On Demisable Fiber Reinforced Plastic Composites

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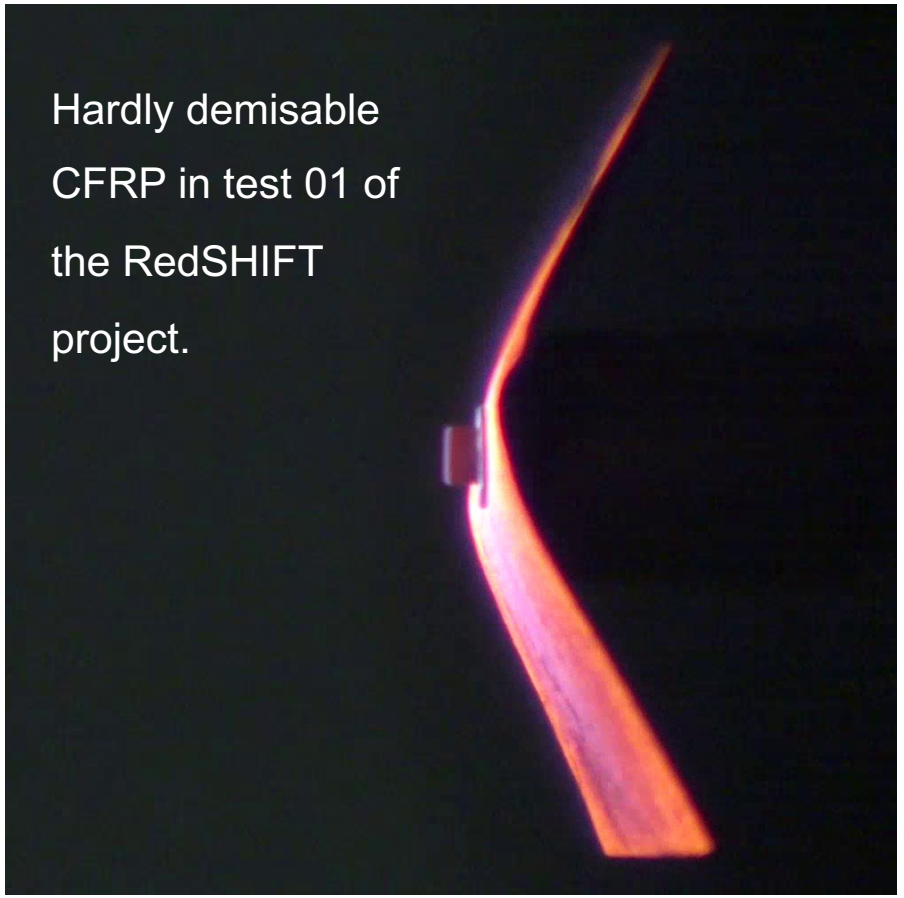
Background

~200 experimental demisability tests conducted on two dozen composites in the last 10 years have shown that fiber reinforced plastics (FRP) typically act like an ablative TPS and have very high demise resistance.

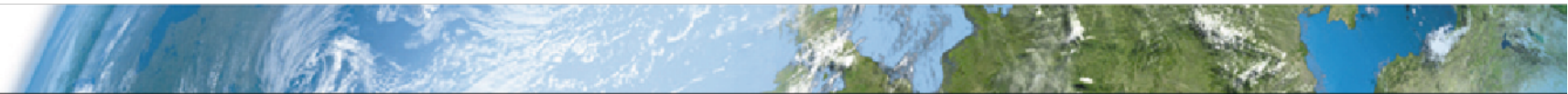
One CFRP in 2015 showed a favorable demise behavior, sparking interest in creation of demisable composites.

Recent research projects tried to learn which parameters / properties lead to beneficial behavior and to design demisable composites.



Hardly demisable CFRP in test 01 of the RedSHIFT project.

