Abstract
This poster presents cryogenic flash boiling for high altitude conditions in liquid rocket engines. A new cryogenic test bench was built for investigating the flash boiling phenomenon of LN2 (liquid nitrogen) and later of the actual propellant LOX (liquid oxygen). With the temperature adjustment and injection system of that test bench variable injection temperatures and variable back pressures can be achieved. These are the dominating parameters for flash boiling. The resulting sprays are visualized by means of high-speed shadowgraphy to investigate the characteristics and morphology of flash-atomizing LN2/LOX jets in dependence on the two injection parameters.

Methods and Materials
The newly designed cryogenic test bench allows variable injection temperatures in the range of 70-120 K. It consists of three main systems: the supply and pressurization system, the cryogenic temperature adjustment and injection system and the vacuum system, as depicted in figure 2.

In these fully flashing sprays the remaining liquid core is quite small and exists only at the injector outlet while the remaining liquid structures are monodisperse droplet systems.

In figure 5 the influence of the injection pressure is shown, which was increased to $p_{inj} = 8$ bar ($10,3$ bar) for the same injection temperature, injector geometry and back pressure range.

Introduction
Technology development for propulsion systems of upper stages like the cryogenic ESC-A engine HM-7B or the future Ariane 6 upper stage engine Vinci and for reaction control thrusters is driven by the invention of new propellants to substitute hydrazine and by new ignition technologies like laser ignition. At high-altitude conditions prior to ignition the liquid propellants are injected into the combustor at near-vacuum conditions. Due to the sudden pressure drop at injection the liquid is in a superheated thermodynamic state resulting in an eruptive evaporation, also called flashing boiling or flash evaporation. The evaporating gases raise the pressure inside the combustion chamber until the equivalence pressure shortly before ignition is reached. To know the composition related to phase, species and temperature distribution is important for both to determine the probability of a successful ignition and to avoid destructive pressure peaks.

The dominating parameters for the flash-evaporation phenomenon are the injection temperature and the back pressure. They both define the degree of superheat $R_s$ or $\Delta T^*$ of the injected liquid, see figure 1:

$$R_s = \frac{p_{inj} - p_{sat}(T_m)}{p_f}$$

$$\Delta T^* = \frac{T_m - T_{sat}(p_f)}{T_{sat}(p_{inj}) - T_{sat}(p_f)}$$

Further dimensionless numbers like the Weber number $We = \frac{\rho u^2 d}{\sigma}$ and the Jakob number $Ja = \frac{p_{inj} \Delta T^*}{\rho c_p T_m}$ can be used to determine the three regimes aerodynamical break-up, transition to flash boiling and fully flashing according to correlations developed in [1].

Figure 1. Definition of the degree of superheat.

Results and Discussion
The evolution of the spray morphology with increasing degree of superheat $R_s$ by variation of the back pressure $p_{inj}$ from 36 to 600 mbar at a constant injection temperature $T_m = 82,5$ K ($\pm$0,6 K) and injection pressure $p_{inj} = 4$ bar ($\pm$0,2 bar) is shown for the injection of LN2 in figure 4. Each shadowgraph image was made 100 ms after start of the injection. The sprays with lower values of $R_s$ show typical features of an aerodynamical break-up like long liquid cores in the spray center line, small opening angles and large liquid filaments. For increasing values of $R_s$ the LN2 sprays become wider and more turbulent flow structures can be observed until the flash boiling process dominates the jet break-up for a degree of superheat $R_s > 12$.

Figure 4. LN2 sprays at different degrees of superheat $R_s$ at $T_m = 82,5$ K, $D_m = 1,0$ mm and $p_{inj} = 4$ bar

Conclusions
With the temperature adjustment and injection system of the new cryogenic test bench LN2 sprays with a constant injection temperature $T_m$ and varying back pressures $p_{inj}$ can be produced. Decreasing the back pressure causes an increase of the degree of superheat $R_s$ and changes the atomization process of the LN2 sprays from an aerodynamical mode into a fully flashing mode. Despite the difference in their physical properties all of the cryogenic LN2 sprays fit into transition correlations [1] developed for storable fluids. Increasing the injection pressure $p_{inj}$ leads to a less dominant flash boiling process with narrower sprays at similar degrees of superheat $R_s$. That means this definition of the degree of superheat is not sufficient for a clear characterization of the resulting spray patterns. Apart from an exact determination of the spray angles droplet size and velocity measurements will be performed by means of phase doppler anemometry (PDA). Finally a test campaign with LOX is planned.

References

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