Acoustics of Ultralight Airplanes

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In view of the stringent noise limits that have been imposed on ultralight airplanes, an experimental and theoretical research program was initiated to investigate specifically the noise sources of ultralight airplanes. For this purpose, flyover and ground static noise measurements on tractor- and pusher-propeller-driven airplane configurations and wind-tunnel noise measurements on isolated full-scale ultralight airplane propellers were conducted. The study showed that pusher-propeller-driven ultralight airplanes were 5–15 dB noisier than those equipped with tractor propellers. Engine noise—even if well muffled—was frequently found to equal propeller noise in magnitude. The experiments have established propeller blade-tip speed and thrust as the important parameters of propeller noise, rather than flight speed or number of propeller blades. Also, at the relatively low operational helical blade-tip Mach numbers, propeller broadband noise, rather than propeller harmonic noise, determines ultralight airplane propeller noise. To comply with stringent noise limits, ultralight airplanes must be of clean aerodynamic design (to minimize drag for low thrust requirements), be equipped with thoroughly muffled engines, and their operational propeller blade-tip Mach number must be limited to values well below 0.5.

Nomenclature

BLN	= number of blades
c_T	= thrust coefficient
D	= propeller diameter, m
f	= frequency, Hz
h	= flyover height (above microphone), m
$L_{A\max}$	= maximum A-weighted sound pressure level (time-constant "slow"), dB
$L_{A,HM}$	= A-weighted sound pressure level of engine rotational noise, dB
$L_{A,HP}$	= A-weighted sound pressure level of propeller rotational noise, dB
$L_{A,P}$	= A-weighted sound pressure level of total propeller noise, dB
N	= rotational speed, rpm
r,R	= source/receiver distance, m
SPL	= sound pressure level, dB; referenced to $p_0 = 20$ μPa
T	= propeller thrust, N
t	= flyover time, s
u	= blade-tip speed, m/s
V,v	= true air speed, m/s
v_G	= ground speed, m/s
β	= blade pitch angle at 75% radius, deg
θ	= radiation direction in the vertical plane, deg
ρ	= air density, kg/m^3

Subscripts

max	= maximum
min	= minimum
0	= reference value

Introduction

IN the past decade, a new type of a technically simple and affordable airplane for leisure aviation has appeared: the ultralight or microlight airplane. The possibility of powered flight "for everybody," initially unrestricted by complicated pilot training and government regulations, has caused a rapid growth in the number and variety of such airplanes. Ultralight airplanes are, by definition, light in weight, ranging from 100 (single seat) to 150 kg (twin seat) empty. They are driven by propellers, utilize high-rotational-speed, 2-stroke or 4-stroke piston engines, and attain flight speeds on the order of 50–100 km/h. Because of such low flying speeds and many pilots' preference to fly close to the permitted minimum safe flight height of 150 m (perhaps to enhance the subjective feeling of speed), the noise from an ultralight airplane is considered a nuisance, although such an aircraft by itself is not necessarily a very powerful noise source.

The current sensitivity to aircraft noise has caused several countries to issue noise legislation. In the Federal Republic of Germany, for example, ultralight airplanes are required to pass a noise test where the aircraft must execute a horizontal flyover at a height of 150 m above ground at maximum continuous engine power. The maximum flyover noise is measured with a microphone 1.2 m above ground; the noise level must not exceed a value of 60 dB(A) for those ultralight airplanes that obtained an airworthiness certificate before the end of 1985. After that date, a 55 dB(A) limit was set.

Although such noise regulations for ultralight airplanes exist, they are not strictly enforced. This might be because little experience exists in measuring the noise specifically from ultralight airplanes. This situation is considered not very satisfactory, and many unresolved problems still remain. For example, should a (certification-type) flight test be required or would perhaps a ground static noise test suffice? Is the A-weighted overall maximum flyover noise level an appropriate measure, or would a time-duration weighted flyover level such as the sound exposure level provide a better measure of annoyance? And how critical is the microphone position of 1.2 m above ground as currently used in all Annex 16-type certification measurements[1] as far as ground reflection effects are concerned.

Beyond the rather fundamental problem of the most suitable noise measure (noise metric), the question remains whether existing and proposed noise limits can be technically achieved at all. Are there differences in the minimum attainable noise level due to different types of ultralight airplanes (e.g., those equipped with tractor or with pusher propellers)? Is there hope to reduce noise by conventional means, such as increasing the number of blades or reducing the flight speed and/or propeller-rotational speed?

