Modern construction methods and adaptive processes will reduce the manufacturing and operating costs of future high-performance aircraft. The days when the cost of a combat aircraft was secondary as long as it fulfilled the required performance levels for speed, rate of climb and armament have long since passed.

Nowadays, even high-performance planes have to combine improvements in performance over predecessor models with savings in manufacturing and operating costs. Under the “Advanced Aircraft Structures” project – whose participants include the Military Aircraft business unit of Daimler-Chrysler Aerospace (Dasa), DaimlerChrysler Research and Technology and the German Aerospace Research Centre (DLR) – new technologies for cost-efficient construction and manufacture are being developed, along with methods of monitoring structural damage and techniques for integrating vibration-damping components.
Fibre-reinforced composites based on glass fibre or carbon fibre have been used for a considerable time in modern high-performance aircraft. Up to now, fibre-composite components have mainly been produced using prepregs – fibre fabrics impregnated with resin. Single prepregs measuring only about one-eighth of a millimetre are placed one on top of the other until the required component shape is achieved, and are then cured in autoclaves.

Although prepregs still represent the most weight-efficient method for producing carbon-fibre reinforced structures, they entail a number of disadvantages. Firstly, the prepregs are susceptible to ageing, because after production they have to be stored in a refrigerator and used within a certain time limit. Also, the prepreg method is not very amenable to automation, and therefore requires a high proportion of manual effort.

As an alternative, work is being conducted on pre-shaping the fibres or fibre fabrics that absorb the forces acting on the component before the resin is added (preform). It is estimated that this approach will achieve cost savings of up to 30 percent – albeit with a slight increase in weight. The techniques applied originate to a large extent in the textile industry. The fabrics are cut precisely to size, draped, and if necessary sewn to ensure that the right shape is retained. Sewing not only prevents individual layers of fabric from slipping, but can also be specifically applied to reinforce components three-dimensionally by connecting the different fibre layers with each other. This prevents for example the delamination that occurs particularly after impact or shock, where the composite material disintegrates.

Under the project, a Eurofighter fuselage shell, a typical carbon fibre reinforced component, was modified so that the supporting ribs could be produced using the preform technique, while the conventional prepreg method was retained for the skin.

The advantages of the preform method can be fully exploited on elements such as the intermediate struts, which are relatively difficult and therefore expensive to produce using prepreg because of their shape – their curvature requires numerous individual layers. Because it was necessary to use a prepreg material qualified for acceptance on the Eurofighter, the resin was introduced by film infusion, in which plates of resin film were applied to the prefabricated component, heated and cured. At the DLR, an alternative process was investigated whereby a component similar to the fuselage shell was produced exclusively using the resin-infiltration preform method. Here, under pressure and in a vacuum, the resin was inserted into the shell and into the stiffeners. Resin infiltration technology enables the use of completely different semi-finished textile products that were not feasible before. Applying techniques from the textile industry (embroidery, etc.), spars or entire profiles, for example, can be produced in fibre-composite material and in some cases even prefabricated.

Vibration damping. Past editions of our magazine have dealt in detail with adaptive systems in connection with the ADIF adaptive wing (Aerospace 1/98) and AROSY (adaptive rotor systems, Aerospace 1/99) projects, and have also described the functioning of the piezoceramic elements mentioned in the following sections.

Under the Advanced Aircraft Structures project presented here, work is being conducted on adaptive vibration damping and on the complex issue of variable-form wings.

The subject of adaptive equipment installation is also addressed, but this has something of an exceptional position in the project as it is being dealt with exclusively by Dasa through contracts awarded to the company ERAS GmbH (development and implementation of adaptive systems).

In a combat aircraft, relatively high vibrational stresses prevail which are anything but ideal conditions for the sensitive electronic and optical devices on board. While rigid installation would, for example, hold a computer firmly in position, it would also expose it to any vibration that occurs. On the other hand, if the computer were mounted using passive vibration dampers in a “soft” layout, it would be completely insulated from environmental influences, but would possibly be subject to excessive movement.
In view of the confined space and the resulting risk of damage, this also would not be an ideal solution.

