sufficient outlet. It is claimed for this system that it enables the wireless operator to work in wireless reception over much greater ranges, owing to the reduction of disturbing noise when listening in telephones. The chief objection to such baffled silencers is loss in horsepower, but in this case such loss is estimated as a fraction of 1 per cent of the total.

Another type of silencer put forward by Whately Smith and described by Hooton* depends on the principles of interference. Here the baffling effect is negligible.

If the exhaust pipes of the two banks of engines be connected together so that the gases can escape by a single vent, there will be elimination more or less complete of the fundamental note, together with the 2d, 4th, and even harmonics. As already stated, the explosion fundamentals from the two exhaust pipes are 180° out of phase, so that there would be destructive interference of the two sounds. The same applied to the above harmonics. The absence of fundamental in the engine

*Hooton, The Engineer, June 9, 1922.

sounds for all the engines results in the elimination of the beats between these sounds. The slowest beats, which may be the most prominent, are thus got rid of for exhaust sound only, as also those of the harmonics referred to.

Further elimination of exhaust sound has been suggested for internal combustion engines of this type, which make use of an interesting experiment of Quincke's, to show destructive interference of sound. An effective demonstration of this case can be thus given. A diaphragm set into vibration by an electrical acoustic oscillator produces a sound of frequency 512 per second. The diaphragm closes the end of a short tube, which divides two lateral branches as shown in diagram (Fig. 4), the branches combining again at a common exit. One of the branches can be extended so that the length of path between diaphragm and exit can be lengthened. Sound passing along the two equal branches escapes at the exit tube with full intensity - the contributions of the two branch pipes being equal both in phase and intensity. On lengthening the pipe, however, by half a wave length of the sound, the two components are of opposite phases and the sound is destroyed. The same effect is produced on sounds of wave lengths 1/3, 1/5, and 1/7, etc., of the above values, since these conditions of phase difference are again realized. Applied to the common exhaust pipe above referred to, a contrivance of this character will eliminate a great deal of the sound which has not already been destroyed by the simple operation of combining the two exhaust pipes as above described.

Enumerating the various exhaust sounds quenched in this manner it will be seen that the operation of combining the two exhaust pipes at their open end eliminates the fundamental F_1, the second and fourth harmonics, etc., c^1, a^1, etc., and the effect of introducing the branched tube is to destroy the first harmonic f and the fifth harmonic c. One more important harmonic the 3d still remains and this again could, if necessary, be filtered out by the employment of a second branched tube of appropriate length.

The only difficulty in this operation is to choose the correct length of branched tube, which depends on the temperature of the issuing gases and can only be found by trial. The method further assumes that the engine revolutions are constant, for the silencing fails for the branched tube if the note alters.

One of the chief disabilities of the passenger is that of being unable to converse; in fact, so great is the disturbance that he cannot hear his own voice. Various attempts have been made to render intercommunication possible. Employment of electrical methods using telephone transmitters and receivers involve the use of special equipment including a flying cap fitted with telephones. To leave the mouth free, the ordinary transmitter may be replaced by a laryngophone - which is a transmitter fastened to the neck near the larynx. This instrument, however, has shown itself to be on occasion insensitive, or incapable of giving good articulation.

For passengers making occasional trips, and not wishing to wear the harness of the electrical devices, a much simpler device is the ordinary speaking tube. One of this type was employed by passengers during cross-channel flights on the Imperial Airways "Argosy," on October 14, and 16, 1927, and was very favorably reported on. On this occasion two separate tubes were employed bound together. Although very little sound losses resulted when speaking, the passenger suffered through not being able to hear his own voice, and as a consequence, almost invariably spoke too loudly. This device has been replaced by a single tube with each end terminated by a mouthpiece and earpiece, so that the passenger can hear himself and modulate his voice correctly. It is found that conversation can be carried on by the voice speaking more quietly than under normal conditions. The tube is made of aluminum spiral, rubber sheathed and silk braided, and is extremely light and flexible.