Demise behavior of composites

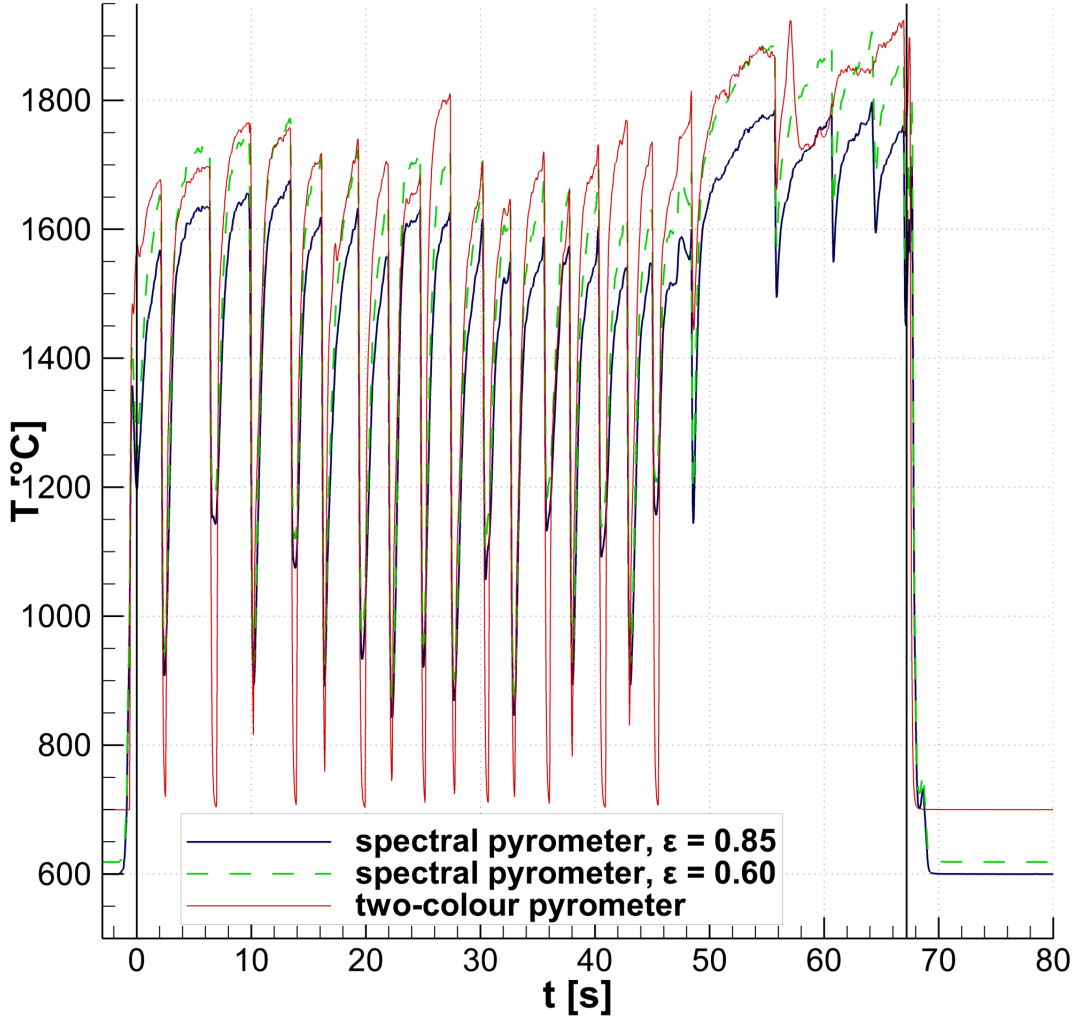


Desired Demise Behavior

The desired demise behavior is characterized by:

- Thermal decomposition and removal of the matrix with
- Subsequent mechanical removal of the reinforcing fiber layers.

The dry fibers will fall onto the ground, but won´t pose a risk to people or property.



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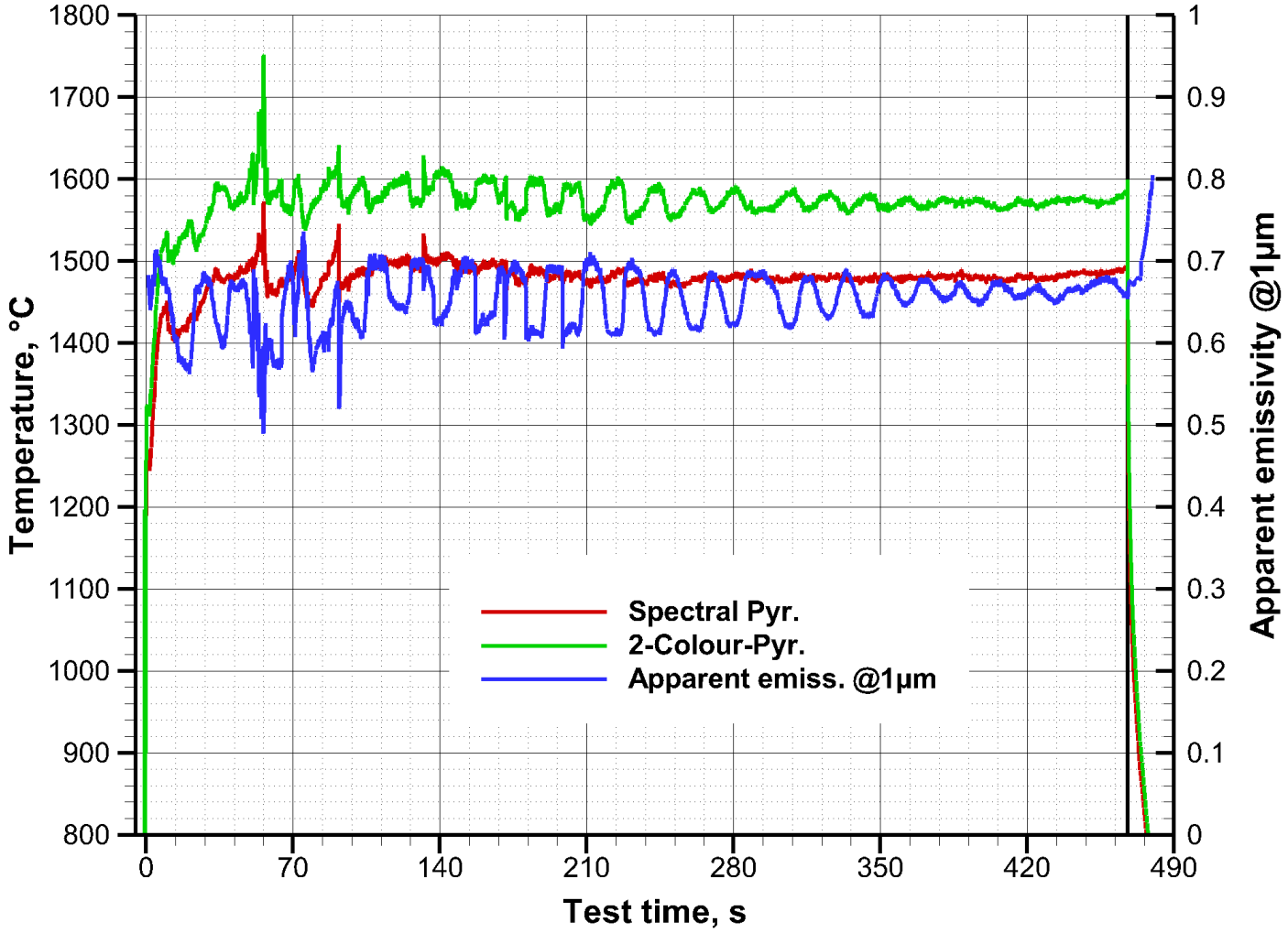
Worst Case

