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Basis of Calculation for Engine Test Runs

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Basis of Calculation for Engine Test Runs

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0 Zusammenfassung

Triebwerksprobeläufe sind als unerlässlicher Bestandteil von Wartungs- und Instandsetzungsarbeiten an Luftfahrzeugen auf Verkehrsflughäfen, Verkehrslandeplätzen und militärischen Flugplätzen mit nicht unerheblichen Lärmimmissionen in der Nachbarschaft der Flugplätze verbunden. In einer 1. Verordnung zum novellierten Gesetz zum Schutz gegen Fluglärm sind außer zum Fluglärm zwar auch Methoden zur Berücksichtigung von am Boden auf Flugplätzen erzeugte Geräuschemissionen beim Rollen der Flugzeuge zum Start und nach der Landung sowie beim Betrieb der Hilfstriebwerke am Boden, nicht jedoch zur Berücksichtigung von Triebwerksprobeläufen enthalten.

Wesentliches Ziel der hier beschriebenen Untersuchungen war deshalb die Erarbeitung eines Vorschlages für eine einheitliche Methodik zur Ermittlung der Geräuschimmissionen von Triebwerksprobeläufen. Hierzu wurde auf der Grundlage der praktischen Gegebenheiten und Randbedingungen bei der Durchführung von Triebwerksprobeläufen auf Flugplätzen (Art und Umfang real durchgeführter Probeläufe, eingesetzte Maßnahmen zur Geräuschminderung u. a.) eine problemorientierte Definition von Triebwerksprobeläufen erarbeitet.

Anhand einer Analyse der vorliegenden Datenbasis (akustische Daten, Häufigkeiten und Dauer einzelner Laststufen bei unterschiedlichen Luftfahrzeugtypen u. a.) wurden die im Zusammenhang mit der rechnerischen Ermittlung von Geräuschimmissionen von Triebwerksprobeläufen bestehenden Probleme ausführlich untersucht. Bestimmte Detailprobleme (z. B. Lärmschutzhallen, Ausbreitungsmodelle) wurden mit Experten der jeweiligen Fachrichtungen diskutiert.

Aus den einzelnen Untersuchungsergebnissen wurden Schlussfolgerungen für die Ableitung einer einheitlichen Berechnungsmethodik für Triebwerksprobeläufe gezogen. Im Zusammenhang mit einer Diskussion der möglichen Einordnung der neuen Berechnungsmethodik in das allgemeine Regelwerk zum Lärmschutz wurden im Ergebnis eine kurz- und eine mittelfristige Lösung zur Umsetzung der Berechnungsmethodik für Triebwerksprobeläufe aufgezeigt. Während sich hierbei die kurzfristige Lösung auf die Methodik ausschließlich der Triebwerksprobeläufe bezieht, wird bei der mittelfristigen Lösung empfohlen, auch die sonstigen Bodengeräuschquellen innerhalb der Grenzen eines Flugplatzes einzubeziehen.

Summary

As an indispensable part of maintenance and servicing work on aircrafts at airports and civilian or military airfields engine test runs cause considerable noise exposure to the neighbourhood. The 1st decree to the newly issued German Act on Protection Against Aircraft Noise include beside regulations for flight noise also regulations for ground noise emissions due to aircraft taxiing and the use of APUs but it does not include ground noise emissions of engine test runs.

The essential goal of the investigations presented here was to work out a draft of a methodology for the determination of the noise exposure of engine test runs. For this, a problem-related definition of engine test runs was worked out on the basis of the facts and conditions of real engine test runs on airfields (sort and extent of engine test runs, noise control measures …).

By means of an analysis of the obtainable data basis (acoustical data, frequencies and duration of different power settings for different aircraft types and others), the problems for calculating noise exposures due to engine test runs were investigated in detail. Special problems (e.g. noise abatement facilities, sound propagation models) were discussed with experts of the respective scientific field.

The different results of the investigations were summarized for the development of a standard methodology for the determination of the noise exposure of engine test runs. In the context of the discussions about the integration of the new methodology in the general system of regulations in the field of acoustics a short-term and a medium-term way to establish the methodology were proposed. With this, the short-term way only refers to the calculation of noise exposures of the engine test runs while the medium-term way also includes all other ground noise sources within the borderline of an airfield.

1 Explanations of Abbreviations, Units of Measurements, Symbols, and Terminology

Glossary

The current topic assumes that the reader is familiar with the common terminology in acoustics. Therefore, only aviation and aircraft technology terminology used in this report will be defined below.

Engine balancing	carried out within the context of engine test runs to balance the torque of the engine running on the other side of the aircraft
Ground noise report (BLG)	a noise report generally compiled in addition to the flight noise report within the framework of the permit process for airports to consider the noises generated on airports on the ground.
Thrust cutback	cutting back on thrust after reaching a certain height after take-off
Fan	Impeller with turbine blades arranged before the compressor in the air inlet of turbofan engines. They distribute the airflow (see turbofan or fan-jet engine)
General aviation	(Allgemeine Luftfahrt) (private and commercial traffic)
Idle, partial power, maximum power	Load conditions of aircraft engines: Idle, partial power, maximum power
Jet	Aircraft with jet engines
Load profile or load curve	it illustrates one or several different demands of loads over a specific time during engine test runs.
Letter or maintenance checks	these are defined test runs during standard maintenance of commercial aircraft designated by the capital letters A, B, C, and D
Maximum thrust on brakes	Maximum engine thrust on the ground still allowing wheel braking
(closed) sound proof hall	Location with several walls or completely enclosed location for engine test runs with roof
Sound proof cabin	location with several sides or completely enclosed by soundproof walls for engine test runs without roof

Blast fence	protective walls that let most of the sound through but the redirect the air and exhaust gas generated by the aircraft's engines.
Pre-flight check	process of standard inspection prior to take-off checking the aircraft's airworthiness for take-off.
Pushback vehicle	specialized vehicle that attaches to the nose landing gear for the taxi in push out (TIPO) procedure at the terminal.
Taxiing	an aircraft's movement on the ground before take-off from the parking position to the runway or after landing from the runway to the parking position.
Test engine	Engine to be tested in an engine test run
Turboprop engine	an engine using a gas turbine core to turn a propeller.
Reverse thrust	Engines are equipped with thrust reversers. These will divert the engine's exhaust temporarily. The thrust produced is directed forward and acts against forward travel providing deceleration. Therefore, it aids in slowing down the forward speed of the aircraft facilitating the engagement of brakes after landing. In propeller-driven aircraft the reverse thrust is created by reversal of the controllable propeller pitch.
Apron	The apron or ramp of an airport is the parking, refuelling, unloading, and loading area for aircrafts.
Conservative approach	considers specifically the worst-case scenario marginal conditions in noise predictions to avoid underestimates of noise emissions; (calculating in a manner "to be on the safe side")
Turbofan/bypass engines:	Modern, low-noise and low-emission construction type
Bypass turbine	of jet engines where part of the stream of air is led beneath the outer shell of the engine around the actual engine.

Abbreviations and Symbols

A_{bar} Attenuation for sound barriers according to DIN ISO 9613-2

ADV	German Airport Association (Arbeitsgemeinschaft Deutscher Verkehrs flughäfen)
A_{fol}	Attenuation for vegetation according to DIN ISO 9613-2
A_{house}	Attenuation for housing developments according to DIN ISO 9613-2
APU	Auxiliary Power Unit (Hilfstriebwerk zur Energieversorgung des Flugzeuges)
A_{site}	Attenuation for developed sites according to DIN ISO 9613-2
AzB	Instructions on the Calculation of Noise Protection Areas
AzD	Instructions on the acquisition of data concerning flight operations
BBI	Berlin Brandenburg International
BImSchG	Federal Immission Protection Act (Bundes-Immissionsschutzgesetz)
dB; dB(A)	Decibel; decibel in consideration of the A evaluation
°C	Degree Celsius
DES	Data acquisition system
DI	Directivity Index (Richtwirkungsmaß)
DIN	German Institute for Standards (DIN Deutsches Institut für Normen e.V.)
ECAC	European Civil Aviation Conference
ETRS 89	European Terrestrial Reference System 1989; a three dimensional European geodetic Cartesian reference frame
FFT	Fast Fourier Transform
GPU	Ground Power Unit (mobile aggregate for the external power supply of aircraft)
Hz	Hertz
i	Control variable
ILA	International Air Show
ISO	International Standardization Organization
Kfz	Vehicle
K_T	Tone allowance according to DIN 45681
L, L_i	Sound pressure level (with and without control variable)
L_{AFmax}	Maximum of the AF-weighted sound pressure level according to TA Lärm (German noise pollution prevention regulation).
L_{AFTm5}	Takt maximum mean assessment level according to TA Lärm
L_{eq}	energy equivalent continuous sound level, mean assessment level
L_{pAmax}	Maximum of the A-weighted sound pressure level
L_{WA}	A-weighted sound pressure level
m	Meter
m/s	Meter per second
min	Minutes
n	Number of incidents or measured values
NAT	Number above threshold (number of sound incidents, which exceed the maximum sound pressure level)

PVF	Plan approval procedure
Q_σ	Standard deviation of emission data of the AzB
Θ	Angle between the aircraft's longitudinal axis and the diffusion vector to the immission point
UTM	Universal Transverse Mercator; geographic Cartesian coordinate system illustrating the earth ellipsoids in a horizontal position
VDI	Association of German Engineers (Verein Deutscher Ingenieure)

2 Reason

For areas surrounding airports, the noise generated by starting and landing aircraft is a significant source of noise burdens. To determine these loads objectively, legislature passed the Aircraft Noise Protection Act in 1971. Only noises, which are generated by airborne aircraft and during take-off and landing, are within the area of validity of this law.

In June 2007, the amended Aircraft Noise Protection Act became effective [1]. With the 1st ordinance with regard to this act [2], a new work of rules was introduced to determine the noise protection areas (AzD: "Instruction to Document Data on Air Traffic" [3] and AzB: "Instruction to Calculate Noise Protection Areas" [4]). For the first time, this work of rules also includes methods to consider noise emissions generated on the ground of airports during taxiing of aircraft to the runway for take-off and after landing as well as during the operation of the auxiliary power units (APUs) on the ground.

In addition to taxiing and APU noises, ground noises are relevant, which are not covered by the new legislation. These are the noises emitted by technical systems (power stations, ventilation and air conditioning technology, etc.), by air traffic on ramps (tankers, pushback vehicles, buses, and other vehicles and equipment required for dispatch and clearance) as well as by engine test runs. In this context, engine test runs take a special position based on the special aspects of the acoustically effective marginal conditions. The calculation methods applied to aircraft noise such as the noises emitted during taxiing, the APU noises or the calculation methods usually applied to systems, and traffic noises in emission protection are not easily adapted.

On the other hand, in many cases due to the level of generated noise emissions and the number and duration of engine test runs, it is unacceptable to disregard these in the evaluation of the impact noise has on areas surrounding airports. Therefore, separate investigations are required for a unified determination of noise emissions caused by engine test runs.

3 Task

Engine test runs are an indispensable part of servicing and repair work on aircrafts on commercial airports, landing fields, and military airports. Currently, the Federal

Republic of Germany has no standardized inspection methods for the noises generated on the ground at airports. The forecast calculations for noise emissions of engine test runs (and for all other noise emissions generated on the ground such as taxiing, APU, etc.) required within the framework of the approval proceedings have been carried out in the past by the experts commissioned with the task according to very different methods. For example, in some cases, the approach followed strictly the methodology of the "old" AzB, in other cases, the general methods in use for commercial noises or the methods used according to VDI 2714 "Propagation of sound outdoors" 1988 [5], VDI 2720 "Noise control by barriers outdoors" 1997 [6], VDI 2571 "Sound radiating from facade elements of industrial buildings" 1976 [7] and DIN ISO 9613-2 "Attenuation of sound during propagation outdoors" 2000 [8]. In this context, acoustically relevant parameters (e.g. for the calculation with A-levels or octave levels, consideration of various load levels, directivity, consideration of meteorological influences) and the evaluation relevant parameters (specifically the evaluation times, additions for particularly troublesome times) were handled quite differently. Because of these various possibilities of design, noise emissions of engine test runs are a controversial subject to discuss among experts. There is no comprehensive compilation of the existing knowledge in this field.

The main objective of the research to be conducted is the development of a proposal for a unified methodology to determine the noise emissions of engine test runs, which should ensure on the one hand the required precision, significance is fulfilled, and on the other hand, the application is practical and uncomplicated.

To handle the research question it is required to carry out a comprehensive analysis of work on engine test runs (expert reports for approval proceedings, investigations to derive at noise mitigation plans, measurement reports, publications, and similar). In addition, experts from the group of airport operators, engine manufacturers and servicing companies should be surveyed on specific topics (such as the design of noise protection halls, load levels during the test runs, etc.). Based on the information about the type and scope of actual facilities for test engine runs and test engine runs carried out at these facilities, test engine runs must be defined in accordance with this research question. The constraints of test engine runs relevant for the determination of noise emissions must be determined and classified (e.g. type of engines, consideration of various load levels, etc.).

Furthermore, based on the analysis of nationally and internationally applied methods a computation method for sound propagation must be selected, whereby it is important to consider the sound propagation close to the ground on the one hand and to discuss the compatibility with AzB (determination of consistent evaluation levels for an energetic summary of a "total" noise pollution) on the other hand. In this context, it must be considered that in practice, there is a large range of various noise mitigation facilities and perhaps even other obstacles affect the propagation paths of noise emission.

Furthermore, the relevance of certain sub-aspects (tonality, scatter of measurement results, etc.) must be clarified.

The original problem definition was prepared and tendered in July 2008. This problem definition included a high priority for components of the problem, which should investigate integration or at least the best compatibility of the newly developed calculation methodology with the new AzB. The significant reason for this was the development of a consistent work of rules to calculate the noise emitted on airports, which considers aside from aircraft noises also the sources of noises on the ground of which test engine runs are undoubtedly a part.

For this purpose, a petition was submitted to the Transport Committee and the Environment Committee of the Federal Council. This petition was based on the proposed calculation method of the Land Lower Saxony [9]. This petition was accepted by the Committee on Transport [10] but rejected by the Committee on the Environment [11]. During its 847th session on 19 September 2008, the Federal Council made a final determination. It decided not to implement any new computation methods for test engine runs into the new AzB. Rather it decided to consider as ground noises only the noise of aircraft during taxiing prior to take-off and after landing as well as the APU noises. The determining aspect for this decision was the fear that if engine test runs were to be considered in the method of AzB, then any actions to protect from noises during engine test runs (noise protection hangars, time and space restrictions for test runs, etc.) would no longer be used adequately.

Because it will not be possible to implement into the AzB a computation method for test engine runs in due time, within the framework of the research question to be investigated here, the expert (acoustic) criteria must be granted higher priority over the demand of best possible compatibility with the AzB.

In accordance with the current research question, the following partial services had to be provided.

Documenting and Analysing Noise Emissions during Engine Test Runs

- Documenting and analysis of literature on the topic engine test runs (publications, expert reports, permit documents, etc.).
- Development of questions, which should be dealt with in individual meetings with contact persons (experts) from certain interested fields. The research questions are to be coordinated with the principal.
- Development of a list of potential contact persons (experts) from the areas of air traffic, aircraft and engine maintenance and acoustic design of halls for engine test runs, who should be questioned on certain special topics and carrying out of surveys. The results of the surveys are to be documented in separate result logs.
- To the extent possible, compilation of facilities for engine test runs.
- Compilation of noise protection regulations and operating restrictions applicable to these facilities.
- Praxis appropriate definition of the term engine test run.
- Illustration of the phases of engine test runs for jet and propeller engines cycle through routinely (duration of engine power controls, use of "balancing engines").
- To the extent possible, a summary of frequency, duration, and operating hours of facilities for engine test runs located at the selected commercial airports, airfields, and military airports in Germany.
- Documentation and evaluation of the national and international procedures applied to determine noise emissions of engine test runs, derivation of proposals for a calculation method.
- Comparative assessment of the shielding effect of various structural forms of noise protection facilities (sound barrier, noise protection halls (open/closed), etc.)

Developing proposals for the calculation of noise emitted by engine test runs

- Assessment of the question about the extent tonality is given in engine test runs and deduction of potential consequences for the calculation algorithm.
- Information about the standard deviation of emission data (Q_σ) in engine test runs.
- Description of directivity of noises in engine test runs.
- Test and comparison of potential alternative sound propagation models in consideration of the various constraints (area of validity of relevant regulations, sound propagation over larger distances, etc.).
- Development of a proposal for the calculation of noise emissions caused by engine test runs (including the criterion of the frequency maximum level (NAT criterion)).

4 Methodological Approach of the Investigation

4.1 General

The method on how to handle the topic is largely illustrated by the question explained in Section 3. The following details the approach taken to procure the required information and sources of information. The information gained from various sources are introduced in Section 6 systematically and thematically sorted. Section 7 explains the necessary conclusions for the development of a calculation method for noise emissions of engine test runs.

4.2 Reviewed Sources

The sources for information on the topic are mainly publications (trade publications, congress contributions, dissertations, etc.) and ground noise reports for plan approval proceedings or modification approval proceedings for airports. Additional sources are unpublished measurement reports and other reports (such as reports on noise abatement measures during engine test runs), published information of airport operators and aircraft manufacturers as well as verbal information and consultation with various experts.

The author of this report already had one portion of these sources. However, in part these were provided by the Federal Environment Agency, researched on the Internet, or procured new by other means. Many of these sources treat only individual, yet very important aspects of the total problematic. The dissertation of THOMANN [12] examines e.g. engine test runs not explicitly; however, the information and research results for measuring and calculating air traffic emissions can in many cases be transferred to the noise emitted and imitted during engine test runs.

In contrast, the ground noise reports compiled within the framework of the plan approval proceedings or modification approval proceedings take necessarily into account the totality of noise immissions caused by engine test runs. In this context, the ground noise report for the expansion of the Frankfurt/Main airport [13] is particularly worth mentioning as current and methodologically highly detailed work. The computation methods applied to engine test runs in the various ground noise reports must be examined separately. In addition, they must be analysed with regard to their applicability to the newly to be developed calculation method.

4.3 Personal Experiences

The author of this reports includes into the research of this topic his extensive experience acquired at military (Ramstein Airbase, Spangdahlem Airbase, Coleman Airfield, and Fliegerhorst Wunstorf) and at civilian (Berlin-Tegel, Berlin-Schönefeld, Braunschweig, Hof-Plauen, and Strausberg) airports. These experiences were acquired during the preparation of ground noise reports for plan approval proceedings or modification approval proceedings and during metrological research within the framework of his consulting services. These experiences were included in the illustration of the results as well as into the deduction of the new calculation method without making detailed reference to the respective source.

4.4 Development of questions and expert surveys

The current research task concerns the integration of information and experiences of other experts, who deal with the problem of air traffic noises in general and specifically with ground noises. Just as important are the information and experiences from the operational praxis at airports, airfields, and military airports. In order to provide a summary illustration of the existing knowledge on noise emitted and imitted during engine test runs, any questions that remained unanswered and required clarification were compiled and systemized.

In particular, the following issues were of interest:

- The number, duration, and load-time profile of the usual test runs including any potential regulations on operational restrictions; the number of the engines used in this context (balancing engine).
- The noise emissions generated during engine test runs including the characteristic of direction and propagation.
- Information about existing noise protection systems and their effectiveness.
- Suitability, advantages and disadvantages of various models to calculate the sound propagation including the development of a variable perhaps considering annoyance relevant criteria (tonality, impulsiveness, etc.).

Individual experts and airport operators were confronted with these questions. The answers or rather the results of the discussions were documented. Unfortunately, it was impossible to convince the airports organized in the Association of German Airports (ADV/Arbeitsgemeinschaft Deutscher Verkehrsflughäfen) to cooperate. Following the decision of the Federal Council on 19 September 2008, test engine runs were excluded from the work of rules of the 1st FlugLSV, i.e. from the new AzB. Therefore, the question for the legal classification of a calculation method for noise immission during engine test runs remains unanswered. Because the legal classification of the calculation method is a decisive factor for a series of its constraints and determinations, the Expert Committee Environment of ADV has decided to wait for clarification of the legal grounds before cooperating in the development of a new calculation method. Therefore, the comprehensive knowledge of the airports that are members of ADV was not available for investigation of this topic. However, the position of ADV was taken as an opportunity to investigate options for integrating the new calculation method into the general work of rules on noise protection and to make appropriate recommendations (see Section 7).

4.5 Existing Proposals for a Method to Calculate Engine Test Runs

The calculation of the noise immissions caused during engine test runs are particularly required within the framework of ground noise reports for plan approval proceedings or modification approval proceedings for airports. The lack of any regulated calculation method allows the experts choosing their own approach with regard to these computations. This does not mean that the results of these calculations are generally subject to a higher risk of error or that there is the risk for a significant underestimation of this noise burdening any affected persons. On the contrary, these calculations are largely carried out by recognized experts, who have a good overview over the entire acoustic work of rules and who are able to select the best calculation process based on the conditions of the precise individual case. Nevertheless, particularly for the reason of this discretionary leeway in selecting any calculation method, the calculations are generally largely conservative.

