33. SYNTHESIS OF AIRCRAFT NOISE

By Ernest G. Hinterkeuser

The Boeing Company - Vertol Division

SUMMARY

Procedures are described for synthesizing the flyover-noise time histories of an aircraft for both take-off and cruise conditions. Special attention is given to the noise level, spectral and directivity characteristics of the source, and the exposure time and Doppler effects which are related to the speed and distance (altitude) of the aircraft.

A proposed jet powered VTOL aircraft capable of carrying 60 passengers over a 500-mile range is used as an example to illustrate the procedures involved in synthesizing the noise of a proposed aircraft. Some applications of such synthesis studies are cited for subjective studies involving future aircraft or proposed modifications to present aircraft.

INTRODUCTION

The problem of minimizing and controlling the ground noise from aircraft terminal operations is receiving the attention of not only the aircraft manufacturers and operators, but also the public segment of our population centers near aircraft terminals. The individual aircraft sound sources and their treatment are being examined for potential noise-reduction benefits to be gained by appropriate design changes and noise-source acoustical treatments. In consonance with an overall approach to evaluate the potential benefits, the subjective reactions of people to the noise from aircraft need to be predicted beforehand, and if this proves difficult or even impossible analytically, a subjective test program using a panel of listeners is preferred.

Boeing-Vertol has developed and successfully applied a unique method for simulating forward flight effects on aircraft sound sources which are subsequently used in listening tests (ref. 1). The techniques and the jury tests together result in an evaluation of the noise from various designs of aircraft or various operating conditions. The predicted aircraft sounds, which are created electronically on magnetic tape and used in a loudspeaker playback system for aural evaluation, may represent an aircraft in its preliminary design stages. In addition to acoustically evaluating a complete aircraft in its initial design stages, the effects of changes or treatments of propulsion components may be appraised. Furthermore, any changes in aircraft operating procedures which affect the external sound field may be simulated and evaluated by actual listening.

NOISE SIMULATION PROCEDURES

There are several approaches possible in simulating the noise from aircraft operations (fig. 1). If an actual noise recording of the individual component creating the noise or a complete aircraft noise signature is available and it is desired to alter some slight operating characteristic such as applied power, a filter reshaping of the frequency spectrum or a boost in electrical gain to the total noise signal will suffice to create a new sound based on the original recording. A more technically challenging but more versatile approach involves the pure electronic synthesis of sounds using audio-tone oscillators, wave-shape generators, and random-noise generators. There is, however, a limit to the number of subjective aural attributes contributing to a believable sound synthesis if several other mechanical manipulations with these electronic sound sources are omitted. In order to describe such a modified electronic synthesis in-detail, a simulation procedure of a VTOL aircraft noise will be outlined as an example. It should be noted, however, that the general techniques are applicable to many types of aircraft sounds, including those of fixed-wing aircraft, and not to VTOL aircraft noise alone.

The particular aircraft, which is a turbofan-powered jet-lift VTOL, is first examined from its operational considerations and airframe design (fig. 2). The aircraft is designed for the short-haul, city center to city center transport market and its details are derived from the study in reference 2. The aircraft has a 500-nautical-mile range and is sized to carry 60 passengers. The airframe consists of a conventional fuselage with forward-swept wings having pod-buried turbofan lift engines at the tips. During vertical take-off these 10 engines provide upward thrust as do the deflected exhausts of the four cruise powerplants located at the rear of the fuselage. As more cruise-engine deflected exhausts are diverted to the rear of the aircraft, forward speed is attained until sufficient aerodynamic wing lift sustains the aircraft in a conventional manner. The lift engines are then shut down and the aircraft proceeds at cruise altitudes to its destination, where the reverse operational procedure is used for a vertical descent and landing.