The worst case is an ablator-like behavior:

- Matrix decomposition act as transpiration cooling, but
- Char yield is high and the sample stays solid.
- Recession is limited by slow oxidation rate.



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Average CFRP

Most CFRPs show an intermediate behavior.

If exposed quickly to very high heat loads, the desired layer by layer ablation can be observed for some duration of time. This is driven by the delamination of fabric layers, not by release of individual fiber.

If the heating rate is lower, the ablator like behavior is observed (e.g. exposure to low heat loads or the rear of the sample in high flux environment).

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What´s the difference between the three CFRPs?

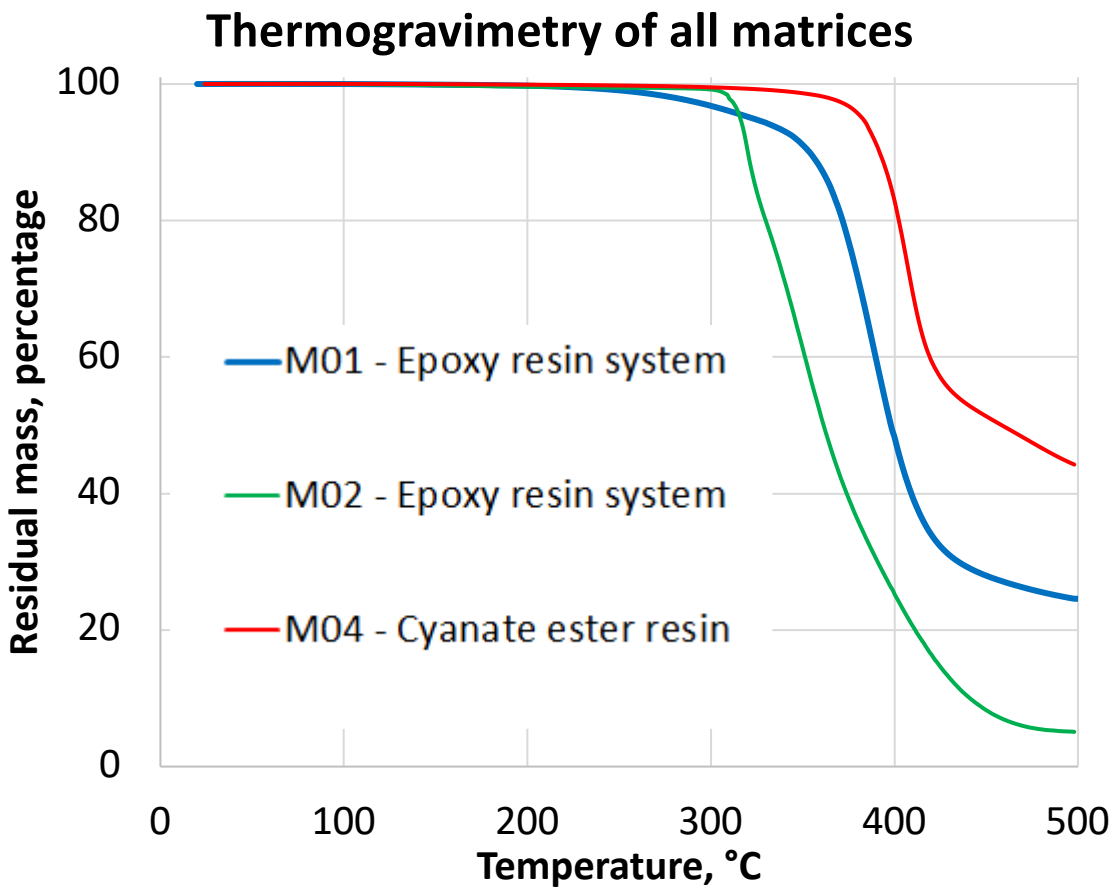
Many properties influence the demise behavior of CFRP, but the single main driver is the char yield*:

High char yield (M04) → TPS like behavior.

Moderate yield (M01) → intermediate behavior.

Low char yield (M02) → lose layers / fibers.