So far this paper has dealt with the most recent type of aircraft, the "Argosy." Reference, however, must be made to an exhaustive study of noise conditions in various types of aircraft by Mr. Whately Smith, on behalf of the Air Ministry. Journeys across the channel were made on three Handley Page airplanes, the W.8, the "Hamilton" and the "Hampstead"; and the De Havilland airplanes D.H.34 and D.H.50. The cabins of these yielded varying amounts of noise. One feature of the investigation was the employment of stethoscope sounding devices, by which variations both in walls and structure were located and qualitative observations were made on the character of the sound. A similar device has been described for locating noises in car engines by Noel-Storr.* It is unfortunate that no instruments have been produced which can in any way measure acoustical effects over the ranges of sound affecting the ear. Those which have been put forward by Webster** and others either do not lend themselves to employment in aircraft or give spurious and most misleading effects due to resonance. In the investigation above referred to, various recommendations have been submitted, some of which have been enumerated in this paper. In addition, considerable importance is attached to the insulation of the airplane cabin from the engine sounds by the employment of shock-absorbing washers consisting of pads of rubber, mascolite, or various felt preparations. Recommendations of this sort are put forward with some diffidence, because of the necessity for safe and rigid construction.

In conclusion, it must be stated that unless some completely new method be used for generating power, and of moving the airplane through the air without the aid of propellers, the passengers cannot be provided with journeys free from a certain amount of noise. So complex is the source, so various are the methods whereby its disturbance reaches the passenger, that no

*Noel-Storr, "Silencers for Marine Engines," Engineering, April, 1921.
**Webster, Nat. Acad. Sci. Proc., 5, 173, 1919.

single drastic and perfectly adequate specific can be suggested to cure the evil.

The improvements above suggested will each afford some relief, and those of immediate use include the treatment of the cabin with sound absorbent materials. Whether we silence the engine, lag the cabin walls, insulate the cabin, or introduce some ventilating system which does not give sound-free access to the interior of the cabin, every specific for reducing sound means some addition to the load and increase in running costs. Nevertheless, it is submitted that the amenities of air travel may be so greatly improved, that any attention given to the various points referred to in the paper will be more than justified.

Some of the investigations on the subject of Cabin Silencing referred to in this paper, have been carried out by the Acoustical Section of the Air Defence Experimental Establishment, with the aid of funds provided by the Department of Scientific and Industrial Research.

The author also wishes to acknowledge help from Dr. E. T. Paris and Mr. Whately Smith, to both of whom reference has been made.

D i s c u s s i o n

Mr. H. E. Wimperis (Director of Scientific Research at the Air Ministry) said that the problem of attaining silence in civil aircraft was one of the most baffling that any man could undertake to solve; there were so many sources of sound, and so many resonators. It was true that in certain conditions sounds could cut themselves out. The rather elaborate calculations made by the very ingenious method illustrated by Dr. Tucker had indicated that under certain conditions it was possible to reduce the sound by something like 95 per cent. That sounded a most hopeful estimate. He was not quite clear, however, whther the user, or series of users, who had had experience of the effects of this reduction by 95 per cent had really given the method a clean bill of health. Had this theoretical figure of 95 per cent really been borne out in practice, not from the experimenters' point of view, but from the point of view of the users whose pleasure the experimenters tried to serve? No doubt Dr. Tucker could recall many instances in which users had expressed satisfaction, but his modesty so far had prevented him from proclaiming them. He asked Dr. Tucker, however, to drop that modesty as far as he was able. Finally, he said that he imagined the ideal would be for Dr. Tucker to have placed at his disposal an airplane large enough to carry him and his staff, as well as his apparatus - his existing apparatus was remarkable, and much of it was due to his own inventive genius - so that he could carry out his experiments under actual flying conditions, as well as on the ground. Dr. Tucker ought to have such a flying laboratory; he (Mr. Wimperis) was trying to get him one, and believed he would be successful. All he asked was that Dr. Tucker should return the laboratory in perfect condition when his experiments were concluded.

