1 Introduction 1

1.1 acoustics. , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , 1

1.2 Sound and physical quantities in the sound field. , , , , , , , , , , , , , , , , , 2

1.3 Perception and derived quantities. , , , , , , , , , , , , , , , , , , , , , , 4

1.4 sound fields and sound sources. , , , , , , , , , , , , , , , , , , , , , , , , , , , 9

2 sound sources 14

2.1 Sound generation. , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , 14

2.1.1 Basic mechanisms in the formation of fluid sound. , 15

2.1.2 Basic mechanisms in the formation of structure-borne noise. 16

2.2 Sound sources on machines and vehicles. , , , , , , , , , , , , , , , , , , 16

2.2.1 Turbofan aircraft engine. , , , , , , , , , , , , , , , , , , , , , , , , , , 17

2.2.2 Motor vehicle. , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , 19

3 fundamental equations for the formation of sound in fluids 21

3.1 basic equations. , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , 21

3.2 Homogeneous wave equation for sound propagation. , , , , , , , , , , , , 23

3.2.1 Solutions of the homogeneous wave equation. , , , , , , , , , , , , , , , 24

3.3 Inhomogeneous wave equation. , , , , , , , , , , , , , , , , , , , , , , , , , , , 26

4 sound emitters 29

4.1 Monopoly. , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , 29

4.2 dipole. , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , 34

4.3 quadrupole. , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , 39

4.4 Moving sound sources. , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , 41

5 Generation of sound by bodies and surfaces flowing around 44

5.1 Flow around compact obstacles. , , , , , , , , , , , , , , , , , , , , , , 44

5.2 Overflow of bodies and surfaces. , , , , , , , , , , , , , , , , , , 47

6 rotors as sound sources 53

6.1 Airplane propeller. , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , 53

6.2 Other open rotors. , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , 58

6.3 fans. , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , 59

6.4 Turbomachinery in flow channels. , , , , , , , , , , , , , , , , , , , , , 62

7 Excitation and emission of structure-borne noise 69

7.1 Waves in solids. , , , , , , , , , , , , , , , , , , , , , , , , , , , , 69

7.2 Mechanical impedances and power transmission. , , , , , , , , , , , , , 72

7.3 Radiation of structure-borne noise. , , , , , , , , , , , , , , , , , , , , , , , , , , , 74

8 Sound generation during roll processes 78

8.1 Mechanisms of Sound Generation. , , , , , , , , , , , , , , , , , , , , , , , 78

8.2 Wheel-rail noise. , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , , 80

8.3 Tire-road noise. , , , , , , , , , , , , , , , , , , , , , , , , , , , , , 81

8.4 Sound generation in gear transmissions. , , , , , , , , , , , , , , , , , , , , , 82

9 Sound generation in diesel and gasoline engines 84

9.1 Noise caused by combustion. , , , , , , , , , , , , , , , , 84

9.2 Noises caused by the piston movement. , , , , , , , , , , , , , , 86

9.3 Influence of design parameters. , , , , , , , , , , , , , , , , , , , , , 87

5 Sound generation by circulating bodies and surfaces

In the following chapter is the sound in the flow around obstacles

be considered closer. In many cases, these are primarily due to turbulence

alternating forces on the surface of the body are the dominant cause. In the

Treatment of sound generation, it makes sense between acoustically compact bodies,

which are small in relation to the acoustic wavelength, and larger bodies and

Distinguish surfaces.

# 5.1 Flow around compact obstacles

If there is an obstacle in a flow, vortex structures may form during the flow around. This is accompanied by unsteady force effects on the surface of the

Obstacle. A very well studied model for such an obstacle (for example

a pipeline) is a rigid circular cylinder. Research has shown that the

Type of flow structures formed in a flow perpendicular to the axis

Cylinder of the Reynolds number

formula

depends on the flow velocity U, the cylinder diameter d and the

kinematic viscosity ν of the fluid enter. For the range of about 80 <Re <105

there is a predominantly periodic detachment of vortex structures from the

Boundary layer of the cylinder flow alternately on both sides of the cylinder

takes place. For higher Reynolds numbers in this area can be found in addition to the periodic and increasingly vortex structures with random time structure. The frequency f0 of

periodic vortex shedding depends on both the cylinder diameter and the

Flow velocity from. It can be achieved by using the Strouhal number

formula

specify in dimensionless form. In a wide range of Reynolds numbers is the

Removal frequency at the circular cylinder about Sr ≈ 0.2. For other cylinder cross-sectional shapes

differing values, but in some cases have also been investigated

and can be found in the literature. So it is possible to be the dominant one

Frequency of vortex shedding and thus the generation of the so-called bat

to determine responsible alternating force.