Aerospace

Aerospace R&D activities utilizing CNTs include protective coatings, thermal management systems, composites, and energy storage related applications. CNTs are especially suited to aerospace applications that include aircraft braking systems (carbon/carbon composites), thermal management, electromagnetic interference (EMI), radio frequency interference (RFI), electrostatic discharge (ESD), lightning strike and composite applications.

APPLICATIONS AND ESTIMATED TIME TO MARKET

- Structural monitoring sensors (3-5 years)
- CNT EMI/RFI shielding (Commercialized)
- Polymer composites (Commercialized)

MARKET POTENTIAL

Market drivers

Due to the risks involved in flying, aircraft manufacturers are striving to make the aerospace components stronger, tougher, and longer lasting. The industry is also seeking to reduce weight in an on-going bid to reduce fuel consumption and, by extension, operating costs. Further, pressure for air travel to be 'greener' has also come to bear. Nanomaterials are utilised in the aerospace industry for improved (or tailored) properties that improve their functional performance (e.g. mechanical or electrical properties) or that deliver multi-functional properties (e.g. lightweight conductive nanocomposites). The bulk of R&D into aerospace applications of nanomaterials at present focuses on structural reinforcement of composite materials. Nanomaterials will potentially allow for the development of lighter, high-performance, robust and cost-efficient, multi-functional aircraft.

CNT applications under development for aerospace applications include composites for lightweight structural components as well as electromagnetic interference (EMI), radio frequency interference (RFI), electrostatic discharge (ESD), de-icing, anti-fouling, lightning strike protection, anti-corrosion and fire-resistant coatings.

The cost benefits of utilizing CNTs are are high in aerospace markets:

• Satellites: weight savings equates to launch cost savings
• UAVs: weight savings equates to savings equates to mission time
• Aircraft: lifetime cost savings for an aircraft is equated from fuel savings.

COMPOSITES

Aerospace composites market: $2.5-$3 billion.
Developmental stage: Commercialized for ESD.

Over the last 20 years the use of composite materials, including carbon fibre reinforced composites has increased in aerospace. These materials are becoming more popular due to their light weight, high strength and corrosion resistance, which has lead to enhanced performance and fuel cost savings. Driven by the high price of oil and concurrent fuel costs, airlines have sought solutions to more efficient aircraft. As a result, the aerospace industry is becoming increasingly dependent on carbon fiber composites, which are lighter and stronger than conventional metals, making them perfect materials for lighter, fuel-efficient jets. They are also in high demand for land and marine vehicles.

It is anticipated that aerospace demand will at least double over the next decade. Overall market demand is forecast to be 1.5-1.8 million tonnes/year by 2023.

CNTs in aerospace composites

CNTs have been incorporated into the NASA Juno spacecraft and other aerospace component applications. Nanocomp Technologies CNT sheet, EMSHIELD, was incorporated as a surface layer on several critical components of the Juno spacecraft, launched in August 2011, to provide protection against electrostatic discharge (ESD).

Nanocomp's Technology is also applied in aerospace cabling, as the substitution of copper with CNT can significantly reduce the weight of aerospace cables. CNT yarns and sheets have been fabricated into braided constructions for conductors and shielding tapes for key electrical cable components.

CNT composites have also been developed for braking applications in the aerospace and aviation industry. Physical and tribological properties are affected considerably by the CNT content in a friction material. CNT-added friction materials showed improved fade resistance and friction stability. CNTs decrease the friction force oscillation during brake application, which was attributed to the increased damping capacity of the friction materials. CNTs decrease the friction effectiveness owing to the lubricating nature of undispersed CNT bundles, and decrease the thermal conductivity of the friction material due to interfacial coupling effects.

COATINGS

Global aerospace and aviation coatings market: $500 million

Developmental stage: Prototype/proof of concept.

Market drivers

Coatings are generally used in the aerospace industry for protecting the structures and surfaces of the aircraft from harsh environments. Stringent regulatory and technological requirements such as resistance to extreme temperatures, extreme climates, corrosion, abrasion and wear of engine parts have lead to an increased demand for more reliable high performance coatings. Nanostructured coatings have been applied in aviation and aerospace for improving the life span, reliability and durability of components; erosion, sliding and wear resistance; improving surface quality; de-icing; and corrosion resistance against pitting, peeling, oxidation and heat. Coatings are currently being developed to detect corrosion and mechanical damage to aircraft skin; react to chemical and physical damage, improve adhesion, and increase the life span of metal parts. Nanocoatings reduce maintenance, decrease life cycle costs, and increase readiness by limiting equipment downtime through exhibiting over six times more protection than conventional coatings. Desirable functional properties for the aerospace and aviation industry afforded by nanomaterials in coatings include:

