Institute of Aircraft Design and Lightweight Structures (IFL)
Technical University Braunschweig
Hermann-Blenk-Str. 35, 38108 Braunschweig

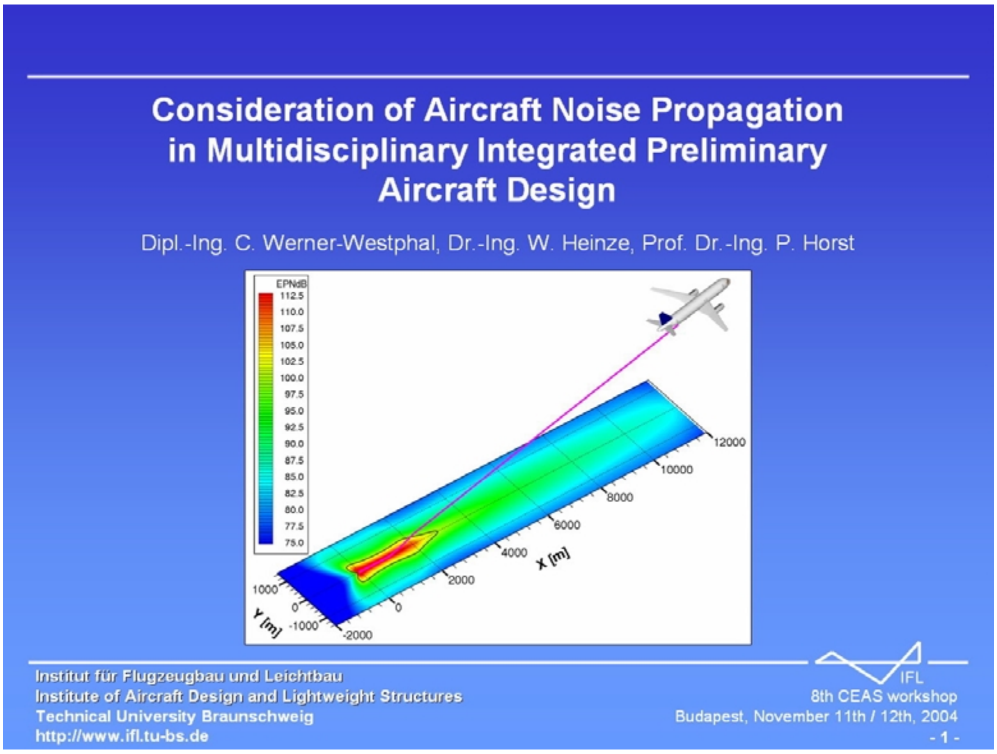
Aeroacoustics of new Aircraft & Engine Configurations
Workshop – Budapest, November 11 + 12, 2004

Consideration of Aircraft Noise Propagation in Multidisciplinary Integrated Preliminary Aircraft Design

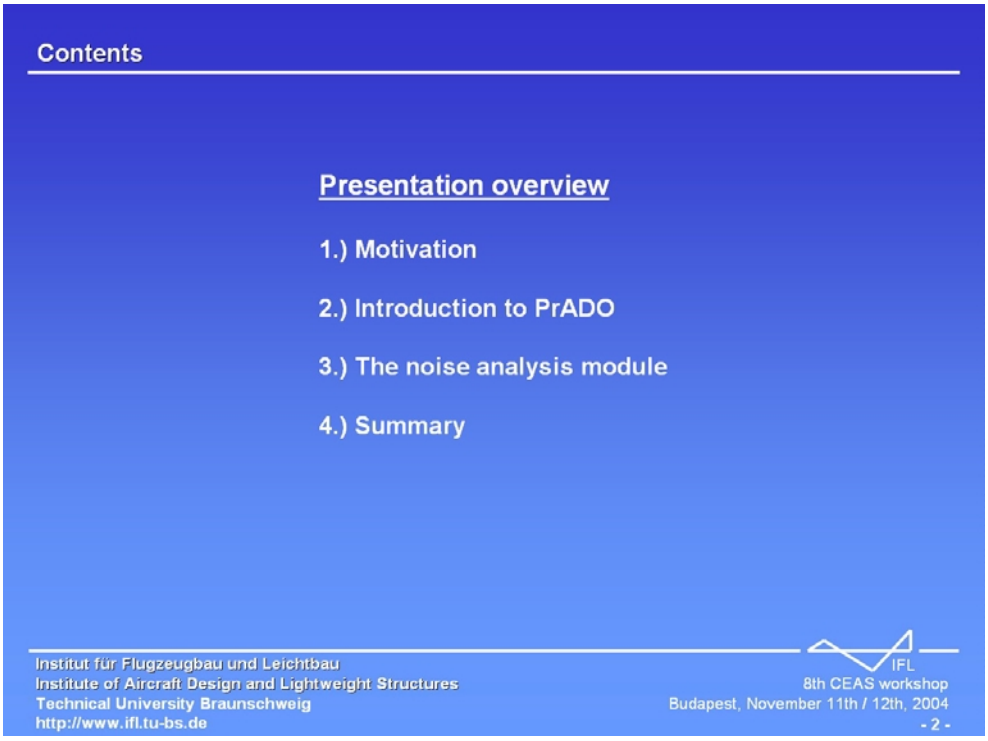
Presentation Contents

Dipl.-Ing. Christian Werner-Westphal, IFL
Dr.-Ing. Wolfgang Heinze, IFL
Prof. Dr.-Ing. Peter Horst, IFL

0.) Introduction

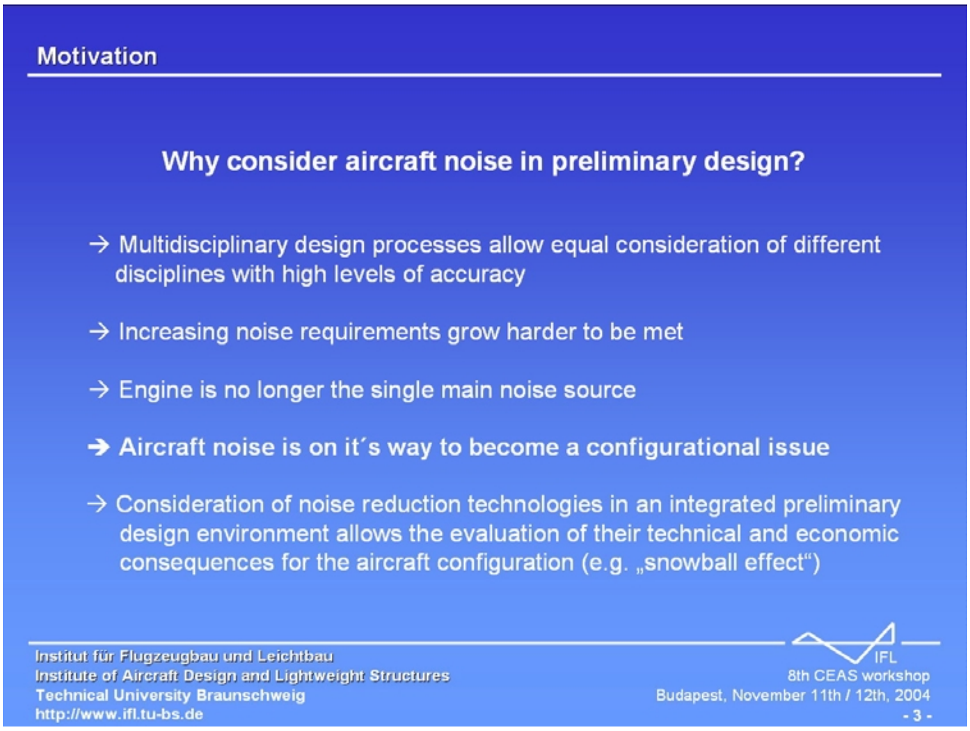


This paper presents the status of ongoing work performed at the Institute for Aircraft Design and Lightweight Structures (IFL) at the Technical University of Braunschweig, Germany. The subject is the consideration of aircraft noise propagation in multidisciplinary integrated preliminary aircraft design. The contents of this paper represent a commented version of the presentation given at the 8th CEAS workshop, Aeroacoustics of New Aircraft & Engine Configurations, held in Budapest, Hungary, on November 11th and 12th, 2004.



