GEORGE SAUNDERS' "TREATISE ON THEATRES" OF 1790 AND OPTIMUM ACOUSTIC PROFILES

M. Barron

Fleming & Barron, 82 High Street, Coton, Cambridge CB3 7PL

We now refer to the eighteenth century as the 'Age of Reason'. Perhaps it should come as no surprise to find enterprising attempts from the period at logical development of auditorium forms. For instance, Pierre Patte in 1782 [1] proposes the elliptical plan form for a theatre because:

> "the elliptical curve ..... possesses the unique ability of preserving from all directions the useful reflections of the voice. ..... Consequently such a theatre could not fail of being perfect."

Patte's concept of acoustic reflection seems sound enough. But it now seems amazing that he was unconcerned by the extreme focusing behaviour from which his preferred form suffers.

The human voice is obviously a directional sound source, which could form the basis of a design profile. Christopher Wren made a now famous statement regarding the implications of its directional nature in churches:

> "Concerning the placing of the pulpit, I shall observe - a moderate voice may be heard 50 feet distant before the preacher, 30 feet on each side and 20 behind the pulpit; and not unless the pronunciation be distinct and equal, without losing the voice at the last word of the sentence, which is commonly emphatical, and if obscured spoils the whole sense."

George Saunders' contribution to the arguments of this period deserves more than passing attention, even though his acoustic understanding is generally quaint, and frequently wrong.

George Saunders' "A treatise on theatres"

George Saunders (1762-1839) was an architect who became Surveyor to the County of Middlesex. (He also apparently wrote an interesting paper on Gothic vaults.) The reason for his interest in theatres is not clear, nor does it seem as if he ever built a theatre himself. His 'Treatise on theatres' [2] was written in 1790 soon after Patte's 'Essai', when Saunders was only 28 years old. The Treatise contains a discussion of "optics and phonics, as they relate to Theatres", accounts of experiments on the voice and development of ideas for good theatre design, stage design etc. The longest chapter in the Treatise contains discussion of 17 theatre designs existing at the time (as well as ridicule for Patte's design!). The final chapter proposes designs for an ideal theatre and opera house.

It may seem somewhat surprising to us now, but both Vitruvius in the first century B.C. [3] and Saunders pay more attention to acoustics than vision. Saunders conducted his own experiment on speech propagation "on a calm day chosen for the purpose and (over) an open plane":

GEORGE SAUNDERS AND OPTIMUM ACOUSTIC PROFILES

"EXP. 1. Having traced a circle of 100 feet in diameter, I placed the speaker in the centre; the distance, therefore, was the radius of 50 feet every way. The hearer moving on the circumference of this circle heard most distinctly when in front of the speaker, not much less so on each side, but scarce at all behind.

EXP. 2. In the same circle, I placed the speaker at 25 feet from the centre, which was 3-4ths of the diameter or 75 feet to the front, and 25 feet behind. He was heard best at the sides and indifferently in front and behind.

EXP. 3. On repeating these experiments, and changing the situation of the speaker, I found the voice reached the circumference most equally when he was placed at 17 feet from the centre. I then, without regarding the circle, traced the extreme distance at which the voice could be distinctly heard every way. The line it formed was that described in Figure 1 (this paper); the situation of the speaker was at A, from which point, at the distance of 17 feet in front, B will be the centre part of the circle which it formed: the extent from speaker to hearer will be 92 feet in front, 75 feet on each side, and 31 feet behind.

The difference of the form made by the voice, and that made by fixed sound, is evidently occasioned by the voice's being pushed forward from the mouth; and this difference will always be in proportion to the exertion of the speaker, and subject to very little variation."

Saunders here exposes an obvious prejudice for the circle, but we find that his comment "without regarding the circle" in EXP. 3 may be accurate.

His view of sound behaviour at room boundaries is less impressive. Influenced presumably by the experience of the whispering gallery, he considered that sound after reflection travelled along the surface. His interpretation of his result in Figure 1 was also compromised by his decision that "sound expands equally in every way". He reconciled this with his experimental observations on the voice by concluding that it was "occasioned by the voice's (form) being pushed forward from the mouth". He had measured this distance as 17 feet and considered it relevant to theatre design. Beyond 17 feet the voice is assumed to expand "equally", hence the circular profile.

