# Sound Radiation from Aircraft Wheel-Well/Landing-Gear Configurations

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**An experimental program was initiated to determine the noise radiation from landing-gear/wheel-well configurations of large commercial aircraft. Scale models of typical nose gear and main gear (synthesized from different type aircraft) were exposed to flow of typical landing approach speeds (up to 65 m/sec) on a stationary outdoor wall-jet flow facility and attached to the wings of an aerodynamically very clean glider (SB-10). Landing-gear noise is composed of sound generated by the interaction of flow with 1) the wheel-well volume, and 2) the external gear equipment. Wheel-well related sound is characterized by discrete tones whose intensity is heavily damped by the spoiling effect of the gear. Externally generated landing-gear noise is mostly of broadband character. The contributions of some dominant features of a gear (shaft, struts, actuators, doors, wheels) to the total sound signature were determined and normalized nose gear and main gear spectra were developed that predict measured full-scale landing-gear noise fairly well.**

## I. Introduction

AIRFRAME noise has gathered considerable interest over the past few years.[1-9] Indeed, noise generation by the airframe in the absence of engine noise may very well constitute a lower bound to aircraft noise which cannot, without major effort, be reduced much further.

The problem of airframe noise is most significant in the approach phase, where engines normally do not operate at full thrust. Invariably, wing slats and flaps are extended to obtain maximum lift and the landing gears are lowered in preparation for touchdown; the aircraft is in a configuration that is often referred to as "dirty." The interaction of airflow with protrusions and cavities in the aircraft structure gives rise to aerodynamically unsteady flow phenomena which frequently constitute a potent sound-generating mechanism.

Various methods and approaches to understand and predict airframe noise have been developed: the "complete-aircraft method"[1,2,8] uses the gross parameters of an aircraft in flight, such as weight, wing aspect ratio, velocity, etc., and relates these to an overall radiated noise level or a spectrum; the "distributed-source method"[5-7,9] considers as many individual components as practical for the subject problem, such as wings, slats, flaps, stabilizers, wheel-wells, landing gear, etc., and treats each of those as independent or interrelated sound sources, whose combined output ultimately determines the overall noise signature.

In an attempt to further the second approach, an experimental program was initiated to study the noise generation and radiation of aircraft landing gear. This paper reports first results of an ongoing study.

## II. Landing-Gear Noise – General Characteristics

Of the various sources of airframe noise, the landing gear has been identified as a major contributor. This is not surprising, considering the extremely unaerodynamic and complex shape of a modern undercarriage (Fig. 1).

Both nose and main landing gear consist of many components, such as wheels, axles, shafts with lateral support struts, drag braces, actuators, doors, and a wheel-well to accept the gear when retracted. All the exposed subcomponents are essentially bluff bodies, inherently shedding an unsteady wake. From the scale of major landing-gear components it is obvious that fairly low-frequency wake shedding phenomena will occur; hence, corresponding sound phenomena will be of a predominantly low-frequency character. On the other hand, small-scale structural elements such as wires, hoses, screw-holes, small-diameter cylindrical struts, etc., are likely to generate high-frequency noise. Hence, one would expect a fairly broad frequency spectrum to be emitted from landing gear.

This is exemplified in Fig. 2, where noise data from five rather different aircraft appear.[1,8] Only those portions of the radiated noise spectra that could *unquestionably* be associated with landing-gear noise are shown. Relevant data were obtained through comparative flyovers with and without deployed gears at otherwise identical test conditions. Levels are normalized to a flight altitude of 100 m, whereas flight speeds range from 81 to 103 m/sec, and wingspan/gross weights from 14.45 m/11,000 kg to 67.9 m/330,000 kg. The levels cover a range of almost 40 dB, with the smaller planes, having fewer wheels, generating relatively less landing-gear noise than the big ones with many wheels.

## III. Experimental Program

### A. Objective and Approach

In order to determine noise generation and radiation characteristics from entire wheel-well/landing-gear con-

