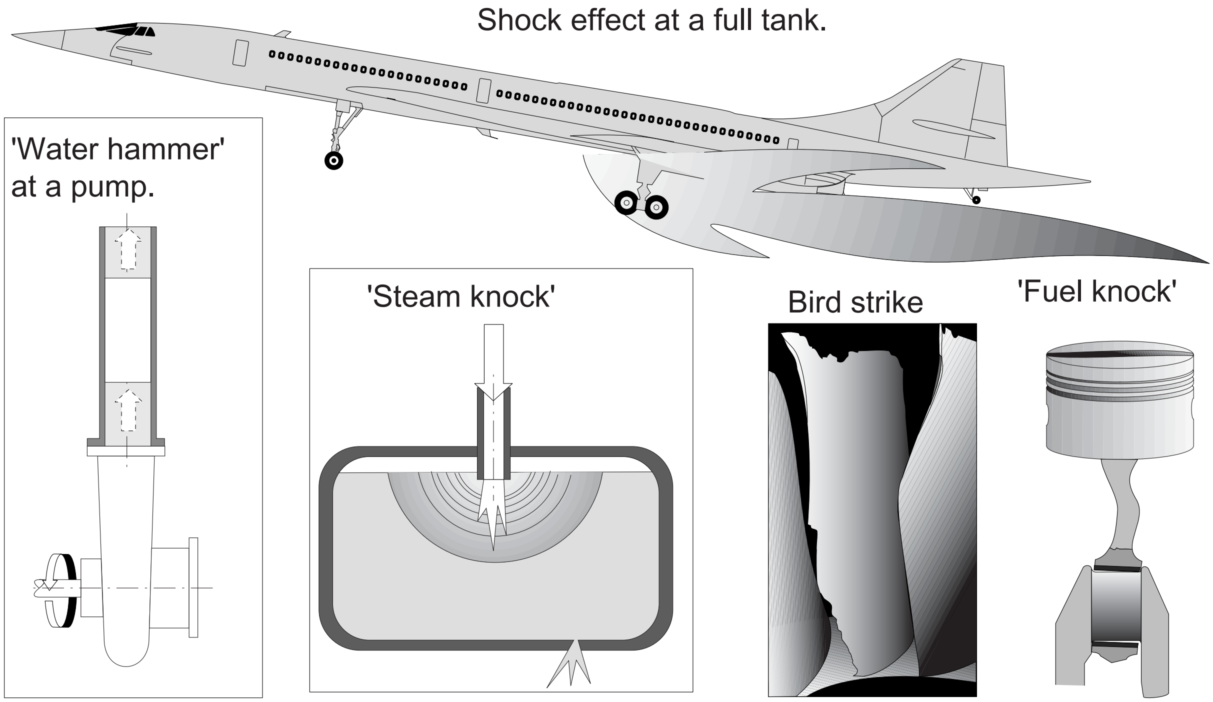
5.2.4 ‘Shocks’, Pressure Buffets and Pressure Waves in Liquids.

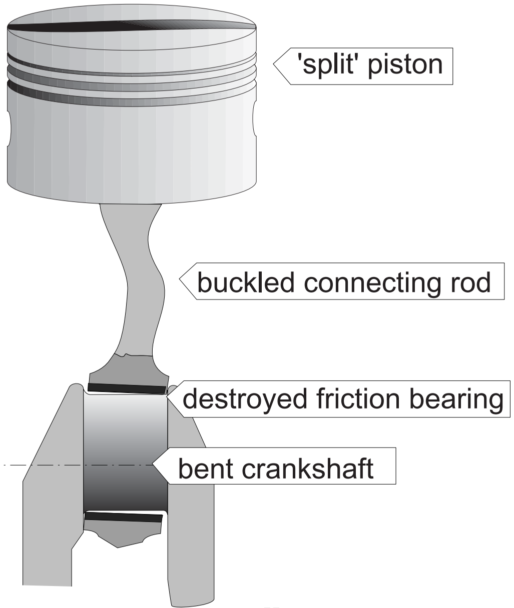


Not always is it easy to find for all the effects the right term. So I will use here the below mentioned terms. The corresponding pictures (Ills) will explain the particular mechansim. Under **liquid shock** is here understood in the following a process at which from **outside mechanical pressure acts at a resting liquid** (Ill. 5.2.4.1-1). This process must not be confused with a **pressure shock**, which develops in a moving liquid column through fast deceleration (Ill. 5.2.4.3-3). Liquid shock occurs as **water hammer** in piston engines like **motors** and **steam engines**. The incompressibility of the liquid causes a catastrophic overload of the components.