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Table 1 Ultralight airplanes tested

Pusher propeller configurations:	
Scheibe/Uli I (2-blade propeller)	
Scheibe/Uli I (3-blade propeller)	
Scheibe/Uli I (4-blade propeller)	
Pohl/Mitchell-Wing (2-blade propeller)	
HFL/Stratos (2-blade propeller)	
Tractor propeller configurations:	
Pioneer/Flightstar (2-blade propeller)	
Eipper/Quicksilver (3-blade propeller)	
Möller/Me 13 (2-blade propeller)	
Icarus/Sherpa (2-cylinder engine, 2-blade propeller)	
Icarus/Sherpa (4-cylinder engine, 3-blade propeller)	
Propeller-propulsion related parameter ranges covered:	
Propeller rotational speed,	rpm 1600–2500
Engine rotational speed,	rpm 3400–6000
Propeller diameter, m	1.3–1.5
Number of propeller blades	2–4

To answer these questions, a comprehensive research program was initiated by the German Aerospace Research Establishment (DLR) Braunschweig Research Center[2,3] involving three basic test phases: 1) flyover noise measurements, 2) ground static noise measurements, and 3) wind-tunnel noise measurements.

Flyover and Ground Static Experiments

Test Airplanes

For the flight and ground static tests, eight different ultralight airplanes were used. One of these could be equipped with a 2-blade, a 3-blade, or a 4-blade propeller, such that a total of 10 different airplane configurations were available. Of these, five had pusher propellers, and five had tractor propellers. Figures 1 and 2 show two of the test airplanes. All test airplanes were powered by 2-stroke piston engines with 1–4 cylinders. The ultralight airplanes (manufacturer/type) that were tested are listed in Table 1.

Data Acquisition

Acoustic Data

For the flyover noise measurements, the microphones were arranged as follows. One microphone each was positioned 1.2 m above a concrete surface and above a grass-covered surface; one was positioned off center in an inverted manner 7 mm above a 40-cm-diam metal plate on grass [International Civil Aviation Organization Annex 16/Chapter 10 recommended microphone arrangement]; and one was laid flat on a concrete surface. All microphones were located within a few meters of each other. These arrangements were intended to provide quantitative information on the influences of ground reflection from grass and concrete surfaces.

For the ground static noise measurements, microphones were arranged on a one-half circle of radius 20 m to one side of the test airplanes. Data were subsequently taken on both sides. These measurements were exclusively made on a concrete surface, and all microphones were laid on the ground.

Flight Height and True Air Speed

Flight height and ground speed were determined by means of two vertically oriented instant-picture cameras. The cameras were positioned under the flight path approximately 50 m before and after the point of vertical flyover above the microphones. Ground speed and true airspeed will not necessarily agree, especially for a lightweight airplane. Flyovers were therefore conducted in two opposing directions; the mean of the two ensuing ground speeds provided a sufficiently accurate indication of the mean true air speed. This speed must be known to determine the helical propeller blade-tip Mach number.

Meteorological Data

Air temperature, relative humidity, and wind speed were measured and monitored through instruments 2 m above ground. Because of the relatively low test-flight heights of typically 50–100 m, air temperature aloft was assumed to agree with that measured on the ground.

Data Analysis

Propeller Rotational Speed

It was not possible to monitor directly the rotational speed of the propellers onboard the aircraft. Instead, the flyover noise time signature of the propeller rotational fundamental frequency was determined from narrowband analyses. From Doppler-frequency time plots, the actual propeller rotational speed can be derived. This speed must be known to determine the helical blade-tip Mach number.

Separation of Noise Components

To interpret the flyover and ground static test data it is important to separate the various noise contributors, foremost the propeller and the engine exhaust. It is also necessary to distinguish between harmonic propeller and exhaust sound and broadband noise. To this end, the following procedure was employed: Narrowband spectra in the frequency range from 0 to 1600 Hz were obtained at 0.5-s intervals during the flyover time span of interest. A typical example is shown in Fig. 3.

The transmission (gear) ratio between engine and propeller rotational speeds was noninteger in all cases but one. Thus, the engine and the propeller harmonics can be readily distinguished as shown in Fig. 3. This information allows one to separately determine the A-weighted propeller flyover harmonic sound and the engine flyover harmonic sound levels simply by A-weighting and summing the respective discrete frequency components (in terms of squared sound pressure). Both together—with added broadband noise components—should then constitute the combined overall A-weighted

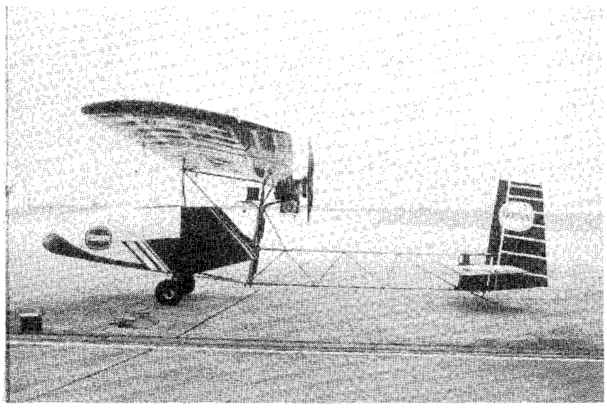

Fig. 1 Scheibe/Uli I 2-blade pusher-propeller ultralight airplane.