Passive damping systems display the unfavourable characteristic that, while the damping effect does improve at higher frequencies, they undergo relatively high deflections in the range of their natural frequency. The aim of the project was therefore to achieve a combination of passive damping for high frequencies and of active, adaptive damping for low frequencies. Like the active gearbox suspension assembly on helicopters (cf. AvenueSpace 1/98), appropriate deflection of the active elements - electromagnetic linear motors (two per axle) that also compensate rotation - work out of phase with the disturbance to ensure that the vibrations are not transferred from the airframe to the sensitive equipment. A demonstrator developed in cooperation with the ERAS company has proved the suitability of the concept in principle.

Adaptive vibration damping, applying a comparable principle, is a damping concept in which vibration disturbance is eradicated by means of variable form wing skin of the component affected, vibrations that occur at high angles of attack on the rudder unit can be combated. The American F-18 fighter/attack aircraft, for example, has to be inspected for possible damage to the rudder every 200 flying hours as a result of such vibration.

For the project, tests were conducted on an active (auxiliary) control surface which is moved to produce the right phase shift. Its effectiveness has already been verified in wind-tunnel tests. Two processes suggested by the Dasa Military Aircraft business unit and the DLR, which envisages the application of piezo-ceramics either on or into the control surface structure and the installation of two active interfaces at the base of the control surface, hold similar promise. Both concepts were tested using a box measuring roughly two metres in height and 80 centimetres in width, whose structure and weight reflected the ratio on a real rudder unit. 2,400 piezo-ceramic elements - combined into four boxes in relation to each other, the triangles remain flat, so that the wing, the rigid wing ribs which give the wings their profile have to be replaced by movable elements, to this end, three approaches are currently being examined. In the belt concept, developed by the DLR, the rib consists of a closed and flexible outer shell - the belt - which is firmly connected with the wing skin, and several spokes flexibly linked to the belt. Dasa proposes a V-web concept in which a continuous, elastic and therefore variable-form wing skin is stiffened by webs arranged in a Y-shape in the longitudinal direction of the wing. The vortex concept is proposed as an alternative, where individual, virtually triangular boxes running span wise are flexibly linked together. The adjoining surfaces of the triangles remain flat, so that the wing surface appears to be faceted. By adjusting the boxes in relation to each other, the shape of the wing can be changed.

For all the processes mentioned, various drive concepts are currently being developed.
Health check. The Advanced Aircraft Structures project is also addressing the subject area of Composite Health Monitoring, in which the condition of fibre-composite materials is checked and any damage detected. As already mentioned, scarcely visible damage can be caused to fibre-composite structures by impacts, damage that can have considerable effects on the aircraft structure.

Two different concepts have also been pursued here. Dasa proposes that acoustic piezoceramic sensors distributed over the aircraft be used to measure the structure-borne noise of an impact, and in the ideal case determine the location and extent of the damage by frequency analysis (acoustic impact recognition). To ensure firstly that the noise produced on impact is not masked by ambient noises, both ambient and impact noises were measured on a modified Tornado main landing gear well flap made of carbon-reinforced plastic. The result is quite promising: The signals emitted by impacts causing damage are at least 25 dB higher than the interference noise; in the frequency range above 30 kHz, which is important for damage analysis, the difference is as much as 48 dB.

The DLR assumes in its proposal that future combat aircraft will in any case be equipped with sensors and actuators integrated in the aircraft structure (structurally dynamic damage analysis). Damage to the structure changes the vibration characteristics, so the existing sensors could be used to identify the vibration spectrum and determine the modal parameters of the aircraft (frequency, damping). Damage information obtained by computer simulation could be collected in a database and used to indicate the frequencies and damping to be expected under specific external influences. This information could then be used during the flight to verify the location and type of any damage.

Further methods for recognition of structural damage could include impact-indicating paint and plastifying optical fibres. The optical fibres are integrated in the fibre structure. On deformation of the structure after an impact the plastifying optical fibre lengthens, and the increased distance travelled by the light can be used as a measure of the damage.

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