Prediction of matrix behavior before demise testing is possible. Thermogravimetric analysis (TGA) reveals the char yield.



* Other properties and parameters were checked in COMP2DEM. See the reports for what else is relevant and how it influences the demise process.

What does this mean?

The influence of the heating rate comes from the correlation with the char yield (see e.g. the flash pyrolysis principle in plastic recycling).

→The (very slow) TGA is conservative and an excellent indicator for matrix behavior.

→High demisability at low heating rates means, that high demisability will also be observed at high loads.

→Low demisability at high heating rates means, that low demisability will also be observed at low loads.

<u>Early exposure and pre-heating of parts during the entry flight is really bad for demisability of composites!</u>

An indicator for a lower char yield is the glass transition temperature Tg.

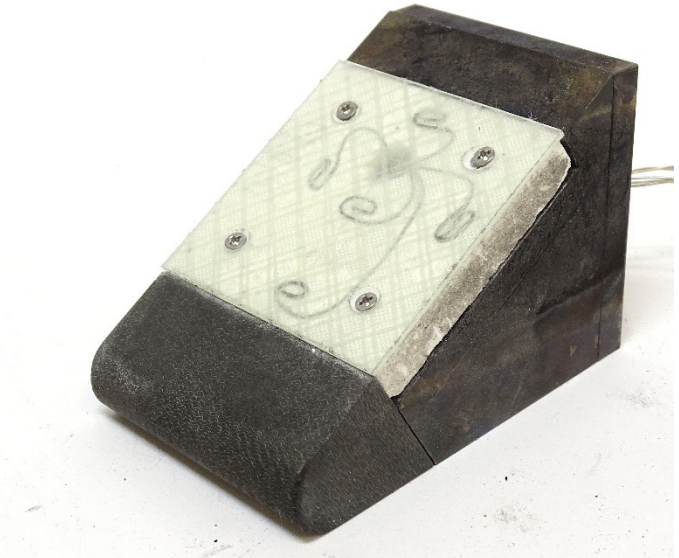
Designing demisable composites