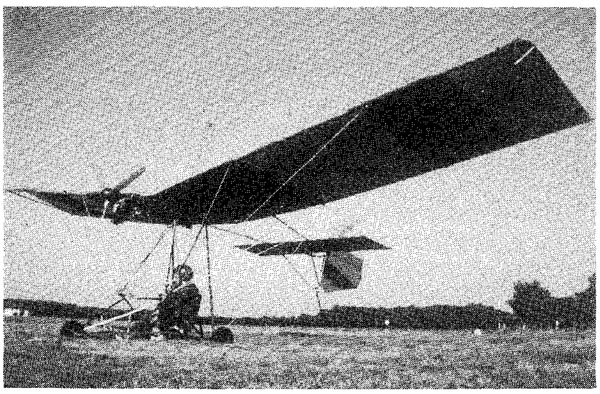

Fig. 2 Eipper/Quicksilver 3-blade tractor-propeller ultralight airplane.

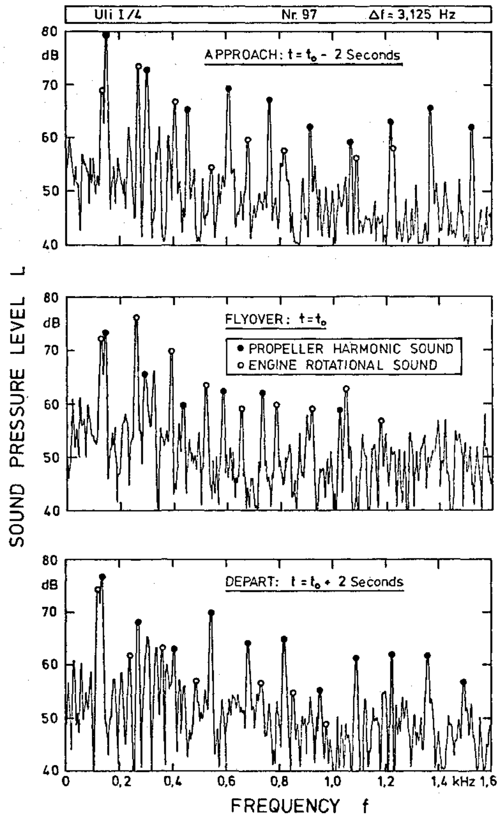

Fig. 3 Narrowband analysis of flyover noise.

flyover noise time history. Figure 4 presents such time histories where the engine harmonic sound contribution is much less than the propeller harmonic sound contribution (other than at the instant of vertical flyover). The sum of the engine and propeller contributions does, however, not yield the total overall flyover noise level time history as obtained by direct analysis. The obvious difference must be attributed to broadband components from the propeller or from the aircraft itself (airframe noise). It will be shown that broadband noise is indeed a significant noise source of an ultralight airplane. In the case of a ground static test, separation of engine and propeller contributions is straightforward since sound signatures are essentially steady state and no Doppler-effect occurs.

Test Results—Flyover Noise Measurements

The data analysis procedures, as discussed, are essential to derive guidelines for the design of low-noise, ultralight airplanes. Noise certification procedures require, however, only the maximum overall A-weighted noise level during flyover. Such "certification noise levels" were therefore determined for all test airplanes in order to check, among other things, whether compliance with the current German ultralight airplane noise regulations is possible at all. From the flyover noise data it was found that none of the pusher-propeller, ultralight airplanes passed the 60 dB limit; only one of the tractor-propeller airplanes just barely met the 55 dB limit.

The difference in test results for the various microphone positions is shown in Fig. 5 for data from all test airplanes. Here the upper representation uses the 1.2-m-above-grass microphone position as the reference, the lower representation the 0-m-above-concrete position. It is of interest to note that the microphone positions laid on the hard surface and 1.2 m above grass yield a statistically significant mean level difference and confidence limit at 95% probability, respectively, of 4.0 dB and ± 0.1 dB, rather than the theoretically expected 3.0 dB. Comparing the positions on grass and 1.2 m above grass still yields a difference of 3.5 dB ± 0.1 dB.

Test Results—Ground-Static Measurements

Ground-static measurements were conducted to determine the noise emission of the aircraft while simultaneously measuring the static thrust of the propeller. Propeller thrust does change under conditions of forward flight; the influence on noise generation, however, is small compared with that of propeller rotational speed. For data interpretation, this ground-static-determined thrust was considered to be a measure for the one occurring in flight.

Expectedly, no firm relationship can be established between the noise data from a ground static test and those from a flyover test. A pusher propeller inherently operates in the highly disturbed wake from upstream airplane components and from the pilot. A tractor propeller operates under undisturbed inflow conditions. In both cases, though, there is a forward flight component not present in a ground static test. For tractor propellers in particular, the effect of forward flight on the ensuing noise was found to be substantial. Under flight conditions, a tractor propeller is much quieter than under static test conditions. Ground static noise measurements are therefore entirely unsuited to derive flyover noise data!

