CHALLENGES FOR INSERTION OF STRUCTURAL NANOMATERIALS IN AEROSPACE APPLICATIONS

E. J. Siochi

NASA Langley Research Center, Hampton, Virginia 23681, U. S. A.
**emilie.j.siochi@nasa.gov*

Keywords: carbon nanotubes, aerospace structures

Abstract
In the two decades since Iijima's report on carbon nanotubes (CNT), there has been great interest in realizing the benefits of mechanical properties observed at the nanoscale in large-scale structures. The weight savings possible due to dramatic improvements in mechanical properties relative to state-of-the-art material systems can be game changing for applications like aerospace vehicles. While there has been significant progress in commercial production of CNTs, major aerospace applications that take advantage of properties offered by this material have yet to be realized. This paper provides a perspective on the technical challenges and barriers for insertion of CNTs as an emerging material technology in aerospace applications and proposes approaches that may reduce the typical timeframe for technology maturation and insertion into aerospace structures.

1 Introduction

1.1 Carbon Fiber Reinforced Polymer Composites

Carbon fiber reinforced polymer composites (CFRP) are the state-of-the-art material systems for lightweight aerospace structures because their strength–to–weight ratio translates into structural weight savings that are critical in this application. Figure 1 shows the specific strength and specific modulus of materials typically used for aerospace structures [1]. Carbon fibers such as IM7 and M46J possess specific mechanical properties that are approximately an order of magnitude greater than aluminum. However, current CFRPs fabricated from these fibers have bulk, macroscale properties far lower than the potential promised by carbon fibers. Defects introduced during processing and manufacturing and/or damage incurred during service life result in severe knockdowns in properties from theoretical to demonstrated properties. These flaws, together with poor interlaminar properties, yield reduced strength and stiffness in the CFRPs as compared to the carbon fibers themselves. To compensate for the reduction in mechanical performance, current practice is to add lamina with off-axis fibers to reduce the potential for laminate splitting and crack propagation. Furthermore, the standard design approach conservatively uses reduced strength and stiffness values to increase factors of safety. Between standard manufacturing practices of adding lamina and high penalties assessed in the design cycle in the form of knockdown factors, the end result is heavier structures, thus negating the mass advantage of CFRPs.

1.2 Carbon Nanotubes

In 1991, Iijima reported the synthesis of carbon nanotubes (CNTs). He also noted the potential for these materials to be engineered to scales required for practical applications [2].

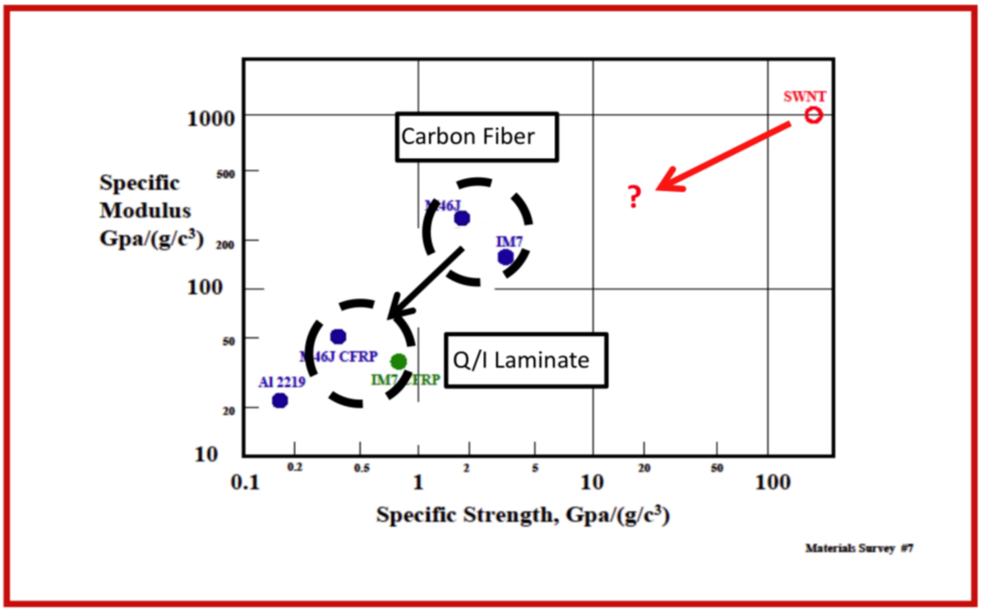

Figure 1. Comparison of mechanical properties for materials used for aerospace structures [1].