Water hammer will be in literature also used in connection with gasstreams (Ill. 5.2.4-8, Lit. 5.2.4-7), if air or other **gases and vapours carry larger amounts of water or other condensates**. These have, compared with the transporting gas stream markedly more mass. They perform an impact loading at a barrier with its high kinetic energy.

Also intruded **fuel** in the combustion space during stand still can trigger a liquid shock at the starts. So in air cooled gasoline motors of an elder type in military use several cases of **fuel knock** have been observed. Thereby the connection rod buckled. The pistons from an aluminum alloy have been symetrically split, starting from the hole for the piston pin.

The consequences of a liquid shock (water hammer, fuel knock) in piston engines.



Ill. 5.2.4.1-1

Ill. 5.2.4.1-1 *(Lit 5.2.4-5 up to Lit. 5.2.4-8): The danger of a* ***liquid shock*** *exists, if a force from outside acts at a stagnant liquid. Examples are cases at which large amounts of* ***fuel*** *or* ***cooling water*** *gather in the combustion space during* ***stand still****. For example cooling water can penetrate as result of the* ***perforation of a wet cylinder liner****. Cause is* ***cavitation*** *(Ill. 55.1.3-10). Also through leakage of the* ***cylinder head gasket*** *dangerous amounts of cooling water can gather during stand still.*

At ***steam engines*** *water hammer is also known. Concerned is here the* ***accumulation of condensed water*** *in the cylinder.*

A further type of a water hammer is possible ***during running motor****. This is the case during passing water at high level. Then* ***water*** *can be ingested in high amounts at not sufficient '****wading depth****' .*

Fuel can accumulate by too frequent ***starting without ignition*** *or a* ***leaking fuel supply*** *during stand still. Also thinkable is* ***oil*** *caused by a* ***turbocharger failure****, if larger amounts get into the air intake. In all these cases it can come to heavy damages because of the incompressibility of the fluid. As results are known '****split****' (light metal)* ***pistons, plastically bent piston pins*** *and* ***buckled connection rods****.* ***Secondary failures*** *can also occur even after a longer time. An example are* ***fractures by dynamic fatigue*** *of* ***crank shafts,*** *warped from liquid shock.*

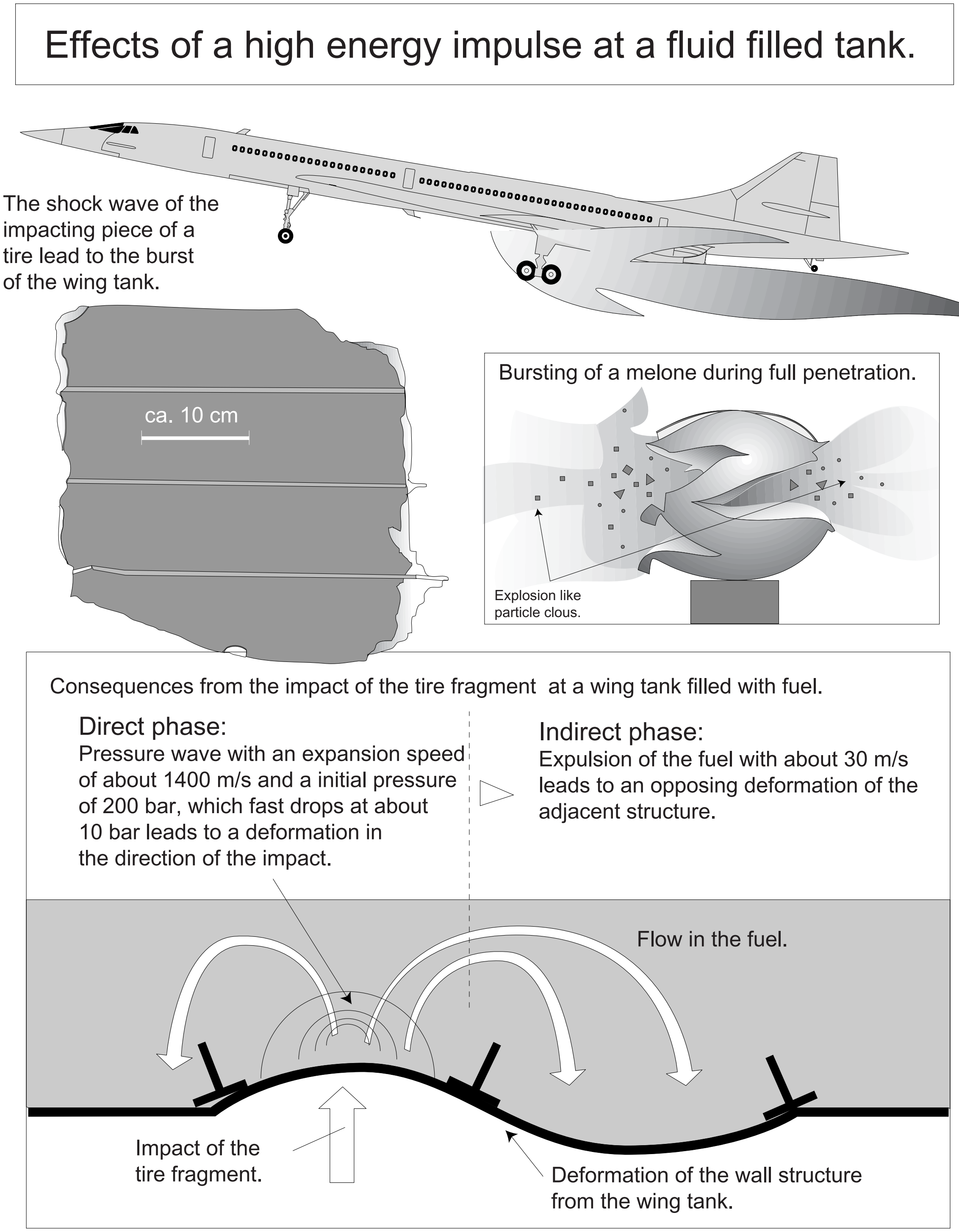
Ill. 5.2.4.1-2 *(Lit 5.2.4-11): This example gives an impression about the* ***effect of shock processes at and in stagnant liquids****.*