The lack of a standardized calculation method and the adaptation of the method inventory on the precise individual case leads, however, to the result that the calculated noise immissions of different cases are not easily compared with one another. In other words, given the same numbers of the imission level, the noise imission caused by engine test runs at airport A may still be different than at airport B. The selection of the method is more or less justified in the individual ground noise reports; however, none of the ground noise reports has thus far carried out a comparative observation of the approach of different experts or has compiled the actual state of knowledge. Therefore, the approach of any of the previous ground noise reports can serve as proposal for a generally applicable method.

In contrast, there is already a proposal for a unified determination of noises caused by engine test runs, which was developed as proposed amendment by the Land of

Lower Saxony for the 847th Session of the Federal Council on 19 September 2008 [9] (see Annex). With the exception of considering the noise protection system, this method contains a complete work of formulas to determine noise immissions caused by engine test runs. This method will be discussed in Section 6 within the context of other acquired information and insights.

5 Defining the Engine Test Run

5.1 Description of Engine Test Runs

The noise immissions generated in neighbourhoods of airports can be principally divided into air traffic noises and ground noises. The ground noises can again be differentiated in a narrower sense into ground noise immissions (sources generated by aircraft) and in a wider sense into ground noise immissions (sources not generated by aircraft).

Ground noise immissions in a broader sense is caused by sources located within the boundaries of an airport, which are not installed on or in an aircraft. Therefore, ground noise sources in a broader sense include technical systems on airports (such as heating system, power plants, etc.), the entire vehicle traffic on the ramp and the airport's own roads and stationary and mobile power supply units for parked aircraft (ground power unit/GPU).

Ground noise sources generated by aircraft i.e. sources of noise on the ground in a narrower context are e.g. taxiing processes after landing and prior to take-off, auxiliary engines of aircraft (auxiliary power unit/APU) and engine test runs. They are seen as air traffic noises (see the definition of air traffic noises in ECAC Doc.) 29, 3rd edition [14]).

Air traffic noises are generated by aircraft, which are airborne or on the runway during take-off and landing. In general, ground noises generated by aircraft are differentiated as noises after leaving the runway after landing or taxiing into take-off position before take-off (in a narrower sense).

In a narrower sense, engine test runs are part of ground noise sources. These are indispensable to ensure safe air traffic. Engine test runs are carried out routinely during maintenance and servicing work and for unscheduled inspections of the engines' functions as well as other aircraft components necessary for the power supply of the engine.

Engine test runs may proceed very differently depending on the type and scope. The kind and type of engine and the problem for which the engine test run must be carried out are influential factors. A relatively short test run in idle is in many cases sufficient for the unscheduled inspection of aircraft components. During the regular maintenance, a large or less large checklist is worked off depending on the flying hours. In general, the engines are set to various load levels up to full load (maximum power, take-off power).

In this context, letter checks (A, B, C, and D checks) are important for commercial aircraft. The A-checks, which are also called minor checks, are carried out every 250 to 650 flying hours depending on the type of the aircraft (and depending on the regulations of the respective airline). B-checks are only carried out on certain older types of aircraft. C-checks (also termed major inspections) take place every 15 to 18 months. The most in-depth test runs are required during the D-check during which a complete overhaul takes place every 6 to 10 years. The respective maintenance programs of this system are based on maintenance handbooks of aircraft manufacturers and they must be submitted by the airlines to the competent government agencies for approval. During these above-referenced checks, engine test runs are required the load-time profile of which differs depending on the various maintenance manual and the problem at hand. Therefore, based on the number of letter checks carried out at a certain airport, the number of idle, partial power, and full power test runs can be estimated.

In general, it is possible to just let the engine run to test an engine in idle. However, for other reasons two engines are frequently operated symmetrically. In test engine runs at load levels greater than idle, it is required to operate a symmetrically arranged engine (so-called balancing engine) usually at a somewhat lower load to balance the torque. In four-engine aircraft, it can happen that during the engine test run all four engines are operated even at load levels up to maximum power (e.g. military sector).

Not all of the different test steps are acoustically relevant. The routine testing of aircraft functions prior to take-off, at the ramp or during taxiing to the take-off position, is also irrelevant for developing a calculation method for engine test runs because the noises generated thereby are already covered by the amended AzB.

In the following, a definition for engine test runs is provided in accordance with the research question to develop a calculation method for noise immissions caused by engine test runs. The bases for this definition are formed on the one hand by the operational practice at airports and on the other hand, by information, experiences and insights, which are explained in the following Sections. However, for a better understanding, the definition is placed at the beginning of this report.

5.2 Definition in Accordance with a Future Method of Calculation

An engine test run is the operation of the engines of an aircraft for diagnosing the functions and components of the aircraft within the framework of routine maintenance of the aircraft or during unscheduled checks and maintenance work. For this purpose, the aircraft is positioned at a certain parking position or in a facility constructed for this purpose. Routine checks of the functions of an aircraft prior to start-up or after landing are not part of engine test runs.

Within the framework of the current calculation regulation, four different load levels namely idle, low partial power, high partial power and maximum power are differentiated. If test runs are carried out routinely at lower power levels for certain types of aircraft or types of engines, then the impact period must be set to zero for the load conditions not under consideration. Any potential powering up or down of the engines during one organized testing procedure, is valued as one engine test run. (Please note: To consider a maximum level criterion (e.g. NAT/number above threshold), perhaps additional regulations may be instituted for the maximum levels that occur multiple times.)

6 Results of the Research and of the Investigation

6.1 Previous Approaches to Calculate Engine Test Runs

In Germany, any calculations of noise immissions of test engine runs have been carried out in the past mainly within the framework of plan approval proceedings for airport modifications or expansions and within the framework of investigations to control noise. Because ground noises at airports were not regulated until the new Air Traffic Noise Act came into effect, the methods could largely be chosen freely. In this context, the methods developed based on general commercial noises such as VDI 2714 [5], VDI 2720 [6], VDI 2571 [7] und der DIN ISO 9613-2 [8] were used as approach. Individual ground noise sources were modelled as point and line sources. In many cases, a number of noise generating actions on the ramps were modelled with the aid of surface sound sources.

The acoustically relevant initial data were determined or estimated by the airport operator with regard to frequency and duration. In this context, for air traffic noises mostly the six months with the most traffic were used as base period for data collection. The acoustical parameters of sound power and directivity were taken from literature or manufacturer's information or estimated based on the AzB sets of data. Measurements were rarely taken by experts, airport operators, or aircraft manufacturers. For sound propagation, the model ISO 9613-2 and prior to the development of ISO 9613-2 the model of VDI 2714 were largely applied. The evaluation times were set at 16 hours during the day and 8 hours during the night in accordance with the air traffic noise calculations. An assessment of the results is largely taken within the framework of a medical report.

Some ground noise reports have not considered the directivity. Even more frequently, structures and vegetation attenuation have been disregarded. The reasons for this disregard were most likely due to the time and effort it would take to process it. However, foregoing these issues was mainly explained by a worst-case approach to the calculations.

In general, it should be noted that particularly because of the freedom to choose a method and because of the sparse data situation in emission data, all ground noise reports are principally based on worst-case approaches. With regard to the engine test runs, this applies particularly

- to the use of the loudest types of aircraft or types of engine representative for all test runs.
- to the assumption that all or a large number of test runs are carried out with maximum power
- to the assumption that a large portion of time test runs are carried out with maximum power

The different methods found in individual ground noise reports are likely significant with regard to the calculated results. In light of the existing uncertainties of the initial data situation and in consideration of the respective worst-case approach, it is however rather unlikely that the ground noise pollution of the affected was substantially underestimated.

Upon the request of affected persons, government agencies, or courts [15], some ground noise reports included an energetic addition of ground and air traffic noise, which is questionable in light of the different applied methods. Because these demands will continue, it should be considered in the development of a calculation method for engine test runs.

Compared to most other ground noise reports, the energetic addition of air traffic and ground noise in the ground noise report for plan approvals of the new Berlin Airport Berlin-Brandenburg International (BBI) is less of a problem because the ground noise calculations followed consequently the method of the (old) AzB. The individual ground noise sources were modelled with AzB means as point, line and surface sources. The propagation was calculated with the model of the AzB.

This approach has also been applied in the new AzB to consider the APU and taxiing noises. In principal, test engine runs can be treated methodologically like the noises of the APUs in consideration of other source data. An appropriately broadly worded amendment proposal of the Land Lower Saxony is available [9].

In Switzerland, engine test runs are seen as commercial source of noise. Obviously, the Swiss environmental legislation does not contain any regulation comparable to BImSchG, §2 paragraph 2, which excludes airports expressly from the area of validity of any corresponding legislation comparable with the German BImSchG (Federal Immission Control Act). The reasons for the consideration of engine test runs as commercial source of noise are primarily based in professional considerations (propagation on the ground, effectiveness of obstacles, etc.) [16]. With regard to the assessment of noise, however, it differs from the standard practice of the Swiss Noise Ordinance by evaluating the potential waking reaction on a 1-hour-L_{eq}.

6.2 Frequency of Engine Test Runs

How often engine test runs are carried out depends largely on whether a maintenance and repair facility is located at the respective airport. For example, after a detailed analysis on a larger commercial airport without a permanently based maintenance operation (approx. 160,000 aircraft movements) 12 scheduled and 444 unscheduled engine test runs were carried out in 2008. Among the unscheduled test runs were 374 idle runs with an average duration of 4.9 minutes and 80 test runs with load levels larger than idle and an average duration of 16.3 minutes. With regard to the total number of test runs, these values are relatively high in comparison to the published numbers for airports with a maintenance base (see further below). According to this analysis, 93% of the unscheduled test engine runs are carried out on the ramps (i.e. the normal parking position) in idle with a duration of only up to 5 minutes, it can be assumed that many airports do not even document or do not register test runs in idle lasting only a few minutes as so-called "engine test runs". This raises the question whether all participants have the same understanding of the term "engine test run".

Information on the number of engine test runs that are carried out at the Frankfurt/Main airport, where the largest maintenance operation of Deutsche Lufthansa AG is stationed, were published by Lufthansa for the years 1995 to 2002 [17]. Accordingly, there are approx. 2,100 to 2,300 annual test runs at the Frankfurt airport. In 2002, 9% of it was full power test runs, 32% partial power test runs, and 59% idle test runs.

The Hamburg airport, which has also a maintenance base of Lufthansa, published the numbers [18] for engine test runs as being 260 to 400 annual runs during the years 1993 to 2004. From 1993 to 1997, these numbers showed an increasing trend while with 300 and 350 test runs the level has been somewhat constant since 1998.

For the expansion of the future Berlin Airport BBI, a ground noise report [19] was prepared in consideration of the database of the Frankfurt Airport and the respective airport movement figures were calculated with 2,190 test runs per year.

For medium size airports, information of the projected engine test runs is specified with 302 annually for the Hahn Airport [20] and with 36 annually for the Leipzig Airport [21].

The information on engine test runs for smaller airports can be taken from ground noise reports for the airports Hof-Plauen specified as 110 annually and Braunschweig specified as 156 annually [22, 23].

In addition, military airports show very different numbers for engine test runs depending on the aircraft type [24, 25, and 26]. In combat aircraft of the Bundeswehr, the range of engine test runs carried out within one unit is between 42 and 372 annual test runs [27].

This information shows that the number of engine test runs can be very different depending on the precise conditions at one particular airport. A classification e.g. based on the number of aircraft movements is not possible based on the available data. Therefore, it is required to document each particular case as precise as possible or to predict the number of engine test runs as substantiated as possible in the event of a forecast calculation.

6.3 Operating Restrictions

From the generally accessible information for German commercial airports [e.g. 28], it is shown that only three commercial airports are not subject to any relevant operating restrictions with regard to engine test runs: Frankfurt/Main[1], Karlsruhe/Baden-Baden, and Berlin-Schönefeld. In this context, the airline's general duty to inform the airport operator about any scheduled test run is not seen as relevant operating restriction.

Some airports require special positions for engine test runs. These positions were among others selected for reasons to minimize the noise pollution of the neighbourhood. There is a general ban on test engine runs on most airports during the night as well as during Sundays and holidays. Idle test runs are excluded in many cases and even from other restrictions (e.g. with regard to special positions).

On airports, which have a facility for noise abatement during engine test runs (see Section 6.9), the use of this facility is generally required regardless of the effectiveness of this facility.

The Saarbrucken Airport generally requires the use of the existing "noise abatement facility". However, there is an additional regulation in place for nights, which considers noise aspects and which restricts the load levels to "usually 70% of the engine's performance".

Nearly all regulations with regard to the above-referenced operating restrictions include exemptions for emergencies and similar contingency situations.

6.4 Duration of the Test Engine Runs; Load-Time Profile

In the simplest case, one or several engines are turned on during an engine test run. They are run in idle for a certain time and if required, they are operated at one or several higher powers and then turned off. The sequence in time of one or several different load levels together with their specific duration is in the following called load profile or load curve.

[1] However, the current approval proceedings for the Frankfurt Airport provide for appropriate restrictions.

Figure 1 shows the time sequence of the sound pressure level in a typical engine test run, which is relatively simple with regard to the load profile. The different test runs in idle, partial power and maximum power are easily recognized. The entire test run took approx. 25 minutes. The APU ensures the power supply before and after the test run.

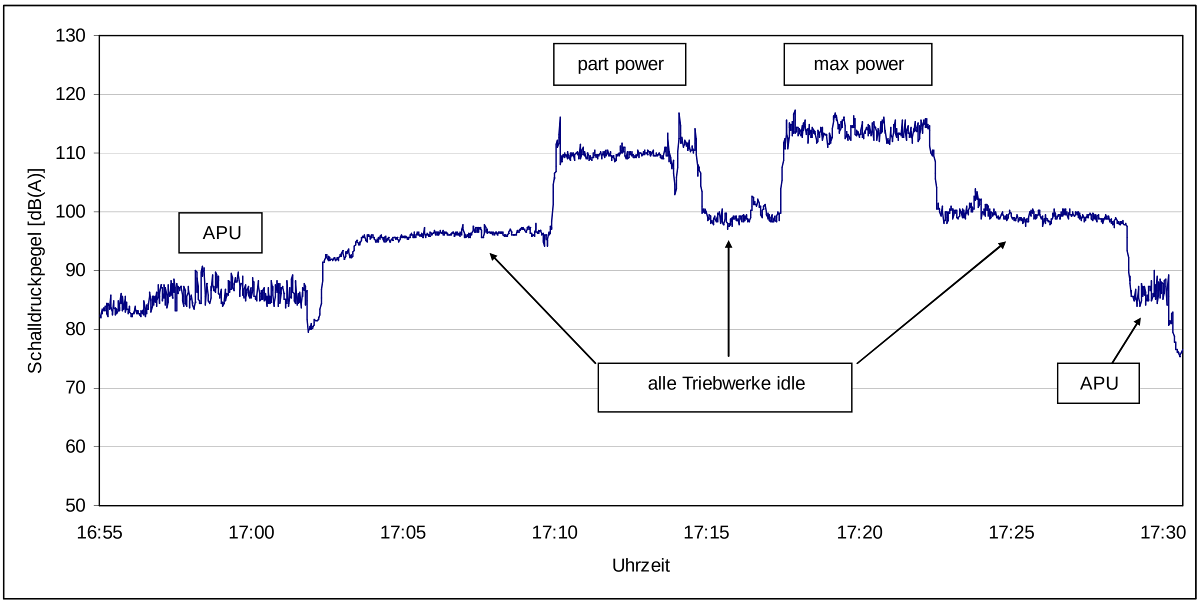

Fig. 1: Level over time during a test run of a jet aircraft in a distance of approx. 100 meters

However, a sequence of different individual tests is carried out more frequently. These individual tests require several different engine settings. Figure 2 shows the time sequence of the sound pressure level in a more complex test run during a routine engine test run of a business aircraft of the type Lear Jet 35. In this context, idle conditions were not only seen as intermediate level prior or after the maximum load but each individual engine was also tested in idle. In addition, the rpm of the engines was continuously increased until the maximum load was reached and the reverse thrust was tested.

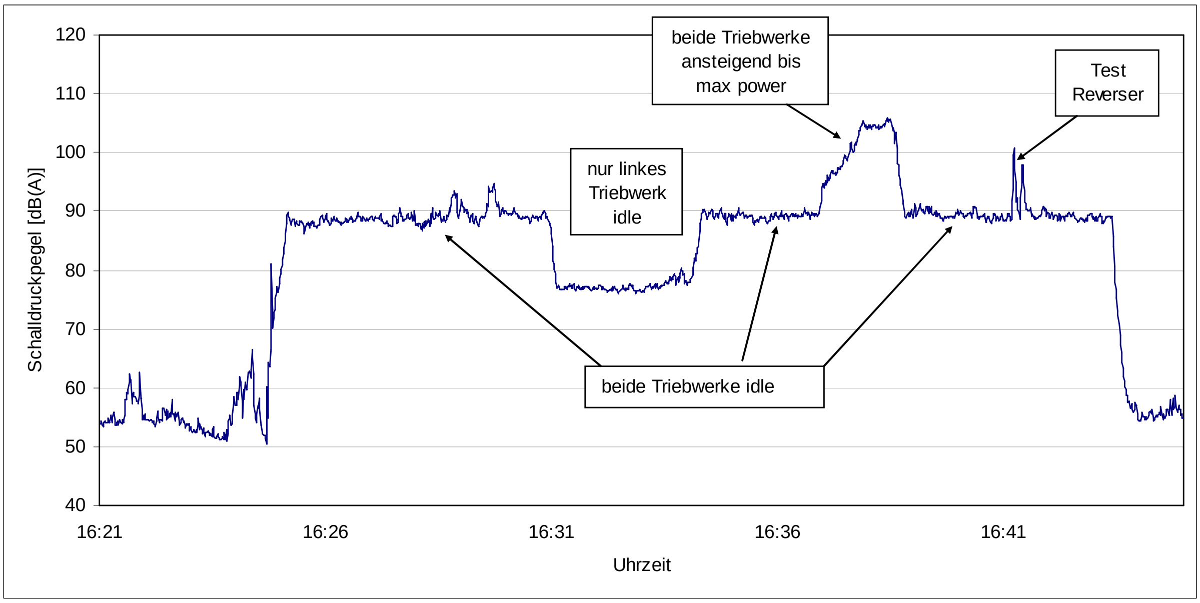

Fig. 2: Level over time during various load conditions in a distance of approx. 50 meters

The two illustrated load over time profiles are only examples for the large variety of possible test runs. Based on the very varied tasks during the execution of test engine runs and based on the multitude of different aircraft types and engines, it is generally quite difficult to determine typical and perhaps generally applicable information on the time sequence of test runs or on the time sequence of individual load levels. Because of the lack of systematic investigations, ground noise reports have been frequently calculated to be on the safe side in the past. In this context, the duration of the test runs was positioned on the upper end of the existing spread based on the airport operator's experiences and it was assumed that 50% of the time the maximum power is applied (in some reports even higher percentages depending on the precise conditions on airports), the remaining time was calculated in idle. Based on the experiences available on larger commercial airports, it was possible to specify this information on time and to differentiate even further load conditions in consideration of the potentially different operation of the engine to be tested and the balance engine without the risk of underestimated the noise immission on the affected neighbourhood.

The thus far most differentiated yet easy to handle calculation method was applied based on analyses of the Lufthansa maintenance operation in Frankfurt/Main for the plan approval of the new northwest runway and the A380 hangar at the Frankfurt/Main Airport [13, 29]. Accordingly, a total of four load levels namely idle, low partial power, high partial power and maximum power or rather take-off power) were differentiated. Engine test runs checking engines only in idle are termed idle runs. Accordingly, the engine test runs, which test both partial power levels, are termed partial power runs. It is standard to use idle prior to the partial power run for warm-up and later for cool-down during partial power test runs. During so-called full power runs, the entire program of various load levels occurring once or several times including the operation of engines under maximum power is worked on. During partial power and full power runs, the balance engine, which is running at levels higher than idle, is also considered at the same proportion of time in the respectively lower load level.

Table 1 summarizes the information of load-time profiles of engine test runs on civilian airports. This Table includes the load curve of the above-referenced amendment proposed by the Land of Lower Saxony during the 847th Session of the Federal Council on 19 September 2008 to amend the AzB.

It shows that the differences with regard to aircrafts equipped with jet engines are relatively minor. The differentiation according to various types of test runs was rarely undertaken thus far. In consideration of the relatively frequent occurrence of purely idle runs, the higher effort to procure data and calculate must be juxtaposed to the benefit of a more exact illustration of reality.

The picture is not so unified with regard to test engine runs of turboprop aircraft types. They show a large spread of different load curves between the so-called small and large runs. A small run is usually only the function test of a certain component while a large run entails a highly complex testing program, which often involves installation of a new engine or after the base maintenance. According to one maintenance firm active in the general aviation sector [30], the reason for this multitude of load curves is their greater variety of types and only few types of aircraft are dominating in numbers such as the 737 from Boeing or the A 320 Airbus. Based on the currently available information, engine test runs cannot be classified with regard to certain test runs or with regard to certain types of engines or aircraft. Therefore, if engine test runs of aircraft equipped with turboprops are to be evaluated on civilian airports, then an analysis of test runs at the respective airport that is as exact and as detailed as possible plays a large role. If this cannot be done, then the calculation must be conservative using the highest values of Table 1.