The carbon-carbon bond in CNTs is a delocalized aromatic bond with bond order of 1.5, between a carbon-carbon single and double bond. This type of bonding, combined with the nanoscale tubular configuration of CNTs, imparts an unprecedented combination of attractive properties to this material, suggesting the potential for revolutionary payoffs in applications such as aerospace structures where lightweight structures are critically important. Further, it has been noted that the current carrying capacity of CNTs exceeds that of copper, and its thermal conductivity is close to twenty times better than aluminum. This combination of electrical and thermal properties, along with extremely high theoretical mechanical properties, has garnered significant interest for use in many structural applications.

2 Challenges and Barriers for Maturation of CNT Structures

The insertion of CFRPs in commercial aircraft evolved over five decades from the time carbon fibers were discovered in 1958 to its current peak where it constitutes 50% of the total weight in Boeing's 787 Dreamliner [3,4]. Are the challenges for insertion of CNT in structures similar to those encountered with CFRPs? If so, are there lessons to be learned from the CFRP development experience?

Iijima's publication spawned significant interest in CNTs. A survey of the literature reveals the exponential surge in publications involving carbon nanotubes following Iijima's publication, especially spurred on a decade later by the United States' government investment in nanotechnology with the launching of the National Nanotechnology Initiative in 2001 [5]. A search for CNT-related papers reveals that there were over 94,000 papers published on this topic between 1991 and 2011. Although mechanical properties of these nanomaterials have often been cited as enablers for game changing concepts, a majority of the papers published are focused on the electrical properties of CNTs. A further analysis of the literature, as shown in Figure 2, reveals that of the approximately 12,000 papers devoted to the study of CNT composites, only about a quarter are dedicated to understanding how the mechanical properties determined at the nanoscale translates into superior performance in structural materials at the macroscale. There has been greater success in demonstrating the enhanced electrical performance enabled by CNTs, while doing the same for mechanical performance has been comparatively more challenging.

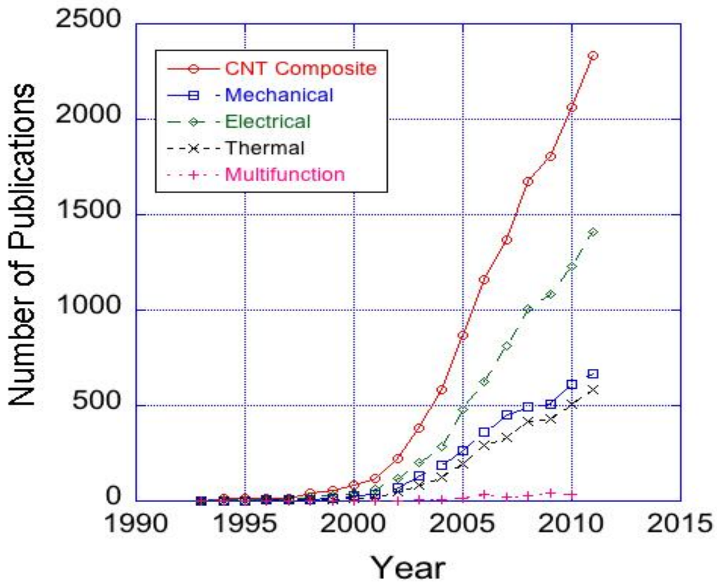

Figure 2. Analysis of carbon nanotube composite literature.

Strides have been made in the commercialization of CNTs in the past decade; however, as with other nanostructured materials, challenges remain in translating basic discoveries to commercial products [6]. Chief among these barriers for CNTs targeted to aerospace applications is the lack of consistency in the quality of CNTs produced in quantities large enough to permit assessment of their utility. It should be noted that requirements for integration into aerospace applications are necessarily more stringent than in applications such as sporting goods. Regardless of the applications, it is unlikely for CNTs to displace CFRPs unless it can be demonstrated that CNTs provide decided performance advantages over the state-of-the-art at acceptable cost to warrant whatever changes need to be made in the established manufacturing/processing infrastructure.