Test Results—Engine Noise Measurements

Although engine noise contributions to the total flyover noise can be extracted by means of the preceding analysis tech-

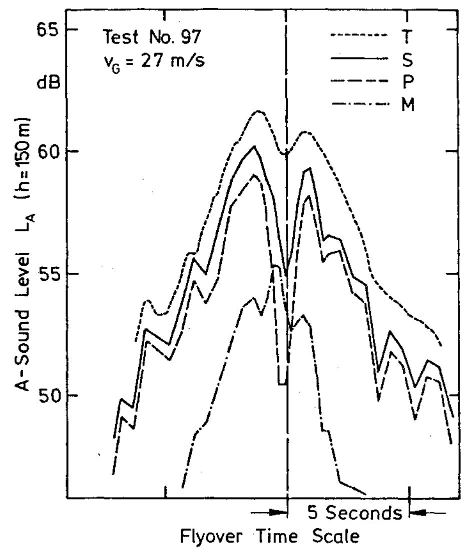

Fig. 4 Component contributions to flyover noise, typical pusher-propeller configuration [propeller rotational noise (P), engine rotational noise (M), sum of P and M (S), and measured total noise (T)].

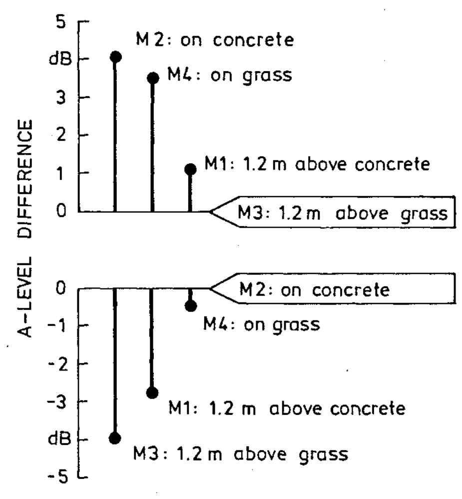

Fig. 5 Mean difference in measured A-weighted flyover noise levels for four microphone arrangements.

nique, it was considered important to make separate ground static noise measurements on engines of ultralight airplanes in the absence of the propeller to determine their noise level vs rpm behavior.

For this purpose, the propeller was removed from the airplane and replaced by a disk brake for measurements under conditions of maximum engine throttle. A typical result from three ultralight airplane engines is shown in Fig. 6. Here, the A-weighted noise level at a lateral distance of 150 m from the engine exhaust orifice is plotted vs engine rotational speed. The data suggest an N^5 dependence for each engine (as equipped with its own muffler).

All engine noise data from both flyover and ground static tests together are shown in Fig. 7. This presentation illustrates the current state of technology with respect to ultralight airplane engine noise and engine noise muffling. The obvious spread in the levels is a consequence of engine and muffler differences. Accordingly, a potential for a 10 dB engine noise reduction for some engines seems to exist.

Wind-Tunnel Experiments

To obtain more detailed information than is possible from flyover noise tests, a comprehensive wind-tunnel test program was carried out using full-scale, ultralight airplane propellers. Primary parameters of interest were number of blades, thrust, power, propeller rotational speed, flow-speed (flight-speed), as well as helical blade-tip Mach number.

Test Setup

Tests were conducted in the DLR Göttingen Low Speed 3-m Wind Tunnel. This tunnel has an open test section, surrounded by a partially anechoically treated test hall. Figure 8 shows the 50 kW propeller test stand in the open test section.

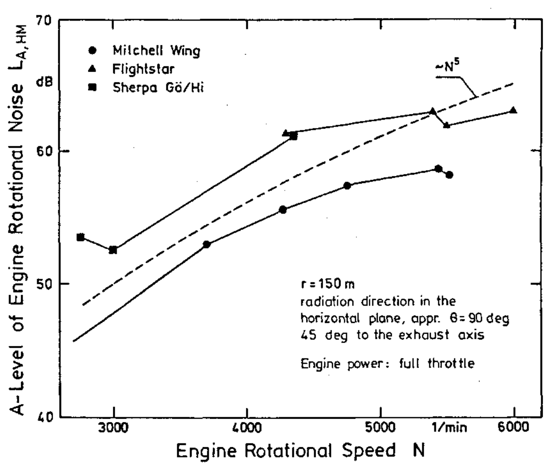

Fig. 6 Engine rotational speed dependence of A-weighted overall sound pressure level for three engines from ground static measurements.

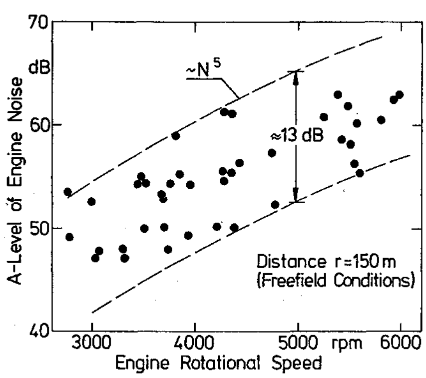

Fig. 7 Engine rotational speed dependence of A-weighted overall sound pressure level for all ultralight airplanes from flyover and ground static measurements corrected to a reference distance of 150 m.