Several predominant noise sources emanate from the lift engine. In order to synthesize these sounds, a detailed prediction of the amplitude and frequency content is first necessary. These predictions are based on references 3 to 5. The downward-sloping broadband spectra with increasing frequency (fig. 3) are representative of the lift-engine primary and bypass exhausts. These spectra are electronically generated and combined using shaped broadband random-noise generators. The upward slope in sound pressure level with increasing frequency represents the lift-engine intake noise, on which several pure tones from audio-oscillators are superimposed by electronic mixing to represent inlet whine. The predicted cruise-powerplant noise (fig. 4) is synthesized similarly. All these four primary noise sources (the lift-engine and cruise-powerplant intake and exhaust noises) are recorded simultaneously on separate tracks of a multitrack tape recorder to represent predicted aircraft noise levels audible to an outdoor observer at a 500-foot distance from the aircraft. These primary, amplitude-time steady sounds then represent the basic noise component library for this particular aircraft from which a composite aircraft noise simulation is derived.

Before the simulation procedure for obtaining the combined total spectrum of an aircraft is described, a particular subjective aspect concerning the natural amplitude fluctuations of noise is noteworthy. The upper portion of figure 5 illustrates the amplitude-time history of an actual jet noise recording. Superimposed on the general rise and decay of the sound envelope representing aircraft approach and recession are random amplitude fluctuations of considerable magnitude caused by wind turbulence, ground reflections, and sound scattering. Although the amplitude rise and decay can be approximated purely electronically by raising and lowering a volume control during a rerecording of a steady-state noise, the amplitude fluctuations cannot be satisfactorily achieved by changes of the electrical volume in small, fluctuating increments. No matter how random the artificially introduced volume fluctuations are, listening to such a record and comparing it with that of an actual jet noise recording reveals the lack of realism still not overcome in this purely electronic approach. (See middle of fig. 5.) For achieving this natural effect, the amplitude-time steady-noise spectra are therefore beamed from a loudspeaker out of doors and rerecorded through a microphone. This method has the desired result of including the natural random-amplitude fluctuations from actual wind noise, sound scattering, and ground reflections. (See lower part of fig. 5.) This latter improved method results in a subjectively superior outdoor aircraft noise simulation as confirmed by critical listening tests.

To achieve the effects of noise directivity, the four basic noise spectra are set to their correct relative volume levels, mixed electronically in the case of aircraft side-line noise, and projected from three separate speakers mounted on top of a vehicle (fig, 6). The cruise-engine inlet noise radiates toward the front of this simulated aircraft; cruise-engine exhaust noise radiates to the rear of the vehicle; and a combination of lift-engine intake and exhaust noise is projected to the side line.

This complex of sound sources is then moved past a stationary microphone which records the total perceived noise (fig. 7). The distance at which the vehicle with its sound sources passes the microphone is dictated by the sound-power generating capacity of the electrical equipment; the amounts of vehicle engine, gear, and tire noises; and ambient sound levels. The geometrical relationship of the moving vehicle position and the stationary microphone recording the total noise is then regulated to simulate the proposed aircraft movements at a 500-foot distance from an outdoor listener. When the vehicle is at position 1, overall noise is low, inlet noise from the front speaker predominates the spectrum, and the aircraft approach noise situation is recorded. As the vehicle advances to point 2, the noise level is at its peak and consists primarily of sounds from the side-directed speaker. As the vehicle proceeds to position 3, representing a receding aircraft, the overall noise level again falls and the spectrum of the cruise-engine exhaust noise from the rear speaker prevails.

The remaining acoustical feature to be added to the total noise recorded by the field microphone is the Doppler shift. (See lower part of fig. 8.) This effect is obtained in the laboratory by rerecording the final sound obtained in the field on a variable-speed tape recorder. By increasing the playback tape speed during the approach portion of the simulated aircraft noise, the entire spectrum is shifted toward the high-frequency end. This playback speed is smoothly brought back to normal at the peak noise level representing the aircraft overhead position. Without hesitation during this entire playback, the tape speed is then brought to below normal to simulate the lowering infrequency of all the spectra which are heard emanating from a receding aircraft. To compensate for the amplitude-time pattern distortion of the noise envelope which would result from these tape manipulations and to obtain finally a symmetrical flyover time history, it is necessary to distort this pattern prior to this Doppler shift procedure. This may be accomplished in the field by driving the vehicle past the microphone so that the approach noise duration is effectively stretched in time. The vehicle is speeded up to shorten the latter half of the flyover noise duration. (See upper part of fig. 8.)