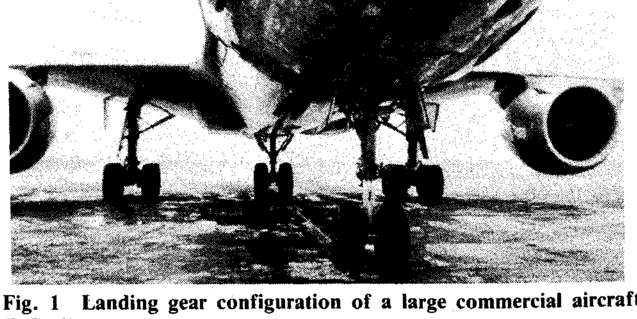

**Fig. 1 Landing gear configuration of a large commercial aircraft (DC-10).**

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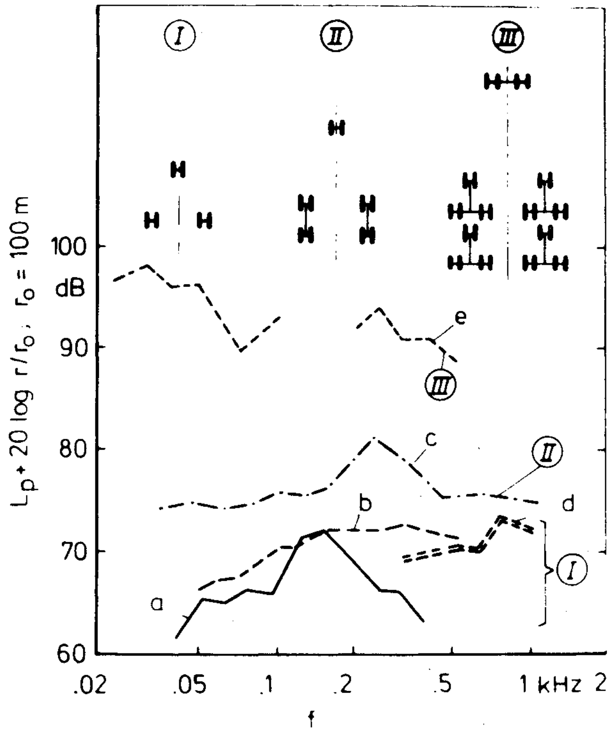



Fig. 2 Maximum landing gear noise at flight altitude of 100 m: a = Hawker-Siddeley HS 125 at 83 m/sec; b = Lockheed Jet Star at 103 m/sec; c = Vickers VC 10 at 81 m/sec; d = British Aircraft Corp. BAC 1-11 at 94 m/sec; e = Lockheed C-5A at 102 m/sec.

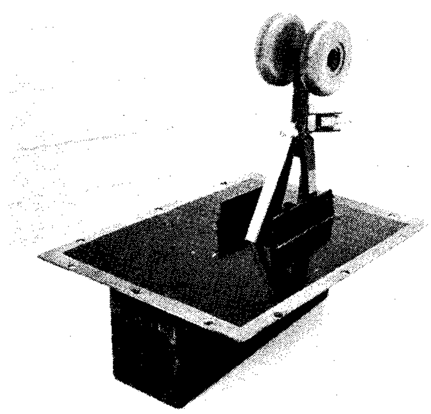


Fig. 3a Nose landing gear model (wheel diam: 0.075 m).

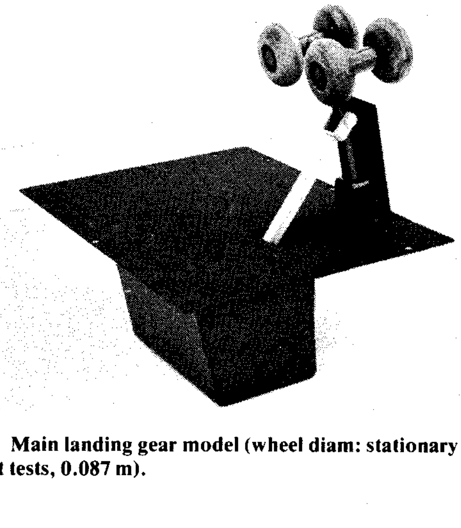


Fig. 3b Main landing gear model (wheel diam: stationary tests, 0.052 m; flight tests, 0.087 m).

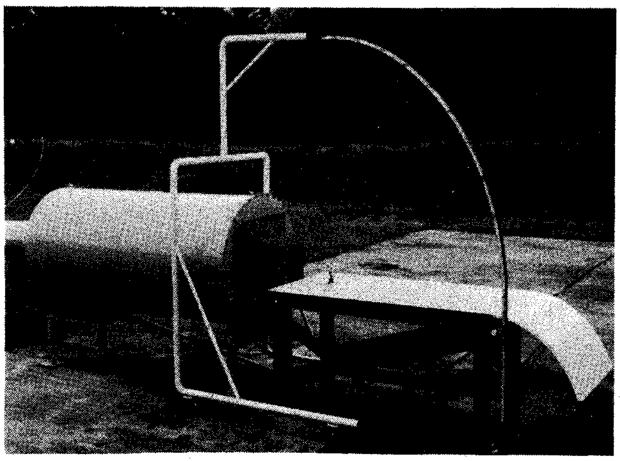


Fig. 4 Wall-jet flow facility.