Major F. M. Green said that Dr. Tucker had examined the conditions that occur inside the cabin. He had shown conclusively that in order to minimize inside the cabin the effect of a noise outside, it was better to use reflecting walls such as three-ply or glass rather than fabric walls. Dr. Tucker also pointed out that the noise inside the cabin might be caused by vibrations transmitted from the rest of the airplane. Is it not possible that for noise caused in this way rigid walls might be very much worse than the fabric walls? The present tendency in motor cars is to cover saloon bodies with fabric and not with metal panels, and it is generally supposed that as a result the car runs more quietly. The noises in a car come partly from the engine and transmission and partly from the vibration caused by the bumping of the wheels over the ground. It is quite possible that in the car the noises caused by bumping are more important than engine noises, because engines are generally well silenced, and that may be the reason why Dr. Tucker had attached more importnace to the external noises in an airplane than to the vibrations coming from the engine and airscrews into the cabin.

Mr. Mealing said he had been asked by Sir Sefton Brancker (Director of Civil Aviation) to express his regret that he was unable to attend the meeting, and to emphasize the importance he attached to the subject of eliminating noise. With regard to

Major Tucker's statement that one could not secure a decrease of noise without bringing about an increase in weight, he pointed out that if the weight of the airplane were increased, the pay load was decreased. The success of the commercial machine depended very largely upon its pay load, and the effect of reducing the pay load of such an airplane, therefore, would appear to be very serious. At the same time, all who were concerned with the management of any form of transport service were learning that the comfort of the passengers must be one of the first considerations. That applied to airplanes as to other forms of transport, and it seems necessary, therefore, that working on those lines some part of the pay load will have to be sacrificed to the comfort of the passengers. Aircraft designers of the future are asked to remember that point very carefully indeed, in the interests of flying generally and of all concerned.

Dr. A. H. Davis (National Physical Laboratory) sympathized with Major Tucker in having to deal with such a difficult subject, for it seemed to him that in aircraft one experienced the maximum production of noise and the minimum facilities for suppressing it. Discussing the merits and demerits of canvas and three-ply wood in the construction of a cabin, he said that although canvas would be transparent to sound, it might not "drum" so readily as three-ply wood, and he asked Major Tucker whether, if three-ply wood were substituted for canvas to reduce the noise coming through the air, there was likely to be any appreciable increase of the noise arising from the structure.

Wing-Commander T. R. Cave-Browne-Cave expressed surprise at Major Tucker's conclusion - which, of course, he would not presume to contradict - that the exhaust was the most serious offender. He asked how many of those present had had the dual experience of hearing an airscrew being spun by an electric motor, the motor being to all intents and purposes silent, and then hearing an engine in a test house, on the Froude brake, which was silent. His own impression was that the airscrew was by far the more noisy factor. One fact which supported this view was the marked extent to which the noise emitted by an airplane was vectorial; there being great difference between the maximum when one was within the plane of the airscrew and the minimum when one was in the direction of the axis of the airscrew. Did not the fact that the noise one heard depended so much upon one's position in relation to the airscrew indicate that the airscrew was perhaps the worst offender?

Dr. Richardson, referring to the possibilities of insulating the cabin from the low-frequency vibrations - the vibrations which were actually transmitted along the cabin, the exhaust pipe, and so on - and the difficulties mentioned by Major Tucker in regard to the insertion of a soft material between the layers of the structure, inasmuch as that would reduce the rigidity of the structure, asked if it would not be possible to use rigid but discontinuous material for that purpose. He suggested, for instance, the use of layers of material such as used in the foundations of buildings for insulating them from vibrations. Discontinuities could be provided for by fixing bolts both from the inside and the outside of the structure, the bolts being of such a length that they would not penetrate the full thickness of the material.

Mr. F. Handley Page said that the paper was a valuable one on a subject which must be dealt with if we were going to make civil aviation a success. He personally considered that one of the great drawbacks to civil aviation was the tremendous amount of noise and discomfort which a passenger has to put up with - and the passenger generally paid double the amount of the first-class railway fare in order to do so. On various occasions, when traveling as a passenger between London and Paris, he had made many observations as to the effect produced upon a passenger when sitting in different parts of the cabin. In a twin-engined airplane, when seated in the cabin between the two propellers, one experienced a difference in beat between the two engines, which resonated, causing a drumming sound, producing a headache which persisted for a long time. If one sat farther back in the cabin, where there were no exhausts from the engine, one invariably found that the noise persisted most in the ear on the side nearest to the engine; i.e., if one were sitting on the right-hand side of the cabin the noise would persist the longest in the right ear, and would probably persist even to the next day.