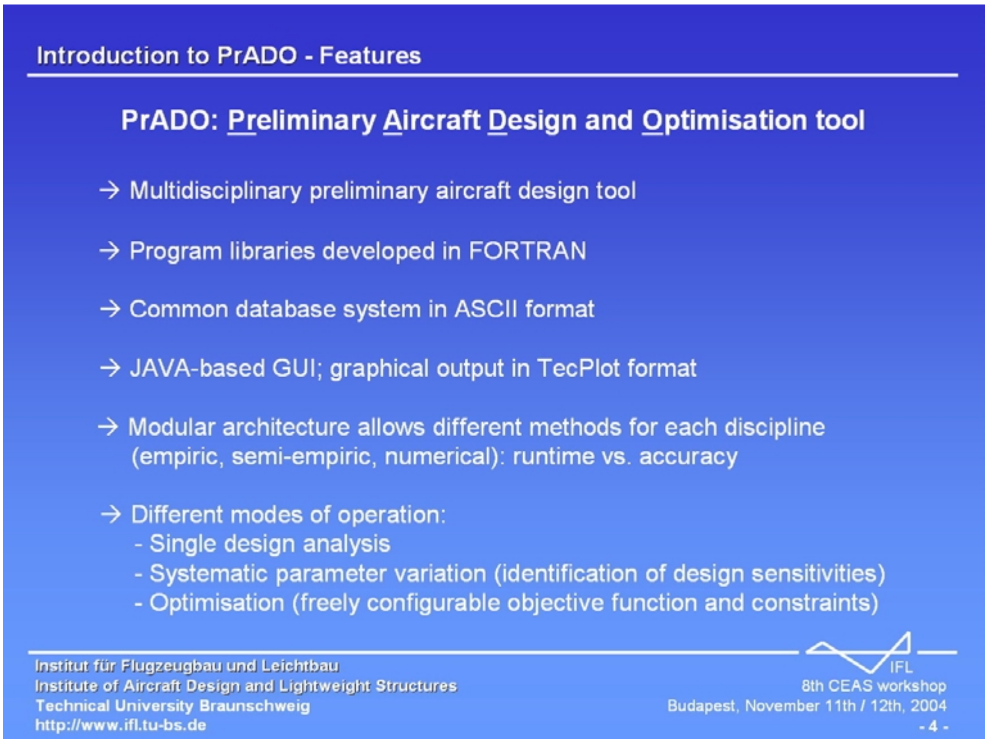
First, a few words will be said about the motivation for considering aircraft noise in the preliminary design stage.
Then, a short introduction will be given to PrADO, the multidisciplinary aircraft design tool developed and used at IFL.
Next the noise analysis module, which has been implemented in PrADO, will be presented.
Finally, the presentation will conclude with a short summary.

1.) Motivation



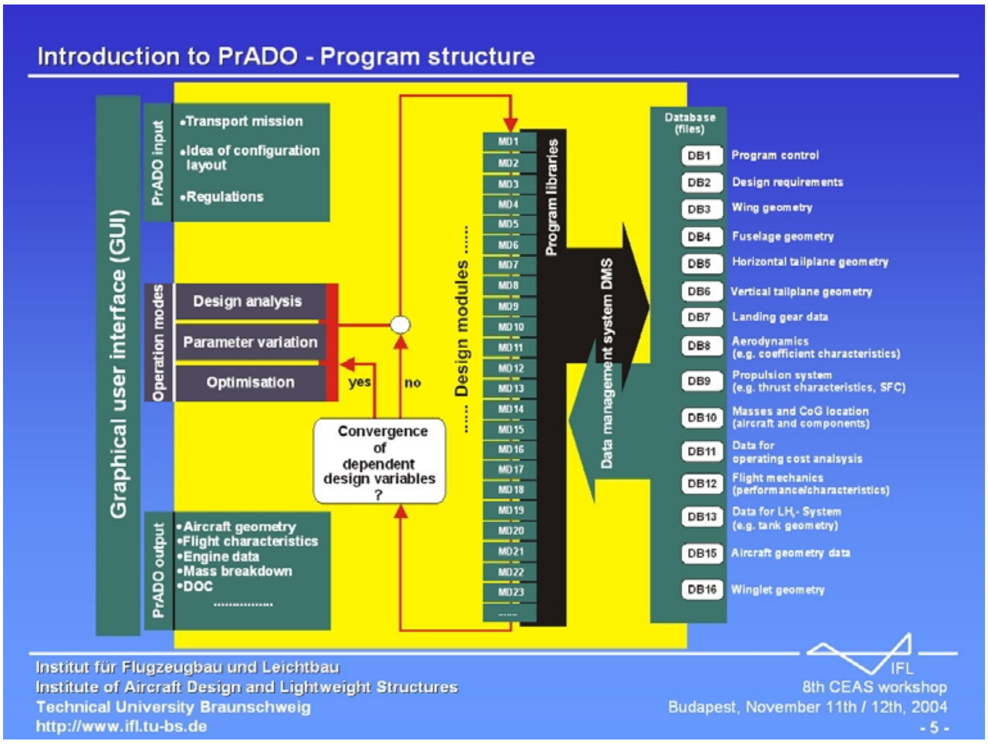
The first question to be faced is why it is worthwhile to consider noise in the preliminary design stage.
First of all: because it is possible. Modern computers provide the capacity to build true multidisciplinary, iterative processes. Different disciplines can be considered at a high level of detail and accuracy.
In the coming years, aviation noise regulations can be expected to become more strict and harder to fulfil. Noise will become more of an issue for aircraft designers.
So far noise has been regarded as being caused mainly by the engines. With great progress having been made in engine noise reduction, this will no longer be true in the future – current aircraft already produce as much airframe noise as engine noise during landing approach. The potential for further noise reduction by improving the engines seems limited.
Further noise reductions therefore require a closer look at airframe noise as well as the utilization of effects such as shielding, making noise a configurational issue.
Aircraft noise should therefore be considered as early in the design process as possible, namely when the configuration is defined.
The main advantage of integrating noise analysis into multidisciplinary integrated preliminary design is that one can automatically see the impact of noise reducing technologies on the overall aircraft, not only economically, but also technically.