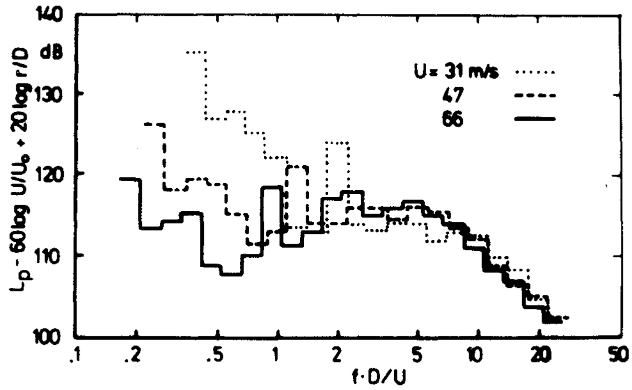



Fig. 5 Normalized nose gear model spectra measured above model ($U_o$ = 100 m/sec).

figurations and from major components, respectively, experiments were made utilizing ground-based facilities and flying test beds. Since landing gear from different type aircraft vary, more or less, representative configurations were construed by synthesizing those from several large commercial aircraft (DC-10, L 1011, Boeing 707, and 747). Thus typical nose-gear and main-gear configurations were determined, and models built, which contained the essential features on a scale basis (Fig. 3). These models were exposed to flow in the speed range of landing approach both on a (stationary) outdoor wall-jet flow facility and on an aerodynamically very clean sailplane. Since these models could be easily disassembled and modified, it was possible to identify the contributions of the various subcomponents of landing gear to the overall sound signature.

### B. Experiments – Stationary Facility

*Wall-Jet Facility*

Figure 4 shows the outdoor "Wall-Jet Flow Facility," located at the DFVLR Trauen Test Grounds. The square nozzle exit measures $0.3 \times 0.3$ m$^2$; flow speeds up to 65 m/sec can be achieved, corresponding to Reynolds numbers of up to $4.3 \times 10^6$/m. Microphones can be positioned at any point around the model center on a hemispherical surface, excluding roughly an eighth-sphere piece blocked by the upstream plenum duct. The models are positioned on the facility table, exposing their gear components to the wall-jet core flow, while the wheel-well parts are submerged in the table.

Although measurements were made at many points, those points lying on an arc around the model in the plane cutting the flow at a right angle were considered most important. First, the effect of the shear layer in diffracting the sound generated at the model and passing at a right angle through

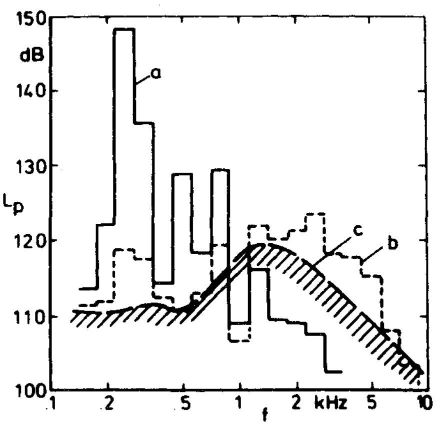



**Fig. 6 Nose gear model cavity-internal spectra for an external flow speed of 65 m/sec: a = empty cavity; b = cavity with gear equipment; c = cavity with gear equipment, broadband component.**

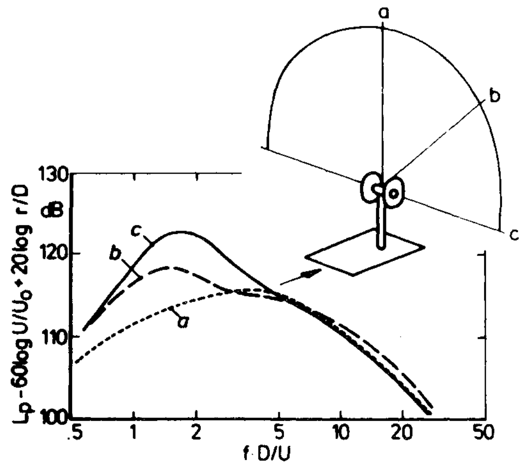



**Fig. 7 Normalized nose gear model spectra at 3 measurement points ($U_o$ = 100 m/sec).**

the shear layer on its way to the microphone is minimal, and second, for low- and slow-flying aircraft, observed sound intensities are usually highest when the aircraft is directly overhead or to the side.

*Nose Gear Acoustic Data*

Complete Configuration: Figure 5 presents ⅓-octave band spectra obtained directly above the model. Frequencies are normalized on a Strouhal number basis with the wheel diameter $D$‡ as the relevant length dimension. Levels are normalized with the sixth power of a flow-speed ratio $U/U_o$ referenced to 100 m/sec and the square of a ratio, employing measurement distance $r$ and wheel diameter $D$. Data collapse very well on this basis, indicating the prevalence of fluctuating-force generating mechanisms. The normalized spectrum assumes a haystack shape, peaking near a Strouhal number of 4. The noncollapsing low-frequency portions are due to facility noise and are to be ignored. The peaks at Strouhal numbers of 0.9, 1.2, and 1.8, respectively, are due to an 800 Hz tone. Since the appearance of this tone and its frequency are speed-independent, at least within a factor of 2, they must be associated with a cavity resonance. Measurements within the cavity in the absence of all gear-equipment indeed show very strong resonances, as is to be expected. Figure 6 is an example of such a measurement for an external flowspeed of 65 m/sec; strong tones also appear at 250 Hz and 500 Hz, both of these lmikely due to Helmholtz resonances. The 800-Hz tone, on the other hand, could be associated with the first lengthwise cavity resonance. Measurement of the cavity internal spectrum with all gear equipment in place shows all these tones to be heavily damped.