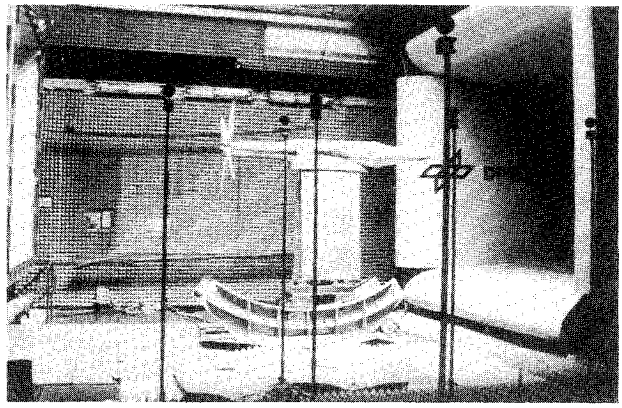

Fig. 8 Ultralight airplane propeller test stand in the DLR-Göttingen 3-m low speed wind tunnel.

Wooden Clark-Y-profile propellers (manufactured by the Mühlbauer MT-Propeller Company, Rosenheim, Federal Republic of Germany) of 1.4-m diam (square tip) with 2, 3, and 6 blades and of 1.6-m diam (round tip) with 2, 3, and 4 blades were tested. Blade pitch angles had been varied between 10 and 25 deg. Tunnel flow speeds ranged from 10 to 30 m/s, corresponding to the typical flight speed range of ultralight airplanes.

Data Acquisition and Analysis

Microphones were positioned in the plane of rotation ($\hat{=}$ 90 deg), 105 and 120 deg in the aft section, and 75 deg in the forward section at various distances from the propeller hub.

Propeller noise contains both periodic and random components. The unaveraged frequency spectrum shows a substantial noise floor. To increase the signal-to-noise ratio, the measured time histories were routinely triggered once per revolution and averaged over many revolutions. This procedure essentially eliminates all random components as well as the stochastic amplitude fluctuations of the periodic components resulting in a clean rotational harmonic time history and frequency spectrum. The spectral harmonics can now be used—after A-weighting and logarithmic summation—to determine the overall A-weighted noise level at the particular microphone position.

Test Results—Undistorted Inflow

For a typical lateral microphone location in the propeller plane, Fig. 9 exemplifies the helical blade-tip Mach number (MH) dependence of the overall A-weighted harmonic noise level for tunnel flow speeds from 15 to 30 m/s. There is, expectedly, very little influence of flow speed, as the relative contribution of the flow speed to MH is small, compared with the blade-tip speeds; in this case, blade loading does not change significantly within the operational regime of flight speeds.

The dependence of the overall A-weighted harmonic noise level on propeller thrust is shown in Fig. 10, where MH and blade number were varied. This representation (for otherwise constant geometric and operational conditions as in the figure legends) indicates that a required thrust may be obtained in a number of ways, yielding different (harmonic!) levels in the course: for example, at a given thrust a 6-blade propeller generates much less harmonic noise than a 2-blade propeller due to an inherently lowered MH.

It should be cautioned, however, that below a certain critical MH it is not the propeller harmonic components that determine the overall level but rather the broadband components. This critical Mach number lies somewhere between 0.50 and 0.55.

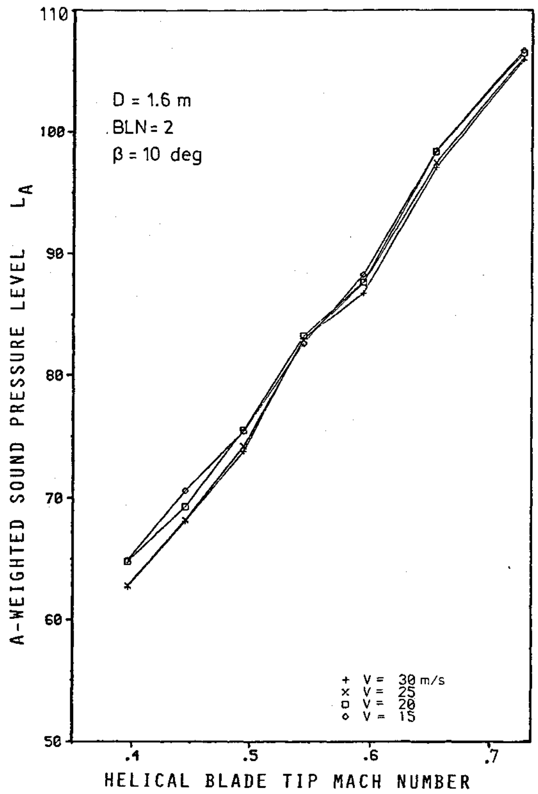

Fig. 9 ***A*-weighted harmonic propeller sound level dependence on helical blade-tip Mach number.**

