PLASTICS: THE NECST GENERATION

Saab and MIT are developing ”post-graduate” carbon nanotube-reinforced plastics.

PONTUS NORDIN (text)
ENRIQUE J. GARCIA,
BRIAN L. WARDLE (computer imaging)
GUNNAR LINN (illustration)

– I want to say one word to you. Just one word.
– Yes, sir.
– Are you listening?
– Yes, I am.
– Plastics.
– Just how do you mean that, sir?
(Excerpt from The Graduate)

* **”PLASTICS.”** The one-word career advice given to Dustin Hoffman’s young movie character Benjamin in the 1967 film The Graduate. Back then, aircraft were built from aluminium alloys. The first commercial carbon fibres had just been introduced as very expensive engineering materials for special military applications. Glass-fibre composites were still considered advanced, but did not have enough stiffness for structural applications in high-performance aircraft. The Graduate pointed to the future of materials engineering with a bull’s-eye prediction. ”Plastics.”

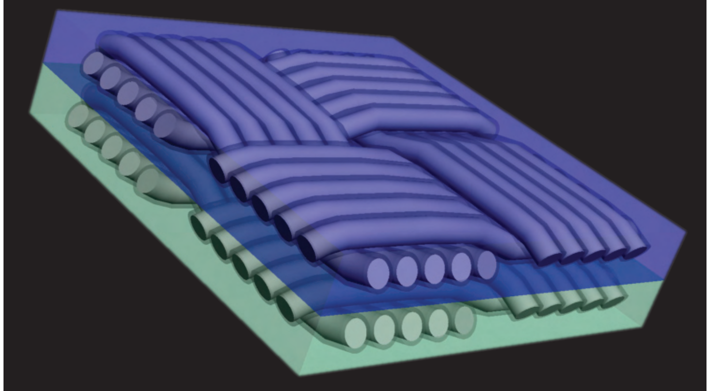
Forty years later, that prediction holds true; carbon-fibre-reinforced plastics (CFRP) now comprise over 50% of the airframe structure of next-generation commercial airliners and military air vehicles. And the next-generation polymeric aircraft materials include nanosized functional additives, in the form of multiwall carbon nanotubes (MWCNT). These MWCNTs – many thousand times smaller than the human hair – aligned and arranged in sophisticated patterns will form engineered nanocomposite materials and structures with far more superior and multifunctional properties than any aircraft material in use today.

Saab has teamed up with Massachusetts Institute of Technology (MIT), where we now define the next generation CFRP with improved fracture toughness, compression strength and bearing strength of bolted joints, just to mention a few potential improvements over today's best aircraft engineering materials. In 2007, the keyword for a prediction of future structural plastics is ”nano”.

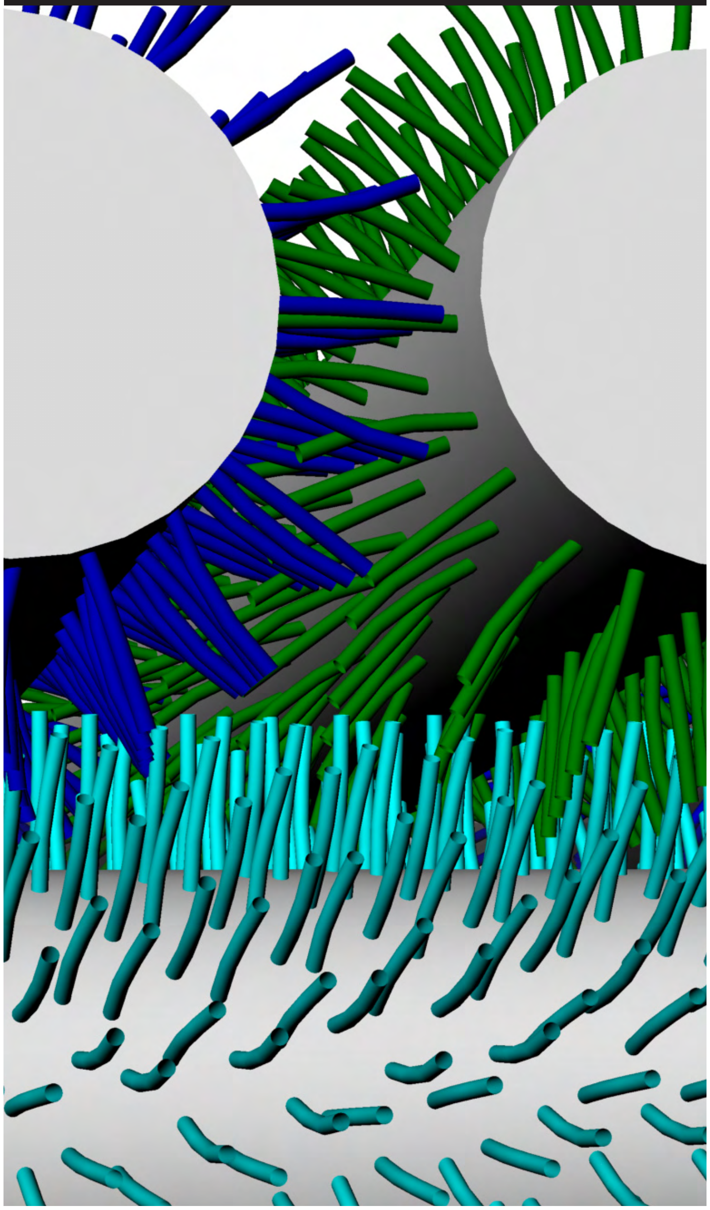
Our collaboration with MIT is called the Nano-engineered composite aerospace structures consortium (NECST), and was initiated in 2006 by Professor Brian Wardle, Technology Laboratory for Advanced Materials and Structures (TELAMS), Department of Aeronautics and Astronautics at MIT. The consortium's current members include Saab, The Boeing Company, EADS/Airbus and Embraer. Saab has carried out in-house work on carbon-based nanocomposite materials since 1999, primarily in cooperation with material suppliers and our strategic partner Bodycote Materials Testing, based in Linköping, Sweden. Our participation in the NECST consortium fits our plans for next-generation structural composite materials very nicely.