If, on the other hand, silencers were provided, and were carried back well behind the rear of the cabin, one would not experience much trouble, and within an hour or two after alighting all the trouble would have passed away. If one traveled in the cockpit, particularly if Napier engines were used, one found that the gears screamed loudly, and gave off a shrill note, which would cause very acute discomfort, even if the ears were wadded with cotton wool. He had noticed the same effect, though to a lesser degree, in a twin-engined airplane using Rolls engines; in that case the note was lower. It seemed to him, therefore, that a good deal of work might still be done in endeavoring to reduce the mechanical noises from the engine, which noises one would be quite certain to notice if they occurred in a motor car which was driven at a slower speed, was provided with adequate silencing, and had no propeller. The first thing to be tackled, he considered, was the question of gears. When the note was low in the gears, the beat which occurred in the propeller sound intensified, and one was apt to notice that more than anything else.

The question for Major Tucker to determine was how much horsepower coming out through the exhaust, and via the propeller on to the air, a human being could actually stand. If one were able to reduce the power installed in the aircraft per passenger, there would be less noise per passenger, and very much more comfort. Incidentally, the aircraft would be more efficient and, presumably, would pay better.

The only time when one really enjoyed flying, on the route to Paris, was when on a summer evening, if the pilot were thoughtful for his passengers, he would throttle down and fly at a height of about 50 feet along a part of the French coast where there was a long stretch of sand. One enjoyed comfort on such an occasion. Probably under those conditions the horsepower per passenger was very considerably reduced, and therefore the sound from the propeller and from the engine was also greatly diminished. He did not know whether Major Tucker, in the course of his experiments in his flying laboratory, would be able to find out with what lessened horsepower and with what diminished power from the engines he could ensure a fairly comfortable journey for his passengers. If he could do so, and could take that as a kind of datum line, he would then be able to find out whether aircraft designers could produce machines employing only that small amount of horsepower per passenger, inctead of continuing the unwarrantable misuse of engines which occurred at the present time, from the point of view of the comfort of passengers. That was a thing which might be looked into, and he offered it as a suggestion. In thanking Major Tucker for his paper, he expressed the hope that in the near future Major Tucker would be able to publish some further results of his investigations.

Captain W. H. Sayers thought that only a small proportion of the sound in an airplane cabin was radiated, and a large proportion was transmitted. He might be a little abnormal, but he could not sleep in most airplanes to-day, and undoubtedly that fact was due to the vibration transmitted through the structure of the airplane. With the long exhaust pipes used to-day, he did not think the exhaust beat would worry the passengers very much.

Dr. Thurston said it seemed to him that the problem of noise in airplanes should be considered from two points of view - the comfort of the passenger, and the effect on the person on the ground. Dealing with the matter from the point of view of the comfort of the passenger, he pointed out that in the most silent type of motor car to-day great care had been taken to isolate the saloon from the chassis. In the case of the Gordon England saloon - which he believed was the most silent of all - the saloon was isolated from the chassis except at three points, so that there was no transmission of vibration from the chassis except at those three points. With regard to the radiant energy, or the sound which came through the air, the obvious thing to do for the comfort of the aircraft passengers was to insulate them as much as possible by using surfaces which would transmit the minimum of energy through them, but care must be taken to reduce the extra weight to the minimum. Dealing with the problem from the point of view of the person on the ground, he said it seemed a mercy, from a defense point of view, that airplanes did make so much noise. It was an ill wind that blew nobody any good. It was appalling to contemplate the difficulty of defending ourselves against aerial attack at night if the airplanes were perfectly silent. What was wanted, therefore, was not so much to reduce the noise as to shield the passengers from its effect.