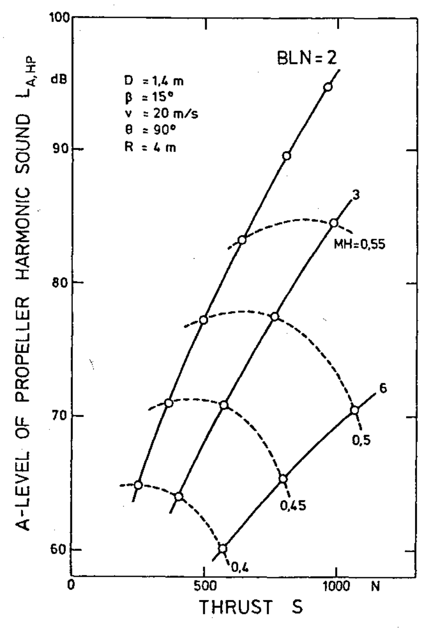

Fig. 10 ***A*-weighted harmonic propeller sound level dependence on thrust with parameters helical blade-tip Mach number (*MH*) and number of blades (*BLN*).**

Test Results—Distorted Inflow

To obtain at least some order of magnitude information on the effect of a substantial inflow distortion, such as caused by the pilot upstream of a pusher propeller on the ensuing noise, the setup in the tunnel was changed to accommodate a (dummy) pilot. The dummy was oriented horizontally to allow measurements under the ultralight airplane's propeller (see Fig. 11).

A comparison of a typical harmonic spectrum for the undisturbed and the disturbed inflow cases is shown in Fig. 12. Clearly, level increases from 10 to 20 dB—especially at the higher harmonics—result from the grossly disturbed inflow; this emphasizes the potentially severe noise problem caused by pusher-propeller ultralight airplanes.

Data Interpretation and Discussion

The experimental results obtained from the flight, the ground static, and the wind-tunnel tests can now be used to derive certain characteristics of the noise from ultralight airplane propellers. Because of the different source mechanisms that govern discrete and broadband propeller noise and rotational engine noise radiation, influences of operational and geometrical parameters are discussed separately.

In the context of this study, the essential propeller noise parameters are *MH*, blade loading, number of blades (*BLN*),

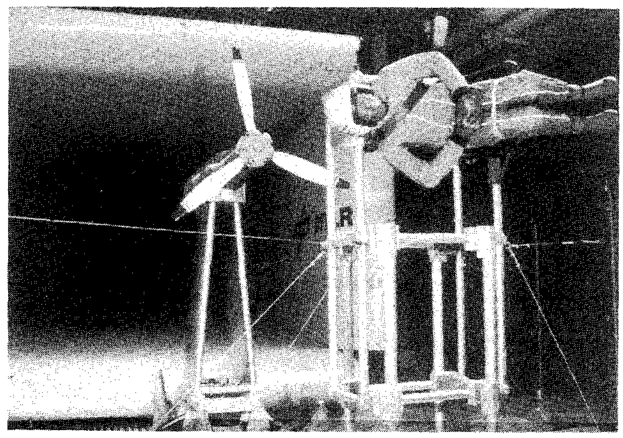

Fig. 11 **Dummy pilot upstream of propeller in tunnel open test section.**

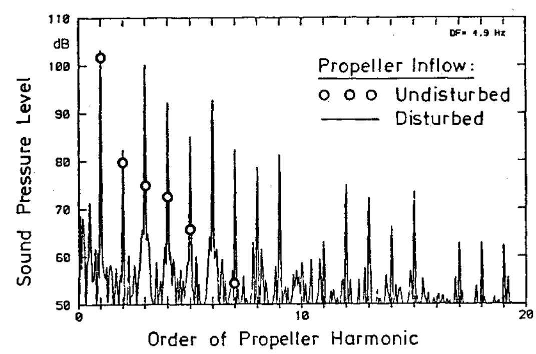

Fig. 12 **Effect of an upstream disturbance (full-size dummy pilot) on the ensuing harmonic pressure time history and spectrum.**

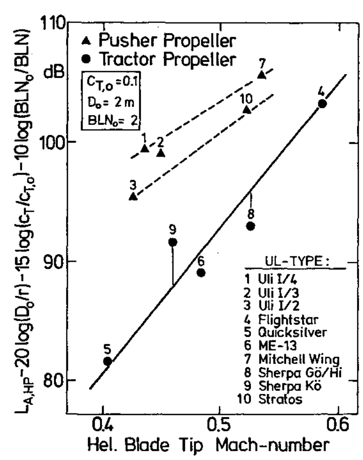

Fig. 13 **Normalized *A*-weighted level maxima of propeller rotational vs helical blade-tip Mach number from flyover noise measurements.**

and propeller diameter (D). Since ultralight airplane propellers typically operate at Mach numbers well below 0.6, rotational thickness noise can be neglected. Data interpretation is to yield the dependencies of noise levels on Mach number, empirically normalized with specified blade loading and propeller geometry.