TODAY, SAAB USES a number of polymeric composite materials, most of them based on carbon-fibre-reinforced thermoset (heat-curing) resins such as epoxy. These composite materials have been defined and standardized by Saab or by our partners in aircraft development projects, primarily Airbus and Boeing. The most common form of CFRP used by Saab is unidirectional prepreg (preimpregnated with resin) tape with all carbon fibres running in one direction in each individual layer, typically no more than 0.13 mm thick. The arranged layers of prepreg, laid up on precise curing tools in engineered stacks, are baked in pressurized ovens called autoclaves, to form the integrated cured laminate structures that, to a large extent, aircraft are built of.

The CRFP materials used by Saab perform just as well as expected and have resulted in significant mass savings for airborne platforms such as the Gripen fighter. However, in order to achieve these mass savings, airframe designs based on CFRP materials must always take full advantage of the anisotropic nature of fibre reinforced materials, which means that the strong and stiff carbon fibres should always be oriented along the primary load paths in the structure, and – if possible – only there. In an optimized CFRP airframe design, fibre-controlled material properties such as high stiffness and strength can typically save 10–15% weight over isotropic materials such as aluminium alloys. Correspondingly, the matrix-controlled mechanical properties of a CFRP design will often limit the use of airframe composites to applications where out-of-plane loads are sufficiently low or where other conditions will favour a fibre-controlled laminate skin design. This means that CFRP laminate characteristics such as damage tolerance, interlaminar shear strength, bolt-bearing strength, heat distortion temperature and other composite material properties primarily controlled by the matrix phase (the cured resin) will determine the minimum laminate thickness in some



Interlaminar (between layers) and intralaminar (within one layer) reinforcement of CFRP by aligned and oriented MWCNTs under development in the NECST consortium. Detail below.