Mr. C. G. Colebrook, comparing twin-engined and single-engined passenger airplanes, said that every twin-engined passenger airplane in which he had traveled had been extremely noisy, and he was skeptical whether one would be able to travel in real comfort even if the noise were reduced to one-twentieth its present intensity. The single-engined passenger airplanes in which he had traveled, on the other hand, were very comfortable, particularly the latest type, the D.H.61. It had a powerful engine - a Bristol Jupiter radial, of 450 HP. - and the degree of comfort attained inside the cabin was a distinct improvement on other airplanes with which he was acquainted. He asked whether Major Tucker considered that this was due to the fact that the engine being in the nose, the machine itself absorbed much of the sound, or whether the fuselage area itself cut off the sound from the cabin, or whether it was due to the use of an extended exhaust pipe, carried back behind the cabin, or to a combination of these causes. The marked difference between the noise of an engine on a wing or one in the nose of the fuselage suggested that the section of the fuselage between the engine and the cabin bulkhead was an efficient sound shield.

Mr. Whately Smith said that when he had carried out test flights in civilian airplanes the noises which annoyed him most were high-pitched screeches. He agreed entirely with Mr. Handley Page's remarks as to reduction gears, for he had definitely located an extremely irritating noise proceeding from the reduction gear of a Rolls engine on a W.8.b. Different people were affected by different types of sound, and designers of airplanes, when considering this question of noise, must cater for people of different temperaments and different sensibilities. The question of propeller sounds had been carefully studied, and was certainly taken into account by a conference at the Air Ministry which was considering the possibility of designing a specially quiet cabin. He agreed also that the structure of an airplane was liable to act as a sounding board in respect of noises issuing from the engines and propellers. Finally, referring to the method of construction of Weyman saloons for motor cars, he said that the use of fabric instead of metal panels was adopted, not for the purpose of reducing noise in the sense that Major Tucker was dealing with it, but because it was less liable to rattle and squeak after long service.

A Speaker said that the device brought forward by Mr. Mallock - with whom he had long been associated - for the purpose of ameliorating the effect of gun shock upon the ear had been the subject of experiment by the Air Ministry in cases where a great deal of the trouble was due to concussion on the side of the head, and not directly through the ear itself. While he agreed that the devices referred to by Mr. Tucker might be quite good, it seemed to him that the Air Ministry were on the right track in seeking to protect the whole of the ear and not merely the opening. He believed something advantageous would come out of the experiments.

Air Vice-Marshal Sir Sefton Brancker (communicated): The author does not touch on the question of metal construction. I would very much like to hear the author's views on metal walls for cabins instead of three-ply. I would suggest also that the author takes an opportunity of flying in the "Calcutta" as soon as she is in commission. Silence is such an indefinite statement that it is extremely hard to incorporate a demand for silence in the specification for a commercial aircraft. I do not think all the attention possible has been paid in the past to obtaining silence, but we are progressing, and, in my opinion, the "Argosy" is better than the W.8 and the W.10; and the "Hercules" is better than the "Argosy." I should very much like to hear a constructor's view on the possibility of "dulling" the sound and vibration which passes along the various members from the engine to the cabin.

The President asked Major Tucker if he proposed to carry out experiments for the mounting of engines by flexible means in order to insulate the engines from the structure of the airplane. He also asked if it was proposed to analyze the noises which passengers had to contend with in the cabin of an airplane. He also suggested that it might be possible, with the aid of the

Department of Civil Aviation, to arrange for Major Tucker to carry out tests on some of the foreign airplanes - as, for instance, on the Junker and Dornier metal monoplanes - because one often heard how superior in quietness some of the foreign commercial machines were to our own. The remarks which had been made with regard to the question of silencing reduction gears would draw attention to the possibilities of the slipper type of reduction gear, which was now being tried on a Jupiter engine, and which would appear to be more silent than any other type of gear normally in use.

Reply to Discussion

In reply to Sir Sefton Brancker, the W.8 is one of the five airplanes on cross-channel service 1925-6, which were tested and it was described as having the noisiest cabin of the group. Of the W.10 we have no experience. No reference was made in the paper to the question of metal construction for airplane cabins. In this case the screening is almost perfect, but the metal may be so thin as to act as a diaphragm in which vibrations are not so readily damped out as with the three-ply walls. A great deal depends on the lagging of the metal walls, which would overcome this disadvantage.