The peaks that appear above 1 kHz, exceeding the "cavity broadband nose," relate to externally generated noise which is picked up by the cavity internal microphone.

Spectra obtained directly above the model, at the side, and under 45 deg, as indicated in Fig. 7, show a basically uniform directivity pattern for Strouhal numbers above 4, and an increase in levels to the side, most pronounced in the Strouhal number regime near 1.5. This behavior shows the dominance of dipole type sound resulting from aerodynamically induced fluctuating forces on the vertical gear portions (essentially the shaft, lateral support struts, and drag brace actuator). In Fig. 7 cavity related tones have been eliminated for clarity.

‡Although any typical length dimension could be taken for frequency normalization, the wheel diameter offers itself as a convenient quantity. In fact, the ratio of geometric quantities of the landing gear, with the wheel diameter being one of them, is fairly constant for certain classes of aircraft. Table 1 presents such ratios for the DC-10 and the L-1011, where $D$ is the wheel diameter, $H$ is the exposed length of the shaft, $A$ is the wheel distance, and $S$ the width of a wheel.

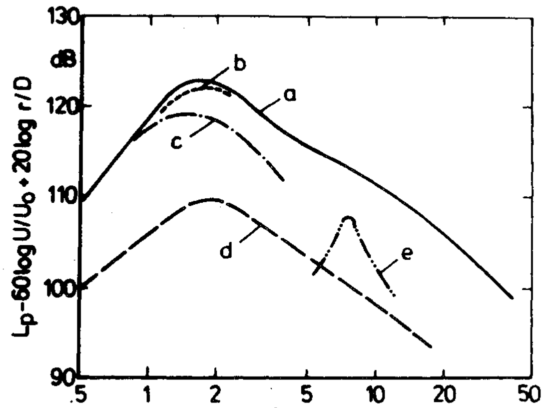



**Fig. 8 Normalized sideline spectra of nose gear model components: a = complete configuration; b = side support struts; c = lower drag-brace and actuator; d = wheel; e = door ($U_o$ = 100 m/sec.)**

Components: In an attempt to further identify those nose gear components that contribute substantially to the radiated noise, individual components were exposed to flow and acoustic data taken. Although this rather coarse approach neglects most or all interaction effects, the results should nevertheless indicate which particular component is likely to be responsible for certain parts of the spectrum.

Figure 8 shows individual sideline spectra of the wheels, the doors, the lower drag brace in combination with the retract actuator, and the side support struts, together with the spectrum of the complete configuration. Again the tone contributions from the cavity have been eliminated, since they cannot be normalized on a $U^6$ basis. Evidently, the side support struts and the drag brace and actuator are responsible for most of the noise, while the wheels and the doors contribute very little to the total noise signature.

Although these findings are strictly valid only for the specific model used, it is believed that the general dominance

**Table 1 Landing/gear/geometric ratios**

| | $D/H$ | $A/D$ | $S/D$ |
|---|---|---|---|
| DC-10 | | | |
| main gear | 0.34 | 1.24 | 0.40 |
| nose gear | 0.34 | 1.23 | 0.35 |
| L-1011 | | | |
| main gear | 0.32 | 1.44 | 0.42 |
| nose gear | 0.37 | 1.27 | 0.33 |
| Average | | | |
| both gears | 0.34 ± 4% | 1.30 ± 6% | 0.38 ± 9% |

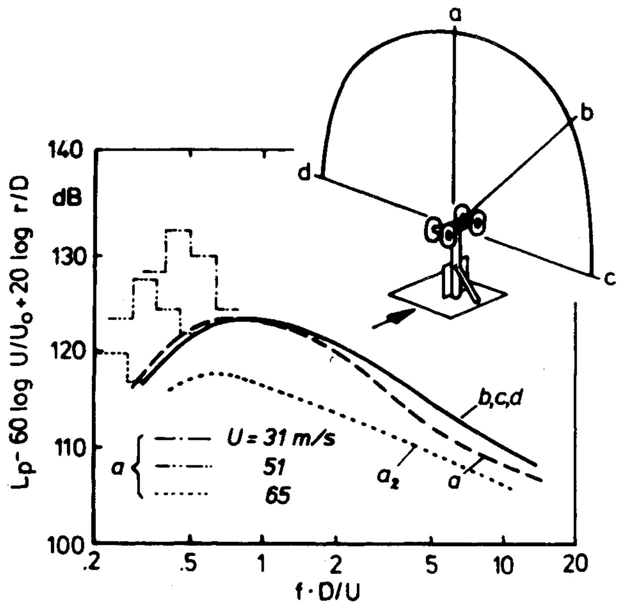



**Fig. 9 Normalized main gear model spectra at 4 measurement points (a, b, c, and d). Spectrum a2: contribution at point "a" of simplified 2-wheel configuration ($U_o$ = 100 m/sec).**

of vertically or near vertically oriented struts, braces, etc., in generating sideline noise are also characteristic for full-scale gear configurations.