<table>
<tr><th></th><th colspan="8">Duration of various load levels during test runs in minutes</th></tr>
<tr><th>Type of test run</th><th>Idle run</th><th colspan="3">Partial power run</th><th colspan="4">Full power run</th></tr>
<tr><th>Load levels</th><th>idle</th><th>idle</th><th>Low partial power</th><th>High partial power</th><th>idle</th><th>Low partial power</th><th>High partial power</th><th>Full load</th></tr>
<tr><td colspan="9">Jet engines</td></tr>
<tr><td>PFV Frankfurt/Main Northwest runway* [13]</td><td>30</td><td>45</td><td>15</td><td>10</td><td>47</td><td>7</td><td>6</td><td>4</td></tr>
<tr><td>PFV Frankfurt/Main A380 Hangar* [29]</td><td>25</td><td>12</td><td>15</td><td>10</td><td>46</td><td>7</td><td>6</td><td>4</td></tr>
<tr><td>PFV BBI [19]</td><td></td><td></td><td></td><td></td><td>44</td><td colspan="2">15</td><td>1</td></tr>
<tr><td>PFV Hahn [20]</td><td>25</td><td>12</td><td colspan="2">25</td><td>46</td><td colspan="2">7</td><td>4</td></tr>
<tr><td>BLG Leipzig-Halle [21]</td><td></td><td></td><td></td><td></td><td>58</td><td></td><td></td><td>2</td></tr>
<tr><td>BLG Berlin-Tegel [31]</td><td></td><td></td><td></td><td></td><td>44</td><td colspan="2">15</td><td>1</td></tr>
<tr><td>Lower Saxony proposed AzB amendment [9]</td><td></td><td></td><td></td><td></td><td>38</td><td>10</td><td>10</td><td>2</td></tr>
<tr><td colspan="9">Turboprop</td></tr>
<tr><td>BLG Wunstorf [26]</td><td></td><td></td><td></td><td></td><td>40</td><td></td><td></td><td>20</td></tr>
<tr><td>BLG Hof-Plauen [22]</td><td></td><td></td><td></td><td></td><td>14</td><td></td><td></td><td>1</td></tr>
<tr><td>BAYR, UBA [32]</td><td></td><td></td><td></td><td></td><td>4</td><td colspan="2">10</td><td>6</td></tr>
<tr><td>Aerodata ("large run") [30]</td><td>20</td><td></td><td></td><td></td><td>30</td><td colspan="2">60</td><td>30</td></tr>
<tr><td>Aerodata ("small run") [30]</td><td>10</td><td></td><td></td><td></td><td>10</td><td colspan="2">20</td><td>10</td></tr>
</table>

Table 1: Load-time profile of various investigations at civilian airports

* Duration of the application of balancing engines is included
BLG: Ground noise report
PFV: Plan approval procedure

In addition, engine test runs in the military sector are not easily comparable with standard values of load curves from the civilian sector because of different constraints. Table 2 shows the engine test run statistic from a large military airport developed over the course of 2 years, whereby a differentiation was made between test runs in idle only and test runs at higher load levels. In addition, it was documented whether one, two, or four engines were involved in the test run. It specifies the average duration per run and in parentheses beneath the maximum duration of the test.

The information in Table 2 shows that contrary to the civilian sector test runs for aircraft with four engines are usually carried out at load levels higher than idle. Furthermore, it shows that despite similar average values the maximum duration is significantly shorter for modern aircraft than for the older C-5. This statement supports the statements made by engine manufacturers and airport operators that based on the advancement in machine diagnostics modern aircraft or types of engines require fewer test runs and the test runs are shorter.

Number of engines	**1**	**2**	**4**	**2**	**4**
Load level	**idle**	**idle**	**idle**	**above idle**	**above idle**
Jet aircraft					
C-20 (Gulfstream IV) n= 10 … 46	26.5 (60)	25,6 (90)		23.2 (60)	
C-21 (Lear Jet 35) n= 38 … 165	13.7 (60)	19.0 (150)		24.0 (90)	
C-17 "Globemaster" n= 35 … 81	15.3 (70)	20.7 (120)	21.3 (56)	14.0 (45)	23.5 (85)
C-5 "Galaxy" n= 40 … 109	18.9 (180)	16.9 (195)	24.3 (230)	16.1 (150)	19.1 (75)
Turboprop Aircraft					
C-130 "Hercules" n= 94 … 451	16.9 (60)	19.5 (180)	22.0 (200)	17.2 (77)	24.5 (150)

Table 2: Average and maximum Time (in parentheses) of test runs of various military aircraft (specified in min; n: Number of respective test runs)

For the military section, it can be concluded that the analysis of the load-time profile is highly significant. Without these types of analyses, (forecast) calculations for engine test runs must be calculated conservatively using the highest values of Table 2.

6.5 Noise Emissions during Engine Test Runs

In general, emission data for individual groups of aircraft can be derived from the AzB datasets. They can be converted based on the reference distance s_{On}. However, this is not trivial because these data include certain constraints of the propagation path [33]. Information about emission data during test engine runs are however available as sound power levels measured results from publications by Airbus AG and from ground noise reports for various airports [13, 20, 21, 34]. Table 3 provides a summary of all available emission data.

Table 3 illustrates the sound power level used in the corresponding plan approval proceedings. These were determined either by measurement technology or by the commissioned expert office. The data of B 747 for the plan approval proceedings of the Frankfurt Airport were interpolated from measured values for maximum power based on the differences determined metrologically between the load levels of the Airbus A 321. The sound power level of the Airbus family was calculated based on the direction-dependent measured values at a distance of 60 meters (see Section 6.6). The sound power level of combat aircraft and military transport aircraft were calculated based on direction-dependent measured values (depending on the type of aircraft, different distances were applied) from the database of the U.S. Air Force.

The last four columns of Table 3 are listed as comparison with the measured data from the noise performance level determined with the emission methods of the AzB, corrected by [9] the level allowance $Z_{TW,m}$ listed for engine test runs. It shows that in some cases there is an excellent agreement between the measured data and the mathematically determined sound power level. However, there are other cases with larger deviations. This results in a need for action to create a dependable, sufficiently large emission database for test engine runs.

The emission data for the aircraft types MD8X and B 747-400, which were investigated as examples for the ground noise report required for the plan approval of the new Berlin BBI Airport, are based on a deduction from AzB data as opposed to the data specified in Table 3. For the maximum power status, the AzB datasets applicable for take-off were used. For the partial power status (cut back power to 85%), the take-off dataset of the AzB of 2 dB for the MD8X and 4.5 dB for the B 747 was deducted and for idle, the AzB datasets for approach were applied minus 2 dB.

This approach resulted in the following sound power levels L_{WA}:

	MD8X	B747-400
idle	136.0 dB(A)	142.0 dB(A)
partial power	152.5 dB(A)	153.9 dB(A)
max power	154.5 dB(A)	158.4 dB(A)

It shows that these data is markedly above the measured values of comparable types of aircraft and engines.

				Sound power level L_{WA} in dB(A)							
				Measured values				calculated from AzB datasets and correction of engine test runs according to [9]			
Literature source	**Type of Aircraft**	**Engine Type**	**AzB-aircraft group**	**Idle**	**Partial power low**	**Partial power high**	**max power**	**Idle**	**Partial power low**	**Partial power high**	**Max power**
PFV Frankfurt*	A 321	V2500-A5	S 5.2	130.8	140.0	148.3	152.6	132.3	139.3	145.8	148.8
PFV Frankfurt*	B 747	CF6-80C	S 7	136.2	144.6	152.5	156.9	137.8	144.8	153.8	158.3
PFV Hahn*	B 747	CF6-80C	S 7	132.0	144.0		157.0				
PFV Hamburg*	B 747	CF6-80	S 7	141.0	147.0		160.0				
PFV Leipzig*	A 300-600	CF6-80C	S 6.1	136.7		149.0	152.6	134.8		147.8	150.3
Database of U.S. Air Force	C-5		S-MIL 1	135.5		158.6	167.0	150.8	157.8	166.4	167.9
	KC-135A			140.6			167.7				
	C-141		S 4	138.3		155.7	156.4	150.8	157.8	166.4	167.9
	C-17		S 6.2	141.1			158.5	137.7			154.8
	C-20		S 1.0	131.7			159.4	132.3			147.8
	C-21		S 5.1	121.9			143.6	129.3			140.8
	C-130E		P-MIL 2	145.3			154.0	133.4	140.1	147.4	149.4
	C-130J			137.9	143.3	151.2	152.8				
	F-16		S-MIL 4	132.5			168.3	143.8			166.9
	A-10		S-MIL 5	122.4			146.8	130.4			146.4

Table 3: Noise emissions during engine text runs

PFV: Plan approval proceedings

* from the information available for 1 engine projected to 2 and 4 engines

				Sound power level L_{WA} in dB(A)							
				Measured values				calculated from AzB datasets and correction of engine test runs according to [9]			
Literature source	**Type of Aircraft**	**Engine Type**	**AzB-aircraft group**	**idle**	**Partial power low**	**Partial power high**	**Max power**	**Idle**	**Partial power low**	**Partial power high**	**Max power**
Airbus (calculated form the information on directional characteristic)	A 340-500/600	RR Trent 500	S 6.3	137.9			155.7	133.3			150.8
	A 340-200/300	CFM56-5C		131.0			152.9				
	A 330	RR Trent 700	S 6.1	134.1			155.8	134.8			150.3
	A 330	PW 4000		135.0			155.3				
	A 330	GE CF6-80E1		138.9			155.5				
	A 321	V2500	S 5.2	137.9			155.7	132.3			148.8
	A 321	CFM56-5B		131.2			154.1				
	A 320	V2500		129.9			154.5				
	A 320	CFM56-5B		131.1			153.0				
	A 320	CFM56-5A		131.1			152.9				
	A 319	V2500		128.9			154.5				
	A 319	CFM56-5B		130.8			152.2				
	A 319	CFM56-5A		130.9			150.7				
	A 318	PW 6000		130.3			153.8				
	A 318	CFM56-5B		130.7			152.1				
	A 318	CFM56-5A		130.9			150.3				

Table 3 (continuation): Noise emissions during engine text runs

PFV: Plan approval procedure

With a few exceptions, all data listed in Table 3 are based on spectral values in the octave or third-octave bandwidth. One example for the sound power emitted in a spectrum (third-octave spectrum) is the C-5 "Galaxy" military transport plane illustrated in Figure 3. Significant are the low frequency components, which are increasingly emitted at higher load levels and which are caused by the open jet, and the increase in the high frequency portions caused by the higher rotations per minute of the fan.

During the test run, individual load levels are typically kept constant over a certain time, which is in the range of minutes. During this time, a relatively constant noise is emitted, which is characterized by a sound power level averaged as energy equivalent. If average energy equivalent levels are calculated as evaluation size, then the propagation of the emission of engines is negligible because it can be expected that they average out of the statistical basis.

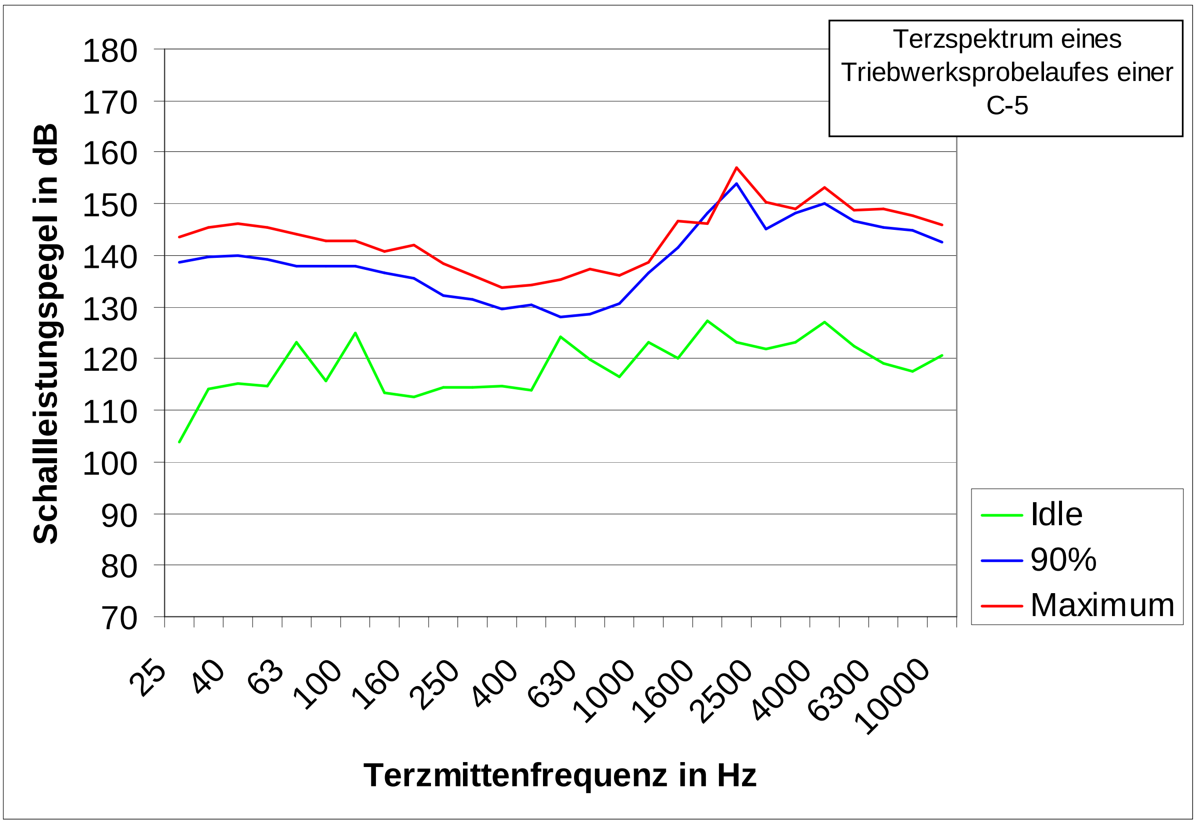

Fig. 3: Frequency dependent noise emissions during a test engine run of a C-5 "Galaxy"

If values based on maximum levels are used as evaluation size (e.g. NAT criteria), then the upper limit of propagation is to be estimated. In the AzB, this is done by a simple standard deviation of propagations within the aircraft group Q_σ, i.e. with the integration of various types of aircraft with different types of engines. In principal, it can be determined that these propagations are the same for test engine runs as it is during the inflight operation of engines. This assumption can be reviewed using the available data material only for the aircraft group S 5.2. The quantity of emission information from Airbus publications is only sufficient for this group. For 11 sound power levels, the standard deviation is 2.3 dB for ground idle and 1.7 dB for maximum thrust on brakes. The corresponding AzB value is for this aircraft group both for take-off and landing Q_σ = 3 dB. Therefore, we can conclude that the AzB values for engine sound propagations can be transferred to the respective calculations for engine test runs.

6.6 Directivity of Sound Propagation

The directivity of sound propagation of aircrafts in flight has been extensively investigated in the past [e.g. 35, 12]. The results achieved thereby can be transferred to the sound propagation on the ground in consideration of the applicable constraints (primarily the various power settings).

In the calculation of air traffic noises in accordance with the AzB, the information for directivity is idealized in the form of three coefficients of a series development of the cosine and specified in generalized manner for all types of aircraft summarized in groups of aircraft and separated for take-off and the approach for landing. In this context, the value for the direction with a maximum sound propagation is standardized.

This approach neglects existing differences between various types of aircraft; however, it allows considering the sound propagation in a coherent mathematical form. Moreover, the idealization of the curve progression has the advantage that the bias of the directivity is balanced by the fewer measuring points achieved through interpolation of measured values in the many graphical illustrations of results.

Furthermore, information is available on the directivity of test engine runs at various load levels. This information was metrologically determined in part as data basis for some ground noise reports of various airports [13, 21, 25]. In the past, noise immissions of engine test runs had been calculated largely based on the loudest type of aircraft visiting the respective airports. In some cases, this was supplemented by a second type of aircraft frequently visiting the airport. Therefore, this information is available only for a relatively low number of (jet) types of aircraft. However, Airbus Corporation has published directivity for the sound emitted on ground during idle (ground idle) and during the maximum thrust possible on brakes) for all current types of aircraft and engine. Therefore, with the exception of the Boeing family, information on directivity of noise generated on ground is available for a large portion of aircraft types seen at commercial airports.

The following Figures 4 and 5 illustrate the directivity of ground noises of the Airbus family separated according to ground idle and maximum thrust on brakes compared to the directivity of AzB for landing and take-off. In this context, it should be noted that the directional effect of aircraft while in parking position on the ground (i.e. during ground idle and maximum thrust on brakes) can be very different to those in flight (i.e. during flight idle or take-off thrust) [35]. The comparison of AzB data with the data measured on the ground does not provide any information as to the accuracy of one or another directivity. It only tells us whether the directivity contained in AzB can or cannot be applied when calculating the sound propagation during engine test runs. The existing uncertainties in applying AzB directivity to engine test runs are considered in the method the Land of Lower Saxony [9] included in its proposed amendment by applying the directivity index standardized toward the safe side to the direction with maximum sound emission.

The graphic illustration of the directivity shown in the following Figures, is not applied as sound pressure level in a related distance as it is in the original data of Airbus but in the general form of the directivity index, which is standard in acoustics

$$DI = L_i - \overline{L}$$

(with $\boldsymbol{DI}$: directivity index, $\boldsymbol{L_i}$: Level of the observed direction, $\overline{\boldsymbol{L}}$: energetic mean of the level in all directions)

(see e.g. [36, 37]). In principal, this directivity index corresponds to the size $\boldsymbol{D^*_{I,n}(\Theta)}$ but not to the directivity index of the AzB, which is standardized toward the direction with maximum sound emission $\boldsymbol{D_{I,n}(\Theta)}$.

Furthermore, it should be noted that due to the strong air turbulences in the exhaust jet of jet engines or the air flow of propeller engines, there are no or only unreliable measured values for angles around the 180°-range

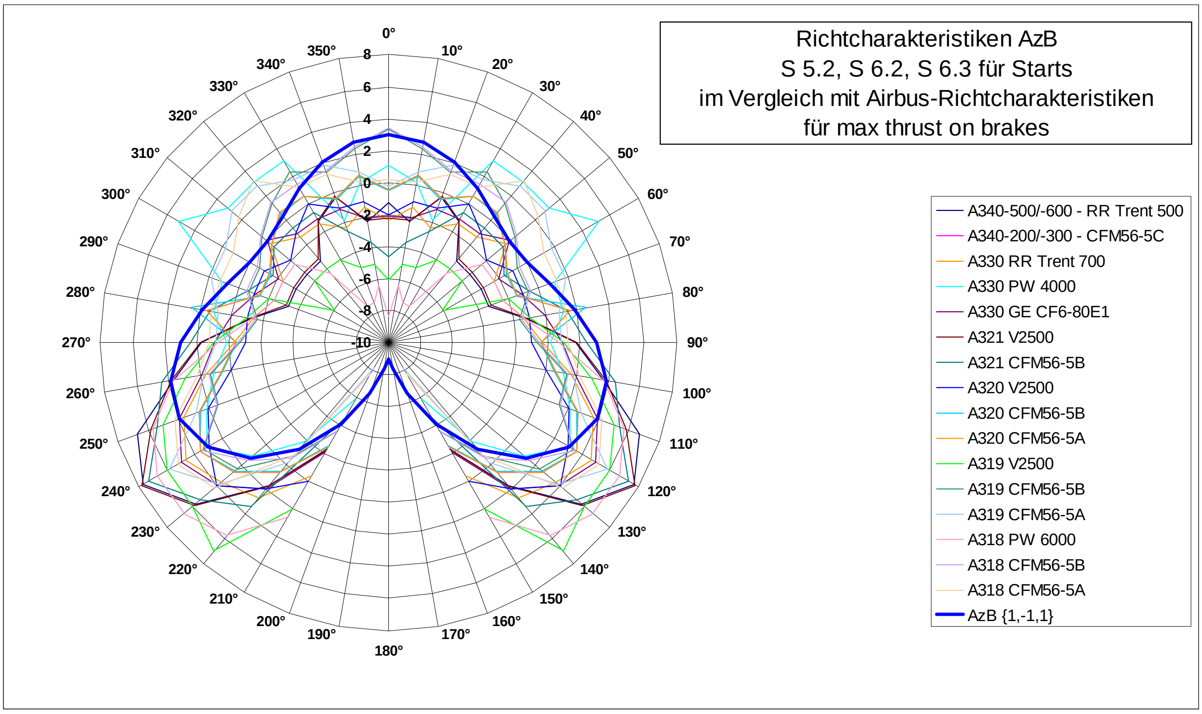

Fig. 4: Directivity of the Airbus family at maximum power on the ground

As shown in Figure 4, the directivity of AzB for take-offs of the most frequently used aircraft types (aircraft groups S 5.2, S 6.2, and S 6.3) can also be applied to the calculation of sound propagation during engine test runs with maximum power.