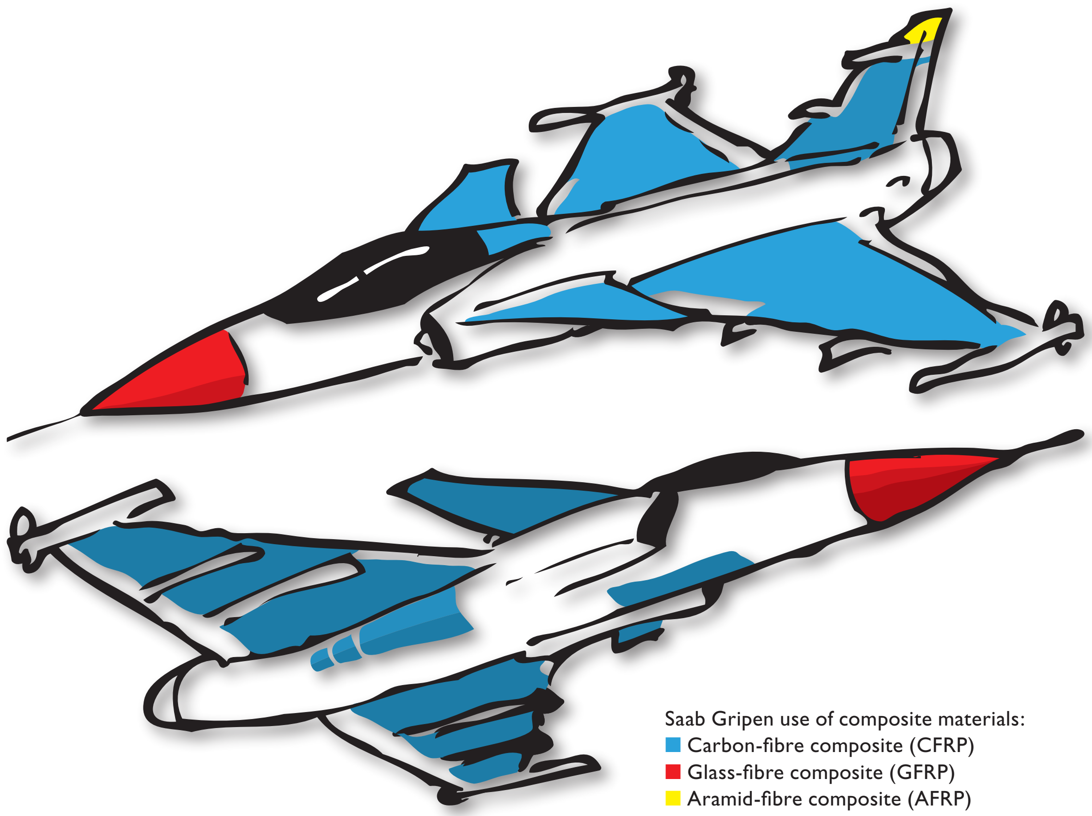
applications, and even exclude the use of fibre composites in other. To put it simply, the matrix material and the related composite laminate properties can be seen as the weakest link in the CFRP composite materials for airframe applications currently used.

CARBON FIBRES – the stiff, strong reinforcing fibres used in many composite materials for aerospace, off-shore and sport equipment – have a diameter of five to eight micrometers. Approximately 1,000 times smaller in diameter, MWCNTs are far more superior to carbon fibres in terms of mechanical, electrical and thermal properties. The mechanical properties shown in the separate table make MWCNT the strongest material known to man. In addition, its electrical conductivity is better than that of copper.

Significant technical challenges associated with MWCNTs are related to the current cost and quality of nanotube production, and difficulties in handling and manipulation of nano-sized tubes with a length-to-diameter ratio of approximately 1,000. Orientation, alignment and impregnation of these separately produced MWCNTs must be carried out using well-defined industrial processes with very good repeatability and high quality of the resulting nanocomposite materials. Separately produced carbon nanotubes are very difficult to disperse in a polymer or a solvent, and it is therefore also difficult to produce well-performing nanocomposite materials efficiently using MWCNT as the functional additive. Mechanical mixing simply will not work, and the chemical processes in use currently range from poor to promising at best.

IF SUCCESSFUL, THE parallel technology development carried out in the NECST consortium offers attractive alternative, or complementary, solutions to dispersion of separately produced nanotubes in the matrix phase of CFRP. NECST is developing scalable industrial processes where the MWCNTs are produced nearly in situ, that is in the correct position and orientation where they will be used in the composite material. The nanotubes are grown as ”forests” of aligned and oriented MWCNTs for optimized mechanical or electrical performance, thereby eliminating the need for complicated additional handling and manipulation.

The improved weight efficiency of structural airframe composites offered by MWCNT, maybe in the order of 10 %, is nothing short of a materials revolution; comparable to the introduction of carbon fibres some 40 years ago. However, the timing and cost efficiency of this material introduction is more uncertain. The three-year NECST research project at MIT and ongoing Saab activities will provide some of the answers, as will other parallel development activities with similar goals in the international aerospace community.



Pontus Nordin
Technical fellow,
Saab Aerosystems
pontus.nordin@saab.se
+46 13 18 30 37

Professor Brian Wardle has declared his interest in dwelling upon interesting implications of NECST technologies in a future issue of Transfer.

MECHANICAL PROPERTIES OF MWCNT AND ITS COMPETITORS

Material	Young's modulus [GPa]	Tensile strength [GPa]	Density [g/cm^3]
MWCNT	1,200	150	1.3–1.4
Carbon fibre	230	7	1.8
Steel	210	0.4–2	7.8
Aluminium	70	0.5	2.7
Epoxy	3.5	0.02	1.3