Contemporary measurement of voice directivity

The most extensive measurements to date of the polar characteristics of the human speaker are due to Moreno and Pretzschner [4], who made measurements at third octaves in an anechoic chamber with several speakers. To obtain a single directional pattern, some frequency weighting has to be applied. In this case it was decided to take the average of 1/3rd octave responses at 500,1000 and 2000 Hz. If this data is replotted in terms of a constant sound level profile, Figure 2 is the result. For comparison with Wren's statement above, the maximum forward distance has been labelled 50. Agreement with Wren's values is good. In reality the profile only truly applies to open air situations without reflections preferential to particular directions or distances. In the case of

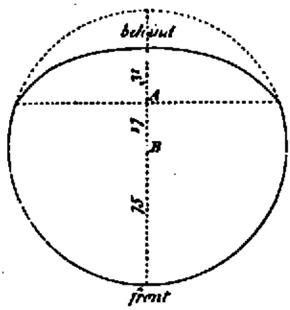

Figure 1. Saunders' profile for limiting distances of intelligible speech. The speaker is at A facing B.

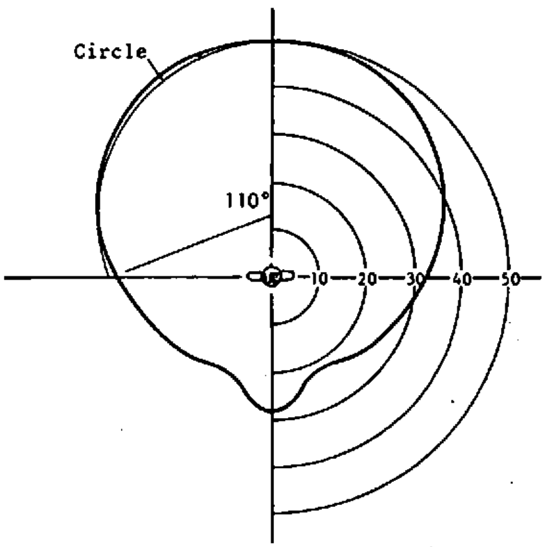

Figure 2. Constant sound level profile for a human speaker, derived from measurements of Moreno and Pfretzschner [4].

a church however the reverberant sound level is likely to be constant with significant early reflections unlikely, leaving the free-space profile as appropriate.

Turning to comparison of Figure 2 with Saunders' result, we do indeed find that the profile in front of the speaker corresponds closely to a segment of a circle. Interpreted in contemporary terms, we know it is the form which is constant, not a specific distance in front of the speaker. The angle at the centre of the segment in Figure 2 is 220°, which can be compared with 205° for Saunders' profile (Figure 1). Saunders' data was thus quite accurate though we have to assume that his actual distance values were influenced by incidental noise at his measurement site. His maximum propagation distance of 92 feet (28m) is rather in excess of distances normally applied to theatres for visual reasons (typically 20m).

Grand Theâtre, Bordeaux

In the section of Saunders' Treatise where he discusses the virtues of various contemporary theatres, he reserves particular enthusiasm for the Grand Theâtre in Bordeaux:

> "All persons acquainted with the theatre at Bordeaux are unanimous in it's favour. They all agree that the voice of the actor spreads more equally in this than in any other theatre. The figure, reckoning at the front of the amphitheatre is nearly equal to it's whole circle; but the wall is cut off at about one fifth of the diameter for the stage opening."

The Grand Theâtre by Victor Louis [5] was completed in 1780 and still stands. The auditorium has indeed a segment of a circle as its plan (Figure 3), which incidentally is constructed of timber. The angle at the centre of the circular segment described by the auditorium is 260° in this theatre. The auditorium is however relatively small so that at stalls level the actor only has to project a maximum of 16m.

Saunders' ideal theatre

Saunders used his speech profile as the basis of his theatre design, which therefore became a segment of a circle.

> "It is clear from the experiments that at 17 feet from the front of the speaker will be the centre to the part of the circle formed by the expansion of the voice; and that in every part thereof the hearers will equally participate in the advantages."

Having described the shape of his profile, it appears that the size of the theatre was developed from the proscenium width. The distance from the stage front to the rear wall of the stalls was 16.8m, but the design stepped back for the two balcony levels with a maximum distance for audience from the stage front of 22.6m. The design held an amazing 2817 people. The angle in plan at the centre of the circular segment described by the auditorium was 230°.