3 Potential Solutions to Overcome Barriers and Challenges for Technology Insertion

If CNTs are to contribute more significantly to the advancement of aerospace structural design, there needs to be a more concerted effort to match system requirements with prioritization of key parameters that need to be addressed in the maturation of CNTs. Such coordinated development will require collaborative efforts that engage the entities along the vertical integration chain spanning suppliers, developers and application integrators. These relationships can be further enhanced by multidisciplinary efforts among scientists and engineers as illustrated in Figure 3, so that the tall poles for the maturation of this emerging technology can be addressed in parallel.

Having appropriate metrics to measure the progress of CNT maturation will likely contribute to shortening of the development cycle to integrate CNTs into aerospace applications. It is also important to understand the necessity of matching the availability of high quality CNTs in quantities necessary for serious consideration during critical structural design and manufacturing windows where decisions on materials choices are made.

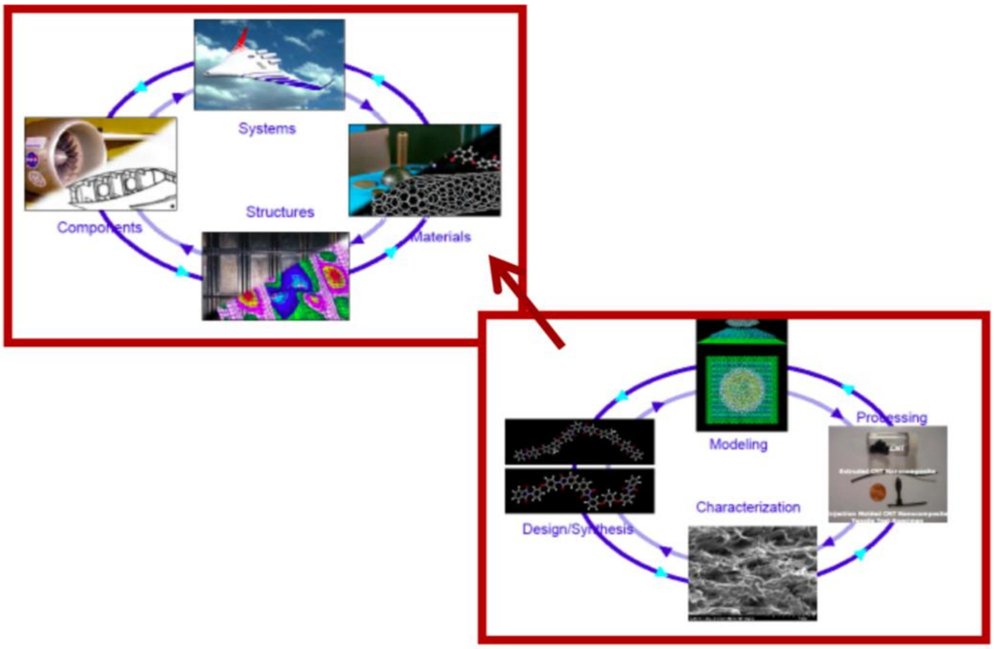

Figure 3. Computationally guided materials development for accelerated emerging technology development.

References

[1] Harris, C. E.; Shuart, M. J.; Gray, H. R. A Survey of Emerging Materials for Revolutionary Aerospace Vehicle Structures and Propulsion Systems. *NASA TM*, **2002-211664** (2002).

[2] Iijima, S. Helical Microtubules of Graphitic Carbon. *Nature*, **354**, pp. 56-58 (1991).

[3] Harris, C. E.; Starnes, J. H.; Shuart, M. J. An Assessment of the State-of-the-Art in the Design and Manufacturing of Large Composite Structures for Aerospace Vehicles. *NASA TM*, **2001-210844** (2001).

[4] 787 Dreamliner Program Fact Sheet, http://www.boeing.com/commercial/787family/programfacts.html.

[5] President's Council of Advisors on Science and Technology. Report to the President and Congress on the Fourth Assessment of the National Nanotechnology Initiative (2010).

[6] President's Council of Advisors on Science and Technology. Report to the President and Congress on the Fourth Assessment of the National Nanotechnology Initiative (2012).