Because ultralight airplane propellers also operate at extremely low advance ratios, normalization of noise data is simply based on the propeller's thrust coefficient

$$c_T = T/\zeta[(N/60)^2 D^4] \qquad (1)$$

The effects of blade diameter and blade number on the A-weighted levels of rotational propeller noise are manifold and cannot be shortcut by means of a simple physical parametric relationship.

Propeller Rotational Noise

Employing basic principles, an empirical analysis was performed using the wind-tunnel test results for different propeller configurations. By correlating appropriate findings with the rotational propeller noise levels from flyovers, good agreement with wind-tunnel data is obtained for tractor propellers (see Fig. 13).

If corresponding data points are approximated by a linear dependence, an empirical equation can be derived for the maximum A-weighted level of rotational propeller noise at distance r:

$$L_{A,HP,\max} = 31.9 + 122\,(MH) + 20\log(D_0/r) + 15\log(c_T/c_{T,0}) + 10\log(BLN_0/BLN) \qquad (2)$$

where

$$D_0 = 2\text{ m}, \qquad BLN_0 = 2, \qquad c_{T,0} = 0.1$$

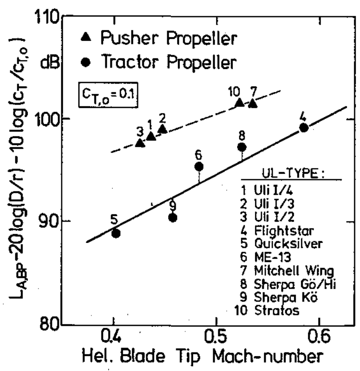

Fig. 14 Normalized A-weighted level maxima of propeller broadband noise vs helical blade-tip Mach number from flyover noise measurements.

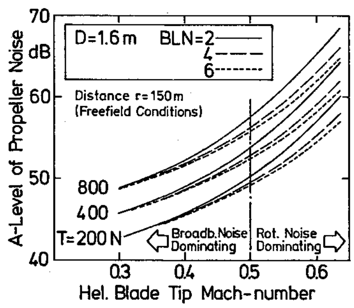

Fig. 15 Estimated maximum A-weighted levels of total propeller noise vs helical blade-tip Mach number for various propeller thrusts and blade numbers (tractor propellers only).

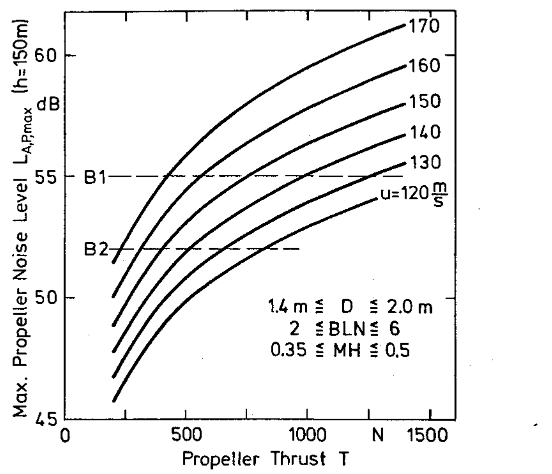

Fig. 16 Estimated flyover noise level as a function of propeller thrust and blade-tip speed.

This equation is valid for the following parameter regimes: propeller diameter, $1.4 \leq D < 2$ m; blade number, $2 \leq BLN \leq 6$; tip mach number, $0.3 \leq MH \leq 0.6$; and thrust coefficient, $0.02 \leq c_T$.

Compared with this result, rotational noise levels from pusher propellers are as much as 10 dB higher as a consequence of the disturbed inflow.

Propeller Broadband Noise

Parametric propeller broadband noise analysis was based on the mean-squared sound pressure to increase with the sixth power of blade-tip Mach number. Broadband noise data from flyover measurements confirm this assumption for tractor propellers (see Fig. 14). Approximating the corresponding data points by a straight line yields an empirical equation to estimate propeller broadband noise levels as:

$$L_{A,BP,\max} = 68.3 + 52.5\,(MH) + 20\log(D/r) + 10\log(c_T/c_{T,0}) \qquad (3)$$

[parameter regimes are the same as for Eq. (2)].

Using Eqs. (2) and (3), the total noise radiation from *tractor propellers* can be calculated. A corresponding result is presented in Fig. 15 based on a propeller diameter of 1.6 m. Manipulating Eq. (3) by Eq. (1), it is obvious that broadband noise radiation depends only on blade-tip Mach number and thrust, whereas blade number and diameter seem to be of no importance in the low Mach number regime.