GEORGE SAUNDERS AND OPTIMUM ACOUSTIC PROFILES

Theatre Royal, Drury Lane, London, 1812

Between 1660 and 1843 Drury Lane theatre was one of only two establishments in London permitted to put on plays. (The other one after 1732 was Covent Garden). Being in a monopoly situation meant frequent rebuilding of the theatre, helped predictably by a few fires. In this case the previous Drury Lane theatre had been totally gutted by fire in 1809. For his rebuilding Benjamin Wyatt [6] was strongly influenced by Saunders' ideas and he therefore followed the circular plan form, with in fact a similar size plan to Saunders' ideal. The theatre had five balcony levels with a total capacity of over 3100 [7]. The foyer areas of Wyatt's theatre remain to this day but the auditorium was not a success for sightline and acoustic reasons. The auditorium was replaced in 1822 by a horsehoe form designed by Beazley. Beazley's auditorium survived for 82 years, until changes were required in order to conform to new fire regulations.

It is easy to appreciate the visual disadvantages of the circular plan form. The viewing angle from seats in the front half of the auditorium but furthest from the centre line will be especially high. This implies that these spectators will be unable to see a substantial area of the stage behind the proscenium. Sightlines with the horseshoe plan are already bad, with a truncated circle they are even worse! From a social point of view, at a time when being seen was often more important than seeing the performance, the horseshoe plan is also more satisfactory.

There are two possible acoustic criticisms of Wyatt's design: focusing and excessive reverberation. Focusing is obviously more likely in a circular plan than a horseshoe, but in reality it may not have been of much concern. Only audience in the stalls (then 'the pit') might have perceived it and that was not the 'refined' section of the audience! The height of the auditorium was 14.6m. Due to the large distance between gallery fronts there was a substantial reverberant room volume which may have resulted in an excessive reverberation time. Whether Beazley's reconstruction would have significantly reduced the reverberation time is not obvious. Since he used the same ceiling, the change was probably small. In fact the evidence that Beazley's design offered valuable acoustic advantages is not clear from the historical record.

Fallacies in Saunders' argument

There are several obvious fallacies in the logical argument which Saunders used to derive his ideal theatre plan:

1. The profile is for direct sound alone but reflections in rooms strongly influence intelligibility. For example, at the back of a large theatre, the direct sound may only be 10% of the received total sound energy.
2. The profile represents a maximum limiting distance. The same form does not have to be followed rigidly for smaller theatres.
3. The profile is for audience positions and need not determine the location of walls in a theatre. In a modern design curved seating rows are perfectly acceptable but walls would generally be made of plane sections to avoid focusing.

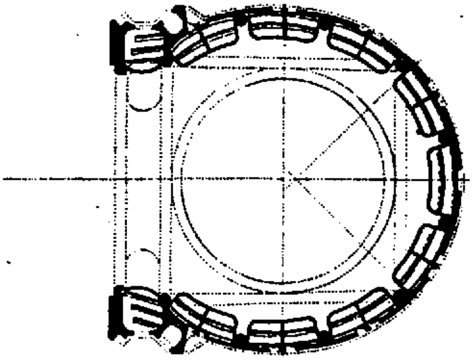

Figure 3. Plan of the Grand Théâtre, Bordeaux.

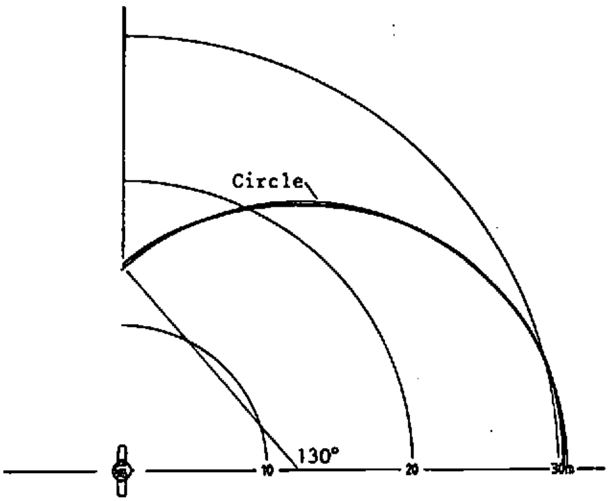

Figure 4. Profile for limiting speech intelligibility for a speaker in a theatre. A fine line circle has been drawn adjacent to the profile.