2.) Introduction to PrADO

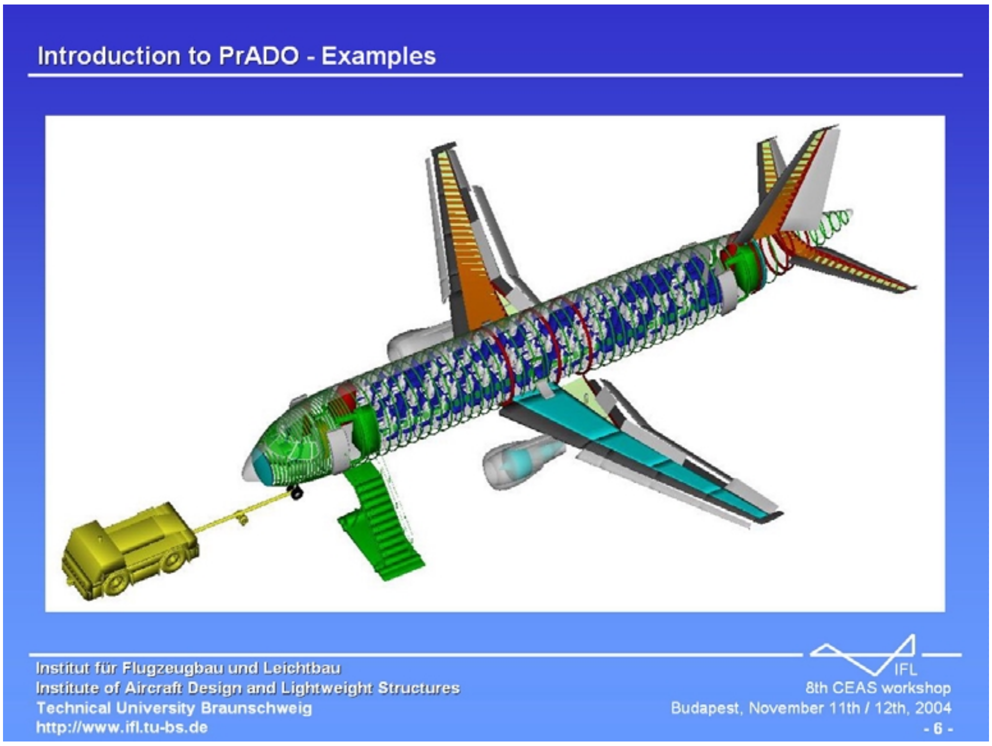


At IFL, preliminary aircraft design is done using the “Preliminary Aircraft Design and Optimisation tool (PrADO)”.
PrADO is a multidisciplinary tool.
The program code is written entirely in FORTRAN.
All aircraft data is kept in an ASCII-formatted file system.
A JAVA-based graphical user interface provides a comfortable front-end; graphical output is produced in TecPlot format.
PrADO’s modular architecture allows for easy interaction of the different disciplines. Several methods with different levels of accuracy can be implemented for each discipline and used as required. Example: Structural mass of the fuselage can be calculated with methods ranging from simple beam models to full FE-analysis.

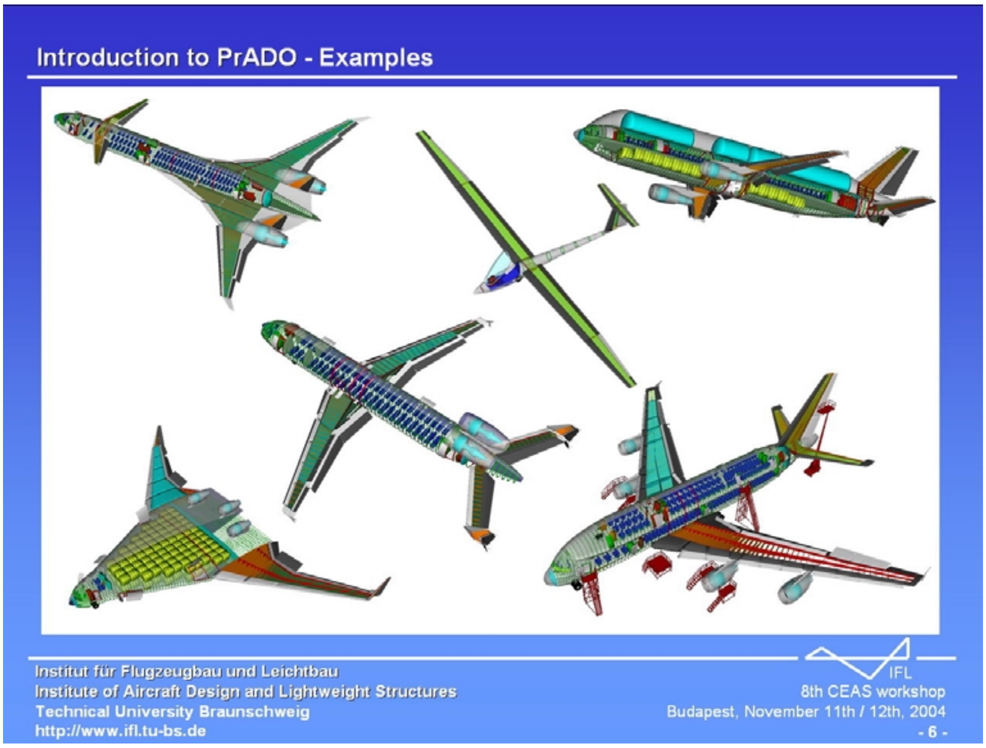
Different modes of operation allow for single design analysis, leading to one fully converged aircraft configuration; parameter variation in order to identify design sensitivities; and optimisation, for which the objective function, design variables and design constraints can be freely configured.



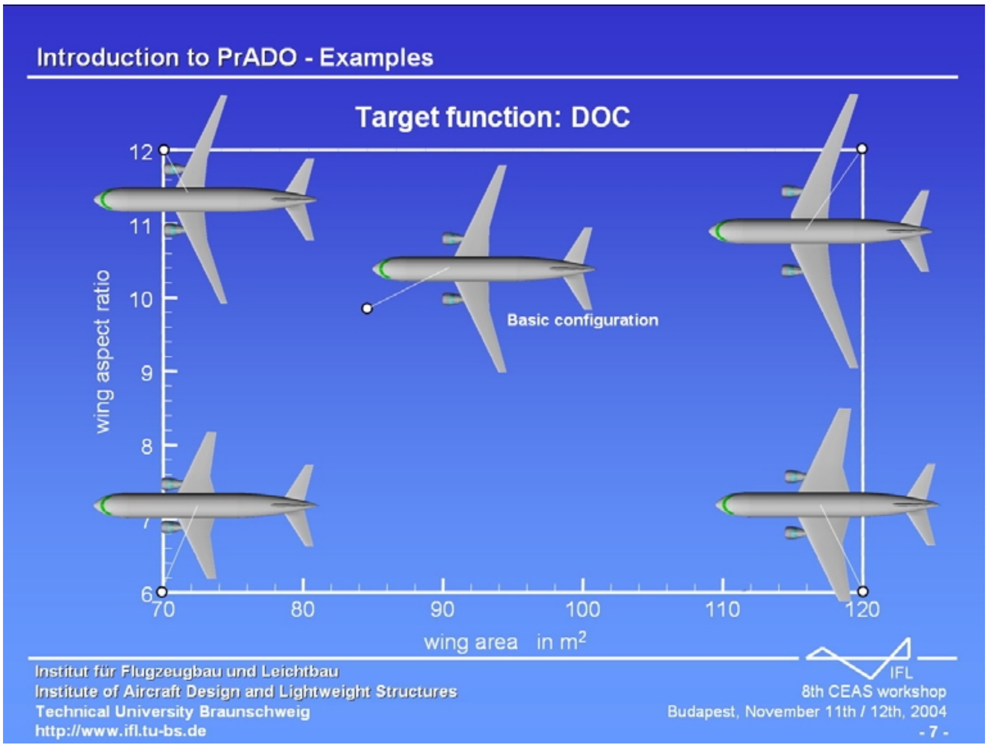
The program structure of PrADO is to be presented.
The user has to provide an input including the transport mission, a basic idea of configuration layout (i.e. conventional, T-tail, BWB, etc.) and regulations or other requirements that have to be met.
This input data are then converted into a set of thematically sorted database files.
The heart of the design process are the modular program libraries…
…which communicate with the database files through a common interface, the data management system.
A control program runs the design and analysis modules iteratively, according to the selected mode of operation.
As a result, PrADO produces all relevant data describing the aircraft configuration, including data for aircraft geometry, flight characteristics, engine, mass breakdown, DOC, and so on.