*Main Gear Acoustic Data*

Complete Configuration: In contrast to the nose gear model, the main gear model is unsymmetric with respect to the flow direction. However, pronounced directivity effects to the right or left should not be expected, since the combination of main support shaft, lower side brace, and door, because of their relative proximity, is likely to act as a compact source. Only the door might provide some shielding for cavity-generated tones.

Figure 9 shows normalized spectra for the main gear model measured at both sideline points, directly above and at 45 deg to one side. Similar to the spectra of the nose gear model, the peaks at Strouhal numbers of 0.24, 0.3, and 0.5, respectively, in the spectra measured right above the main gear model could be associated with a cavity resonance at a frequency of about 300 Hz.

Both sideline spectra are virtually identical; less sound is radiated up, again indicating the predominance of a vertically oriented dipole source which radiates primarily toward the side. However the level difference between an observation point above and to the side of the model is less pronounced, most likely due to the interaction of the two axles with attached wheels which are prone to radiate substantially in the upward direction. Some contribution from the side brace, being oriented less steeply than the corresponding brace on the nose gear, should also be expected at the observation point above. All spectra exhibit a haystack shape, peaking at a Strouhal number near 0.8.

Components: Also shown in Fig. 9 are the results of a component-contribution test. Using a simplified gear configuration, either with two axles and wheels which produce essentially the same spectrum as the fully detailed model or with one axle only, showed the one-axle configuration to be quieter by up to 6 dB. Thus, the interaction of forward-axle shed flow with the rear axle does increase the radiated noise in the "upward" direction.

*Discussion of Results*

The test results, obtained with the nose gear and main gear models on the stationary flow facility, indicate that landing-gear noise is composed of sound generated by the interaction of flow with 1) the cavity volume, and 2) the external parts of the gears. Cavity-related sound is characterized by discrete tones, whose frequencies are related to cavity dimensions on the basis of "room resonances" or of Helmholtz resonances. Although the frequency of these tones is independent of the external flow speed, their appearance and disappearance and their intensity are not. As in any aeroacoustic resonance phenomenon involving flow and a volume acting as resonator, tones tend to appear and disappear suddenly depending on the available supply of flow energy to sustain a certain resonance condition. Although tone intensities could be extremely high if the cavities were empty, the spoiling effect of the gear components drastically reduces tone intensities both inside the cavity and, correspondingly, outside. Still, these tones must be considered individually and cannot be represented in a convenient nondimensional form. When the cavity is semiclosed, as is the case when the gear is deployed and the main doors have been closed again, the physical situation does not resemble that of a rectangular cavity with one side being entirely open. Hence, classical cavity pressure oscillations[10] with predominantly longitudinal response patterns do not occur, and frequencies and levels cannot be computed in a straightforward way as would be the case for the simple "open-box-type" cavity.

The noise produced by the external parts of the gear scales very well on a flow-speed-to-the-sixth-power basis and must therefore be related to aerodynamic dipole sources, as would be expected for aeroacoustic mechanisms based on the interaction of flow with solid bodies. Hence, disregarding cavity related tones, landing gear noise can be presented in nondimensional form.

Typical nose gear configurations exhibit a more pronounced directivity pattern than typical main gear configurations. The first ones radiate relatively more noise to the side, owing to their predominantly vertical orientation and their rather slender shape. The latter ones radiate sound more uniformly, with only a slight predominance to the side, pointing toward a mechanism with many, rather randomly oriented, dipole sources.

The "smoothed"§ spectra of the nose gear peak at relatively higher (wheel diameter based) Strouhal numbers ($S \approx 1.6$ to 4) than those of the main gear ($S \approx 0.8$ to 1.0).

The dominant sources of the nose gear assembly are the lower drag brace in combination with the retract actuator and the lateral support struts. The wheels and the doors contribute very little to the total sound signal. The dominant sources of the main gear assembly are, quite likely, the shock-strut and the side brace, and in the case of a 4-wheel bogie, the interaction of the wake from the forward wheel set with the rearward wheel set.

**C. Experiments – Flyover Measurements**

While the stationary measurements allowed a fairly detailed investigation of individual noise contributors and directivity patterns, they lacked the important feature of the relative motion of source and receiver. Flyover measurements were considered important to determine whether "ground-obtained" test results could be applied to a realistic flight situation.

*Test Plane, Test Site, and Procedure*

In order to obtain a sufficiently high signal-to-noise ratio between model-radiated sound and the airframe noise of the plane, an aerodynamically very clean glider – the Braunschweig Akaflieg SB-10 – was selected.[12]

The test site was the Fassberg Military Airport. This airport is located in a remote area and exhibits exceptionally low background noise. The measurements were conducted on

§The term "smoothed" indicates that cavity-related discrete tones have been eliminated.