In reply to Mr. Wimperis, the case of silencing worked out mathematically was given by way of illustration, and does not produce the results of actual experiment. The conclusions arrived at, however, are perfectly sound as they are based on work of Sabine which has been checked experimentally.

The application of the principle described to civil aircraft has not been possible, requiring, as it does, exceptional facilities which have not been available. As Mr. Whately Smith pointed out, recommendations were put forward by us at an A ir Ministry conference, and it is believed that these have been incorporated to some extent in the construction of a new seaplane - the "Calcutta." The new "flying laboratory," which it is hoped will soon be available, would serve for the testing of any new instrument for measuring noise, and when such an instrument is produced, more satisfactory measurements of cabin sound can be made.

In reply to Major Green and other speakers, the transmitted noise from the engine along the cabin walls is certainly greater than with flexible walls, if the sources of sound are in intimate contact with them. Noises like those of tappets and gears would be more prominent unless good insulated mounting is used. In the "Argosy" type, however, and with double engine machines, the wing structure does not give so good a channel for vibrations to pass as would occur for an engine mounted on the fuselage itself. The propeller noise is generated in the air and arrives at the cabin walls chiefly by air-borne rather than by structure-borne waves, and the same may be said about a large part of the engine exhaust.

In reply to Wing-Commander Cave-Browne-Cave, the relative importance of exhaust and propeller sounds is rather difficult to estimate. It is my belief that with engines unsilenced, as they are in the "Argosy," the total sound output for all aspects is greater than for the propeller. For the purpose of microphone recording the acoustical output is of the same order of magnitude.

In reply to Dr. Richardson, the employment of insulation of the type he suggests has been advocated.

The physiological effects observed by Mr. Handley Page are very interesting - of this I have no experience. With regard to the noise of gears, a good deal of advantage would be gained for an engine mounted on the fuselage, if, as in the case of the "Argosy," there was a section of cabin between the engine and the cabin bulkhead. This point was raised by Mr. Colebrook.

The value of horsepower per passenger giving limit of tolerable sound would be very difficult to measure, human beings having such varying sensibilities. Obviously, sound comfort was closely related to horsepower, and persons flying in small machines would realize the benefit. The psychological test which Mr. Handley Page advocates would be very interesting to carry out; it has already been done by Harvey Fletcher, but only with loud telephone sounds.

Captain Sayers' view does not coincide with mine, but I agree that sleep might be more interfered with by vibrations communicated to the subject mechanically, and in modern aircraft, especially triple-engined machines, there is, of course, much more disturbance of this kind. The "Argosy" uses very short exhaust pipes in the wing engines - longer ones would no doubt reduce the sound to some extent.

Dr. Thurston's remark on the desirability of insulating the cabin from the structure is fully concurred in and if there is no constructional difficulty it is strongly advocated.

In reply to the President, an opportunity of trying foreign machines would be welcomed as a claim has been made that these are quieter than the British.

The analysis of noise in the airplane cabin is extremely difficult, as at the present time no instruments have been produced capable of doing this work.

Proposing a vote of thanks to Major Tucker, the President said the members of the Society were grateful to him because not only had he shown where the trouble lay, but he had also indicated how we should effect an improvement. They were also indebted to him for the trouble he had taken to provide the varied apparatus for the purposes of demonstration. If civil aviation was to prosper the noise problem must be energetically tackled.

(For Part I, see Technical Memorandum No. 473, Part I.)

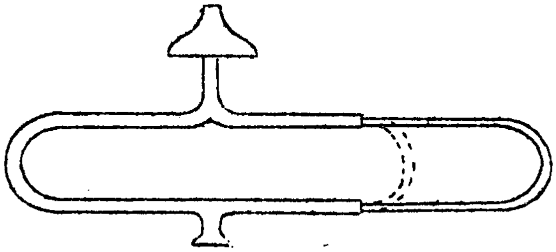

Fig. 4 Quincke's apparatus to illustrate principle of elimination of the odd harmonics in engine exhausts.