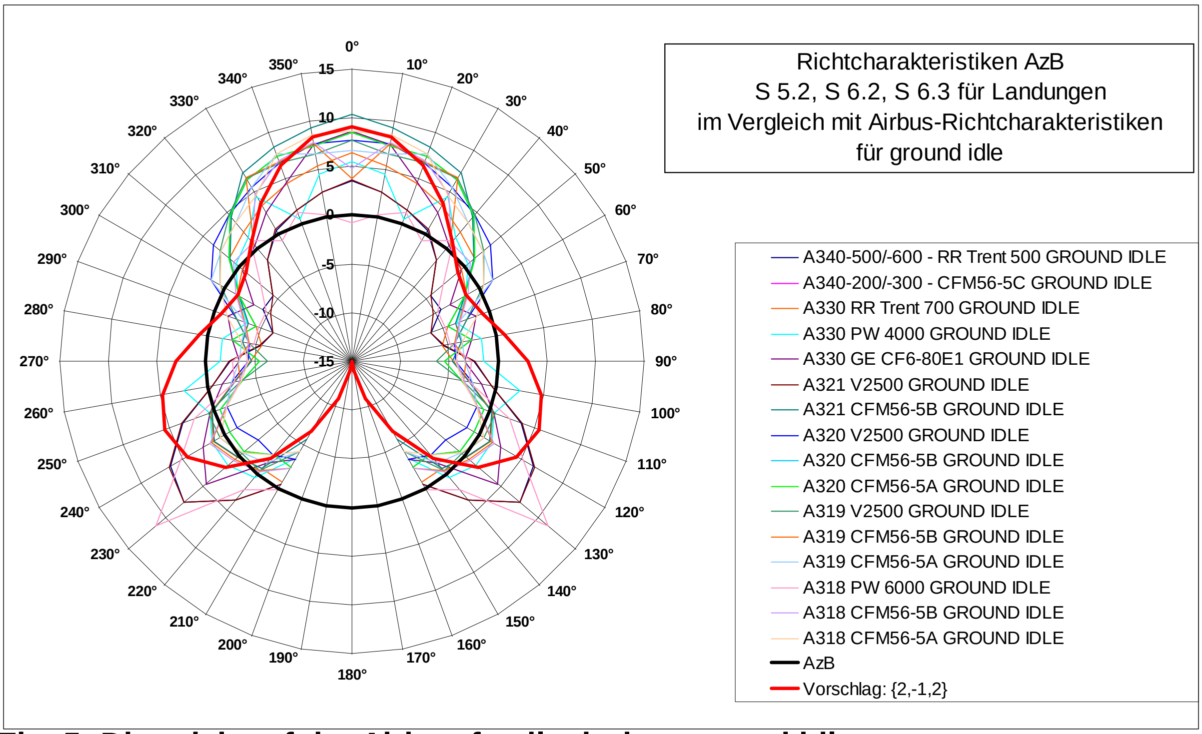

Fig. 5: Directivity of the Airbus family during ground idle

During the approach for landing, the direction coefficient applied in accordance with the AzB represents however a uniform, i.e. undirected sound propagation into all directions. Figure 5 leads to the conclusion that this idealized directivity of the AzB for landings cannot be applied to engine test runs carried out in ground idle. Instead, it is suggested to apply a mean directivity, which can be described with the coefficient (2 -1.2). These directivity should be valued as compromise for the values of the Airbus family using 3 coefficients as specified in Figure 5. For the individual types of aircraft and engines, e.g. in A 319 with CFM56-5A and V2500 as well as A 321 with CFM56-5B, it is surely possible to accomplish a better individual adaptation as well as a better group adaptation using more than 3 coefficients [33].

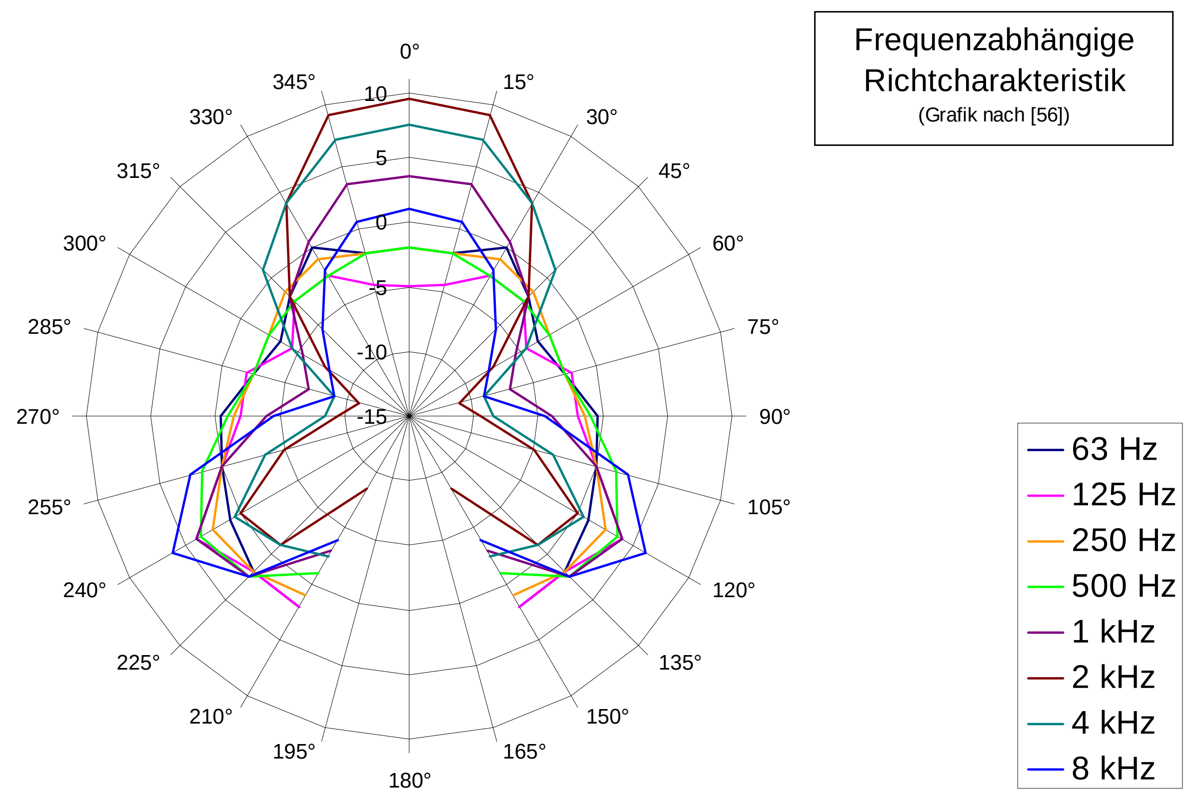

Fig. 6: Frequency dependent directivity illustrated on the example of the B 737 (idle) [56]

In general, the directivity is dependent on the frequency. Figure 6 shows an example of a frequency dependent directivity for a Boeing B 737 at idle [56]. The illustration in Figure 6 shows the plausible trend that the directional dependence is getting more pronounced with an increase in frequency. However, Figure 6 demonstrates that it is possible for jumps to occur between neighbouring frequency bands.

For simplification purposes, ground noise reports apply frequently only the directivity of the frequency integrated A-weighted level. Some ground noise reports do not consider the directivity at all. Even in the datasets of the new AzB, the coefficients of the directivity are the same for all frequencies of one certain aircraft group with the exception of the aircraft group S-MIL 6 (Eurofighter). With regard to the deduction of a calculation method for test engine runs, it is also suggested to consider the directivity only frequency integrated at first. The reason for it, is the lack of a systematic compilation of data based on which the frequency dependent direction characteristic of aircraft types can be classified into various aircraft groups. Furthermore, it should be noted that a frequency dependent direction characteristic could not be determined by a localization of sources of all frequency components in one common point (centre of the aircraft) [35]. The measurement results thus far available for the frequency dependent directivity should be seen as critical because not all measurement distances were sufficiently large for the low frequency ranges. The measurements published by Airbus were taken e.g. in a distance of 60 meters, which is insufficient for low frequencies according to [35].

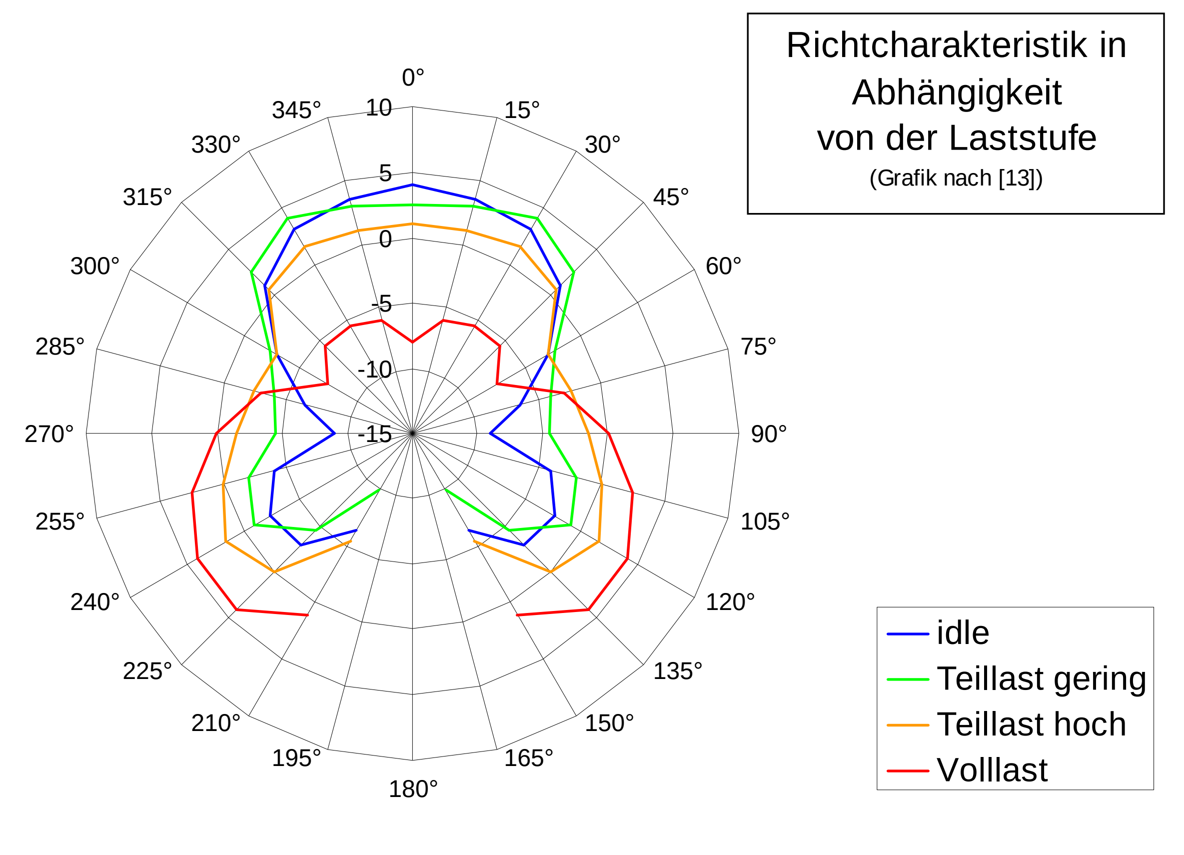

Fig. 7: Directivity dependent on various load levels illustrated on the example of an A321 with a V2500-A5 engine [13]

The previous observations have assumed that with regard to load levels landing and idle as well as take-off and maximum load are principally comparable. The ground noise report for the plan of the northwest runway at Frankfurt Airport, the directivity for four different load levels were used based on the Airbus measurements [13]. As seen in Figure 7, the sound emission in idle is mainly directed toward the nose of the aircraft. As the load level increases, the emission direction shifts toward the aft of the aircraft, i.e. toward the engines' outlets. Therefore, for all other load levels suitable intermediate values are to be found.

The previous explanations refer all to the directivity of civilian jet aircraft. The directivity are fundamentally different for aircraft with turboprop or piston powered engines because of the engines' physical mode of action. The directivity for turboprop aircraft are included in [12] and with regard to engine test runs in somewhat older investigations by the Federal Environmental Agency [32, 38, 39]. The following Figure 8 shows the directivity for the transport aircraft C-130 E (AzB aircraft group P-MIL 2) used by the military.

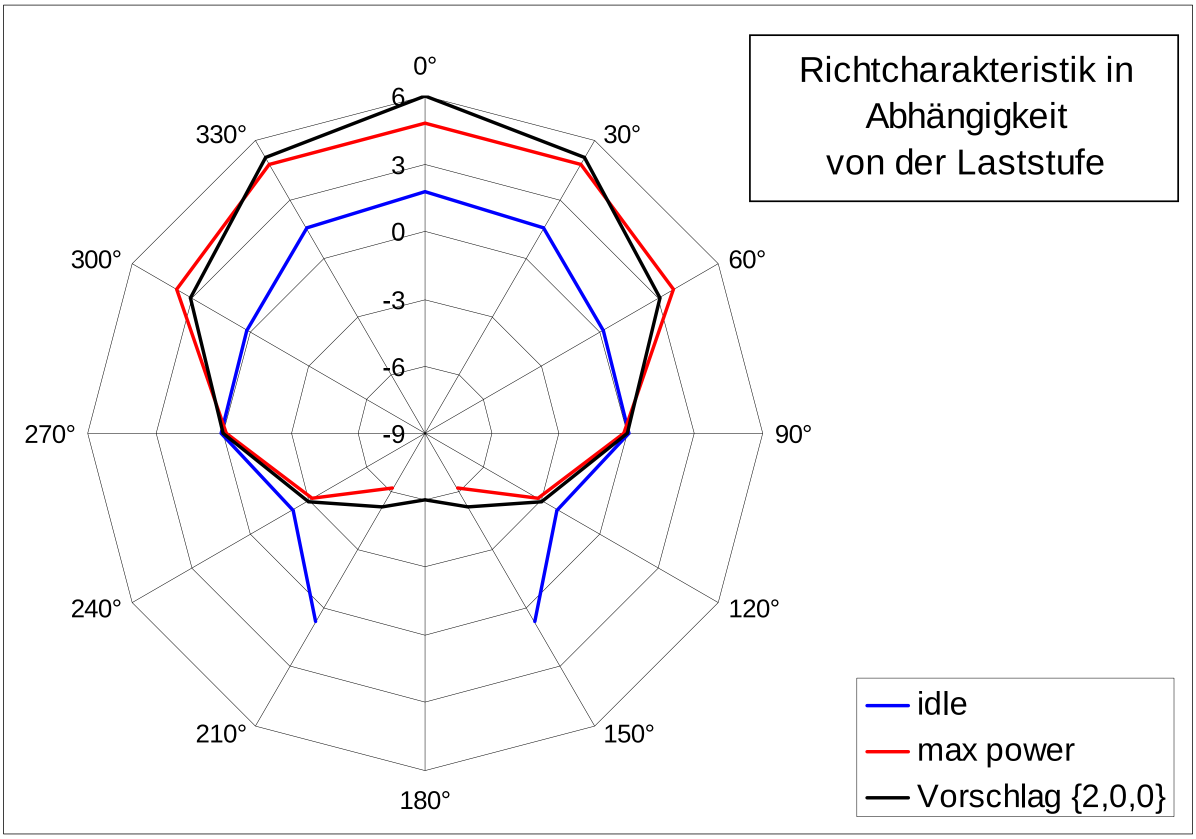

Fig. 8: Directivity of a turboprop aircraft C-130 illustrated for various load levels

As opposed to jet aircraft, turboprop aircrafts emit sounds rather toward the front. This sound emission characteristic intensifies with an increasing load level. In this case, too, the coefficients specified in the AzB (take-off or landing) do not provide a satisfactory approximation to the true sound emission characteristic. Therefore, it is suggested to use a directivity described by the coefficients {2,0,0} for engine test runs on turboprop aircraft.

As shown in Figure 9, the directivity of the AzB clearly deviates from true conditions also for combat aircraft.

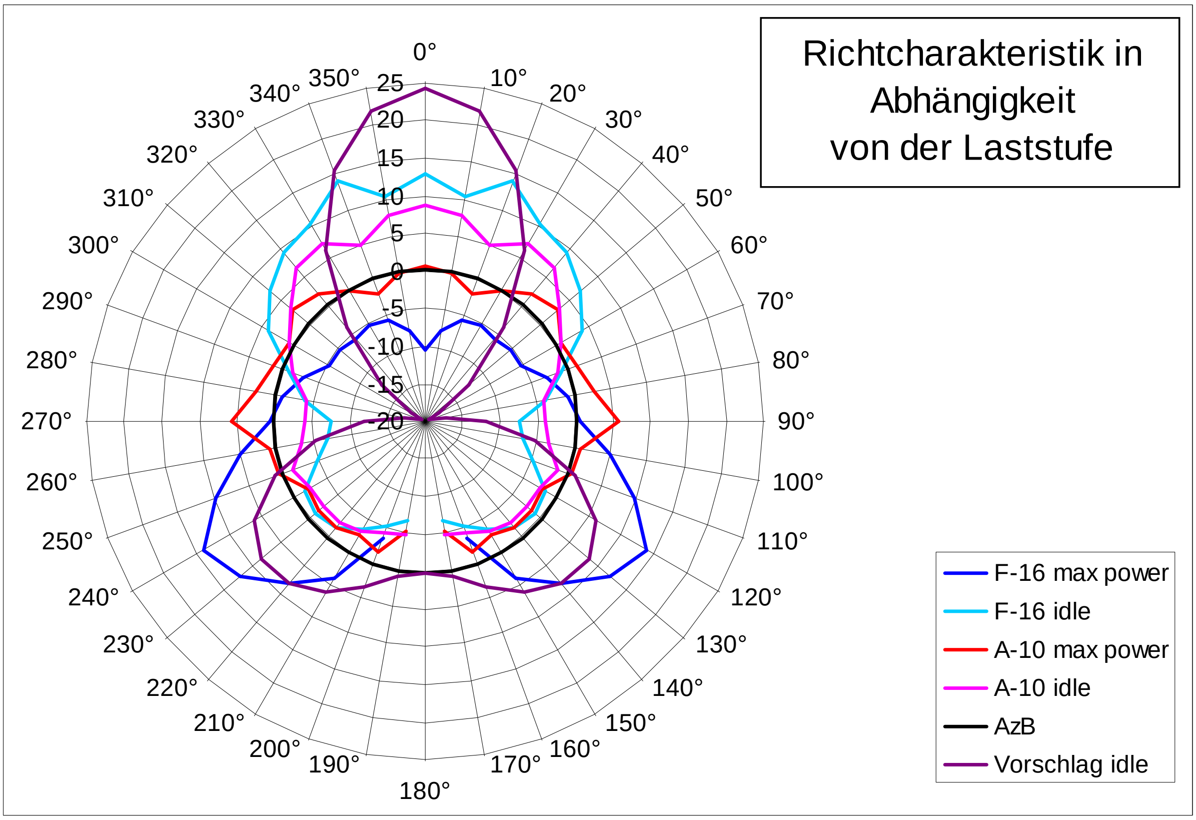

Fig. 9: Directivity for various combat aircraft illustrated for various load levels

In summary of this Section, it can be concluded that the directivity in engine test runs is generally a significant constraint, which should not be neglected as suggested in some ground noise reports in the past. On the other hand, the database for a specific classification of directivity for various aircraft groups is still not sufficiently large. This applies particularly to the database of the frequency dependent directivity. In many cases, it is not possible to derive at directivity applicable to engine test runs from the coefficients of the AzB. In this context, further investigations are needed, which could surely deliver not only results for the calculation of engine test runs but could also improve the database of the AzB.

6.7 Tonality

In connection with complaints about noise immissions during engine test runs, the consideration of the particularly annoying effects of specific individual frequency components of noises (tonality) has been requested frequently in the past in a similar manner as demanded in TA Lärm or in other work of rules on noise immissions. The (old and new) Aircraft Noise Act and the corresponding AzB do not provide for a separate noise allowance for tonality. In DIN 45643, Part 1, "Measurement and assessment of aircraft sound, measurements and parameters" from October 1984 [40], the allowance K_T for tonality of aircraft noises is principally included; however, in annotation 4 of this DIN, the application of K_T is waived for commercial jet aircraft because there is no tonality in these aircraft[2].

In this context, it should be noted that the noise characteristics of jet engines has changed over the years particularly with the introduction and advancement of turbofan engines. In the meantime, there are measurement results, which provide information on a tonality of modern turbofan engines under certain marginal conditions. At this time, systematic investigations are not available on this subject.

Within the framework of the current research question, such systematic investigation of tonality for aircraft noises cannot be carried out; however, at this point examples of the tonality of aircraft noises under various marginal conditions should be demonstrated based on available sound recordings.

The tonality of noises was determined in accordance with the methodology of DIN 45681 [41]. This methodology can be applied to engine test runs without restrictions. For aircrafts moving in flight, the initial question that must be raised is whether the change in frequencies caused by the Doppler effect or other influences allows applying DIN 45681.