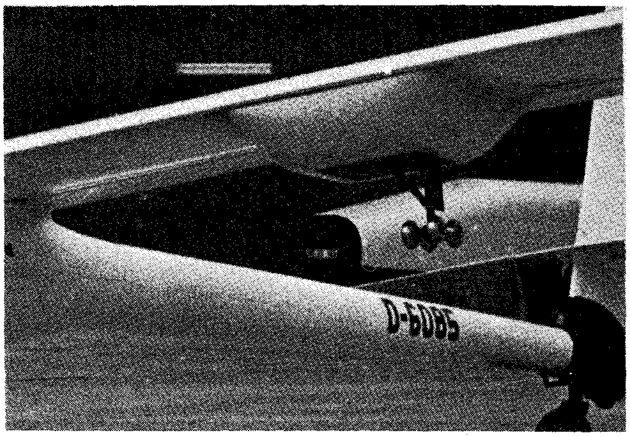



Fig. 10 Main gear model partly submerged in aerodynamic housing on wing of SB-10 glider.

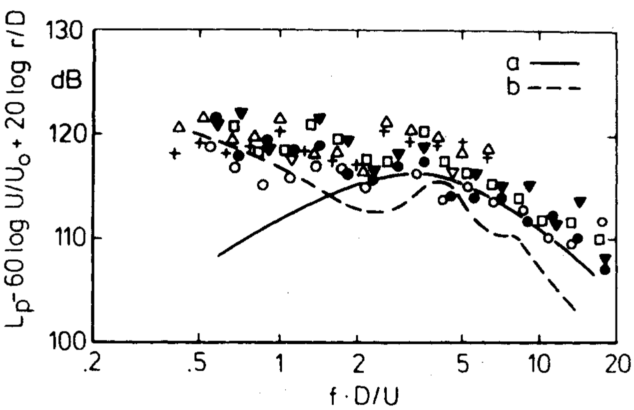



Fig. 11 Nose gear model normalized flyover noise spectra. Data points refer to different flights. a = stationary test data; b = glider self-noise ($U_o$ = 100 m/sec.)

November 25, 1975, with air humidity around 70%, temperatures near the freezing point, and windspeeds around 3 m/sec. Rms-pressure-time histories were obtained through seven microphones laid out on the test ground at a height of 1.2 m.

In order to derive a sound pressure level spectrum, the peak level in the time history of each frequency band was determined and plotted vs frequency. Thus the maximum flyover-noise spectrum was obtained. Data were corrected for atmospheric absorption. No correction for Doppler-shift was necessary, since, for the flight speeds and altitudes flown, its effect was minimal when only the maximum sound pressures were considered, which for all practical purposes occurred when the plane was directly above or within a few degrees from vertical above the microphone.

*Nose Gear Acoustic Data*

The cavity part of the model was submerged into an aerodynamically shaped housing, which itself was attached to the wing of the SB-10, about 2 m from the airplane centerline. Figure 10¶ shows the arrangement. The housing was rather bulky because of the fairly deep cavities of the models. The leading surface curvature of the housing resulted in a local overvelocity on the model of 8 to 16%, which was accounted for in the data reduction.

Figure 11 shows flyover noise data, obtained from six different flights. Data are normalized in the usual way, employing a (60 log $U/U_o$) and a (20 log $r/D$) term for levels, and a wheel-diameter-based Strouhal number for frequencies. In Fig. 11 cavity-generated tones have *not* been eliminated;

¶Figure 10 actually shows the main gear model on the plane.

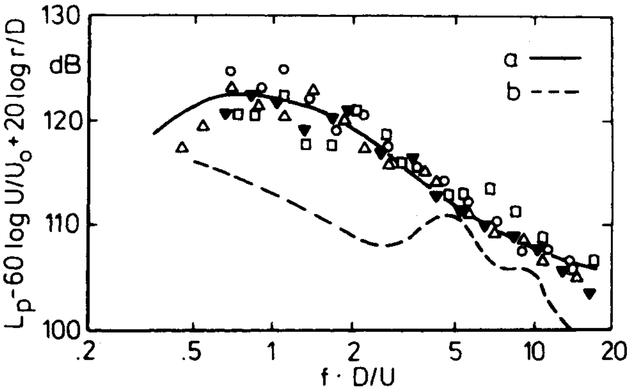
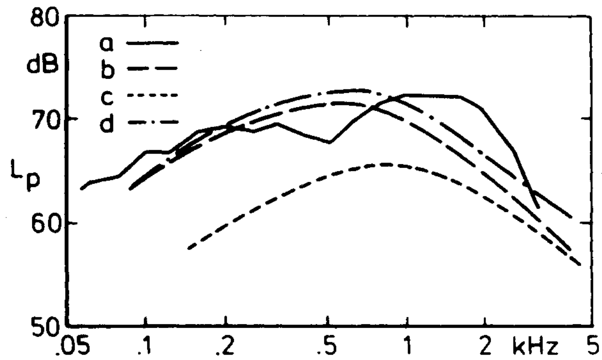
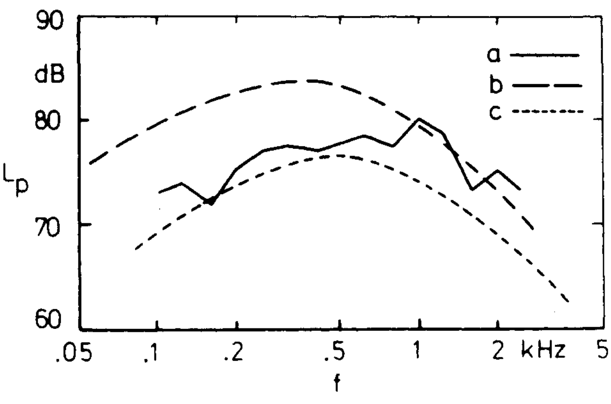