GEORGE SAUNDERS AND OPTIMUM ACOUSTIC PROFILES

The first point constitutes the major criticism. Amazingly the same error was perpetrated by Izenour [8], when he superimposed onto auditorium plans the speech profile measured by Knudsen [9] in the Mohave desert. Experience of large church spaces indicates immediately that speech intelligibility is affected by room reflections. Unfortunately, in order to derive a design profile, more variables need to be included.

An optimum theatre profile ?

To derive a theatre profile, we require a measure of speech intelligibility and a theory for sound behaviour in theatres suitable for prediction purposes. The 50ms early energy fraction or 'Deutlichkeit' is a good predictor of speech intelligibility in quiet environments. Seats with an early energy fraction greater than 50% tend to have adequate intelligibility. (Our experience in theatres suggests that signal-to-noise problems are much less common than impulse response problems.) It proves to be a reasonable assumption that the number of early reflections in a theatre is approximately constant. In other words if we take the directionality of the voice into account, the early sound energy within 50ms is approximately a constant factor times the direct sound energy. The value of the factor varies from theatre to theatre. In this case I have assumed the factor to be 3, implying two reflections of energy equal to the direct sound.

The late sound is calculated from the reverberation time (1s) and auditorium volume (5000m^3). It is assumed that only sound energy entering the auditorium (i.e. 72%) will contribute to the late sound; energy entering the stagehouse is assumed to be absorbed. Measurements in real theatres (and concert auditoria) show that late sound energy arriving more than 50ms after the direct sound is a function of source-receiver distance; the level decreases for more distant receiver positions. This aspect is also included, according to the revised model proposed in [10].

The assumed quantities were all chosen on an arbitrary but realistic basis. Figure 4 shows the profile of 50% values for the early energy fraction in such a theatre. It proves to be very close to a segment of a circle. The enclosed angle is 260°, identical with the Bordeaux Grand Théâtre!

Relevance to modern design

The circular plan form is obviously inappropriate for a proscenium theatre. However if one superimposes a circular acoustic profile on a fan-shaped visual profile we arrive at a familiar plan form. For spectators to see a reasonable proportion of the stage, they should not lie beyond a line inclined at, say, 30° to the main axis of the theatre taken through the edge of the proscenium. (In earlier theatres with deep perspective stages the angle should have been even smaller.) These two profiles leave us with a plan form very close to the horseshoe, which proved to be almost ubiquitous for theatre design in much of Europe during the eighteenth and nineteenth centuries.

A further criticism can be levelled at such an exercise in developing an optimum profile, in that it assumes the actors only face directly onto the auditorium. As soon as an actor changes his orientation the profile rotates with him. In the case of the thrust-stage theatre (which does not have a proscenium opening) actors are obliged to perform at times with audience behind them. In this case the optimum profile is simply a circle with the actor at its centre.

It is interesting to compare this observation with the experience of the two major thrust-stage theatres in Britain. It is generally accepted that the acoustics of the Sheffield Crucible perform better than those of the Chichester Festival Theatre. In the case of the Crucible, the plan is octagonal with its centre at the principal acting area. The actor facing forward has to project only 18m. On the other hand the centre of the hexagonal Festival Theatre is over audience in front of the stage; the actor has to project 23m here. There are in fact several other reasons for the acoustic superiority of the Sheffield theatre but this analysis highlights one significant factor.

References

[1] P.Patte 1782 'Essai sur l'architecture theâtrale', Paris.
[2] G. Saunders 1790 'A treatise on theatres', London.
[3] Vitruvius (1960) 'The ten books on architecture', Dover Publications, New York.
[4] A. Moreno and J. Pfretzschner 1977 Acoustic Letters, 1, 78-84. Human head directivity in speech emission: a new approach.
[5] V. Louis 1782 'Salle de spectacle de Bordeaux', Paris.
[6] B.D. Wyatt 1813 'Observations on the design for the Theatre Royal, Drury Lane', London .
[7] R. Leacroft 1973 'The development of the English playhouse', Methuen, London.
[8] G.C. Izenour 1977 'Theater design', McGraw-Hill, New York.
[9] V.O. Knudsen 1932 'Architectural acoustics', John Wiley, New York.
[10] M. Barron and L-J. Lee (accepted for publication by the Journal of the Acoustical Society of America) Energy relations in concert auditoria, I.