DIN 45681 does not differentiate between stationary and non-stationary sounds. The lower application limit is specified by averaging times of 3 seconds. "Signals with very high level and/or frequency dynamic, which no longer correspond to a time averaging of 3 seconds, can therefore no longer assessed by this standard" [41]. Given these requirements, the determination of tonality of aircraft noises can surely be done in many cases without any problems with the methodology of DIN 45681, particularly if the distance to the aircraft is larger. In addition, the research question examined here does not deal with the assessment of a precise noise pollution situation based on reference value comparison. It rather deals with the general assumption whether aircraft noises contain tonality or not.

The following Figures 10 and 11 illustrate the narrow band spectrum of an engine test run of a military transport aircraft in idle and one inbound for landing in a relatively large distance to the airport (13 km to the threshold, 2.4 km lateral to the ap-

[2] Please note: This DIN is currently being revised. The above-referenced statement on tonality will perhaps be revised.

proach). The prominent tonal components can clearly be recognized. Therefore, the assessment in accordance with DIN 45681 shows correspondingly high allowances of 5 dB and 6 dB.

Table 4 lists the tonality allowances determined in accordance with DIN 45681 as an example for a serious of different marginal conditions in noise emissions of aircraft in flight. It shows that tonality can truly be a problem in modern aircraft during both take-off and landing. However, it can also be seen that despite similar distances from the airports, the values of tonality can be different.

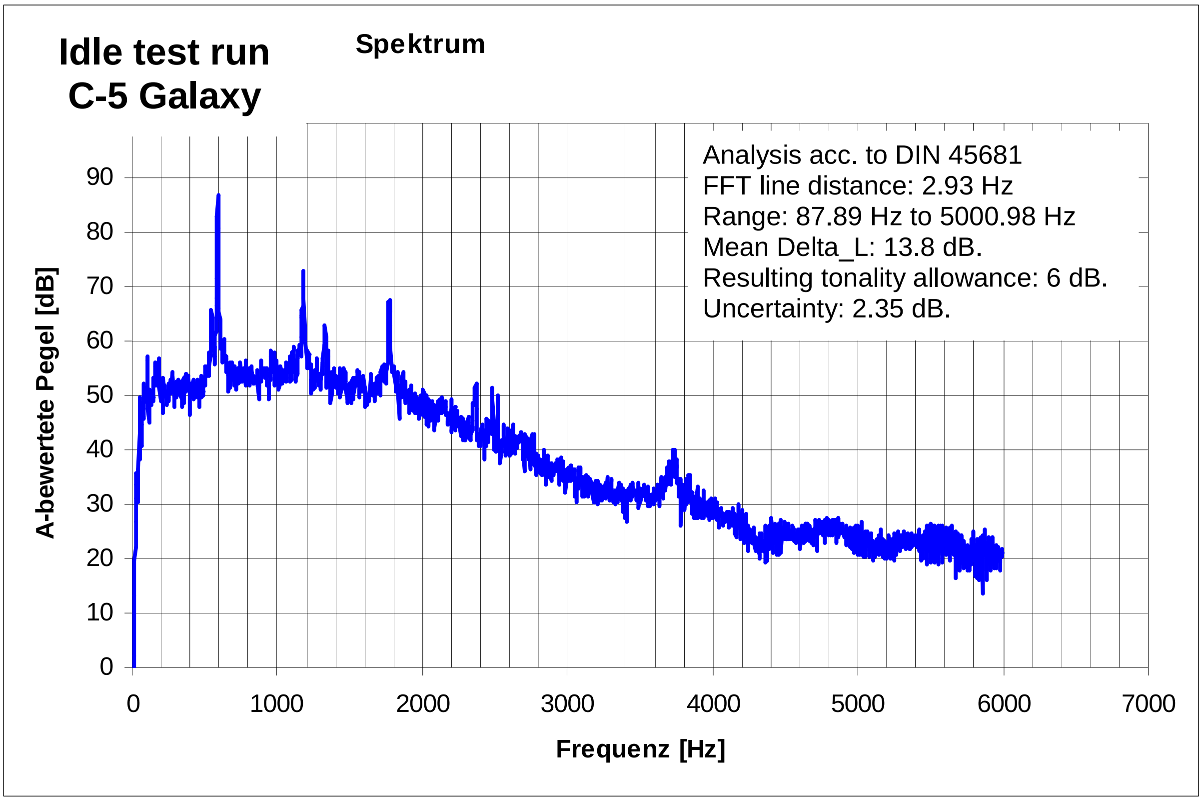

Fig. 10: Tonality during test engine run

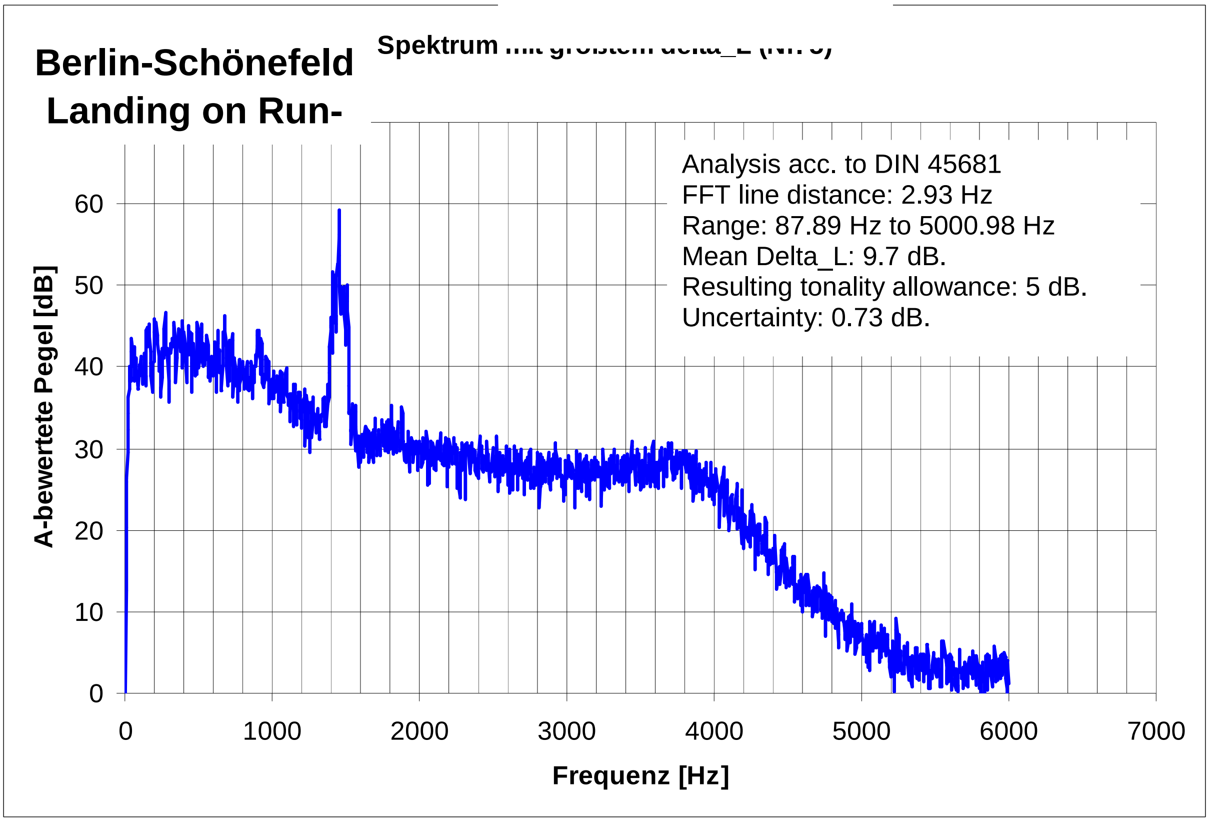

Fig. 11: Tonality during approach for landing of a jet aircraft A 319

The results of Table 4 are based on sound recordings of measurements, which did not focus on the documentation of aircraft noises. Therefore, certain information of interest is not available (such as type of aircraft, take-off or landing, etc.). However, this information was available in another measurement, which was carried out simultaneously on two measuring points in different intervals. The measurement points were on the extended axis of the airport runway approx. 800 meters and approx. 3,000 meters away from the threshold. Through this arrangement of measuring points, there were always two measuring points available for the same aircraft, which flew over both measuring points in sequence.

Table 5 includes all tonality allowances determined in this context. In the individual lines of Table 5, the tonality allowances for various types of aircrafts are specified. The two values for the tonality allowance shown in each line were the result of the same type of aircraft flying over the measuring points.

The differences in tonality are not as well pronounced in these better-controlled marginal conditions than in the values specified in Table 4. The tonality at the two measuring points differs by a maximum of 1 dB despite the fact that the aircraft is identical.

In addition, the difference of tonality of different aircraft of the same type and otherwise identical conditions (take-off/landing, measuring point) is only larger than 1 dB in one singular case. Therefore, it is likely that the type of aircraft or type of engine and the corresponding engine settings at the time of measurement play a role for the characteristic of tonality (in the values specified in Table 4, this cannot be determined in every case). If the differences are larger, then surely meteorological influences play a role as well.

Measurement	Type of Aircraft	Distance to the airfield	Lateral distance	Mean Delta_L	Tonality allowance K_T	Uncer-tainty
		m	m	dB	dB	dB
Start						
Berlin-Tegel		3600	1200	2.3	2	0.4
Berlin-Schönefeld West	B 737-800	1000	250	2.2	2	0.6
Berlin-Schönefeld West	B 737-800	1000	250	1.6	1	0.6
Berlin-Schönefeld West	A 319	1000	250	9.5	5	0.8
Berlin-Schönefeld West	A 319	1000	250	7.9	4	1.3
Approach						
Berlin-Schönefeld East		13000	2400	9.7	5	0.7
Berlin-Schönefeld East		13000	2400	1.0	1	0.4
Berlin-Schönefeld East		13000	2400	0.1	1	0.3
Berlin-Schönefeld East		13000	2400	4.7	3	1.0
Berlin-Schönefeld East		13000	2400	9.8	5	0.9
Berlin-Schönefeld West	A 319	1000	250	0.8	1	0.3
Berlin-Schönefeld West	A 319	1000	250	0.2	1	0.2
Berlin-Tegel		6800	400	0.0	0	0.0
Berlin-Tegel		10500	2800	5.0	3	1.0
Berlin-Tegel		10500	2800	0.3	1	0.3
Berlin-Tegel		10500	2800	0.2	1	0.2
Berlin-Tegel		10500	2800	0.0	0	0.0
Berlin-Tegel		10500	2800	5.9	3	0.8
Berlin-Tegel		10500	500	6.7	4	1.0
Berlin-Tegel		10500	500	0.5	1	0.3
Berlin-Tegel		10500	500	8.8	4	1.0
Berlin-Tegel		10500	500	7.8	4	0.6
Berlin-Tegel		10500	500	7.7	4	0.8
Holding Pattern						
Berlin-Schönefeld (ILA)	Eurofighter			0.1	1	0.2

Table 4: Tonality under various constraints

	Type	Tonality allowance K_T in dB	
		Measuring point 800 m	Measuring point 3000 m
Take-off on 08	C-5	3	4
	C-5	3	4
	B 747	0	1
	B 747	2	1
	B 747	1	1
	C-130	3	2
	C-130	3	4
	LJ 35	0	1
	LJ 35	1	1
Runway 26	C-5	5	5
	C-5	5	4
	B 747	3	4
	B 747	4	4
	C-130	1	1
	C-130	1	2
	LJ 35	3	2
	LJ 35	3	3

Table 5: Tonality in relation to flight status and measuring distance for various aircraft

Measurement	Type	Distance to the Aircraft	Mean Delta_L	Tonality allowance K_T	Uncer-tainty
		m	dB	dB	dB
Test Runs					
partial power	C-141	1700	1.9	1	1.2
Idle	C-5	1700	13.8	6	2.4
partial power	C-5	1700	3.8	2	0.8
Idle	C-130E	100	6.2	4	0.4
partial power	C-130E	100	11.1	5	0.6
max power	C-130E	100	1.7	1	1.2

Table 6: Tonality during engine test runs of military transport planes

Table 6 contains the tonality allowances for engine test runs determined in accordance with DIN 45681. Here, too, it is determined that the tonality poses truly a problem for the assessment of respective noise immissions. The values specified here as examples support the plausible assumption that tonality decreases with higher load levels.

In summary, it can be concluded that aircraft noises can have tonal character during flight and during emission on the ground. Applying a respective allowance must be integrated in the context of the respective assessment system. If the calculation methodology to be developed for engine test runs should be used to deliver a level value to assess both flight and ground noises at a certain airport and this value can be energetically added to the calculation results of the AzB, then it does not make sense to consider tonality in engine test runs because this is irrelevant in flight and ground noises calculated in accordance with the AzB.

In general, with regard to the consideration of tonality, it should be noted that this is a generalized allowance, which is added to the measured or calculated immission value in accordance with a subjective impression one gets at the site of immission. Depending on the distance between the source and immission location and in relationship to other marginal conditions, the tonality of a specific noise may be different, which is subject to additional uncertainties due to the subjective assessment of the respective recipient.

DIN 45681 includes a proposal for the objective determination of the tonality allowance based on the metrologically determined low band analyses of the sound. This manner allows avoiding the uncertainties connected to the subjective assessment of tonality. However, the impossibility remains to calculate the tonality at a certain site of immission in a (predictive) propagation calculation based on source data, which usually are only available as octave or as third-octave spectra. For this purpose, a propagation calculation with low band spectra would be required, which seems impracticable within the framework of today's possibilities. Therefore, the only way that remains is to consider any possible tonality of noise immissions of engine test runs by way of averaged allowances added to the calculated immission value. However, systematic examinations on the characteristic of tonality at various marginal conditions would be required in this case. Until such examination results are available, it is suggested to postpone the use of a tonality allowance in (predictive) immission calculations.

6.8 Consideration of Maximum Levels

The noises of airborne aircrafts at certain immission sites are generally singular, clearly differentiable events with a relatively low value range of effect duration (a few seconds to up to one minute). Each event has a clear maximum, which is characterized by a respective maximum level L_{pAmax} (slow or also fast assessed).

The results of the medical and social response research prove relatively clearly that an (energy equivalent) averaged value is insufficient to assess the effects of air traffic noises particularly to identify the disturbing effect during the night. In acoustically effective singular events, it is obvious to define assessment variables based on singular events or maximum levels. From a medical perspective, anything disturbing the sleep during the night is obviously tolerable up to a certain extent. Therefore, on part of noise impact research, a measure of evaluation was defined based on the combination of a certain maximum level together with its frequency of occurrence. The assessment measure is called NAT (number above threshold). It should delineate the maximum permissible number of maximum levels with waking potential.

The concept of NAT has inherent problems, which should not remain unmentioned despite their wide application in Germany. For example, at airports with a high number of aircraft movements during the night, it is possible that a large number of events that take place at larger distances are just below the level criterion but they have an annoying effect solely due to their frequency. In praxis, these cases do not pose a great problem because of the parallel applicable restriction of the average level. On the other hand, airports with relatively few movements during the night, e.g. military airbases, often show that very high maximum levels significantly exceeding the level threshold specified by the NAT criterion occur less often than the frequency also restricted by the NAT criterion. In this context, the affected persons are less frequently annoyed but if they are then with very high individual event levels. Discussions with affected persons in the past have shown that the NAT criterion is a problem particularly when the frequency of the respective threshold level is undercut by 1 event. The affected persons inevitably assume that the forecast results or the air traffic statistics are made to look better and an enormous effort is put forth into the proof and counter-proof for each additional flight event.

Compared to the air traffic noise, the noises of technical systems generated on the ground have time structures that are of a significantly higher complexity as well as a longer impact duration that is distinctly more inconsistent. Therefore, the definition of a NAT criterion does not make much sense in the regulation area of these systems

(TA Lärm [42]). In this context, "… only individual short term noise peaks …" (TA Lärm, Section 6.1) are restricted by the specification of a maximum level L_{AFmax} applicable over the entire assessment time (day/night).

Furthermore, the work of rules does not know any NAT or other maximum level restrictions with regard to the time structure for the only source of noise comparable with the air traffic noise namely the noise emitted by the railroad traffic.

With regard to the development of a calculation method for noise immissions of engine test runs, the question is to what extent maximum levels should be considered. Such a decision must be made in the context along with the legal allocation of this calculation method.

If a calculation procedure should be based on or modelled after the regulations of the AzB, then methods to calculate NAT criteria are required. The difficulty is in the delineation of single events. In principal, each individual engine test run organized in the same manner could be used as reference time during which only one maximum level is defined. However, this does not satisfy the standard praxis in engine test runs, which runs various load levels greater than idle several times during an organized and connected test run and therefore, these form clearly definable time intervals with their respective own local maximums. On the other hand, however, based on the great variety of different test runs and based on the frequently required changes of the test sequence because of current test results, the determination of a statistic of individual load conditions requires a barely acceptable time and effort. As shown in Figure 12, it is not always possible to delineate individual load conditions.

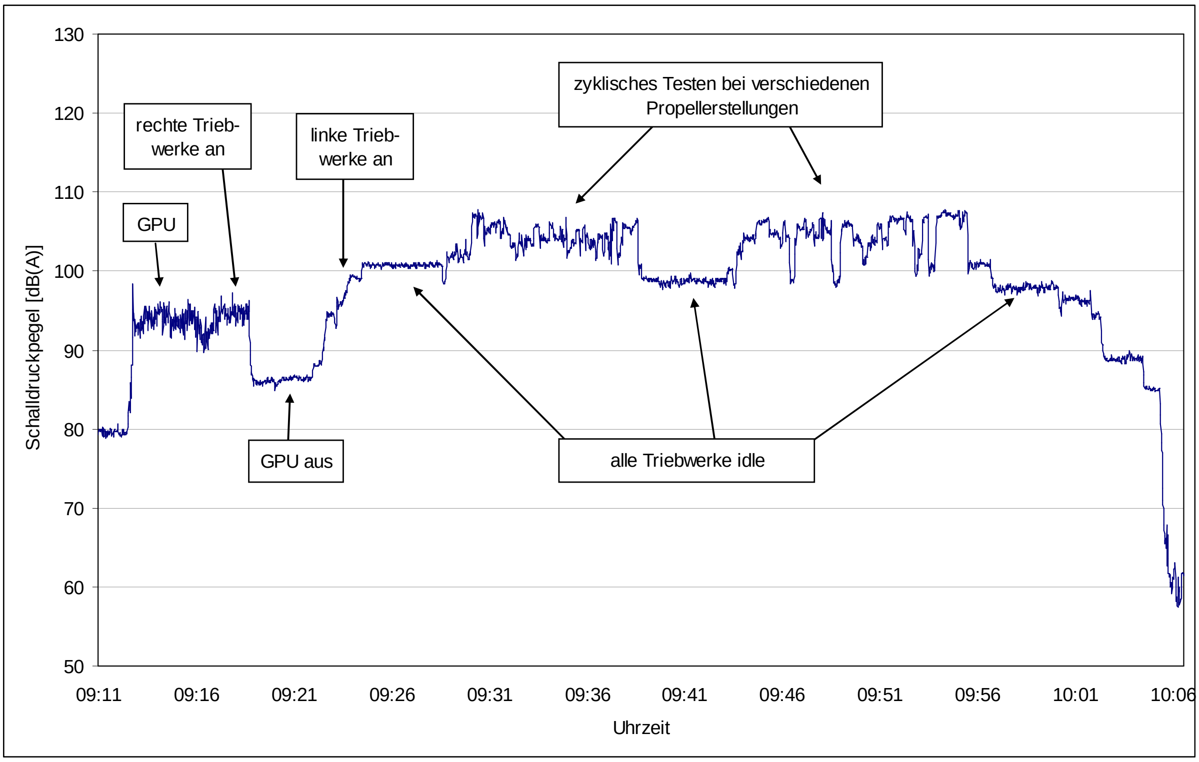

Fig. 12: Level over time during a test run of a turboprop aircraft C-130 in a distance of 60 meters

Figure 12 shows the level over time sequence during the test engine run of a four-engine turboprop aircraft during which in two different cycles first rough and then fine adjustments were carried out on the rotor blades. It shows that there are no indications for time restrictions of various local maximums during the first cycle. For this Section, only one single maximum level can be specified. During the second cycle, a time interval can be defined because the sound pressure level decreases to nearly idle; however, these occur nearly consecutively in time so that counting maximum levels multiple times seems questionable.

If NAT criteria should be calculated for engine test runs then it seems to make more sense to apply a specific factor in consideration of the occasionally set maximum conditions, i.e. for the mathematical increase in the number of maximums. This was practiced in the ground noise report for the expansion of the Frankfurt Airport [13, 29] by applying a factor of 1.5 to the respective highest run load condition (partial power high or max power). This approach is practicable. It seems appropriate for the affected persons and therefore, it is suggested to be included in a calculation method for engine test runs. An additional certainty is added by considering the propagation of noise emission of engines with Q_σ (see Section 6.5).

If a calculation method for engine test runs should not be adapted to the rules of the AzB, then foregoing the implementation of NAT criteria would simplify this methodology. In accordance with the usual regulations for noise immissions of other (ground) noise sources, the total maximum level during the assessment time could be considered as criterion. Any limit or reference value for the maximum level could be used in a manner e.g. to avoid even a one-time awakening during the night. In addition, the annoying effect of maximums occurring in shorter time intervals could be considered by a size for impulsiveness, e.g. L_{AFTm5}. However, it should be noted that this is only feasible when measuring real noise events. The database is largely non-existent for forecasts of engine test runs considering impulsiveness.