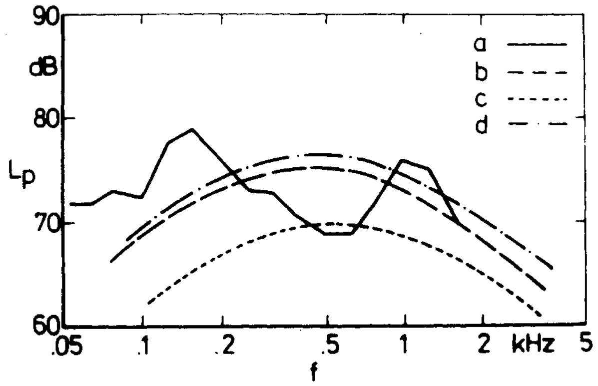

Fig. 12 Main gear model normalized flyover noise spectra. Data points refer to different flights. a = stationary test data; b = glider self noise ($U_o$ = 100 m/sec.).




a) Lockheed Jet Star: flight alt. 152 m; flight speed 103 m/sec




b) BAC 1-11: flight alt. 46 m; flight speed 103 m/sec




c) Hawker Siddeley HS 125: flight alt. 46 m; flight speed 83

Fig. 13 Comparison of predicted and measured landing gear noise: a = measured full-scale data; b = predicted 2 nose gears; c = predicted 1 nose gear; d = sum of b and c.

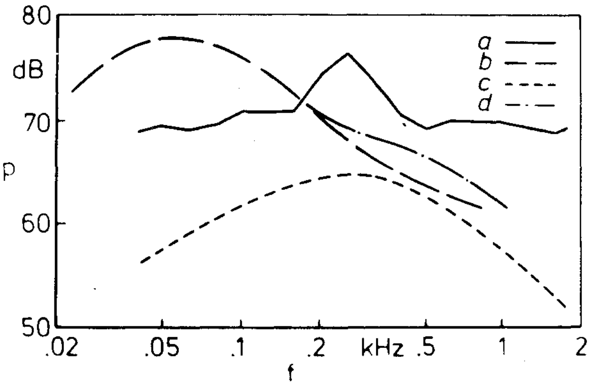



**Fig. 14 Comparison of predicted and measured landing gear noise for Vickers VC 10 (flight altitude = 183 m, flight speed = 81 m/sec): a = measured full scale; b = predicted 2 main gear; c = predicted 1 nose gears; d = sum of b and c.**

hence the Strouhal number range from 2 to 4 is affected by the presence of tones, which are not amenable to straightforward normalization. Compared to the glider-generated noise, the nose gear model is a comparatively weak sound source. Thus only the portions of the spectrum in the Strouhal number range between 2 and 3.2 and above 5 could definitely be associated with nose gear model radiated noise. All other portions of the spectrum are obliterated by glider self-noise, which is also shown in Fig. 11. In addition, the appropriately normalized data from the stationary tests appear in Fig. 11; the agreement in the frequency range not affected by glider self-noise, i.e., above $S = 5$, is acceptable. Below the peak frequency, glider-generated noise prevails and nose gear data cannot be identified.

*Main Gear Acoustic Data*

Flyover data from the two main gear models exceeded glider self-noise sufficiently to permit their definite identification. Data were obtained from five flights. Figure 12 shows normalized flyover noise data from the two main gear models, together with glider self-noise, and the smoothed normalized noise spectrum of the main gear model as determined on the ground-based facility. Reflections of gear-generated noise on the lower wing surfaces may emphasize or de-emphasize certain frequencies, which contributes to the scatter.

*Discussion of Results*

Although the SB-10 is an aerodynamically very clean sailplane, and radiated levels are comparatively low, it was to be expected that noise generation from fairly small models, representing only minor protrusions from the clean glider shape, would be difficult to detect. Indeed, identification of the noise attributable to the single nose gear was only possible in certain frequency regimes, mostly in the high Strouhal number range. Furthermore, from the stationary tests it was known that radiation in a downward direction (now seen from a flight reference frame) was much less than to the sides.