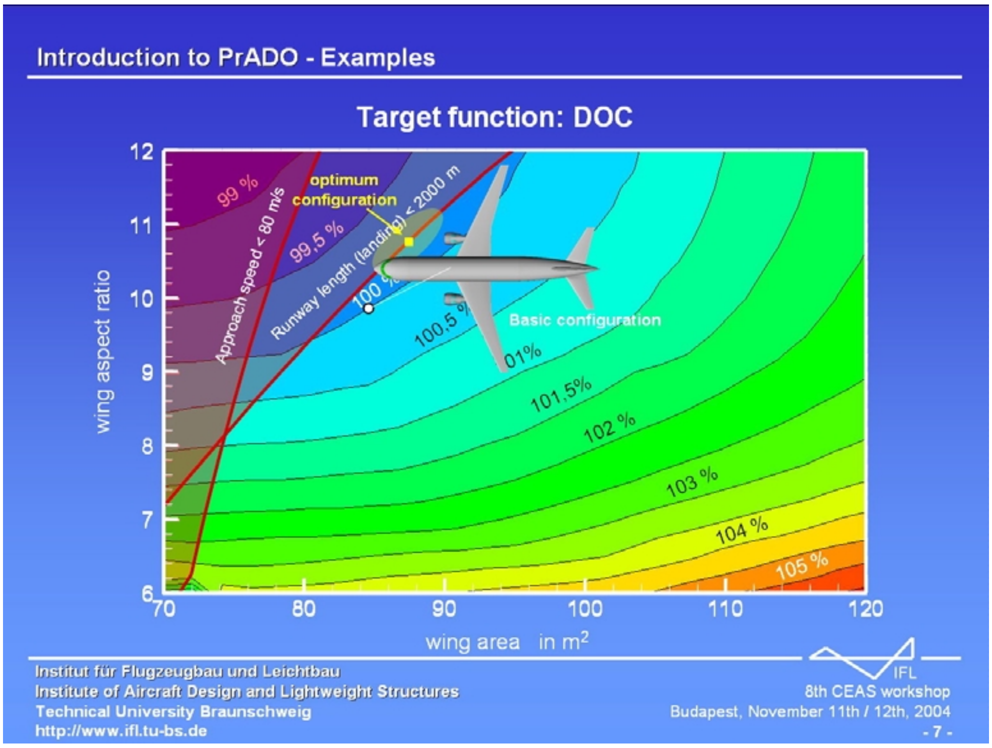
This is an example of the geometry model used in PrADO.



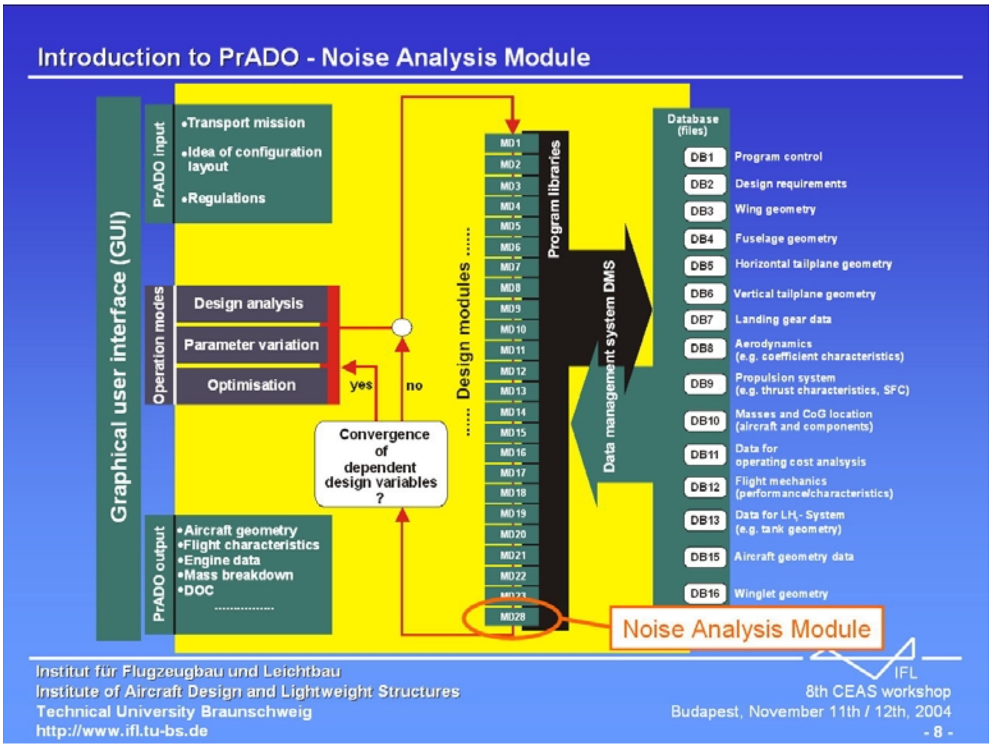
Different configurations modelled in PrADO.



As an example of results that can be produced, a variation of wing area and wing aspect ratio will be regarded.

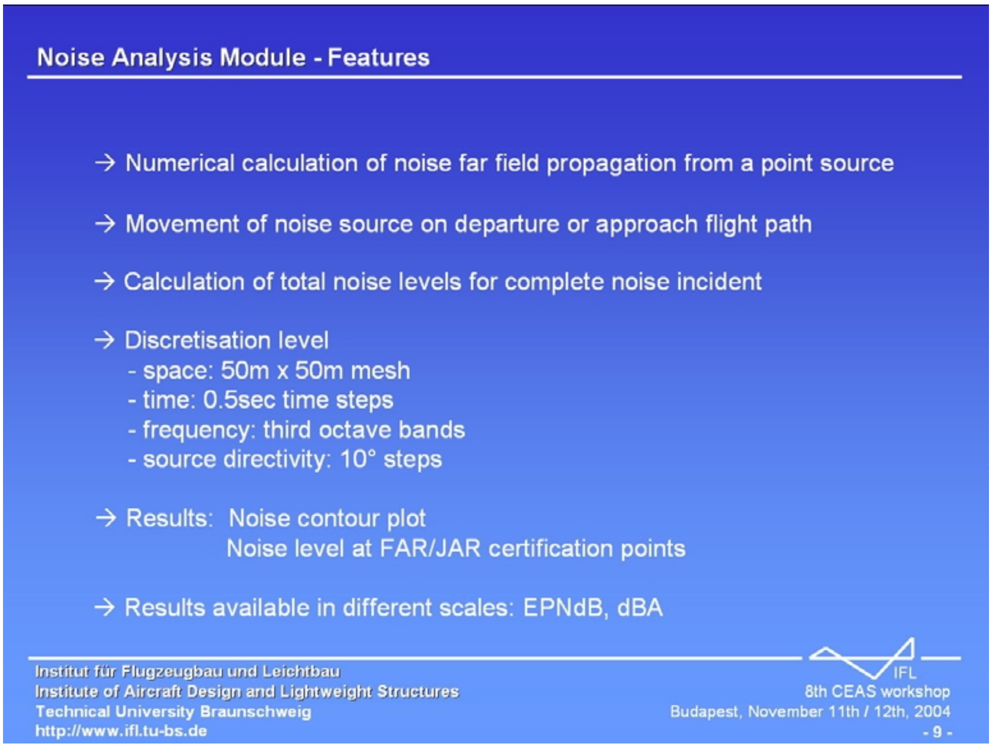


When exploring the design space, each configuration will have a certain DOC value, resulting in something comparable to a response surface.
If design constraints are added to this, it is possible to identify the optimum configuration.
When used in optimisation mode, PrADO uses a search algorithm to accelerate the search for the optimum configuration.