The investigation of this catastrophic aircraft accident shows, that dangerous fuel exit at a wing tank can be explained by the impact of a tire fragment (about 4,5kg). This happened during the start, when a larger metal stripe was overrun at high speed. The tire fragment was thrown from the landing gear against the wing. Thereby the wing skin was deformed, which in this case serves also as the wall of the full fuel tank. As result two sequences of the tank wall fracture have been discussed.

Failure hypothesis 1*: In the fuel at the* ***not penetrating*** *impact a* ***shock wave*** *developed (sketch below). An evaluation showed, that it propagated with about 1400 m/s and an initial pressure of 200 bar. The indirect pressure shock near the impact produced a pressure of about 10 bar. The movement of the fuel itself (white arrows) lays markedly below* 10^2 *m/s. These effects produce a S-shaped deformation of the tank wall and the break-out (sketch middle left). This failure hypothesis was estimated as the most probable.*

Failure hypothesis 2 *is evaluated as less likely. It correlates the burst of a fruit during the passsing of a projectil (sketch middle right). At the impact of a mass and the* ***penetration*** *with high speed its kinetic energy is transferred to the liquid/fuel. Around this zone a cavity is formed (vapour formation?). At full tank like in this case*

Liquid shocks through strike influence at a filled hollow space.



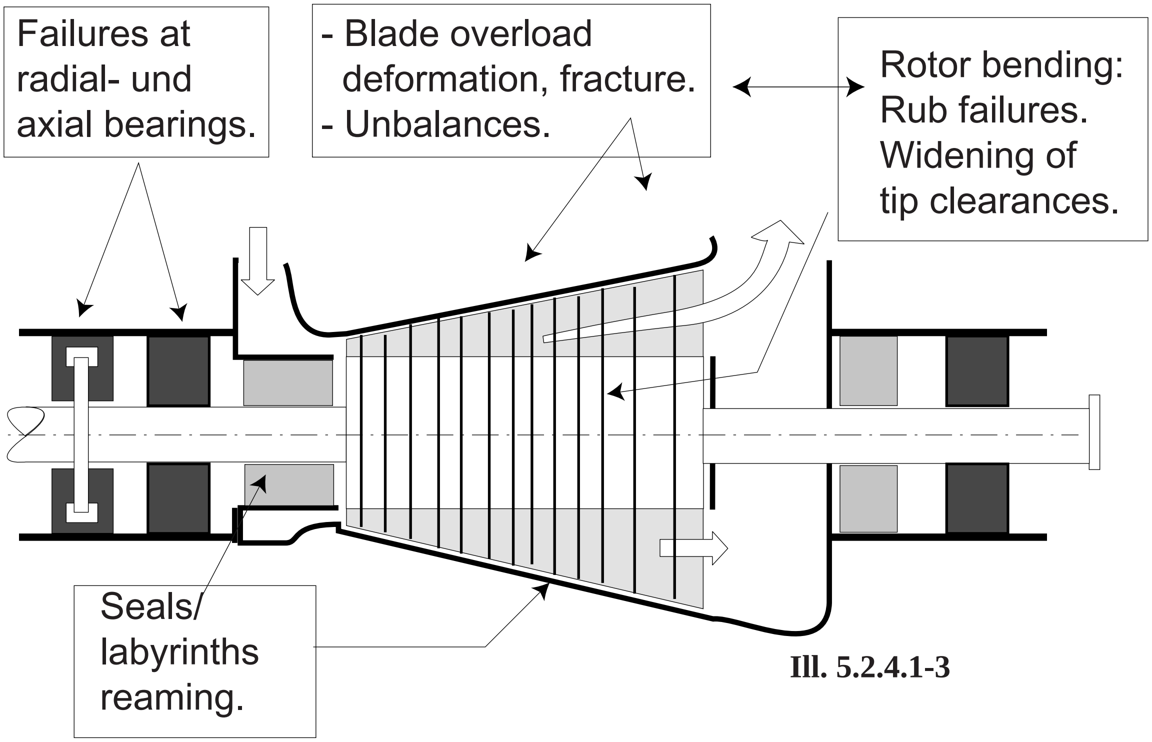
Ill. 5.2.4.1-2

*this additional volume causes a displacement and loads the tank structure. This phenomenon is called in the specialist literature ‘**pressure surge**’ .*

Liqid shock in stgeam turbines.

From liquid shocks endangered steam turbines.

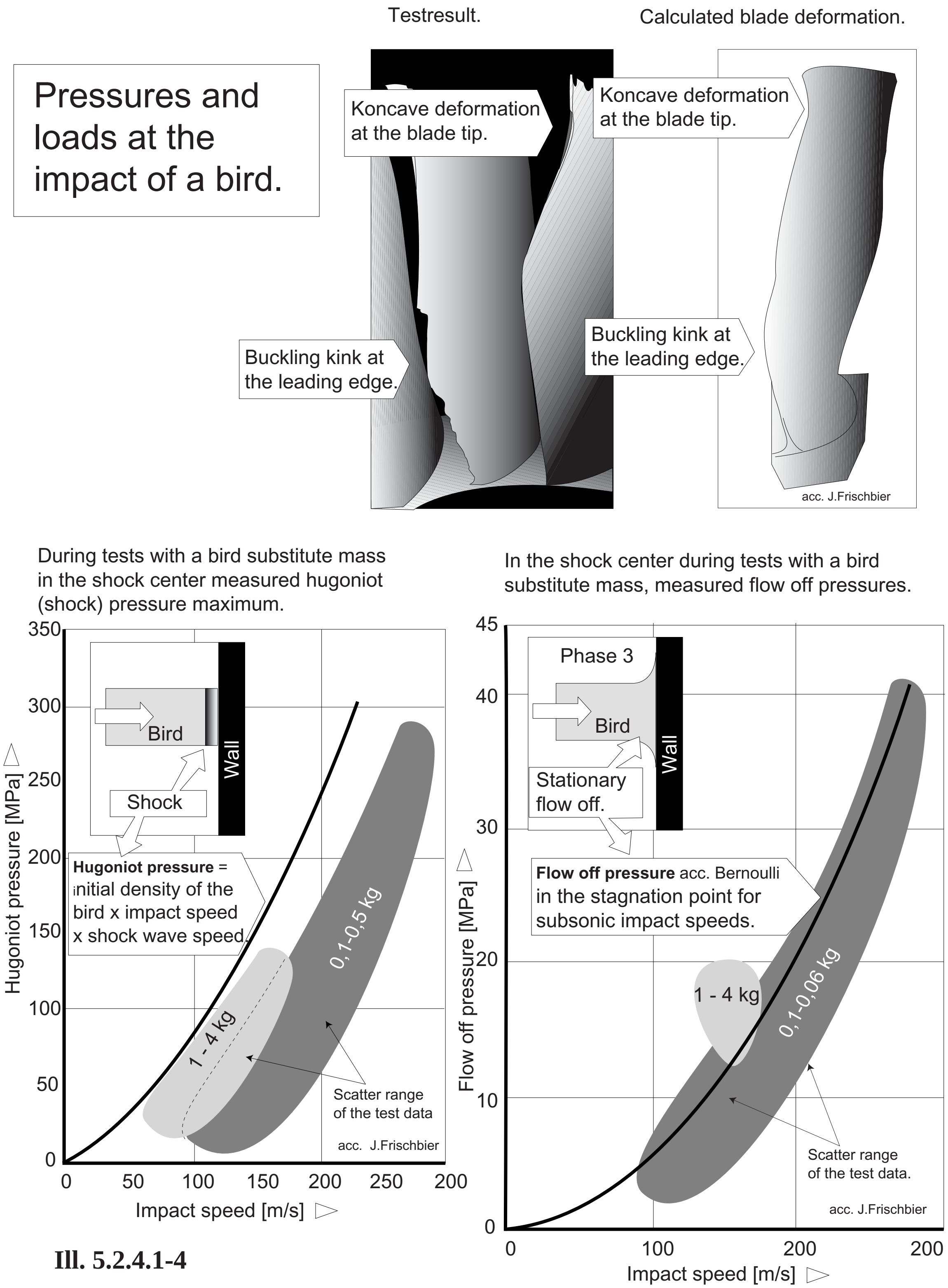
Water penetration at:
- Preheaters.
- Interstage superheaters.