6.9 Noise Protection Systems

On German commercial airports, which are subject to the new Aircraft Noise Act and therefore the AzB, at least 8 of these airports are known to have noise abatement facilities for engine test runs (noise abatement facilities or noise protection facilities). The following explanations of noise abatement facilities on civilian airports are based largely on the information provided by Mr Meyer, LSB Gesellschaft für Schallschutz mbH in Hamburg, who was responsible for the acoustic design of these noise abatement facilities [43]. The information on noise protection hangars on military airbases is based on information provided by the Federal Defence Ministry [27] and on personal experiences and knowledge of military airbases [44, 45].

Noise protection facilities for engine test runs are principally classified as follows:

- simple wall/simple unidirectional barrier
- U-shaped enclosure through a wall/barrier (sound insulation cabin),with or without gate to lock the fourth side
- Noise protection hangar open in the front
- Noise protection hangar open in the rear
- Noise protection hangar with open front and rear
- Noise protection hangar "closed" on all sides

Noise abatement facilities on civilian airports are mostly designed as sound insulation cabins, i.e. noise abatement walls arranged in the shape of a U and frequently with one gate to lock the entrance. However, these are designed without a roof (noise suppressor device or run-up cabin). The sound insulation effect of these facilities called noise suppressor cabins is sufficiently large in close proximity of these facilities (15 – 20 dB (A)). However, the lack of a roof restricts their effectiveness in larger distances despite considerably high walls (20 m): approx. 6 – 10 dB (A) at distances of 200 m; approx. 3 – 6 dB (A) at distances greater than 1,000 m [46].

Munich, Hamburg, Düsseldorf, and Leipzig-Halle have mostly constructed closed noise abatement hangars (noise abatement hangar or noise reduction shelter). The term "closed" means in this context that the aircraft is enclosed in all directions but primarily also toward the top by shielding building components and the sound propagation is more or less impaired in all directions. However, openings are unavoidable because of the necessary air supply and ventilation.

The art in designing these hangars is the combination of partially opposing aerodynamic and acoustic requirements with possibilities provided by construction technology to create a very large lightweight hangar. The use of a roof shielding the sound toward the top is favourable even under aerodynamic considerations because it avoids better the recirculation than noise suppressor cabins and it increases the independence from wind directions. The required air inlets and outlets are outlets for sound. One part of the hangars leads the air supply through components with sound absorbing insulation. Therefore, the noise attenuation is increased for the components arranged at the nose or side of the noise of the aircraft. To extract the exhaust jet of engines, the hangar side oriented toward the aft is open and a barrier is erected in a certain distance from it, which redirects the exhaust jet toward the top. To combine open hangar sides with a noise-deflecting wall will result in a somewhat higher-level reduction than a comparably high sound abatement wall.

Fig. 13: Soundproof hangar at the Leipzig-Halle airport
(source: information sheet 210, Donges Stahlbau GmbH)

Just like the noise suppressor cabins, which are open on top, all noise abatement hangars are unique in their design and construction. In part, hangars are designed in a manner that aircraft are pushed into them with the aft first and in part, that aircraft roll in with the nose first. The hangar in Düsseldorf does not have a gate. The hangar in Munich is rather a tunnel open in front and in back. Hangars often have slot-shaped openings in the centre of the hangar roof that can be closed. This helps to accommodate aircraft with very high rudders.

Figure 13 illustrates this on the example of the noise abatement hall at the Leipzig-Halle airport.

Sound protection pyramid constructed in Berlin-Tegel represents a special case. A three-sided pyramid was constructed by two sound insulated walls standing at an angle to one another. This pyramid is open in one direction. The aircraft to be tested is positioned with its aft within this pyramid; the noise faces the open side. For the jet exhaust, an opening is installed in ground proximity at the otherwise closed edge of the pyramid. It is redirected toward the top by a barrier wall erected behind this opening.

The hangar and cabin components are in part made of concrete and in part as metal structure. The roof is generally constructed from light metal. Hangar and cabin walls are lined with sound-absorbing insulation on the inside.

Roof and walls have such high noise attenuation that they contribute little or nothing in case of concrete walls to the total noise emission. The only problem caused by low frequencies affects both noise attenuation and the absorbing lining. The remaining noise emission of noise abatement facilities is therefore determined solely by the more or less noise emitting openings.

Proof of the hangars' effectiveness is carried out metrologically by examining the compliance with the specified reference values of noise imission in the neighbourhood [47]. Any retrograde calculation to a size for the effectiveness of the hangars is impossible. Moreover, there is no known research that determined the noise attenuation of individual hall components. At most, generalized estimates on the effectiveness of these noise abatement facilities are available [39].

Based on the construction of these noise abatement hangars, it is estimated that the noise attenuation of the light metal construction (walls, roofs) is in the range of 20 dB. The air inlets reinforced by sound absorbing liners have a noise attenuation of approx. 5 dB to 10 dB. The noise attenuation of an air outlet protected by a deflecting wall lies likely within the same range.

The inside noise level in front of the hangar components depend in addition to the acoustic parameters (sound power level, spectrum, directional effect, absorption, and reflexion on the ground) decisively on the geometric arrangement of the engines on the aircraft and within the hangar (distance to outside building components) and therefore on the shielding effect of the cell and the aircraft's wing. For this reason, the inside levels in front of the outside building components are different for nearly any type of aircraft or at least for all types of aircraft that are not significantly similar constructed. Therefore, the emission from the hangars toward the outside will be different as well.

Based on the fewer different types and the smaller dimensions of combat aircraft, the above-referenced situation for noise abatement hangars is not quite such a problem on military airports (with the exception for transport aircraft). In Germany, every military airport (Fliegerhorst), where fighter jets are stationed, has a noise abatement hangar for engine test runs of fighter jets. The construction types are provided by few manufacturers. Figure 14 shows a principle drawing of such a noise protection hangar.

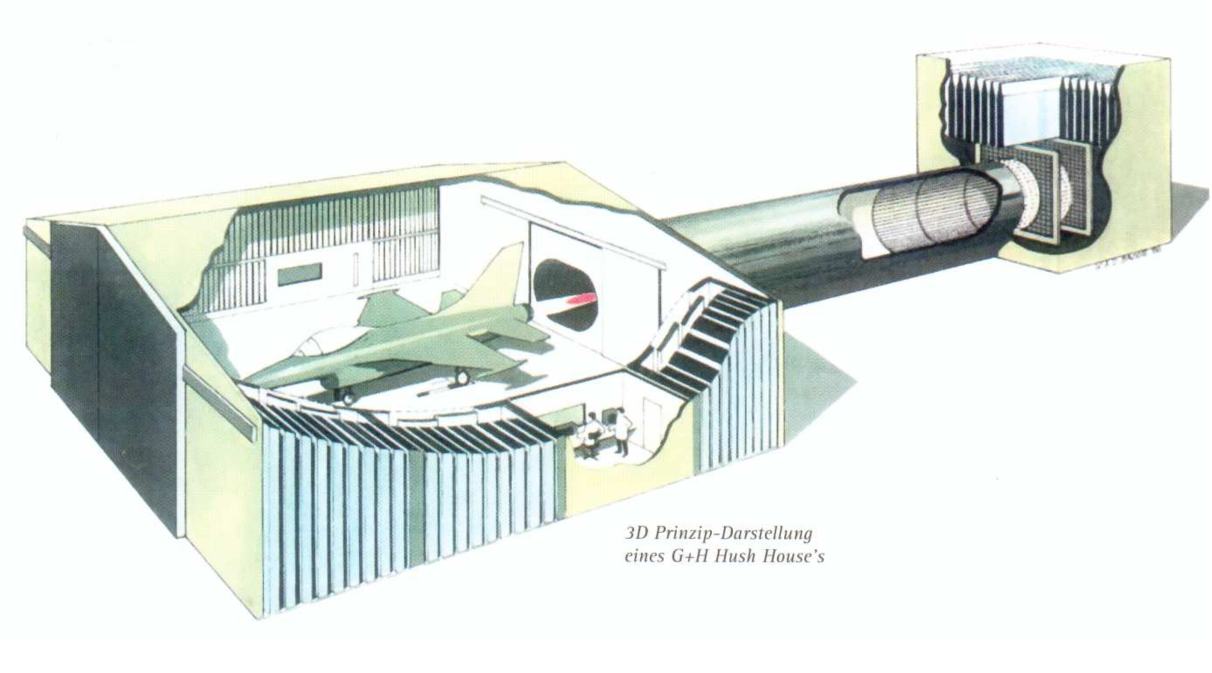

Fig. 14: Principle drawing of a noise protection hangar for combat aircraft

(Source: Company Brochure G+H Schallschutz GmbH)

As opposed to the noise abatement hangars used for wide-body aircraft in the civilian sector, the air outlet is led here through a relatively long (20 m) duct lined with sound absorbing material. A shaft open toward the top is at the end of this duct. The exhaust jet is deflected toward the top through this shaft. Walls and roofs are made of concrete and therefore negligible with regard to noise emission. The noise attenuation of the air inlets mostly arranged on the front side is comparable with those on hangars at civilian airports. The noise attenuation of the air outlet is somewhat better.

The noise abatement facilities pose a large problem under the aspect of developing a calculation requirement for engine test runs. The level reducing effect of noise abatement walls and barriers can be explained by the shielding value described in DIN ISO 9613-2 or VDI 2720. However, this would be a violation of the AzB, which does not know of such shielding for APU and taxiing noises.

However, it is impossible to model noise abatement hangars with the currently available computation methods. The calculation of a noise emission using a standardized propagation calculation is not the problem here but the determination and modelling of the noise emitted through outside building components and openings of the hangars. Even knowing the acoustically relevant parameters in engine test runs as illustrated in Section 6, it is currently not possible to determine the necessary inside level in front of the outside building components and openings of the hangar. The standard calculation requirements for noises within rooms (e.g. VDI 2571) presuppose mostly a diffuse sound field. The sound propagation in this highly turbulent medium within a hangar during engine test runs evades all these calculation processes. Moreover, nothing is known about the directional effect of noise emitted through the openings of the hangar.

VDI 3760 [48] may offer a way out of this dilemma because it does not require a diffuse sound field. On the other hand, the calculation methods of this VDI has been developed for workplaces, i.e. mainly for shallow rooms with a relatively high number of diffusors. To what extent inside levels in a noise abatement hangar without significant smaller diffusors but with a relatively large aircraft with shielding effect can still be calculated and if so with which accuracy limits cannot be assessed without further research. The directional effect of the hangar's openings is questions that remain unanswered with this method.

Therefore, approximation methods must be found or new calculation methods must be developed to consider noise abatement hangars in the calculation process for engine test runs. An approximation method is being discussed among groups of experts. This method should consider in a simplified manner the level reducing effect of hangars by using a triplet of directional effect factors in the same form as described in the directional effect of aircraft in the datasets of the AzB. Figure 15 shows an example (without further proof) of how such approximation could like.

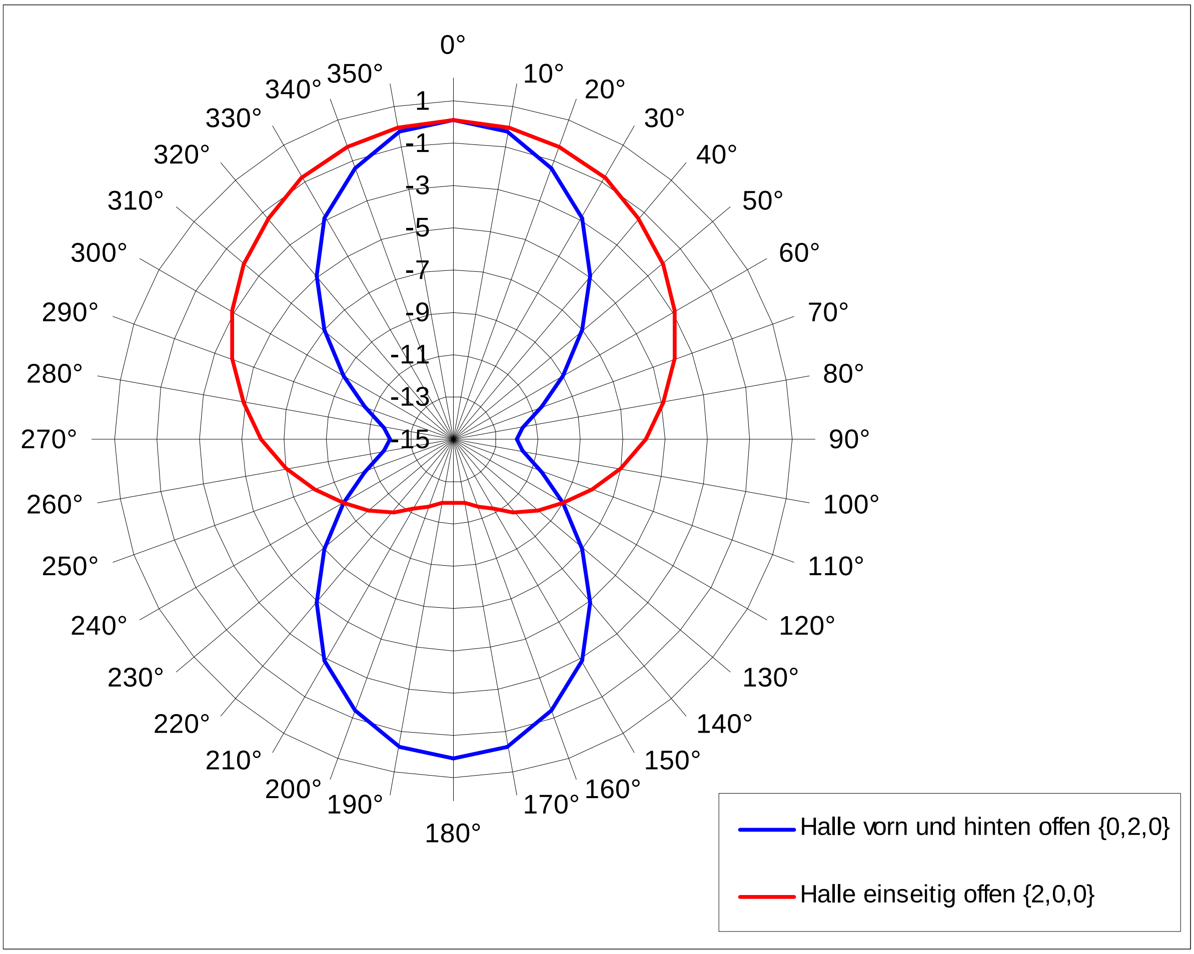

Fig. 15: Example for the consideration of noise abatement halls with directional factors

Knowing that a rough approximation procedure would be better than no procedure, this approach could be applied until more exact research results become available. In addition to the simple applicability, another advantage would be the methodological proximity to the AzB. The disadvantage is the strong simplification of sound emission of a noise abatement hangar, in particular the level reduction, which depends on the distance because of the diffraction around the deflector wall, surely exists. Moreover, the potential reciprocal impact on the directivity of the respective aircraft is currently unknown. Therefore, further examinations about the applicability would be required prior to deciding on this method whereby it raises the question whether it does not make more sense to apply this effort to develop a better and more precise methodology.

With regard to the noise abatement hangars, it should be considered that demands in terms of "limit values" were made on these hangars by the competent government agencies. The noise abatement hangars must comply with these "limit values" in the neighbourhood during engine test runs. In Hamburg and Düsseldorf, a maximum level of L_{AFmax} = 65 dB(A) must be maintained to the nearest residential buildings [47, 49]. The immission values during an engine test run during the night lasting 5 minutes at maximum power, 15 minutes at partial power high and 40 minutes at idle are within the range of the reference value of 45 dB(A) applicable to mixed neighbourhood during the night in accordance with TA Lärm. Depending on the type, duration, and frequency of test runs and the other marginal conditions, it may be realistic to neglect the engine test runs in the hangar compared to the air traffic noises and other ground noises.

6.10 Propagation Models

In Germany, there are currently two propagation models, which are relevant with regard to the research question: The propagation model of DIN ISO 96 13-2 and the AzB.

The calculation method of the AzB can be used for engine test runs relatively easily. A respective proposal [9] has already been developed. In addition to the methodological compatibility with the calculation method of ground noise sources "taxiing" and "APU", the existing database with emission data of aircraft groups and corresponding directivity is an advantage in this approach. Any existing deviations, e.g. with regard to directivity (see Section 6.6) can be considered relatively easy through separate datasets for engine test runs (similarly e.g. to the APU) and perhaps through the potential necessity to update the data inventory of the AzB.

A problem is the treatment of obstacles along the propagation path (reflexions, shielding, vegetation, structures, etc.) and the noise mitigation measures installed on several airports such as noise abatement barriers (one-sided, in the shape of a U, or all the way around). In general, it is possible to take supplemental calculation terms from other propagation models (e.g. A_{bar}, A_{fol} from ISO 9613-2). However, this would equal a methodological breakup with AzB because it does not consider such obstacles (primarily for ground sources such as "taxiing" and "APU"). Currently, a meaningful consideration of the effect of closed noise abatement hangars within the framework of the AzB method is not practicable without further research.

The calculation model of ISO 9613-2 allows considering deflections and reflexions as well as noise mitigation measures and from very complex building structures and complete structures on the airport to entire villages. Only the consideration of the effect of closed noise abatement hangars is not easily integrated into the calculation system because there is currently no generally applicable methodology for the calculation of the sound insulation of such hangars as described above in Section 6.9.

If ISO 9613-2 were applied, the incomplete database to describe the sources would be a disadvantage. Although, the most important noise power levels and directivity, i.e. for the most widely used and loudest types of aircraft and engines, are available. However, supplements are required. It is possible to convert the datasets of the AzB with the reference distance s_{On}. However, additional work must be carried out to prepare the data (see Section 6.5).

The limited accuracy as the distance between sources and immission sites increases is another disadvantage of ISO 9613-2. In section 9, ISO 9613-2 estimates itself the calculation accuracy with ± 3 dB for sources and receiver heights of up to 5 m and distances of up to 1,000 m. This standard does not make any statements for larger distances. Annotation 24 of this standard points out expressly that the specified uncertainties are means, which can be "... significantly larger ..." [8] in measurement comparisons in an individual case.

Praxis shows that significant deviations can occur already at distances larger than 500 m. One example is known from personal measurements where at a distance of 1,000 m between point source and immission location and near to no wind, the differences between the calculated and the measured value were more than 10 dB(A).

Another propagation model developed for shooting noises of large calibre weapons of the German Military [50] is surely better suited for calculations at large distances. Information on the details of this model is currently not available. A commercial computational implementation has not happened.

Several different models are available internationally. Of particular interest is the European project IMAGINE [51] and the Scandinavian project Nord2000 [52]. A propagation model combining aircraft noises and ground noises applied internationally is not known.

Thus far, the results of project IMAGINE have not been applied in praxis. No information is available that would permit estimation of the suitability of models to calculate noise immissions of engine test runs and commercial implementation in a computational program.

The Scandinavian model is available in Germany in a commercial computational implementation. Compared to ISO 9613-2, it allows a significantly more detailed consideration of various weather influences and it is said to carry out relatively exact calculations even at larger distances [53].

If propagation models are compared in accordance with ISO 9613-2, the AzB, and Nord2000, then the differences in calculation results are minor when considering large distances from source to receiver (around 6 km), provided the meteorological conditions (15°C, 70% relative humidity, mild downwind of 2 m/s) in the calculation are comparable and the ground effects are neglected.

In addition, if ground effects, which are considered differently by the individual propagation models, are integrated then the calculation differences that occur in the standard case of a sound-absorbent surface (grass area) and distances of approx. 1.5 km are still within the range of the general uncertainty of forecast models (for the differences of Nord2000 and the AzB compared to ISO 9613-2 see Figure 16). The calculation results according to ISO are generally lower than those according to NORD2000 and with the exception of a distance range between 500 m and 6 km, they are also lower than those according to the AzB.

Larger differences occur only at larger distances and particularly in consideration of meteorological conditions deviating from the standard case. For the above-described case from personal measurement work, a near agreement between the measured and the calculated result was found at a distance between a point source and the immission site of 1,000 m applying Nord2000 and considering a slight headwind of 2m/s.