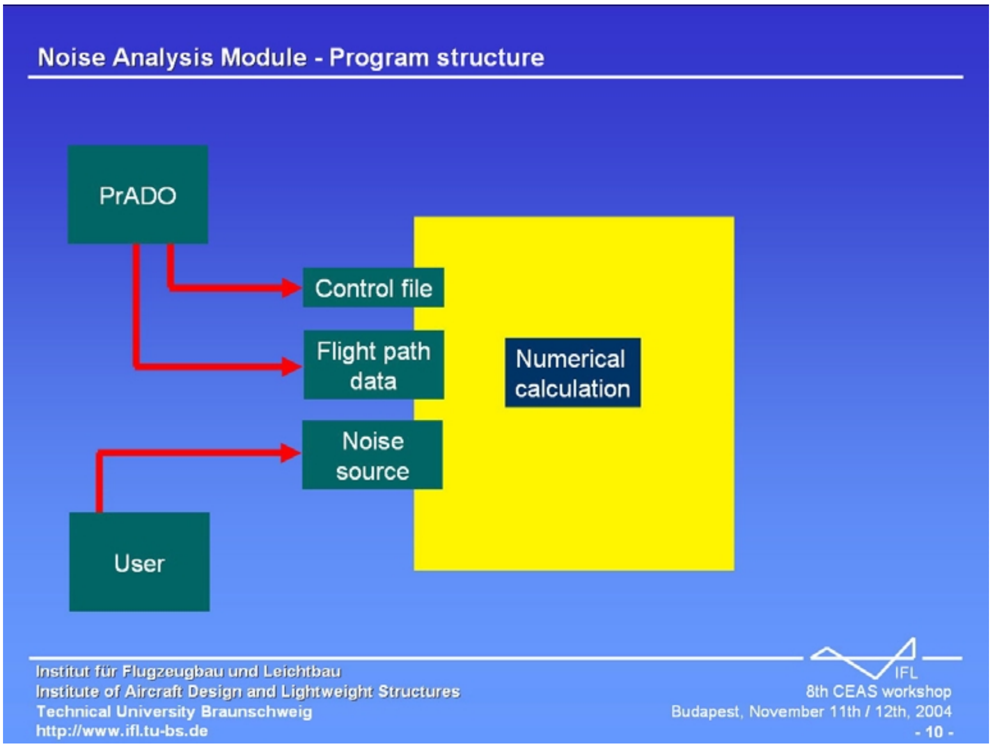
Given the modular program structure, introducing a new discipline into the process is done by simply inserting a new module as has been done for noise analysis.

3.) The Noise Analysis Module

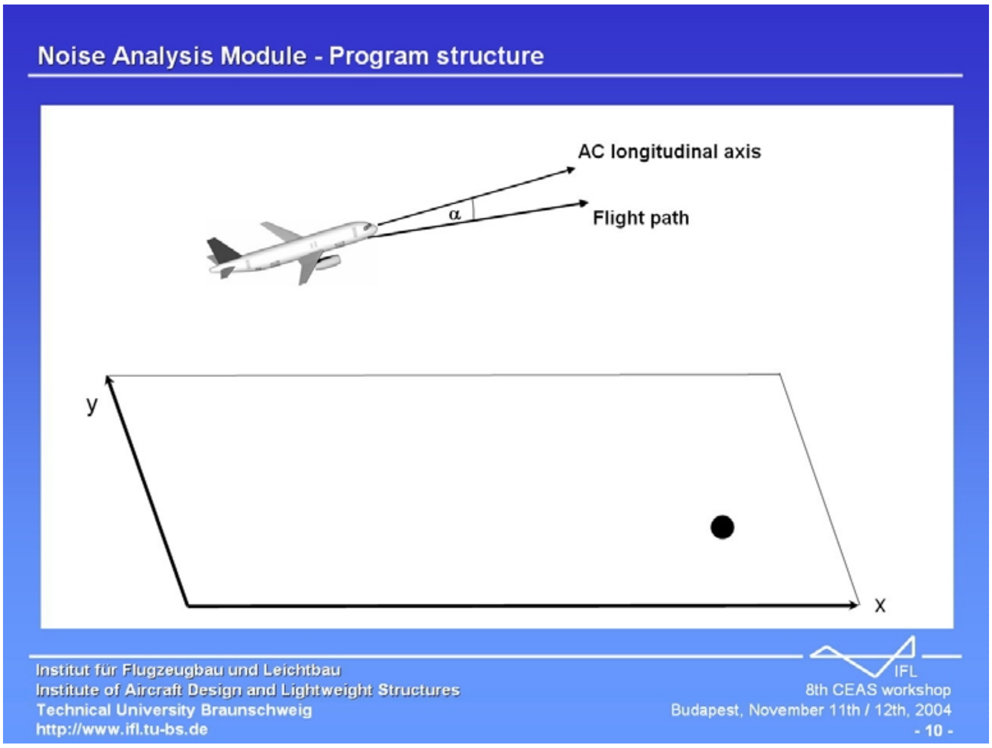


What the Noise Analysis Module does is numerically calculate noise propagation in the far field from a point source.
This point source is moved along a departure or approach flight path.

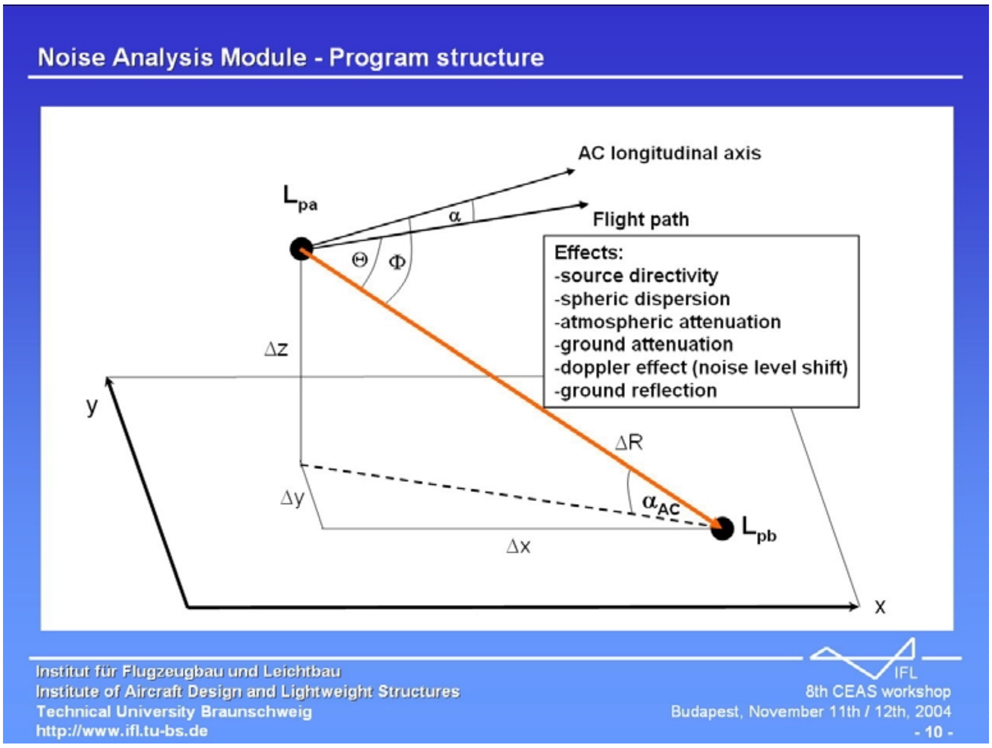
Total noise levels for the surrounding area are calculated for the complete noise incident (take off or landing).
This is done in a 50m x 50m mesh and in time steps of 0.5 seconds. Source noise levels are provided in third octave frequency bands, and with directivity steps of 10°.
The results of the calculations include contour plots of the surface around the runway as well as explicit noise levels for the certification points.
Results are available both in EPNdB and in dBA.



