sity of Cambridge. Most of the work had been done on large models e.g. 1:8 scale, although trials at 1:50 were under way. By scaling the wavelength of the sound by convenient factors and drying out a model sufficiently to counter absorption by the air itself (which is substantial at very high frequencies), signals can be fed into the model and scaled measurements taken. Based on experience of sound absorption by the various materials and seats at full scale, substitutes are selected for construction of the model to match this absorption at the smaller scale.

The particular benefit of the smaller 1:50 scale is that the size is sensible for building within a reasonable time. The model also offers the Design Team potential for study of a number of non-acoustic aspects of the design. We therefore decided to construct a varnished timber model to 1:50 which included the ceiling and scope for its movement to both the intended positions. Arrangements were made for tests to be carried out at Cambridge University. Absorption by seating was modelled and a variety of sound source and listener positions were checked in terms of sound distribution, 'early' to 'late' sound energy ratios and the influence of minor changes in the geometry. An attempt at reverberation time prediction was also made.

As a result, modifications were made to the ceiling and account was taken of measurements which indicated very strong 'early' sound, good sound distribution and reverberation times possibly not as short as might be predicted by conventional calculation (perhaps as a result of screening of many seats by the overhang).

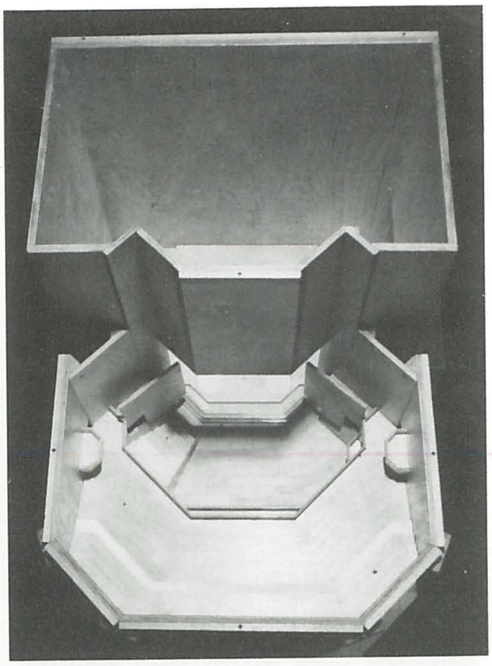
Although the model could not provide entirely confident prediction of the room acoustics characteristics, and a large number of assumptions had been made (particularly about the role of the fly tower on the auditorium), the trends and clues offered very helpful support to the assessments being made at the time.

Under-balcony reinforcement

At this stage, there emerged a number of particular points of interest. It was felt that the deep balcony overhang would tend to encourage less successful listening beneath. As a result, a passive sound reinforcement system tied in with show relay was introduced under the balconies. This system is designed to throw tiny quantities of sound down to the listener from above with appropriate delay and frequency content to be similar to a reflection from an overhead panel. It is passive in as much as it does not need adjustment by the sound operator during performance. A similar principle was followed for the Assisted Resonance system. Loudspeakers feeding multichannel AR signals were interspersed with the show relay feed loudspeakers under the balcony.

Orchestral enclosure

A further challenge was the orchestral enclosure. Here it was not necessary to collect the sound and throw it out to the audience. With such a small volume,



The 1:50 scale model of the auditorium at Cambridge University afforded much valuable information on acoustic performance.

loudness was not at issue. What was needed was sufficient containment to avoid undue domination by the fly tower and means for the orchestral players to hear one another, thus allowing them to establish the necessary blend. There was substantial evidence that players receive cues from other players primarily via mid/high frequency reflections, and any enclosure or partial enclosure should be able to provide diffuse mid/high frequency reflection.

Another influence on the design was the need for ease of installation and dismantling. Eventually it was decided that a combination of tall lightweight screens behind and around the orchestra and a lightweight overhead reflector could do what was needed. Following experience with lightweight structural fabric for buildings, one option seemed to be to stretch a very tough impervious fabric over frames almost like a drumskin. This had many attractions in terms of quick assembly and demountability, the material is very durable and cables and threads behind allowed some adjustment of the tension and thereby some adjustment of the acoustic response. Laboratory tests on the fabric had been carried out and, although there was a fear that the 'drumskin' might continue to drum audibly after the music stopped, this was found not to be so.

A number of options for the overhead diffusing reflector were considered. Two strong candidates suggested by the Architect were (a) a space frame with lightweight panels built in and (b) an inflatable element which used the convex profile of a series of ribs to diffuse the sound. The latter was selected and the final arrangement involves structural fabric screens plus an inflatable overhead reflector hung almost horizontal (slightly higher at the forestage end) with lighting frames clipped on below. This was an unusual approach to say the least. Certainly, the acoustic results have been good and experience of its use should allow scope for the best geometry to be refined. The screens have been sized to allow them also to be used below the stage behind the orchestra in the pit, and the overhead reflector can be deflated and hung in the fly tower.

Assisted resonance

The Assisted Resonance installation is based on the principles applied for previous systems. However, during the design period, the designers/suppliers of the system – AIRO Ltd. – developed improvements in the controls incorporating self-monitoring and diagnostic test procedures and a wide range of facilities for adjustment and control. As a result, the Client has a sophisticated tool for reverberation control and considerable scope for adjustments as a result of experience in use.

Services noise control

In general, established techniques were used for control of noise from services. Large ductwork was necessary to reduce air velocities. Extensive jobside attenuation and acoustic lagging were introduced. The movement of the ceiling posed particular problems on the final feeds to the moving part of the ceiling. Large flexible extendable ductwork was used, carefully aligned and cut to such a length as was needed to avoid buckling or distortion which might encourage air noise close to the terminal.

Dry runs

The building has extensive technical facilities and it was agreed with the Client that a number of dry run performances should take place to iron out difficulties prior to opening the building. This offered a useful opportunity to commission the acoustics of the auditorium during a variety of performances, selected for their differing content – speech, amplified speech, classical music, a rock band, variety, opera etc.

The room acoustics, sound insulation and control of noise from services were found to be close to design targets, and early listening has been very encouraging. Assisted Resonance has been introduced gradually with the musical events, again with encouraging results and appropriate settings have been recommended. There are probably many combinations of stage arrangements and different uses of the auditorium still to be tried, but the pattern of events to date suggests that acoustic design has made a valuable contribution to the success of the building. Time will tell.

CLIENT	: City of Plymouth
ARCHITECTS	: Peter Moro Partnership
THEATRE CONSULTANTS	: Carr and Angier
STRUCTURAL/ SERVICES CONSULTANTS	: Ove Arup & Partners
Q.S.	: Davis Belfield & Everest
ACOUSTIC CONSULTANTS	: Sound Research Laboratories Ltd.