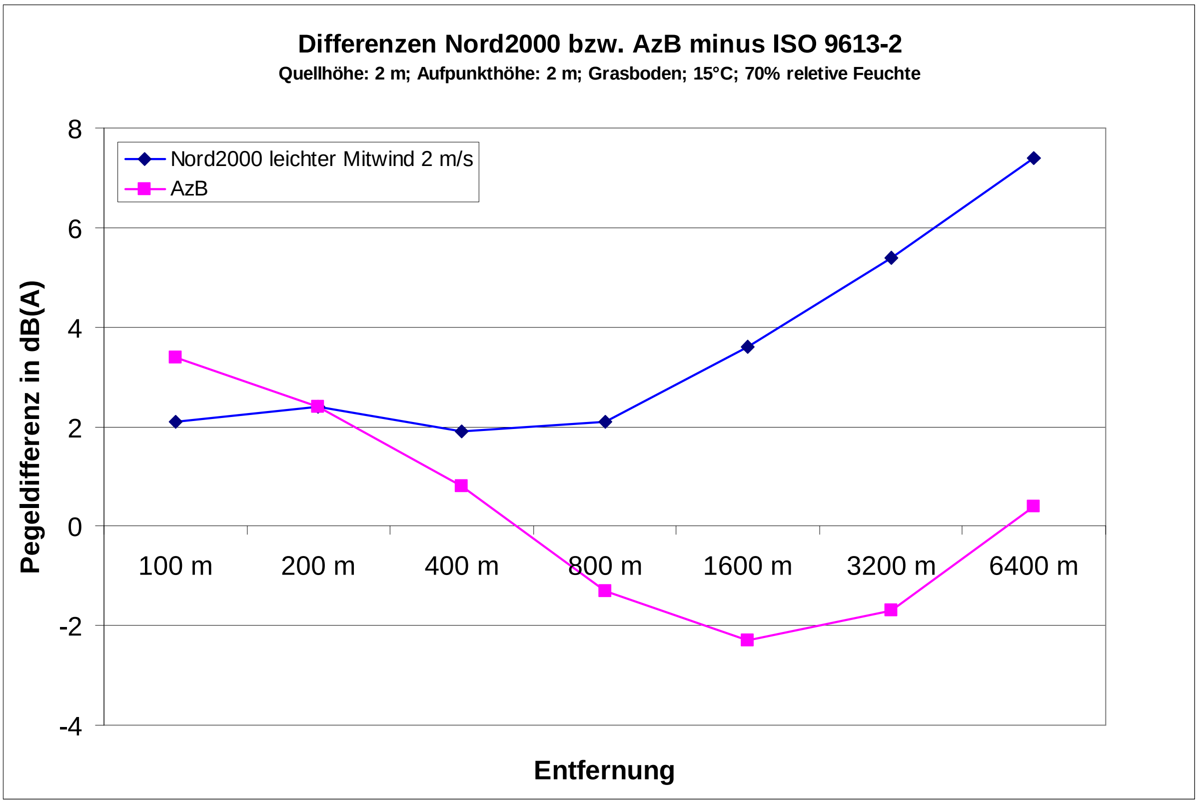

Fig. 16: Calculation differences among different propagation models

To decide on a propagation model for the calculation of noise immissions of engine test run is closely tied to the goal of the calculation method. If an assessment value should be determined for engine test runs, which should be computed with the calculation results of aircraft and ground noise pollution in accordance with AzB to determine noise protection areas, then the propagation model of the AzB should be used for reasons of compatibility. However, because the AzB was not developed for near ground sources, it requires compromises with regard to the consideration of obstacles along the propagation path and with regard to consideration noise mitigation measures (noise abatement hangars).

If the calculation method for engine test runs should be integrated in Germany's applicable work of rules for systems (TA Lärm, BlmSchG), then preference should be given to the propagation model of ISO 9613-2. The disadvantages connected with this method must be accepted.

However, if it is the goal to develop an independent calculation procedure for engine test runs according to the current state of knowledge and without consideration of compatibility, then the applicability of Nord2000 or another procedure, the calculations of which are still sufficiently precise for distances over 1,000 m, should be more closely investigated.

7 Derivation of a Calculation Method

7.1 Summary Assessment of the Examination Results

From experience and the current knowledge, a series of conclusions can be drawn on the development of a unified method to calculate the noise immissions of engine test runs. These conclusions must be fundamentally seen under two aspects:

- Methodological integration of the calculation method into the system of the AzB.
- Methodological integration of the calculation method as system noise

The following Table 7 lists the differences, which must be considered when implementing a calculation method for test engine runs into one of the two basic methods. It can be seen that

- the description of sources can be handled in both methods
- however, the propagation calculations show differences among both methods. These differences are insignificant for any decision
- reflexions can be neglected
- meteorological influences exist but are insignificant for the decision whether this method should be selected or not
- shielding through walls and similar barriers are difficult to treat in the AzB but not impossible
- noise abatement hangars cannot be modelled in the AzB
- noise abatement hangars are also rather difficult to treat using the other methods.

If it is decided that the calculation method for engine test runs should be integrated within the methodological framework of the AzB, then reflexions and weather influences should be neglected. Shielding, attenuation by structures and vegetation (if required or if desired) can be considered by including respective calculation terms from other works of rules. However, this constitutes a breach of other methodological foundations of the AzB because these influences on the propagation path are not considered within the ground noise sources of taxiing and APU regulated by the AzB. The same applies to the consideration of noise abatement walls or a combination of noise mitigation systems consisting of noise abatement walls (such as noise protection cabins that are open on top). Currently, the AzB does not provide for any sensible method to consider noise abatement hangars unless the very roughly approximating directional factors are used.

In principal, it is consistently possible to model engine test runs as system noises similar to general ground noise sources (TA Lärm, ISO 9613-2). All other ground noise sources can generally be compared but the desired comparability with aircraft and ground noise sources of the AzB is not possible. However, the consideration of noise abatement hangars is a problem in this case as well and it can only be approximated through the examination of individual cases.

	Calculation Method	
	AzB	**Other Ground Sources (e.g. ISO 9613-2)**
Sources		
Initial data to describe the source	sufficiently available (take-off/landing); adapt for test runs	incomplete; convertible from AzB
directivity	adapt for test runs	incomplete
load curves	classification with 4 load levels; specifications for standard impact durations; use preferably project-related data	
Frequencies	from project-related information; standard frequencies (e.g. number of test runs in % of aircraft movements) cannot be derived without airport statistics	
Propagation Model		
geometric propagation; air absorption	insignificant differences	
ground effect or additional ground attenuation	there are differences but insignificant for decisions	
reflexions	impracticable to implement	included
meteorology	impracticable to implement	only long term effects with c_{met}
Propagation Obstacles		
Shielding (walls)	e.g. A_{bar} from ISO 9613; however, methodological breach	included
shielding (structures)	e.g. A_{house} or A_{site} from ISO 9613; however, methodological breach	included
shielding (vegetation)	e.g. A_{fol} from ISO 9613; however, methodological breach	included
noise abatement barriers	such as walls, see above	included
sound protection cabins (U-shaped enclosure)	such as walls, see above	included
closed noise abatement hangars	cannot be implemented	standard methods cannot be applied; case-by-case examinations

Table 7: Comparison of the requirements on a calculation method for engine test runs depending on the integration into the existing work of rules

In summary, it can be said that the integration of a calculation method in the methodological framework of common ground noise sources compared to the integration within the methodological framework of the AzB is seen as more favourable. However, the significant disadvantage of this approach is that it does not generate any compatible calculation results. Therefore, the actual design of the new calculation method should attempt to achieve a high compatibility with the methodology of the AzB.

7.2 Integration of the new Calculation Method into the Work of Rules on Noise Protection

Societal and therefore political aspects are decidedly important when introducing requirements and regulation to determine and assess noise emissions affecting the surrounding areas. Any noise sources without societal relevance (e.g. offshore drill platforms) do not require regulation. A regulation of other sources of noise (e.g. the noise of playing children, church bells, etc.) is undesired by society (politically). In light of recent court rulings, the example of playing children has particularly shown however that any related marginal conditions are (can be) subject to constant changes.

The integration into a specific work of rules of a certain type of source is a question of definition and a political or legal kind of question. In this context, interests other than acoustical or other professional aspects are frequently in the foreground. The necessary delineation of areas of validity of a work of rules has led to professional and political discussions in other regulations on immission protection. For example, it is difficult to understand from a professional perspective why car parking spaces as part of a shopping centre are significantly stricter evaluated according to TA Lärm than public parking spaces based on RLS-90.

Similarly, from the author's professional point of view, it is incomprehensible why the new AzB considers as ground noise sources e.g. the auxiliary power unit (APU) of aircraft but not the ground power unit (GPU) of airport operators. And without mistaking the specifics of noises of engine test runs, it is furthermore incomprehensible just why engine test runs, the noise emission of which in many cases is more significant than the one of the APU, are not seen as part of aircraft related ground noise sources.

However, it should not be disputed that engine test runs present a societal relevant source of noise, which must urgently become part of a unified approach within whatever work of rules. This request is substantiated by all experiences of the past years, which were won within the framework of plan approval proceedings for airports and the consequential public hearings and court proceedings.

The calculation methodology for engine test runs can principally be integrated at various levels:

I Amendment of the AzB based on § 3, paragraph 2 FluglärmG (power to issue statutory ordinances)

II Inclusion under the term facility of the BlmSchG

III Statutory ordinance within the framework of § 32 Air Traffic Act (LuftVG).

IV Development of a technical work of rules within the framework of DIN or VDI

V Non-binding recommendation of a work group

Each of these options contains different constraints (advantages or restrictions), which influence the professional design of the calculation methodology for engine test runs.

After the new AzB became just recently effective within the framework of a legal ordinance, it seems unrealistic to amend the AzB (option I) within a reasonable time. Based on its urgency, it is not recommended to wait with this problem until the legal ordinance is due for review. Therefore, another way must be found to implement a calculation methodology for engine test runs within a short time.

The implementation within the framework of a separate statutory ordinance within the BImSchG (option II) or the LuftVG (option III) is at all likelihood a much too lengthy process. In addition, an implementation within the framework of the BImSchG would likely cause significant legal problems due to collisions with §2, paragraph 2 BImSchG. From a professional viewpoint, significant problems are seen with regard to the BlmSchG. After a summation of noise immissions from airports (see [15]), the justified requests of residents will face insurmountable methodological obstacles (e.g. quiet times and annoyance allowance, unsuitable hour during the night, etc.).

The calculation methodology for engine test runs could be published as non-binding recommendation, e.g. as proposal for a guideline of the Federal Environmental Agency (option V). This would be a suitable option for a **short-term** implementation of a calculation methodology for engine test runs into practical applications. The experiences with similar dossiers (e.g. Bavarian Noise Study on Parking Spaces [54], Hessian Study on Delivery Noises at Consumer Markets [55]) demonstrate that the respective calculation processes are accepted and used comprehensively by professionals. There is a large leeway with regard to the methodological design of the calculation requirement.

The work required to implement it within the framework of DIN or VDI committees (option IV) is in the limitation to a calculation methodology for engine test runs comparable with that of a non-binding dossier. The author believes that the implementation within the framework of a DIN standard is preferable over a non-binding dossier because of the quality assurance inherently ensured in the DIN committees and because of the balanced consideration of all affected groups. Because a series of other aircraft noise relevant regulations have been developed within the framework of DIN, therefore, at this point it is suggested to develop a DIN standard. To avoid another piecemeal, this DIN standard should not only include the calculation methodology for engine test runs but also ground noises, which are generated within the boundaries of an airport. Insofar, this option of implementation would be a rather **medium-term** solution.

In consideration of the differentiation made between aircraft related and not aircraft related ground noise sources described in Section 5.1, the regulations of the new AzB with regard to taxiing and the APU noises (aircraft related sources) could be accepted into this DIN without any collision and it could be supplemented by the method to calculate noise immissions generated by aircraft unrelated ground noise sources (GPU, ramp traffic, technical systems, etc.) at the airport's premises. Furthermore, this DIN standard will include engine test runs as aircraft related noise source for lack of other methodological regulations. In existing methodological freedoms of design, the focus should be on a best possible compatibility with the AzB so that aircraft and ground noise can be energetically combined if required.

However, from the author's professional viewpoint, the best solution would be to work on a **long-term** unified work of rules, which considers all noises generated by the operation of an airport. It would have the benefit of a closed work of rules covering all noises generated by an airport and emitted to the surrounding areas. It would not require any additional work because it would consider several parallel procedural paths. There would not be any dispute about the integration of certain sources. It would be more clearly arranged and it would not have methodological problems in adding up noise immissions of various works of rules.

The methodological handling of the large number of individual sources on the ramp could integrate e.g. the APUs through modelling of surface sound sources and it would present no significant problem. For the past years, this approach has become standard and tried practice in ground noise reports. Only the consideration of closed noise abatement hangars still presents a methodological problem, which has to be dealt with in the long term.

The following Sections 7.3 and 7.4 explains the precise implementation of a short term and medium term solution within the framework of the above-described constraints. At this point, no further explanations will be made to the goal for a long-term implementation of the above-described best solution because it would require the experiences with the short term and medium term solutions.

7.3 Proposal for an Implementation of a Calculation Methodology for Engine Test Runs in the Short-Term

As described in Section 7.2, the publication of a proposal for a "Guideline to calculate noise immissions caused by engine test runs on airports", which could be published by e.g. the Federal Environmental Agency, would lend itself to a short-term implementation of a calculation methodology for engine test runs. For reasons of a short-term implementation, this methodology should be restricted to noises emitted by engine test runs. In connection with the regulations of the new AzB, the ground noise immission would be covered in a narrower sense (aircraft related ground noises). The integration of other, thus far not regulated ground noise sources (ground noise immissions in a broader sense) should be reserved for processing in the medium or long term.

The change request of the Land of Lower Saxony to amend the AzB by the calculation method for engine test runs [9], the wording of which is included in the Annex of this report, could serve as foundation for the preparation of such a guideline. As can be seen, this proposal for change is a nearly completely developed work, which requires only an editorial adaptation to the intended form of publication.

It does not regulate, however, the level reducing effect of noise abatement hangars. This is justified on the one hand that the development of a calculation method for noise abatement hangars is not possible in the short term for reasons described in Section 6.9. On the other hand, the building permit for the few noise abatement hangars that exist on German commercial airports was in every one of the cases most likely connected to the compliance with certain noise emission conditions in the neighbourhood. As described in Section 6.9, these immission restrictions are in the precisely known cases held so strictly that the engine test runs carried out in the noise abatement hangars are upon initial approximation negligible compared to other ground noises.

If there are no such conditions imposed within the framework of the construction of the respective noise abatement hangar, or if other information on relevant immission portions of the engine test runs carried out in the noise abatement hanger is available from certain immission sites in the neighbourhood (e.g. in form of residents' complaints), then these noise immissions from engine test runs carried out inside noise abatement hangars should be approximated by estimation. For this purpose, an approximation process with directional factors or in an individual case based on a precise object (perhaps in connection with measurements) can be applied in accordance or in expansion of the procedure described in Section 6.9.

7.4 Proposal for an Implementation of a Calculation Methodology for Engine Test Runs in the Medium-Term

7.4.1 General Information

Based on the information of the previous Sections, the following describes a calculation methodology for engine test runs and for other relevant ground noise sources with regard to modelling. The appropriate formulas are completely known and extensively detailed in the corresponding source references. Because a significant recommendation of the current examination does not refer to the medium term development of a DIN standard of **all** ground noise sources at an airport not considered in the AzB, therefore, the textual formulation of the calculation requirement is initially waived.

The consideration of other ground noise sources at airports (ground noise sources in a broader sense) within the framework of a calculation requirement for noise immissions was not subject matter of this problem definition. To develop a calculation methodology that combines these ground noise sources with the engine test runs requires further research. Therefore, the following describes only the architecture of the calculation methodology in reference to the engine test runs.

7.4.2 Description of Sources

The location of engine test runs is to be modelled acoustically as point source. The source coordinates are three dimensional with geography x and y coordinates (because of the AzB compatibility as UTM coordinates ETRS 89) and as z coordinate for the height of the engine above ground.

The z coordinate can be specified in groups of similarly classified aircraft types. The classification of aircraft groups of the AzB can be used for this purpose and for the emission relevant initial data. This classification has been tried and tested. It has been continuously updated in the past and the author believes that there is nothing that would oppose the general application of this classification to engine test runs. The differences in engine test runs between aircraft with jet engines, turboprops, and piston engines do not seem so severe that different regulations would have to be applied to a calculation methodology. Of course, attention must be paid to the influence factors (sound power, directivity, and load curve) caused by the type of engine.

In the point source of the calculation model, the emission of all engines of the particular aircraft is assumed in a concentrated manner. The situation of errors caused by engines is neglected because they deviate from reality.

Other emission relevant initial data are: average number of test runs per aircraft group and per day (separated by 16 hours during the day and 8 hours during the night), the average duration of test runs, differentiated by the load levels idle, partial power low, partial power high, and maximum power as well as differentiated by the engine to be tested and the balancing engine as well as other engines (e.g. during 4-engine test runs).

Because of the concentration of the noise emission of all engines in one point source, the time proportions of individual engines run at individual load levels must be added. The time-weighted sound power of all load levels can be added energetically. Standard values should be defined for the time proportions of individual load levels. These values should be oriented on the longest known times. However, preference should be given to the project related times actually determined for the respective airport. The number of engine test runs to be considered for individual aircraft groups can only be determined project specific.

The sound power of individual load levels can be deduced from the acoustic emission data of the AzB. As an alternative, the mathematical description of the emission approach of the proposal of the Land of Lower Saxony [9] may be applied.

Applying the directivity of individual aircraft groups of the AzB is not supported. In this context, the general approach of the AzB using coefficients of a series development gives rise to criticism (at least the number of coefficients is subject for discussion).

On the contrary, this approach has clear advantages when compared to a metrologically determined directivity with few supporting points (sometimes only 6 measuring points in the half circle). The few examples described in Section 6.6 have shown however that the datasets for landing and take-off specified in the AzB show significant deviations from the directional effect during idle and maximum power on the ground. In this context, further effort is necessary to create a needed database.

7.4.3 Propagation Model

For a short term implementation of a calculation methodology for engine test runs (see Section 7.3), the propagation model of the AzB is preferable because it has the best compatibility with the AzB. However, the AzB has been primarily developed for noise sources, which are more or less in the air at larger heights. A propagation model that is handles surfaces sources, shielding, obstacles, and reflexions along the propagation path relatively easy is preferred in the medium term implementation of a calculation methodology for engine test runs in a work of rules which also considers other ground noise sources. Under these constraints, the advantages of ISO 9613-2 outweigh the disadvantages (uncertainties in large distances). Reflexions are for the case of noise immissions of engine test runs rather insignificant because of the relative large distances between sources, immission types, and reflecting obstacles. However, they can be considered in the propagation model of ISO 9613-2 without any problems.

Weather conditions are also contributing to propagation. Weather conditions have primarily a significant impact if the distances are large and cannot be considered within the framework of the AzB or only globally by the ISO 9613-2 (c_{met}). Considering weather conditions would currently mean applying a non-standardized propagation model in Germany. In light of the long-term improvement of the method inventory and particularly the improvement in the preciseness of the results with regard to larger distances, it seems to make sense to examine the use of alternative propagation models such as the Nord2000.

7.4.4 Shielding and Noise Abatement Systems

The author believes that the neglect of the shielding effect of obstacles in some ground noise reports does not take into account the issue of engine test runs. Already very high structures at airports can have a shielding effect. The shielding effect of noise deflection walls or of noise abatement cabins open to the top may not be high at larger distances; however, it is not so low to justify neglect.

Therefore, it is suggested that the calculation methodology for engine test runs considers the shielding of obstacles in accordance with ISO 9613-2 or VDI 2720. For the following reasons, the methodological breach with the AzB is seen as reasonable:

- Compared to the aircraft noise and the noises emitted during engine test runs, APU and taxiing noises play a significant role only in special cases.
- Taxiing noises cannot be reduced effectively through shielding measures because of the freedom from obstacles, which must be considered.

Noise abatement hangars, i.e. enclosures of aircraft that are largely closed can currently only considered on a case-by-case basis. A generalized method to model such hangar can currently not be developed without a significant research effort. If this work cannot be accomplished within the framework of the new calculation methodology, then what remains is only the review of a possible neglect or the estimation within the framework of individual assessments as described in Section 7.3.

7.4.5 Calculated Parameters

As acoustic parameters, the energy equivalent continuous noise level and maximum level distribution (NAT criteria) are calculated.

Allowances for impulsiveness (L_{AFTm}), for tonality and information incorporation as well as special quiet times are not assigned. It is estimated that noises from engine test runs can be tonal to a certain extent; however, for reasons of compatibility with the methodology in AzB, such allowance is waived. A separate consideration of impulsiveness or information incorporation due to noise characteristics is irrelevant. The maximum levels caused during engine test runs are determined by the maximum level distribution.

The hours of evaluation are during the day from 06:00 a.m. to 10:00 p.m. and during the night from 10:00 p.m. to 06:00 a.m. Sundays and holidays are not considered separately in accordance with the Aircraft Noise Act. This allows comparing it to the calculation methods applicable to other means of transport.

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Annex

Proposal of the Land Lower Saxony for the 847th Session of the Federal Council to amend the AzB

262/TOP 21/NI 3

Petition

of the Land Lower Saxony

with regard to the

<u>1st FlugLSV/Amendment Engine Test Runs</u>

BR-Drs. 566/08

<u>1. FlugLSV:</u>

- At the end of § 2, paragraph 1 of 1 FlugLSV, the words "and engine test runs" are inserted after the word "aircraft".