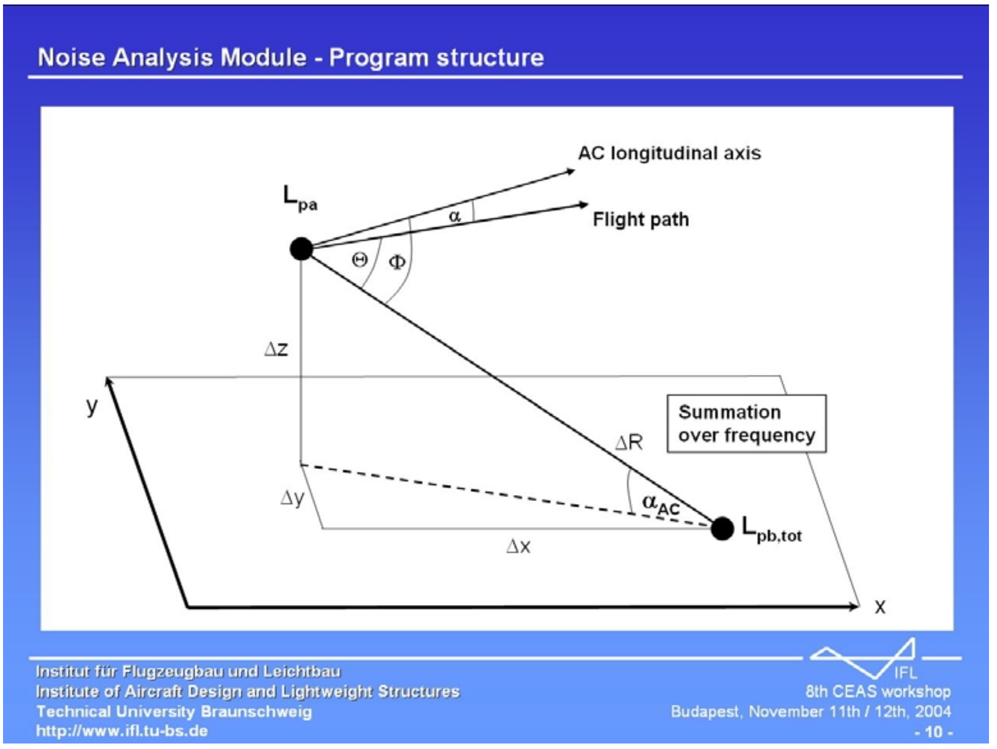
In its current version, the Noise Analysis Module receives input from both the user and PrADO.
PrADO provides a control file with runtime options (based on user input).
Based on parameters set in the program and on current aircraft data, PrADO calculates flight paths for departure and approach.
Currently, the user is required to provide the noise source.
The Noise Analysis Module then performs the numeric calculations.



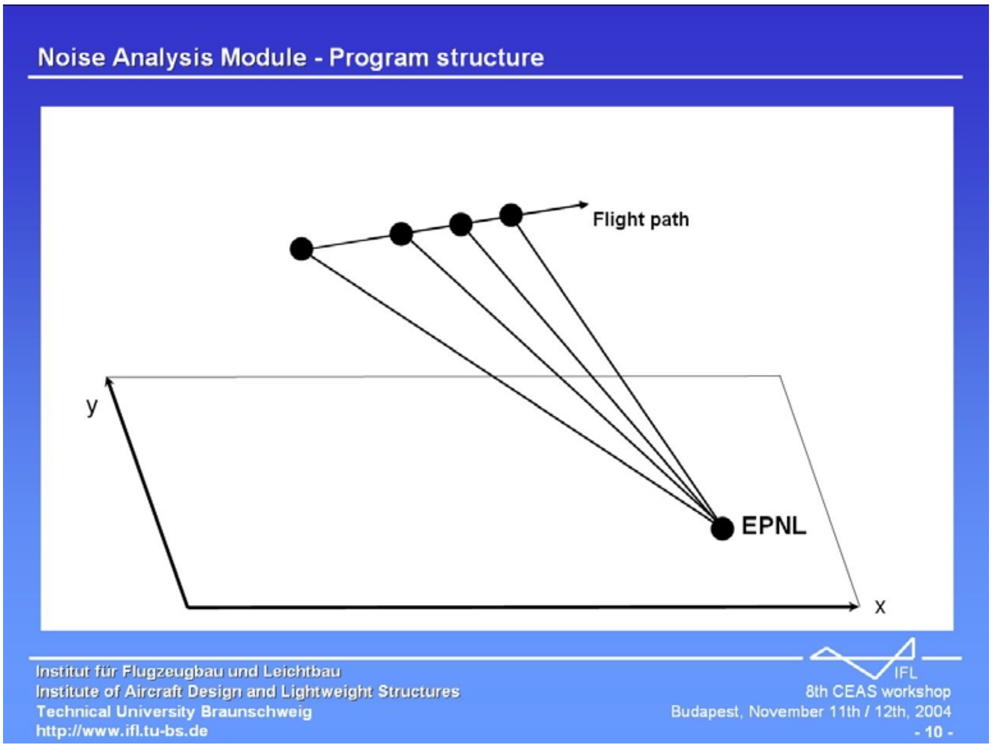
The starting point is the aircraft at a given position and a given orientation and flight path, as well as an observer point.



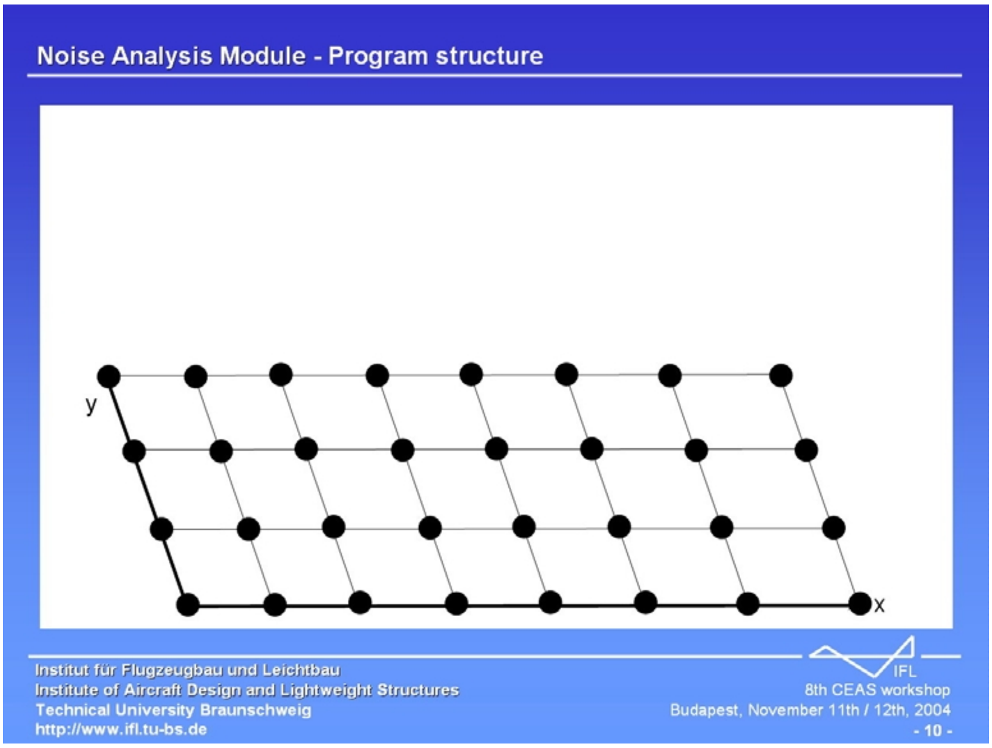
The aircraft is reduced to a point source with a given sound pressure level Lpa. With the relative positions of aircraft and observer, emission and immision angles can be determined. With these angles, and taking into account the effects of source directivity, spheric dispersion, atmospheric attenuation, ground attenuation, noise level shift and ground reflection, the sound pressure level at the observer point (Lpb) is calculated.