Design Criteria for Low Noise Ultralight Airplanes

The acoustic experiments have clearly shown that the observed increase of 10–15 dB for a pusher-propeller configuration against a tractor-propeller configuration cannot really be compensated by acoustical changes such as lower rotational speeds. The following considerations for optimum combinations of geometric and operational propeller parameters to result in low-noise ultralight airplanes are therefore restricted to tractor-propeller configurations.

Certain parameters have comparatively little influence and can be removed from further considerations: the air density, air temperature, and airspeed. In this case, the helical blade-tip Mach number is solely a function of propeller rotational speed and propeller diameter. One can now express the thrust coefficient [see Eq. (1)] as a function of the helical blade-tip Mach number and propeller thrust only. The only remaining free parameters of influence are then propeller diameter, number of blades, propeller thrust, and helical blade-tip Mach number.

Figure 15 shows the dependence on the helical blade-tip Mach number of the propeller A-weighted noise level (containing both harmonic and broadband components) for various propeller thrusts and blade numbers. Data are referenced to a flight height of 150 m, a constant flight speed of 20 m/s, and a propeller diameter of 1.6 m. The noise level increase grows with Mach number. Also, blade number becomes increasingly important. Different from the data shown in Fig. 15, for a propeller diameter of 2.0 m, noise levels are lower for high MH. The effect of these two latter parameters (diameter and blade number) vanishes, however, for helical blade-tip Mach numbers below 0.4, such that below this Mach number the thrust remains the only parameter of importance as broadband components now dominate the propeller noise.

To achieve minimum propeller noise, it is thus generally advantageous to aim for minimum blade-tip speeds for any required propeller thrust. Should such speeds still result in blade-tip Mach numbers above 0.5, it would then be indicated to increase the propeller diameter and, if feasible, the number of blades. Because propeller thrust (at these low tip Mach numbers) is of such importance, it is now also strongly advisable to aim for a good aerodynamic design of the ultralight airplane itself.

It should be pointed out that the levels, as shown on the ordinate of Fig. 15, are free-field values. Because noise certification under ICAO-Annex 16 requires flyover noise being measured with a microphone 1.2 m above a grass surface, one may utilize the information in these figures and subtract 4 dB to account for the difference in microphone height and add 6 dB to account for the free-field condition; hence the current A-weighted noise-level limits in the Federal Republic of Germany of, respectively, 60 dB and 55 dB would correspond to levels of 58 dB and 53 dB on the ordinate scale of Fig. 15.

The levels as shown in this figure pertain to the propeller only. They would be strictly valid if the engine contribution was at least 10 dB less than the propeller contribution. This assumption is, however, quite unrealistic. An ultralight airplane engine, even if well muffled, is more likely to contribute at least the same noise level as the propeller. In this case, the permissible maximum propeller noise level must be lowered by another 3 dB.

Depending on the required propeller thrust, one may now select an appropriate combination of blade number and tip speed. If the helical-tip Mach number can indeed be held below approximately 0.5, a further simplification is possible in representing ultralight airplane noise level vs propeller thrust, because now blade-tip speed would be the only free parameter. Such a simplified representation appears in Fig. 16. Here the limit $B1$ pertains to an ultralight airplane where the propeller dominates and $B2$ where propeller and engine contribute equally. The tip speed corresponding to the noise limit can now be achieved with any combination of rotational speed and propeller diameter.

Conclusions and Recommendations

The results of this study can be summarized as follows.

1) Propellers with helical blade-tip Mach numbers below 0.5 radiate predominantly broadband noise; at higher Mach numbers, harmonic noise components dominate.

2) The A-weighted overall propeller-harmonic level rises almost linearly—gaining 12 dB per one-tenth increase in helical blade-tip Mach number. The overall propeller broadband noise also rises linearly with approximately 6 dB increase per one-tenth increase of the helical blade-tip Mach number.

3) At a given helical blade-tip Mach number, higher thrust loadings generate higher propeller noise;

4) Distorted inflow increases propeller noise by 5–15 dB depending on the aerodynamic characteristics of the disturbance.

The stringent noise certification limit of $L_A = 55$ dB for current and future ultralight airplane designs in the Federal Republic of Germany can only be complied with if the aircraft is designed along the following guidelines:

1) Configurations where the inflow into the propeller rotational plane is highly distorted (pusher-type airplanes) must be excluded.

2) The helical propeller blade-tip Mach number should not significantly exceed a value of 0.45 if the engine noise is much less than the propeller noise, and of 0.40 if both noise components are of equal magnitude.

3) The aircraft should have a very clean aerodynamic design to minimize ("noise producing") thrust requirements.

4) The engine must be fitted with an acoustically efficient exhaust muffler.

Following these guidelines should make it possible to design and construct a low-noise, ultralight airplane which—in all likelihood—is not a "pain in the air," but rather a flight vehicle that would be acceptable to both the operator and the public.

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