# BENDING INSTEAD OF SNAPPING

## Researchers at the DLR Institute of Aeroelasticity are investigating just how flexible an aircraft wing can be

by Christine Unger

**Aircraft wings bend while in flight. To see this for yourself, all you have to do is look out of the window during a flight. Beyond a certain limit, these wing deflections become known as 'large deformations'. Professor Wolf Krüger of the DLR Institute of Aeroelasticity explains whether these deformations are dangerous, the conditions in which they occur and why modern wings are becoming increasingly elastic.**

**Is it normal for a wing to bend in flight?**

: Absolutely! The majority of an aircraft's mass is concentrated in the fuselage, which is pulled downwards by gravity. This is counteracted by lift, which forces the wings upwards and allows the aircraft to fly. These opposing forces require that the wings bend. If they did not, they would have to be very rigid, and that would make them very heavy. So this deflection is factored into the design of the wing and is part of its normal behaviour.

**At what point does it become a 'large' deflection?**

: That depends on the size of the plane and its wingspan, the materials used and the construction of the wings. Whether a deflection is regarded as 'large' or not depends on the dimensions of the plane. As an example, consider the deflection at the wingtip of an Airbus A340. During a flight, its wingtip deflects at least two metres when compared to its shape on the ground. This might seem a lot at first, but it is actually normal for a commercial aircraft. The wingspan of an A340 is 60 metres. So the ratio of the deflection to the length of the wing is seven percent. During extreme manoeuvres, the deflection can be more than twice this amount. Some cargo aircraft have even greater wing deflections. The wings of the Boeing 787, which are made of carbon fibre-reinforced polymers (CFRP), have around the same span but have a deflection of three metres during flight. Under maximum load, during gusts of wind or manoeuvres, the deflection can be as much as 8.5 metres. This is a deflection of 28 percent and is well within the territory of 'large' deflections. As a general rule: if the deflection at the wingtip is more than 10–15 percent of the length of the wing, it is considered a 'large deformation'.

During the static tests, forces representing the aerodynamic lift experienced in the wind tunnel pull the wing upwards.

**Do these deformations occur for all types of aircraft? Why do they become so large?**

: You can see the effects best in gliders. Wings with a large span but a short depth – also known as the wing's chord – produce less drag. That is why the wings of all high-performance gliders are particularly slim and, as a result, flexible. However, this trend is now spreading to commercial aircraft, which is leading to increased wing deflection. The advantage of the reduced drag for commercial aircraft

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is a corresponding reduction in fuel consumption. Whereas previously, greater wingspans automatically entailed more weight, which would become unsustainable beyond a certain point, new construction techniques and materials such as CFRPs make these so-called 'high aspect ratio' wings possible. With the right materials and optimal design, we can even use the deformation to reduce the forces acting on the wings. Ideally, this would also reduce the weight of the wings. This method is known as 'aeroelastic tailoring'. Passenger comfort is also improved as it allows the vibrations of the aircraft structure to be reduced in a controllable way. Large deformations also occur outside of aviation, for example in the blades of wind turbines, where a slim design is also beneficial.

**What are the consequences of a deformation being 'small' or 'large'?**

: Even the way they are considered in our calculations is very different, and this is at the centre of our work at the DLR Institute of Aeroelasticity. When a wing bends, its centre of gravity shifts, and it appears to get shorter. This deformation also causes the directions of the local lift forces acting on the wing to rotate. If the deflection of the wing remains small, these effects can be neglected in any calculations.



**Professor Wolf Krüger** is the Head of the Loads Analysis and Aeroelastic Design Department at the DLR Institute of Aeroelasticity and leads the Multibody Systems in Aeronautics and Astronautics department at Technische Universität Berlin. He is involved in international youth exchange programmes and strongly supports the atmosphere of international cooperation at DLR. What does he enjoy most about his work in aeroelasticity? "The wide range of disciplines, the interplay between simulation and experimentation and the great working atmosphere at the Institute."

It is common and very helpful to use assumptions like this that simplify the process of calculating the forces acting on an aircraft and adapting its structure accordingly. Such simplifications also keep the required calculation times for the analyses relatively short.

**The Institute of Aeroelasticity is developing ways to more accurately model wings experiencing large deformations. What exactly are you working on at the moment?**
: In order to model large deformations, we need to use appropriately comprehensive mathematical approaches. We can no longer rely on simplifications. In aerodynamics, these techniques include 'computational fluid dynamics' and 'non-linear vortex lattice' methods. To model the structure, we use 'finite element' or 'multibody simulation' software. We approach the problem from two angles of complexity – speed and detail. On the one hand, a method was developed at the institute, within the scope of a doctorate, which can represent non-linear structural deformations using fast analysis methods. On the other, we also use complex finite element models which depict aircraft structures with a high degree of detail.

**That sounds like a lot of time in front of a computer...**
: … That may be true, but we also conduct experimental tests of our methods. Since flight tests requiring the use of a commercial aircraft are very costly, we start off with laboratory and wind tunnel testing. In Göttingen, we carried out a series of wind tunnel tests with specially designed wings where we tested our design and simulation methods as well as new measuring techniques. For example, we tested a forward-swept wing whose tip almost touched the top of the wind tunnel without reaching its own structural limits. It was made of layers of a fibre composite material. These layers are arranged so that the angle of attack does not increase if the wing bends, as is normally the case with forward-swept wings. Using this approach, we optimised both the design and the construction materials. Structural optimisation of this kind, achieved using an unconventional arrangement of laminates, is an example of aeroelastic tailoring for which our institute has been developing a variety of approaches for many years.