Ill. 5.2.4.1-3

Ill. 5.2.4.1-3 *(Lit. 5.2.4-7 and Lit. 5.2.4-8): Gets water (condensate) in higher amounts into a steam turbine also here in the literature will be spoken about* ***water stike****. But here the* ***impact of liquid*** *is concerned, usually as drops (see* ***drop impact****, Ill. 5.5.1.2-6). Thereby the high relative velocity acts. Caused by shocklike rising, unsymmetric acting* ***hauling forces,*** *it comes to an overload. The results are damages at the* ***thrust bearings****, the damage of* ***seals*** *like* ***packing boxes*** *and the overload of* ***blades*** *up to fracture. Above this, caused by the high heat conductivity, obviously* ***thermal gradients*** *can occur during contact with the liquid, that generate dangerous* ***schaft bows*** *at turbo engines.*

Processes similar to liquid shock during the impact of a biological body.



Pressures and loads at the impact of a bird.

Testresult.

Calculated blade deformation.

Koncave deformation at the blade tip.

Buckling kink at the leading edge.

Koncave deformation at the blade tip.

Buckling kink at the leading edge.

acc. J.Frischbier

During tests with a bird substitute mass in the shock center measured hugoniot (shock) pressure maximum.

Hugoniot pressure = initial density of the bird x impact speed x shock wave speed.

In the shock center during tests with a bird substitute mass, measured flow off pressures.

Flow off pressure acc. Bernoulli in the stagnation point for subsonic impact speeds.

Ill. 5.2.4.1-4

Ill. 5.2.4.1-4 *(Lit 5.2.4-12): For* ***laboratory tests*** *with gas pressure canons (air, helium) normally* ***alternative masses*** *are used instead of original birds. Different mixtures of caoutchouc,* *'plasticine' or gelatine with other materials (e.g., wood wool) however show results which are not sufficient realistic for* ***proofs****/certifications in the aeroengine. A mixture from 85 % water and 15% air reproduces the pressure progress most realistic (Ill. 5.2.2-12). Anyway during* ***acceptance tests*** *of an aircraft engine type must be used shortly before the test pulled down* ***birds****.*

The diagrams below are applied for measurement data at plates during vertical impact with a cylinder shaped water-air- bird alternative mass. The ***shock pressure*** *(hugoniot pressure) is almost 10 times higher than the* ***flow-off pressure*** *(Ill. 5.2.2-2). The impact velocity increases the pressure exponential. This show the measurement data in agreement with the calculated curve. For a better evaluation by the practitioner should be remembered, that the MPa data correspondent the ten times of the numerical value in bar. Thus impact pressures up to several 1000 bar occur and flow-off pressures in the range of several 100 bar. With this, materials like* ***fiber reinforced plastic*** *(FRP) of a nosecone (Lit. 5.2.4-4), the lining of air intakes and aeroengine nacelles are far overloaded. This is even true for an inclined impact also for light metals of the walls of airplane fuselages. Its failing can produce dangerous* ***secondary failures of a bird impact****.*

Also typical failure modes at compressor blades, especially fan blades (sketches above left), can be amazing good simulated with computer supported calculations which consider the shock effects (sketch above right). This impressive demonstrates the good realistic applicability. ***Crack formation*** *in the impact region must be seen in connection with an* ***embrittlement effect*** *of the blade material during* ***high speed deformation*** *(Ill. 5.2.2-2, Ill. 5.2.2-8 and Ill. 5.2.2-9).*