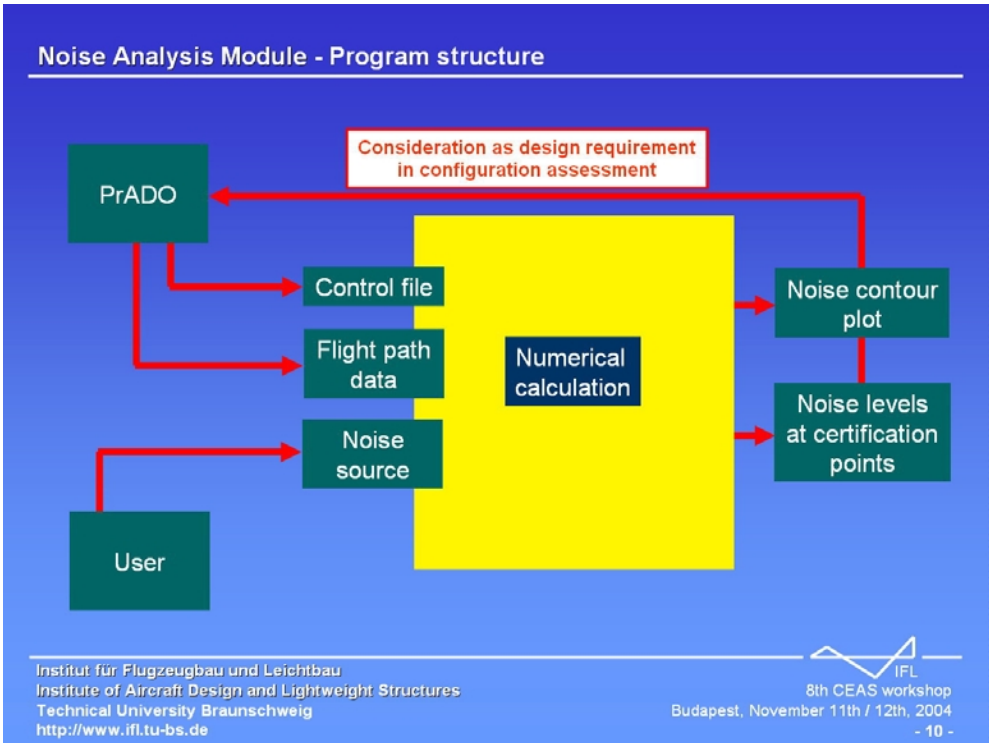
The total sound pressure level at the observer point (Lpb,tot) is obtained by summation over the frequency bands.



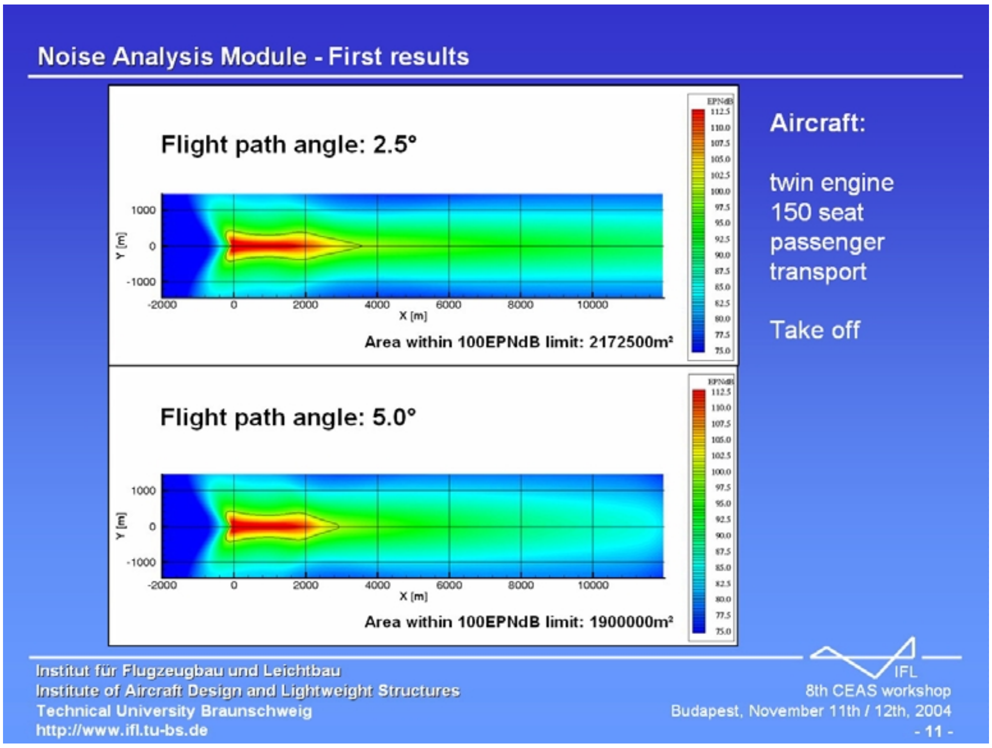
By repeating this calculation for different aircraft positions throughout time, the effective perceived noise level (EPNL) can be determined.



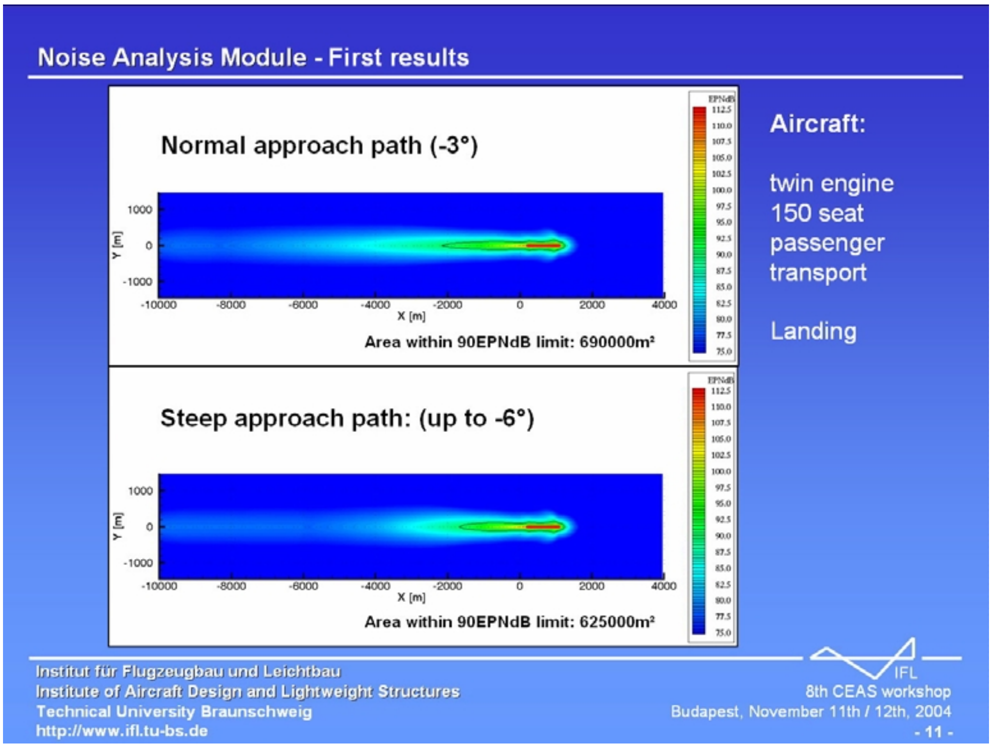
This calculation is performed for the whole surface mesh.