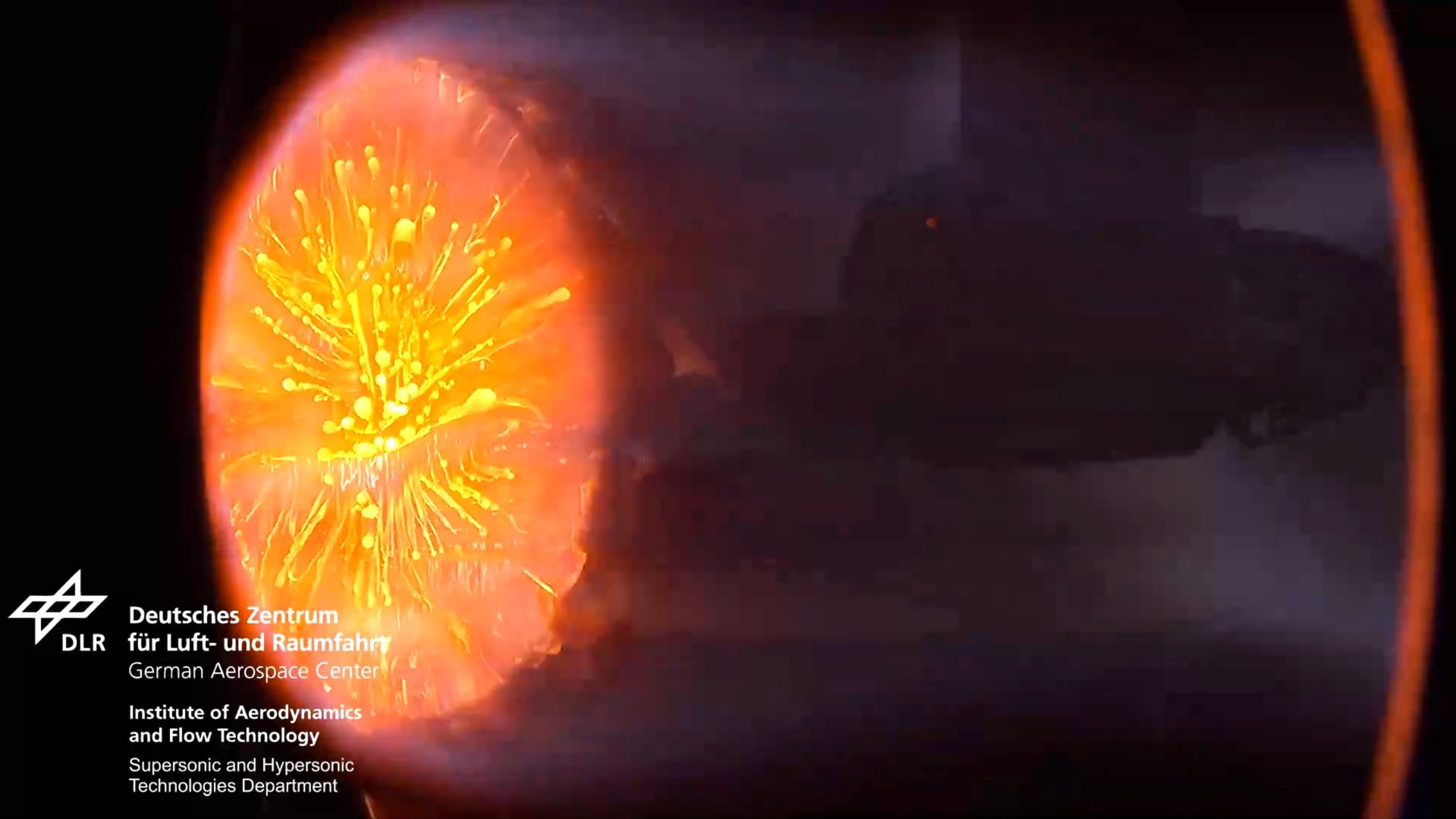
Creating demisable composites

Using the gained knowledge, creating a demisable composite should be easy:

- Use the demisable matrix system to make GFRP demisable.
- Select an epoxy matrix system with low Tg for having another demisable matrix option.
- Use an organic reinforcing fiber that decomposes to further improve demisability.

Want to guess which composites showed the expected behavior?





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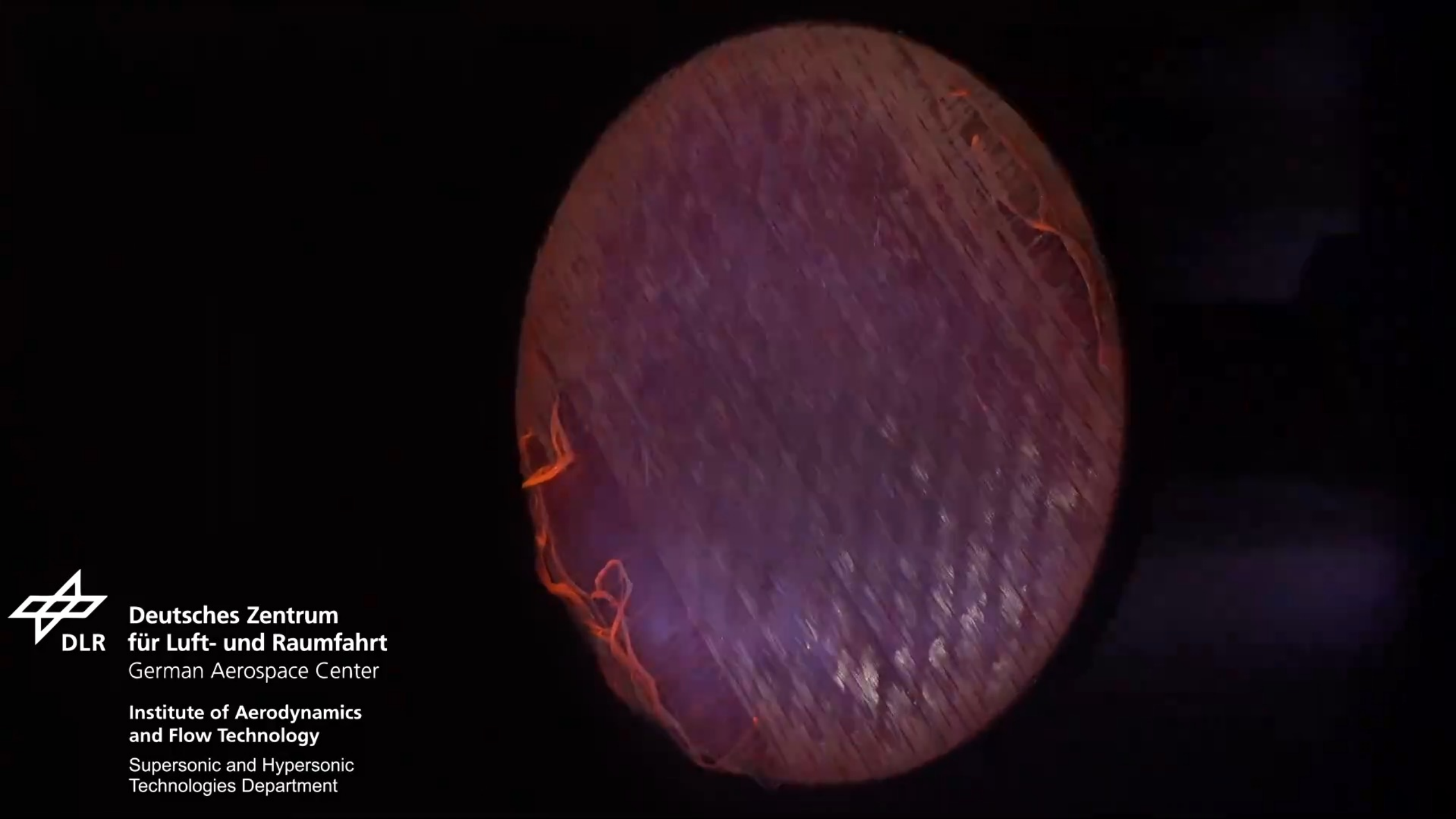

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GFRP with demisable matrix system

The glass fiber becomes sticky when melting and can form a protective layer that prevents mechanical removal of fiber strands or layers.

The GFRP was tested again at low heat loads, expecting that this would mean the glass fiber remained inert and did not melt , thus changing the demise behavior. But, the fiber still sintered, forming a protective layer on the surface.