**Do you work with project partners from within Germany as well as abroad?**
: Correct. This is a field of both high academic and industrial importance. Aircraft manufacturers are very interested because as aircraft wings are made progressively more lightweight – such as through the use of fibre composites – they will experience increasingly large deformations and will require new structural designs. One important area of research currently on the agenda is the use of new materials with unconventional properties. We develop new approaches within internal projects across multiple DLR institutes, within the aviation research programme in collaboration with Airbus, and in national and international cooperation with research institutes and universities such as Technische Universität Braunschweig (TU Braunschweig), ONERA (France), Delft University of Technology (TU Delft, Netherlands) and the University of Michigan (USA).

The interview was conducted by **Christine Unger**, editor at the DLR Institute of Aeroelasticity.


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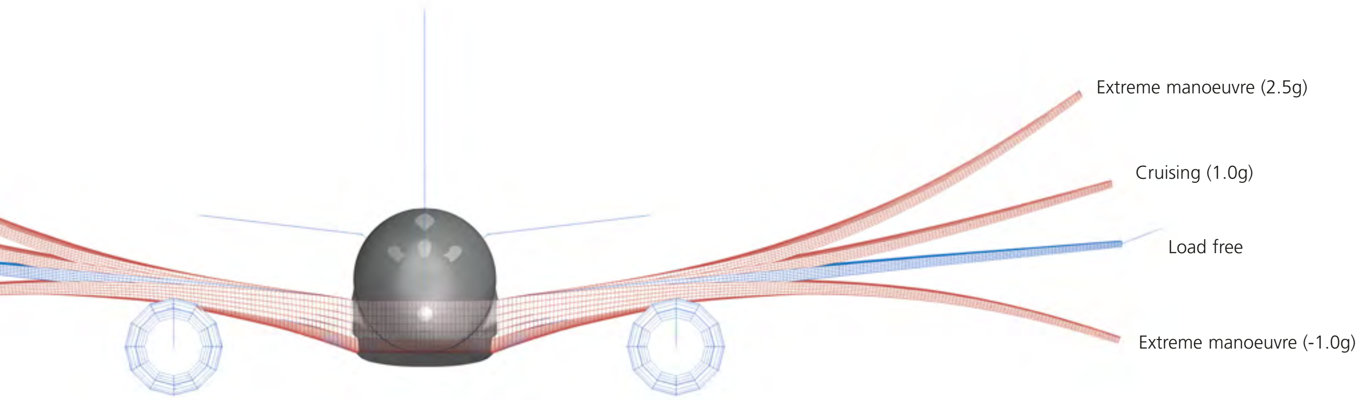
The X-HALE light aircraft was developed and tested at the University of Michigan and tested in collaboration with the DLR Institute of Aeroelasticity using new simulation methods.




This simulation shows how an aircraft wing deforms during flight. 'g' represents the force relative to the strength of gravity.

## DLR INSTITUTE OF AEROELASTICITY:

The DLR Institute of Aeroelasticity deals with physical phenomena that occur in nature and engineering, particularly in aircraft. Researchers study the interaction between aerodynamic forces and elastic structures such as aircraft wings, which deform and vibrate when forces act upon them. These effects impact the design and operation of aircraft. Researchers at the Institute calculate aeroelastic behaviour using numeric analysis methods and then carry out wind tunnel and flight tests to validate their calculations, all in order to improve the safety and performance of new aircraft designs.

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The wing flex of the Concordia glider is clearly visible in flight

## GLOSSARY:

**Aeroelastic Tailoring:** A method for designing wing structures where specific features of the material, such as directional stiffness, are specifically exploited to reduce the loads that act on an aircraft in gusts of wind and when manoeuvring. This method is extensively used for fibre composites.

**Carbon fibre-reinforced polymers (CFRP):** Composite carbon fibre materials contained in a resin. The direction in which the carbon fibres are laid determines the stiffness of the material and can be adapted to different load directions.

**Finite element software:** Computer software for structural analysis and investigating the aeroelastic properties of aircraft. The model of the structure being investigated is divided up into many simple objects, such as small beams, sheets, cuboids or tetrahedrons, which are known as 'finite elements'.

**Multibody simulation software:** Computer software used in vehicle development and the design of wind turbines. It represents dynamic systems as a combination of individual bodies that are flexibly joined by springs or other forces. This method is particularly suitable for analysing large rotations.

**Non-linear structural deformations:** In linear deformations, the deflection is proportional to the force applied – if the force is doubled, the deflection also doubles. This is a good approximation when the force applied is small. With greater force, the ratio of the force applied to the deflection is no longer proportional, and the direction in which the structure deforms may also change under greater forces.

**Forward-swept wing:** To allow high-speed flight, aircraft wings are not positioned at right angles to the body but are 'swept' backward or forward. In conventional commercial aircraft, the wing points, or is 'swept', backward. Forward-swept wings are unusual, but they have many advantages and are therefore studied in many DLR projects.