The results of these calculations are available as noise contour plots and as explicit noise levels for all certification points.
The results are fed back into the design process where they serve as criteria in the evaluation of the configuration. Noise criteria can be defined as constraints or even as objective functions.

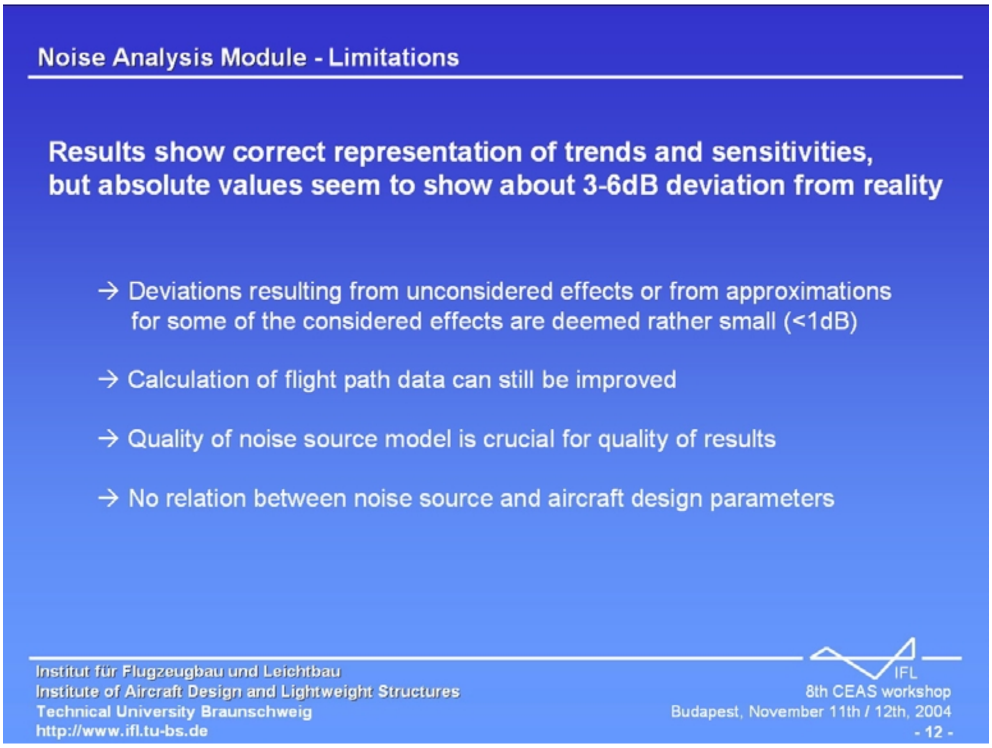


An example for take off is shown. Between both plots, the flight path angle has been varied from 2.5° to 5°.
First of all, the shape of the noise contour corresponds well to what can be found in the literature. As is to be expected, the steeper departure flight path leads to lower noise levels only in the area where the aircraft is already airborne, thus moving the tip of the 100EPNdB area closer to the runway.



For landing, overall noise levels are (of course) far lower than for take off. Basic trends are the same: a steeper approach angle helps to reduce the area affected by high noise levels.

The plots show results for a normal approach with 3° glide slope, on the one hand, and a steep approach with up to 6° glide slope in parts of the flight path, on the other.



All in all, it is to be noticed that few calculations have been made so far. Trends and sensitivities seem to be represented correctly. However, the computed absolute values tend to be 3-5 dB too high for take off and around 6 dB too low for landing. While this is a relatively small deviation considering the little amount of data the results are based on, it is still a considerable difference.

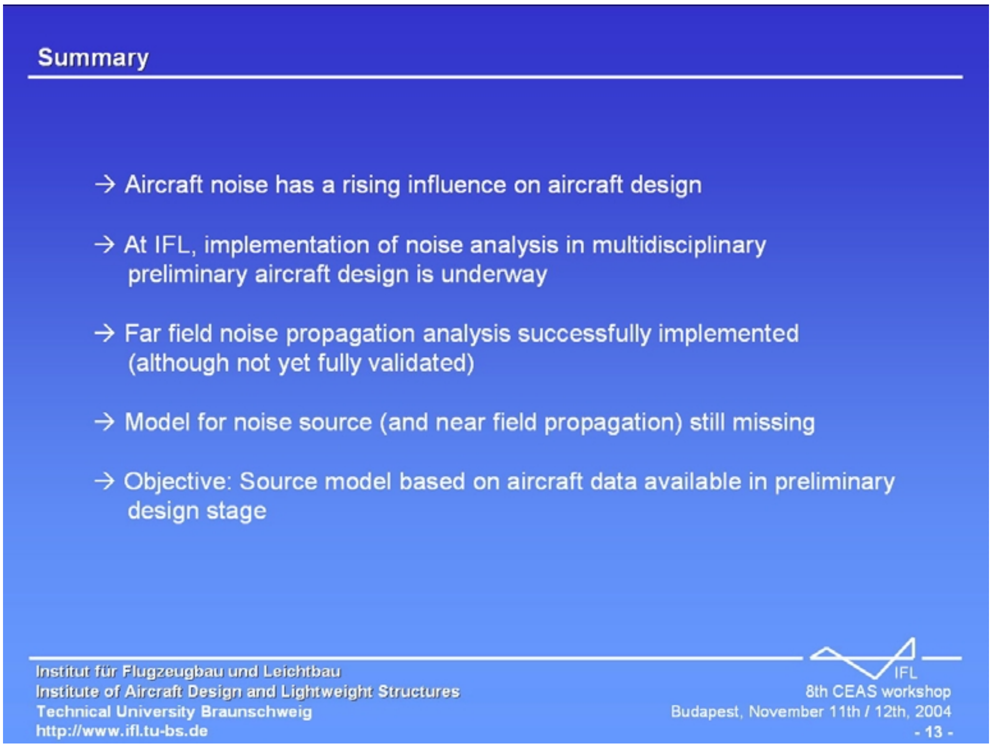
Deviations in the propagation model (e.g. those arising from unconsidered effects or from approximations made) are deemed rather small.

The way in which the flight path data are generated leads to thrust settings lower than those that would be actually used during landing approach (in final approach, for example, a higher thrust setting than required is usually selected in order to accelerate engine run up in case of a go around). This accounts for part of the deviations in noise levels for landing.

The main reason for the deviations observed is assumed to be the source model. The quality of the source automatically limits the quality of results that can be obtained.

The main limitation of the Noise Analysis Module is the fact that noise source data have to be provided explicitly by the user, and no relation exists between the noise source and the aircraft design parameters (which change throughout the design process).

4.) Summary



The contents of this presentation are to be shortly summarized.
It is to be expected that the configuration of future generations of transport aircraft will be influenced by noise related criteria in far greater scale than that of present aircraft.
As a result of this, at IFL work has begun to incorporate noise analysis into multidisciplinary integrated preliminary aircraft design.
Far field noise propagation analysis has been successfully implemented, although it has not been fully validated yet.
A model for the noise source (and near field propagation) is still missing, the objective being to find a parametric model based on aircraft data available within the preliminary design process. Perhaps a model with point sources (for engines, landing gear, slats, …) and a ray tracing analysis of the near field could serve for this purpose – This point would be welcome as a matter of discussion.