The simulated aircraft noise now contains all the subjectively important aural characteristics of transient aircraft flyover noise. The aircraft sounds obtained at this stage may be further developed by spectrum shaping and by changes in the amplitude-time characteristic to simulate other distances or even indoor observer positions by reducing the spectral energy by an assumed or measured building sound transmission loss.

CONCLUDING REMARKS

The methods outlined herein have been used at Boeing-Vertol in subjective rating experiments using several different types of aircraft in the take-off and cruise modes. The techniques are also being applied for in-house evaluations of future aircraft designs and for proposed modifications of existing aircraft before hardware is committed to flight testing or production.

REFERENCES

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4. McKaig, M. B.; and Sawhill, R. H.: Procedures for Jet Noise Prediction. Boeing Doc. No. D6-2357 TN, Boeing Co., 1965.
5. O'Keefe, J. V.: PNdB Ground Contour Determination for Jet Aircraft. D6-15082 TN, Boeing Co., 1966.

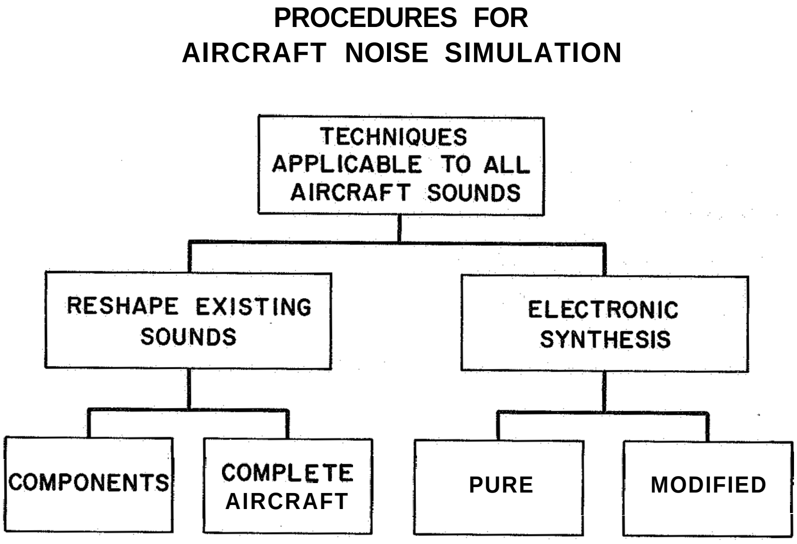

Figure 1

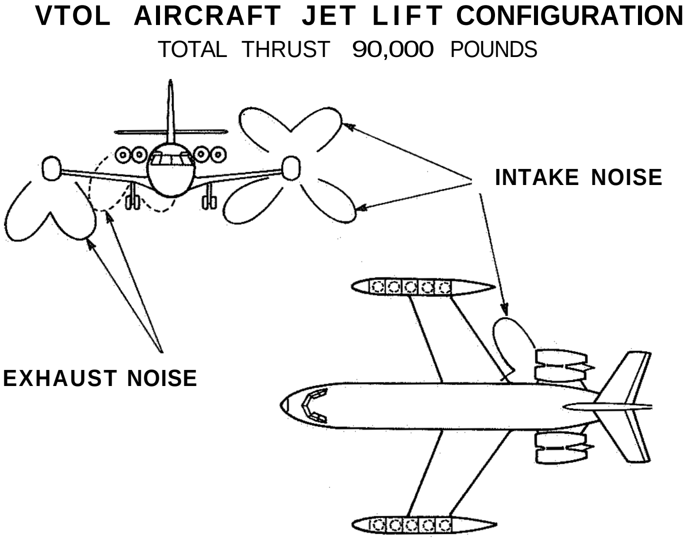

Figure 2

PREDICTED JET LIFT TAKE-OFF SPECTRUM

LIFT POWERPLANT

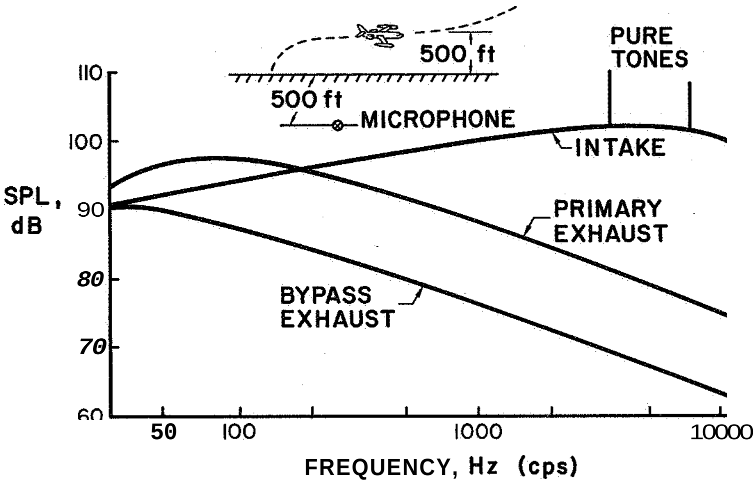

Figure 3

PREDICTED JET LIFT TAKE-OFF SPECTRUM

CRUISE POWERPLANT

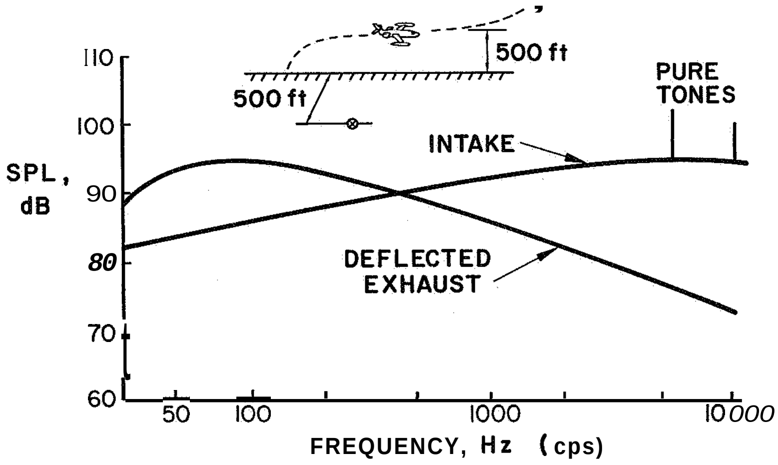

Figure4

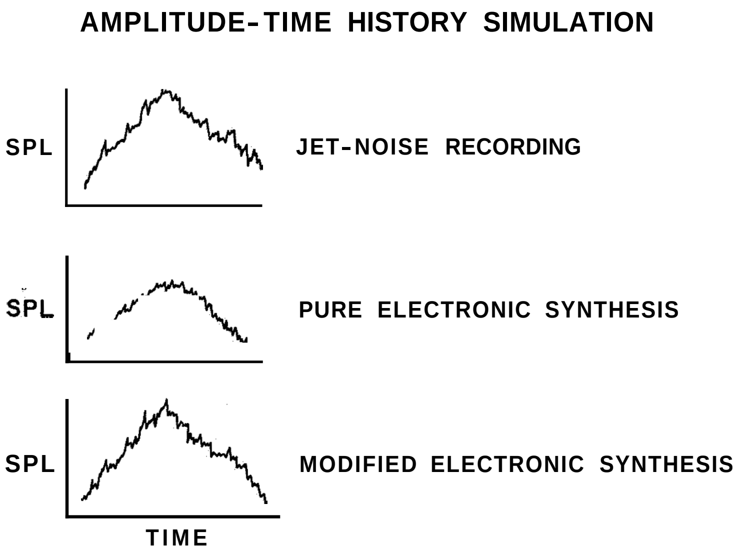

Figure 5

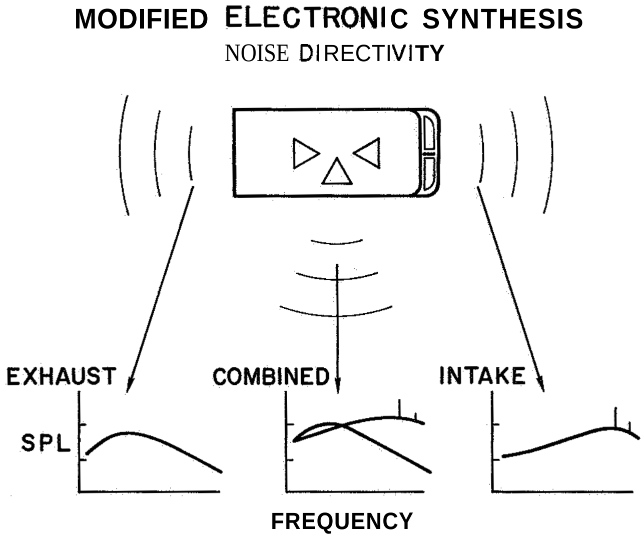

Figure *6*

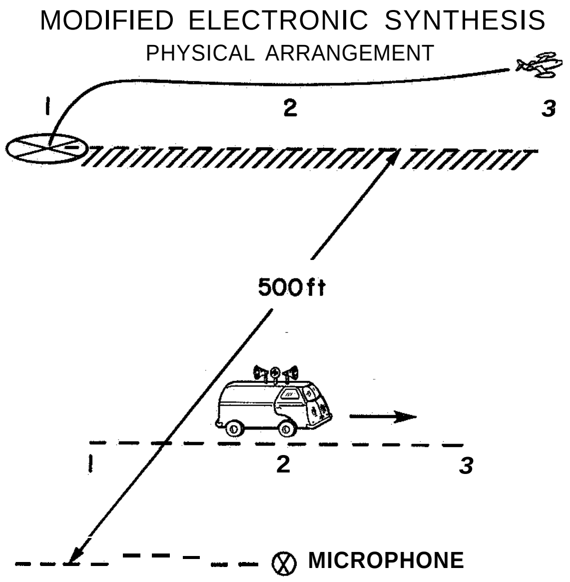

Figure 7

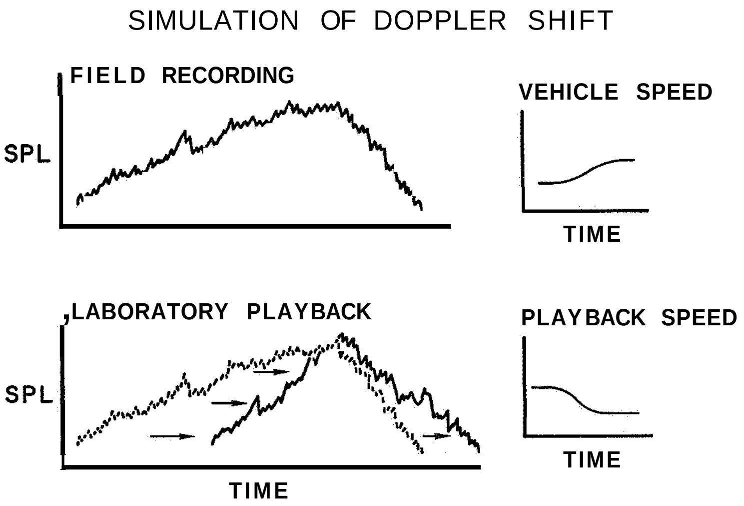

Figure 8