→A demisable matrix system does not necessarily make a composite demisable!

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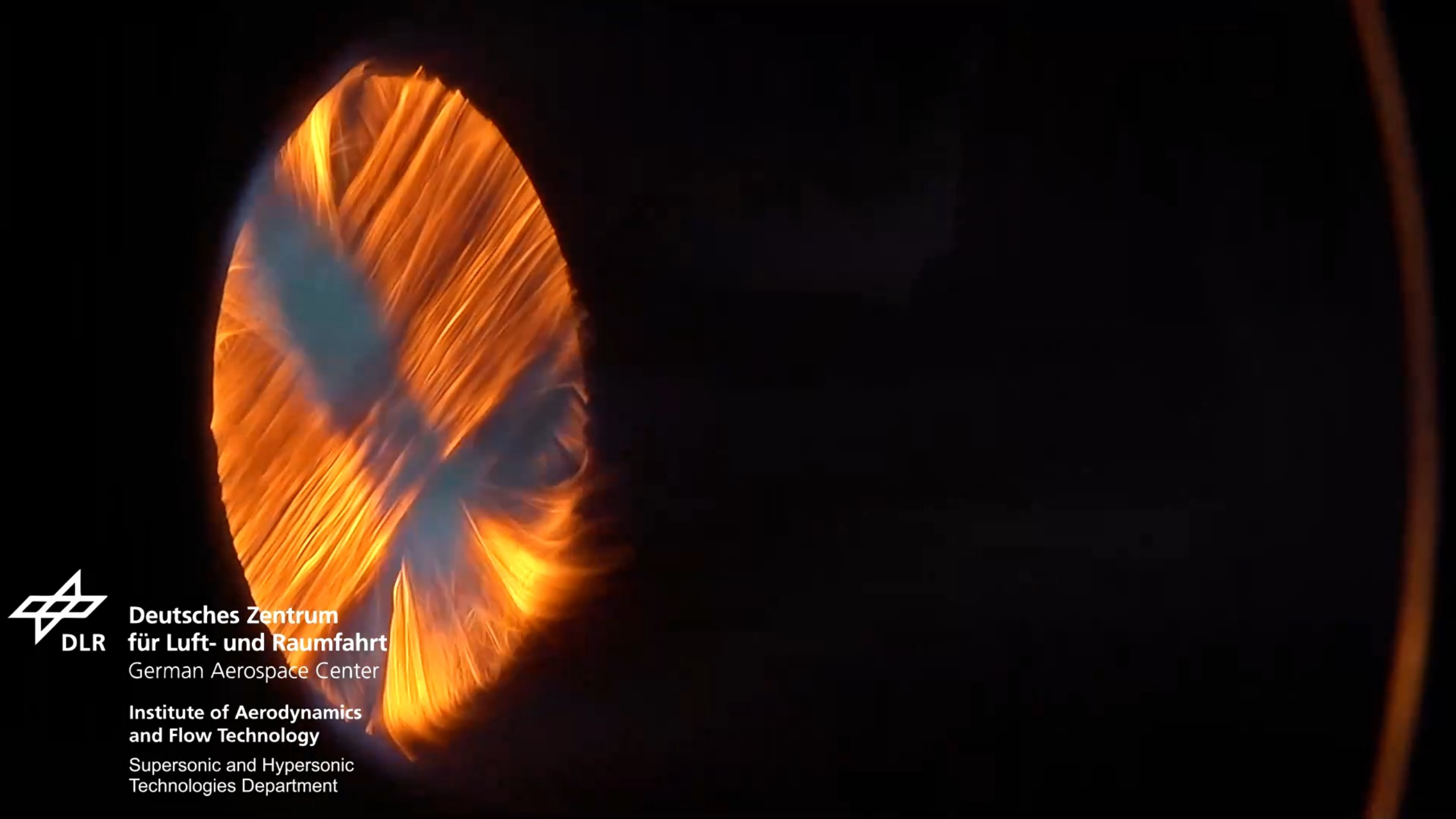
Organic fiber

The supposedly demisable organic aramid fiber chars when being heated, effectively becoming carbon fiber.

The shrinkage of the fiber makes it lift off, which produces an insulating layer upstream the sample.

Similar behavior was observed on samples with low char yield matrix and unidirectional fiber layers. Aramid fiber may actually increase the demise resistance of general composites.

→ Organic fiber does not mean demisable fiber!