In contrast, main gear noise was characterized by a more uniform radiation pattern. By virtue of the wheel interaction noise, and also since two models instead of only one were flown, a sufficiently large signal-to-(glider self) noise ratio was obtained.

## IV. Conclusions

The model tests have established that the major components, such as shaft, actuators, drag braces, and wheels, combine to produce a haystack-shaped spectrum with farily well defined, although rather shallow, peaks. When represented on a Strouhal number basis these peaks can be related to typical length dimensions of the landing gear, such as the wheel diameter. For nose gears with a 2-wheel bogie, the Strouhal peak lies near 4; for the main gear, near 0.8, considering sound radiation in a downward direction. For a DC-10 type aircraft at an approach speed of 75 m/sec, for example, nose gear related noise should peak near 300 Hz, main gear related noise near 45 Hz. Wheel-well related tones should occur at frequencies well below 200 Hz.

### A. Comparison of Model Data with Full-Scale Flight Data

Comparison of test results both from the ground-based and the flyover measurements with data from full-scale flight tests is possible only on a qualitative basis, because the models were idealized configurations, geometrically simulating only the gross features of a landing gear and leaving out all the little details that probably constitute rather important sound sources in the medium- to high-frequency range.

Hardly any direct measurements of full-scale landing gear noise were made. Some data are published, however, that show the effect of lowering or retracting the gears.[1,8] Portions of the spectra that can be associated with landing gear noise were used to compare full-scale flight and (stationary) model test data, as shown in Fig. 13 a-c. In interpreting these comparisons, it should be kept in mind that in no case was an exact model of the specific landing gear under consideration available. In fact, to derive full-scale data from model tests for the cases of the JetStar (Fig. 13a), the BAC 1-11 (Fig. 13b), and the HS 125 (Fig. 13c) only nose gear model data were used. The main gears of these three aircraft consisted of two 2-wheel bogies; hence it was considered more appropriate to add up the relevant contributions of three 2-wheel bogies to obtain the total landing gear noise, rather than to employ main-gear model test results with a 4-wheel-bogie to predict noise radiation from 2-wheel bogie type main gear.

Considering then the predicted and measured landing gear noise spectra, one finds a rather acceptable agreement for the JetStar and the HS 125, while in the case of the BAC 1-11 levels are overpredicted. The VC-10 (Fig. 14) is an aircraft which actually has a main gear with 4-wheel bogies; hence the main gear model data were employed to predict its main gear noise. Low frequency levels, however, are overpredicted. It can only be assumed that model and full-scale geometries were too different to obtain full agreement.

### B. Prediction Approaches

The general agreement of full-scale landing gear noise predicted on the basis of scale-model test results with measured full-scale landing gear noise indicates the validity of the normalized (broadband) spectra as presented in Figs. 7 and 9, respectively, for directions directly down, to the side, and half-way between under 45 deg. These spectra are hence proposed for predicting the noise produced by the dominant features of landing gears.

Prediction of noise due to small scale geometrical features, radiated at higher frequencies, is not possible with the available experimental data. Here a still more detailed investigation of individual components and subcomponents would be required to derive prediction schemes.

## References

[1]Gibson, J., "Non-Engine Aerodynamic Noise Investigation of Large Aircraft," NASA CR-2378, 1974.

[2]Healy, C., "Measurement and Analysis of Aircraft Farfield Aerodynamic Noise," NASA CR-2377, 1974.

[3]Morgan, H. and Hardin, J.C., "Airframe Noise – The Next Aircraft Noise Barrier," AIAA Paper 74-949, Los Angeles, Aug. 12-14, 1974.

[4]Hardin, J.C., Fratello, D.J., Hayden, R.E., Kadman, Y., and Africk, S., "Prediction of Airframe Noise," NASA TN D-7821, 1975.

[5]Hayden, R.E., Kadman, Y., Bliss, D.B., and Africk, S., "Diagnostic Calculations of Airframe-Radiated Noise," AIAA Paper 75-485, Hampton, Va., March 24-26, 1975.

[6]Revell, J., "Induced Drag Effect on Airframe Noise," AIAA Paper 75-487, Hampton, Va., March 24-26, 1975.

[7]Revell, J. and Healy, C., "Methods for the Prediction of Aerodynamic Noise," AIAA Paper 75-539, Hampton, Va., March 24-25, 1975.

[8]Fethney, P. "An Experimental Study of Airframe Self-Noise," RAE Tech. Memo Aero 1923, 1975.

[9]Meecham, W.C., "Theory of Airframe Noise," JASA, Vol. 57, No. 6, Part II, 1975.

[10]Heller, H. and Bliss, D., "Physical Mechanisms of Flow-Induced Pressure Fluctuations in Cavities," AIAA Paper 75-491, Hampton, Va., March 24-26, 1975.

[11]Dobrzynski, W., "Freistrahlprüfstand zur Durchführung von akustischen Modellversuchen", DLR-Mitt. 75-22, 1975.

[12]Jane's *All the World's Aircraft*, 1973/1974.