Annex 1 (AzD):

- p. 47: Insert after Section 5.4.2.3

5.4.2.4 Engine test runs

5.4.2.4.1 Coordinates of engine test run positions (UTM32/33 (ETRS89))

5.4.2.4.2 Operating data

Aircraft group	Number of engine test runs Day (06:00 a.m. to 10:00 p.m.)	Number of engine test runs Night (10:00 p.m. to 06:00 a.m.)	Duration of load level [s]			
			Level 1:	Level 2:	Level 3:	Level 4:
P 1.4						
P 2.1						
P 2.2						
S 1.0						
S 1.1						
S 1.2						
S 1.3						
S 2						
S 3.1						
S 3.2						
S 4						
S 5.1						
S 5.2						
S 5.3						
S 6.1						
S 6.2						

Aircraft group	Number of engine test runs Day (06:00 a.m. to 10:00 p.m.)	Number of engine test runs Night (10:00 p.m. to 06:00 a.m.)	Duration of load level [s]			
			Level 1:	Level 2:	Level 3:	Level 4:
S 6.3						
S 7						
S 8						
P-MIL 2						
S-MIL 1						
S-MIL 2						
S-MIL 3						
S-MIL 4						
S-MIL 5						
S-MIL 6						
Total						

p. 17 Insert after the explanation "to Section 5.4.2.3"

"To No. 5.4.2.4:

For modelling engine test runs, the coordinates of positions of aircrafts undergoing engine test runs must be entered into data collection system in reference to raster-north (UTM illustration according to the aircraft's position in zone 32 or 33 (mean meridian 9° or 15°), ellipsoid GRS80, date ETRS89).

Moreover, the scope of use of the engine test runs must be specified for the individual aircraft groups during the assessment time (180 days). Day and night must be differentiated.

The AzB uses the following standard values for load level durations under Section 7.4.1:

- Load level 1 (full power) 120 s
- Load level 2 (high partial power) 600 s
- Load level 3 (low partial power) 600 s
- Load level 4 (idle) 2280 s

Information on the scope of use of engine test runs are only required in the data documentation system if an airport has deviating information with regard to the forecast period.

Annex 2 (AzB)

- p. 40: Insert after Section 7.3

7.4 Calculation of the contributions to engine test runs

Engine test runs are carried out on the airport's premises to check the engines or to service the engines of aircraft. They are carried out in several phases (load levels), which differ in terms of duration and engine power. These parameters are described by the following values in the AzB for a load level marked in the index with m:

$t_{TW,m}$ Duration of the load level m [s],

$O_{TW,n,m}$ Octave sound pressure level of load level m [dB],

$Z_{TW,m}$ Level allowance of load level m [dB].

The AzB differentiates between the following four load levels:

- Load level 1 (full power)
- Load level 2 (high partial power)
- Load level 3 (low partial power)
- Load level 4 (idle)

The load level durations $t_{TW,m}$ are specified in number 5.4.2.4.2 DES. If the duration for one load level is set to zero, then this load level is not carried out during the test run.

Annotation 1:

If no durations are specified for load levels in the DES, then the following values apply: $t_{TW,1}$ = 120 s, $t_{TW,2}$ = 600 s, $t_{TW,3}$ = 600 s and $t_{TW,4}$ = 2280 s.

Octave level $O_{TW,n}$ for load levels 1 and 2 is based on octave level O_n of the departure data sets (dataset No. (1) of data sheets according to Section 5.3). For load levels 3 and 4, the octave level of the arrival datasets must be used.

For the level allowance $Z_{TW,m}$ for the load levels consult Table 10.

Aircraft group	Level allowance for load level [dB]			
	Level 1:	Level 2:	Level 3:	Level 4:
P 1.4	0	-5	0	-7
P 2.1	0	-2	0	-7
P 2.2	0	-1	0	-7
S 1.0	3	0	0	-7
S 1.1	3	0	0	-7
S 1.2	3	0	0	-7
S 1.3	3	0	0	-7
S 2	3	0	0	-7
S 3.1	0	-3	0	-7
S 3.2	0	-3	0	-7
S 4	3	1.5	0	-7
S 5.1	0	-1	0	-7

Aircraft group	Level allowance for load level [dB]			
	Level 1:	Level 2:	Level 3:	Level 4:
S 5.2	0	-3	0	-7
S 5.3	0	-2	0	-7
S 6.1	0	-2.5	0	-7
S 6.2	0	-3	0	-7
S 6.3	0	-2	0	-7
S 7	0	-4.5	0	-7
S 8	0	-4.5	0	-7
P-MIL 2	0	-2	0	-7
S-MIL 1	3	1.5	0	-7
S-MIL 2	0	-6	0	-7
S-MIL 3	4.5	-1.5	0	-7
S-MIL 4	0	-6	0	-7
S-MIL 5	0	-2	0	-7
S-MIL 6	0	-6	0	-7

Table 10: Values of the level allowance $Z_{TW,m}$ for the four load levels during engine test runs

The AS-valued sound pressure level $L_{pAS,m}$ during engine test runs at a set load level m is determined by the octave level O_n of the respective aircraft class according to the following formula:

$$L_{p\mathrm{AS,m}} = 10\,\lg\left(\sum_{\mathrm{n}=1}^{8} 10^{0{,}1\cdot(L_{\mathrm{n,m}}+A_{\mathrm{n}})}\right) \quad \mathrm{dB} \qquad (48)$$

with

$$L_{n,m} = L_{W,n,m} + D_{I,n} + D_{s} + D_{L,n} + D_{Z,n} + D_{\Omega} \text{ dB} \qquad (49)$$

and

$$L_{W.n,m} = O_{TW,n,m} + Z_{TW,m} - D_{s}(s_{On}) - D_{L,n}(s_{On}) - D_{\Omega,0} \text{ dB} \qquad (50)$$

whereby:

n on-going octave band number

A_n frequency correction for the A-evaluation for the n octave band

$L_{W,n}$ sound power level for the auxiliary power unit for the n octave band

$O_{TW,n,m}$ octave sound pressure level for load level m and reference distance s_{On}

$Z_{TW,m}$ additional level for load level m

$D\Omega_{,0}$ solid angle for reference conditions ($D\Omega_{,0}$ = 3 dB)

D_s distance

$D_{L,n}$ air absorption for the n octave band

$D_{L,n}$ ground attenuation for the n octave band

The equivalent continuous sound level $L_{pAeq,TW,Tr}$, generated by engine test runs of aircraft group k at the test run position l at one immission site in relationship to the evaluation time T_r, is the result of a triple summation process:

1. Summation over all N_{TW} engine test run positions
2. Summation over all N_{LK} aircraft group
3. Summation over all N_{LS} load levels

$$L_{pAeq,TW,Tr} = 10 \lg\left[g_r \cdot \frac{T_0}{T_E} \sum_{l=1}^{N_{TW}} \sum_{k=1}^{N_{Lk}} \sum_{m=1}^{N_{LS}} n_{Tr,TW,k,l} 10^{L_{pAS,TW,k,l,m}(s_l)/10} \cdot t_{TW,k,m} \right] \qquad (51)$$

with

$L_{pAS,TW,k,l,m}(s_l)$ AS-evaluated sound pressure level, which is generated at the immission site by the load level m of an engine test run of the aircraft group k on one engine test run position l

T_E	survey time ($T_E = 1.5552 \cdot 10^7$ s, i.e. 180 days)
g_r	weight factor to convert the collection time to the evaluation time (1.5 for day and 3 for night)
$t_{TW,k,m}$	duration of load level m of an engine test run of aircraft group k
$n_{Tr,TW,k,l}$	number of engine test runs of aircraft group k at the engine test run position l during the evaluation time T_r within the collection time T_E
s_l	distance of the engine test run position l from the immission site
l = 1, ..., N_{TW}	on-going index of engine test run positions
k = 1, ..., N_{Lk}	on-going index of the aircraft group k = 1, ..., N_{LS} on-going index of load levels

The generated AS-evaluated maximum sound pressure level $L_{pAS,max,TW,k,l}$ generated by an engine test run of aircraft group k at the test run position I at one immission site is determined by the AS-evaluated sound pressure level generated during the maximum power level.

$$L_{pAS,max,TW,k,l} = L_{pAS,TW,k,l,m=1} \text{ dB} \qquad (52)$$

with

$L_{pAS,max,TW,k,l}$	maximum AS-evaluated sound pressure level generated at the immission site by an engine test run of aircraft group k at the test run position l
$L_{pAS,TW,k,l,m}$	AS-evaluated sound pressure level generated at the immission site by an engine test run of aircraft group k at load level 1 at the test run position l

<u>Annotation 2:</u>

The attenuation of shielding will be calculated according to DIN ISO 9613-2:1999, Section 7.4. In the calculation of the shielding effect by obstacles during engine test runs carried out outdoors (e.g. barriers); attention must be paid that the diffraction of the upper edge of an obstacle must be used instead of the value used in DIN ISO 9613-2:1999 ground attenuation in A_{gr} with the analogous size $D_{Z,n}$ according to Section 7.2.5.

p. 40: Chapter 7.4 (previous) is to be changed as follows.

7.5 Calculation of the Equivalent Continuous Level

The contributions of the airborne traffic to the equivalent continuous sound level are the result of a triple summation process:

1. Summation over all N_{Ts} segments of the flight path
2. Summation over all N_{Fw} flight paths
3. Summation over all N_{LK} aircraft classes

The equivalent continuous sound level $L^*_{pAeq,Tr}$ related to the evaluation time T_r at one immission site is the result of the combination of this contribution with contributions of the APU operation and engine test runs:

$$L^*_{pAeq,Tr} = 10 \cdot \lg\left(g_r \cdot \frac{T_0}{T_E}\left[\sum_{k=1}^{N_{Lk}}\sum_{l=1}^{N_{Fw}}\sum_{m=1}^{N_{Ts}} n_{Tr,k,l} \cdot 10^{\frac{L_{pAE,k,l,m}(s_{k,l,m})}{10}}\right] + 10^{\frac{L_{pAeq,APU,Tr}}{10}} + 10^{\frac{L_{pAeq,TW,Tr}}{10}}\right) \text{ dB} \quad (53)$$

with

$L^*_{pAeq,Tr}$	equivalent continuous sound level at the time of evaluation T_r
T_E	survey time ($T_E = 1.5552 \cdot 10^7$ s, i.e. 180 days)
T_0	reference time (T_0 = 1 s)
g_r	weight factor to convert the collection time to the evaluation time (1.5 for day and 3 for night)
$L_{pAE,k,l,m}$	the noise exposition level generated at the immission site by a movement of the aircraft group k on a segment m of the flight path l
$L_{pAeq,APU,Tr}$	the equivalent continuous sound level generated by the APU operation during the evaluation time T_r
$L_{pAeq,TW,Tr}$	the equivalent continuous sound level generated by the engine test runs during the evaluation time T_r

$n_{\mathrm{Tr,k,l}}$	number of aircraft class k movements on flight path l during the evaluation time T_{r} within the collection time T_{E}
$s_{\mathrm{k,l,m}}$	distance of the aircraft class k on the segment m of the flight path l from the immission site [m]
k = 1, ..., N_{Lk}	on-going index of aircraft classes
l = 1, ..., N_{Fw}	on-going index of flight paths
m = 1, ..., N_{Ts}	on-going index of segments of a flight path

- p. 41: Equations (49) to (53) in Chapter 7.5.1 (previous) are transferred therefore to (54) to (58).

- p. 42: Chapter 7.5.2 (previous) is to be changed as follows.

7.6.2 Calculation of Level Frequency Criteria

The number NAT($L_{p,\mathrm{Schw}}$) of times the threshold value $L_{p,\mathrm{Schw}}$ of the AS-evaluated maximum sound pressure level $L_{p\mathrm{AS,max}}$ at any given immission site is exceeded, is the result of the summation of air traffic movements over all aircraft classes and flight paths as well as the summation of engine test runs over all aircraft groups and engine test run locations as:

$$\mathrm{NAT}(L_{p,\mathrm{Schw}}) = \sum_{\mathrm{l=1}}^{N_{\mathrm{Fw}}} \sum_{\mathrm{k=1}}^{N_{\mathrm{Lk}}} n_{\mathrm{Tr,k,l}} \cdot \mathrm{F}\left(L_{p\mathrm{AS,max,k,l}}\right) + \sum_{\mathrm{l=1}}^{N_{\mathrm{TW}}} \sum_{k=1}^{N_{\mathrm{Lg}}} n_{\mathrm{Tr,TW,k,l}} \cdot \mathrm{F}\left(L_{p\mathrm{AS,max,TW,k,l}}\right) \tag{59}$$

with

$$\mathrm{F}\left(L_{p,\max}\right) = \begin{cases} 1 & \text{für} \quad L_{p,\max} > L_{p,\mathrm{Schw}} \\ 0 & \text{für} \quad L_{p,\max} \le L_{p,\mathrm{Schw}} \end{cases} \tag{60}$$

whereby:

$L_{p\mathrm{AS,max,k,l}}$	largest AS-evaluated maximum sound pressure level according to Gl. (58) generated at the immission site by a movement of aircraft class k on flight path l

$L_{pAS,TW,max,k,l}$	maximum sound pressure level according to Gl. (52) generated at the immission site by an engine test run of the aircraft group k at the location l
$L_{p,Schw}$	threshold value of the AS-evaluated maximum sound pressure level as required by the level frequency criterion
$n_{Tr,k,l}$	number of aircraft class k movements on flight path l during the evaluation time T_r within the collection time T_E
$n_{Tr,TW,k,l}$	number of engine test runs of aircraft class k at the engine test run position l during the evaluation time T_r within the surveyed time T_E
$F(L_{p,max})$	the weighting function required to describe the level frequency criterion
$k = 1, ..., N_{Lk}$	on-going index of aircraft classes
$k = 1, ..., N_{Lg}$	on-going index of aircraft groups
$l = 1, ..., N_{Fw}$	on-going index of flight paths
$l = 1, ..., N_{TW}$	on-going index of locations of engine test runs

This approach implies fly-bies of an aircraft class at a distance *s* do always generate the same maximum level value $L_{pAS,max}$ at the immission site. In praxis, it can be seen that level distributions are nearly equal to a normal distribution for a fixed combination of aircraft type and flight path:

$$\mathrm{w}(L_{pAS,max}, \overline{L}_{pAS,max}, Q_\sigma) = \frac{1}{\sqrt{2\pi} \cdot Q_\sigma} \cdot \exp\left[-\frac{1}{2}\left(\frac{L_{pAS,max} - \overline{L}_{pAS,max}}{Q_\sigma}\right)^2\right] \quad (61)$$

with

$L_{pAS,max}$	AS-evaluated maximum sound pressure level
$\overline{L}_{pAS,max}$	mean value of the AS-evaluated maximum sound pressure level
$Q\sigma$	standard deviation

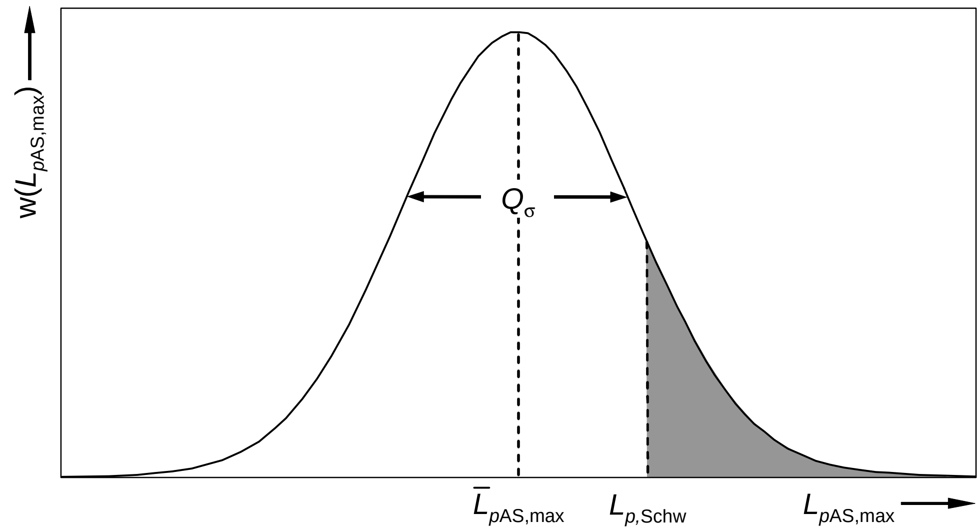

Illustration 1: Normal distribution of AS-evaluated maximum sound pressure levels with the mean value $\bar{L}_{pAS,max}$ and the standard deviation $Q\sigma$. $L_{p,\mathrm{Schw}}$ is the threshold value based on the frequency maximum level criterion.

To consider this fact, in GI (59) level function F is replaced and after Gl. (60) through a normal distribution with the aircraft class typical standard deviation $Q\sigma_{,k}$ and integrated over the part of distribution, which is above the specified threshold value in the frequency maximum level criterion.

$$\mathrm{NAT}(L_{p,\mathrm{Schw}}) = \sum_{l=1}^{N_{\mathrm{Fw}}} \sum_{k=1}^{N_{\mathrm{Lk}}} n_{\mathrm{Tr,k,l}} \cdot \int_{L_{p,\mathrm{Schw}}}^{\infty} \mathrm{w}\left(L_{p\mathrm{AS,max}}, L_{p\mathrm{AS,max},k,l}, Q_{\sigma,k}\right) \mathrm{d}L_{p\mathrm{AS,max}}$$
$$+ \sum_{l=1}^{N_{\mathrm{TW}}} \sum_{k=1}^{N_{\mathrm{Lg}}} n_{\mathrm{Tr,TW,k,l}} \cdot \int_{L_{p,\mathrm{Schw}}}^{\infty} \mathrm{w}\left(L_{p\mathrm{AS,max}}, L_{p\mathrm{AS,max,TW},k,l}, Q_{\sigma,k}\right) \mathrm{d}L_{p\mathrm{AS,max}} \quad (62)$$

Please note:

The octave level O_n is generally determined based on an energetic averaging of measured level values. The mean value resulting therefrom is under the assumption of normally distributed levels by $Q\sigma^2 \cdot \ln(10)/20 = 0.115 \cdot Q\sigma^2$ larger than the mean of the normal distribution. Therefore, to determine the frequency maximum level criterion the mean value of the distribution is overestimated.

Subsequent changes:

Annex 2 (AzB)

- p. 40 Chapter 7.4 becomes 7.5
- p. 41 Chapters 7.5 and 7.5.1 become Chapters 7.6 and 7.6.1 respectively
- p. 42 Chapter 7.5.2 becomes 7.6.2
- Table 10 in Chapter 8.5.5 becomes Table 11
- p. 54 The following abbreviations are to be included in Section 12 "Index of Abbreviations and Formulas"

$L_{p\mathrm{AS,max,TW,k,l}}$	[dB] maximum AS-evaluated sound pressure level generated at the immission site by an engine test run of aircraft group k at the test run position l
$L_{p\mathrm{AS,TW,k,l,m}}$	[dB] AS-evaluated sound pressure level generated at the immission site by an engine test run of aircraft group k at load level 1 at the test run position l
$L_{p\mathrm{AS,TW,k,l,m}}(s_\mathrm{l})$	[dB] AS-evaluated sound pressure level, which is generated at the immission site by the load level m of an engine test run of the aircraft group k on one engine test run position l
$n_{\mathrm{Tr,TW,k,l}}$	number of engine test runs of aircraft group k at the engine test run position l during the evaluation time T_r within the collection time T_E
$O_{\mathrm{TW,n,m}}$	[dB] octave sound pressure level of load level m
s_l	distance of the engine test run position l from the immission site
$t_{\mathrm{TW,m}}$	[s] duration of the load level m
$t_{\mathrm{TW,k,m}}$	[s] duration of load level m of an engine test run of aircraft group k
$Z_{\mathrm{TW,m}}$	[dB] level allowance of load level m
l = 1, ..., N_{TW}	on-going index of engine test run positions
k = 1, ..., N_{Lk}	on-going index of the aircraft group
k = 1, ..., N_{LS}	on-going index of load levels

Justification:

Aircraft noises consist of air traffic noises and ground noises. An air traffic noise is generally defined as a noise generated by an aircraft during its operation on the runway of the airport and/or in flight. The ground noise, however, is defined as a noise generated by an aircraft at the airport, which is not an air traffic noise, i.e. e.g. generated by taxiing of aircrafts on the airport premises, during the operation of auxiliary power units of aircrafts (APUs) or generated by engine test runs. This corresponds to the definitions in the international air traffic noise calculation method (see e.g. ECAC.Doc. 29, 3rd Ed.).

It is repeatedly alleged that the legislator would like to retain the meaning of the term "aircraft noise" as in the previous Aircraft Noise Act (Gesetz zum Schutz gegen Fluglärm) also in the amended version of this Act. Insofar, the differentiation between aircraft noise on the one hand and ground noise on the other as has been applied to the Aircraft Noise Act since 1971 does still apply.

If the allegation would apply, then taxiing and the operation of APUs as stated in the new AzD/AzB could not be considered because it would not be covered under the Aircraft Noise Act. However, it would be more expedient to integrate engine test runs into the air noise calculation because they generally contribute the most to the ground noises. This would result in a closed solution to calculate aircraft noises in the surrounding areas of airports.

The consideration of the engine test runs in the 1st FlugLSV does not limit the possibilities of this air traffic law to continue utilizing its instruments to levy conditions to restrict permissible acoustic pollutions in the neighbourhoods of airports.