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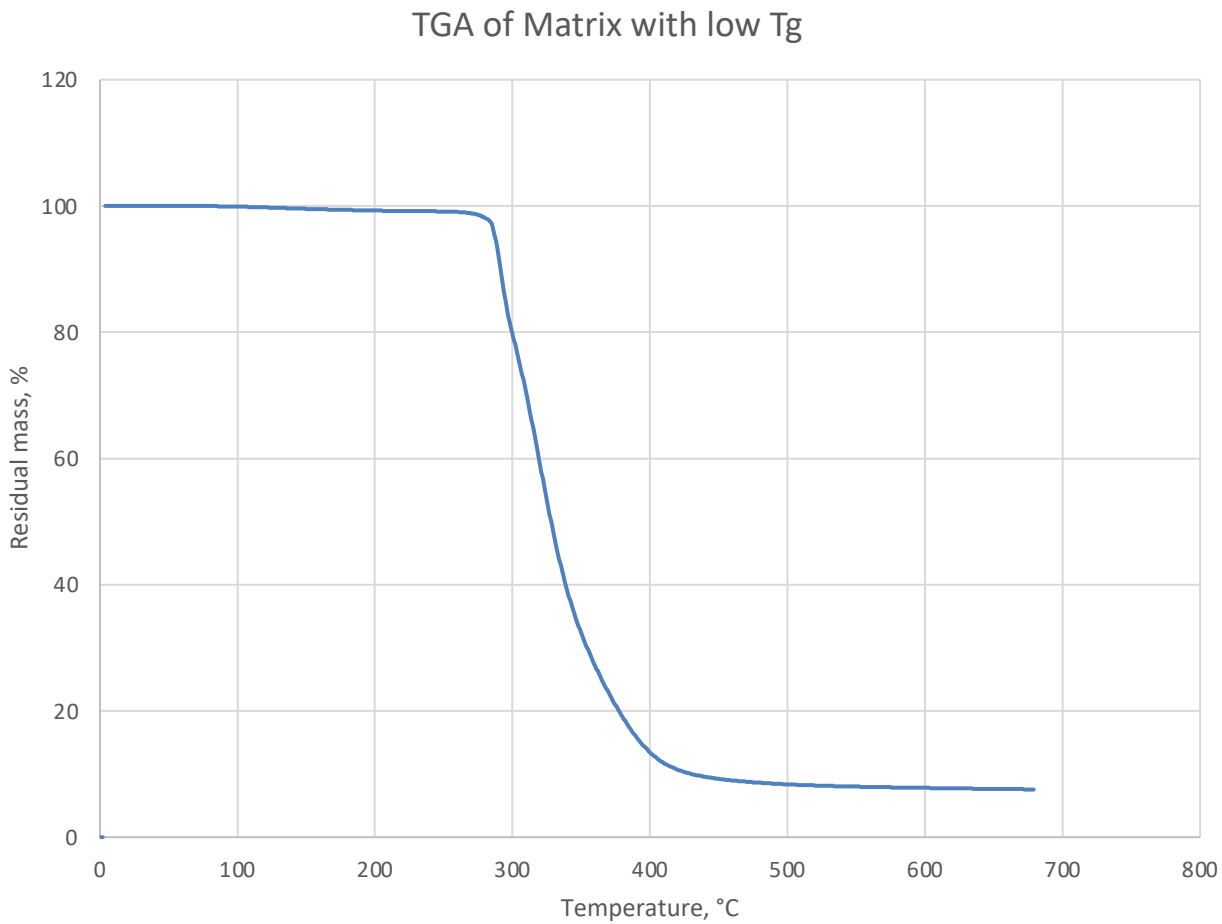
Matrix with low Tg

Selecting a random epoxy matrix system with low glass transition temperature was successful.

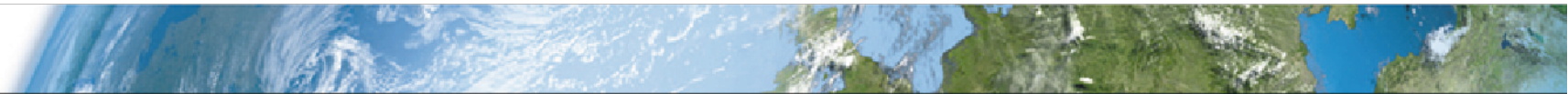
The TGA showed a low char yield.

The composite made with that matrix showed the targeted behavior.

→Low Tg is a helpful criterion for pre selection!



Assessment of demisability



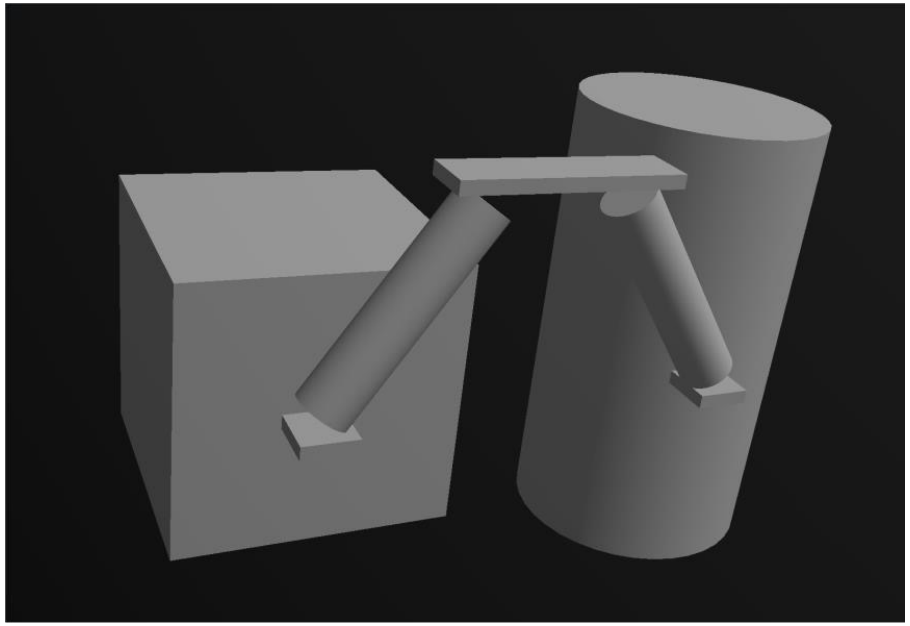
Entry flight simulations

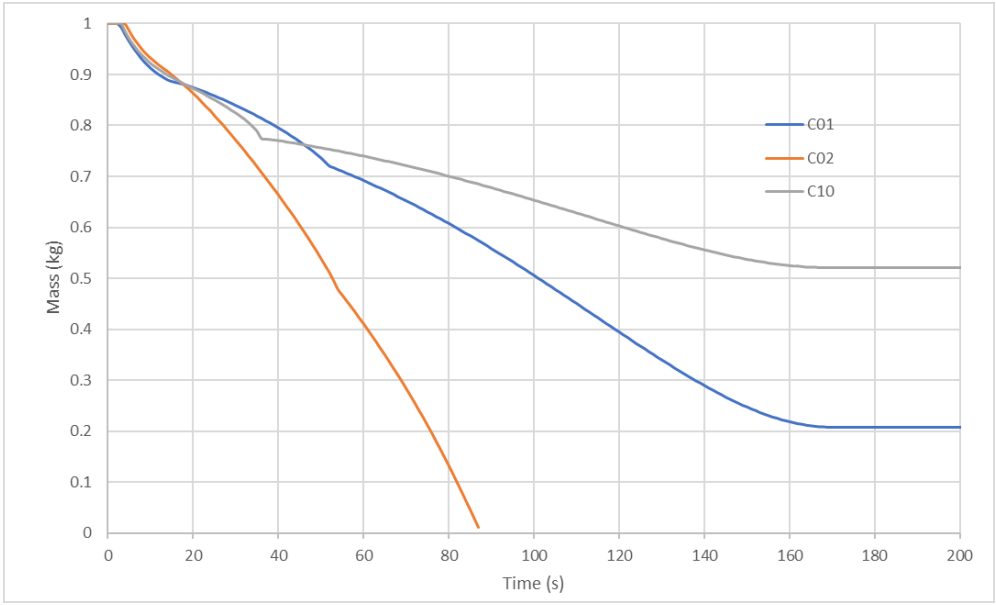
A ” Simple heat Balance Integral” model was developed and entry flight predictions on some objects were performed in COMP2DEM.

The demisable CFRP demised completely in case of the box (bottom right image) and the BiPod, but not for the tank (low ballistic coefficient).

The ablator like composite and the average composite survived in all cases.

→ Demisable CFRP can work and can make a difference.





DRAMA model

Parameters for the equivalent metal model of DRAMA were also derived by comparison against the SBI.

Aluminum data from three different aluminum alloys (ESA TRP DEPT).

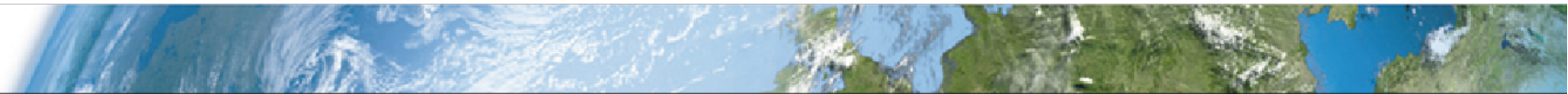
Titanium data from ESA TRP CHARDEM (Ti6Al4V).

→Demisable CFRP is still much worse than aluminum, or titanium (at very high fluxes).

→Usual composites are often practically non-demisable.

Property	Aluminum	Titanium	Demisable CFRP	Average CFRP
Density kg/m³	2700	4500	1580	1580
Demise temperature, °C	660	1700	1187	1187
Emissivity	0.46 - 0.70	0.7	0.9	0.9
Heat of Demise, MJ/kg	1.1	1.5	10	24

Summary



Conclusions

- Fiber precursor, diameter and sizing, weave, layup, fiber volume fraction etc. all have an impact on the demise behavior (tests and results not shown here), but the matrix and its char yield are dominating.
- Every detail can change the behavior and every composite must be qualified. Even if only changing the curing temperature!
- A low char yield matrix gives the desired behavior with carbon reinforcing fibers, but not with others fibers.
- Early exposure is really bad for demisability of composites.
- Low glass transition temperature is a good criterion for pre-selection of matrix system.
- Low char yield in TGA analysis means that the material will likely show the desired behavior and is a sufficient criterion for selection of a material for demisability testing.
- **“Demisable composites” can be just demisable enough, but they are still problematic.**

Recommendations

There is a lot of potential (and need) for further improving the understanding and the demisability of composites:

- Many parameters/properties have been checked, but others have not. They may be interesting for D4D (e.g. thermal conductivity of the matrix).
- Thorough experimental investigation of selected composites for providing sufficient data for numerical modelling (e.g. several tests on one composite at different fluxes and pressures).
- Testing in a dynamic environment (e.g. with the rotation device in L2K).
- Novel concepts to demisability enhancement of composites (e.g. exothermic decomposing matrix).