- Reduced weight and increased strength (carbon nanomaterials)
- High temperature control/resistance (SiC Nanopar-

ticles in SiC-particle-reinforced alumina, Yittria stablized nanozirconia)
• Electrostatic discharge, EMI shielding and low friction (CNT, graphene, nanoaluminium, copper, iron, silver nanoparticles)
• Corrosion/Wear Resistance (silica nanoparticles, aluminium, Nanorystalline Carbide, Diamond like Carbide and metal dichalcogenide, TiN nanocrystallites embedded in amorphous Si3N4, graphene)
• Easy reparability & reusability
• Less maintenance & increased durability.

CNTs in aerospace coatings

A number of aerospace companies and agencies are developing CNTS and graphene coatings to add special characteristics to aircraft frames and interior and engine parts and component surfaces, which can include properties such as: self-cleaning; de-icing; anti-fouling; improved hardness; wear and corrosion resistance; improvement in fuel efficiency; and improved thermal performance and flame retardancy.
CNTs and graphene are seen as an alternative to the more traditional carbon black/graphite or metal particle additives; their high conductivity and high aspect ratio result in the formation of percolated conductive networks within coatings at very low loadings.
According to the Environmental Protection Agency, 25 million gallons of deicing agents are applied to aircraft at U.S. commercial airports each year. The aviation industry is also using energy-intensive pneumatic and electric anti-icing systems on aircraft to prevent ice formation on wings and other surfaces. GE are one of a number of companies developing anti-icing nanocoatings that reduce ice adhesion and have also been shown to delay the onset of ice formation. Battelle has also developing anti-icing coatings incorporating CNTs. Another development is the deployment pf CNTs as anti-icing coatings on unmanned aerial vehicles (UAV) in military applications. Current de-icing methods are not compatible with aircraft as small as UAV's. They are generally more complex, heavier, and require more power. De-icing technology utlizing CNTs is significantly lighter than other de-icing systems. Application aslo utilizes simple painting methods-coating the surface of the aircraft with a fibrous, CNT-enhanced coating that prevents ice from building up on the area of application (http://136.142.82.187/eng12/Author/data/2122.docx). The EU-funded SANAD project is combining graphene with CNTs to make a coating for planes that can be connected to the electrical system and heated up to stop the build-up of ice. SAAB has also filed a patent for the development of de-icing coatings. The graphene additive could strengthen the acrylics and shield against EMIinterference.

SENSORS

Aerospace sensors market: $200-$300 per annum.
Developmental stage: Applied research.

Radiation-resistant CNT-based semiconductor devices have been developed to withstand the rigorous conditions of space. Nanotube sensors could be used for early detection, exhibiting electronic properties that vary in response to a predetermined molecule, for increased passenger safety in aircraft.

PRODUCT DEVELOPERS

Buckeye Composites

Conductive elastomers for aerospace applications, non-metallic EMI shielding for electronic enclosures, lightning strike protection of composites, ionic liquids for lubricants, greases, and single phase thermofluids for extreme environments. www.buckeyecomposites.com

General Nano LLC

Manufactures long, aligned, pure Carbon Nanotube (CNT) materials for aerospace and defense applications seeking improved mechanical, electrical, thermal and optical performance. www.generalnanollc.com

M.E.R. Corporation

The company's fullerenes are utilized in composite materials showing exceptionally high-strength and lightweight structure materials for aerospace and military applications, and conductive flexible films for electrical and thermal management applications. www.mercorp.com

Minnesota Wire

The company produce lightweight CNT-enhanced cables with potential applications in aerospace. www.mnwire.com

Mitsui Chemicals America, Inc

AURUMTM CNT Grade is a dust-reducing, high-antistatic nanocomposite consisting of thermoplastic polyimide and carbon under the trade name AURUM CNT Grade. Thermoplastic polyimide is used for applications such as automotive parts, aviation engine parts and the processing jigs for semiconductors. www.mitsuichemicals.com

Nanocomp Technologies, Inc.

The company's proprietary product is the CTex™ CNT yarn and CNT mats. Main application markets are in aerospace and aviation markets for nanotube materials to save weight in a variety of complex systems, as well as to provide electrostatic discharge (ESD) and electromagnetic interference (EMI) shielding components. www.nanocomptech.com

Nanocyl

AquaCyl™ incorporates CNTs in waterborne application systems (coatings, films). An example of application is antistatic coating. The dispersion contains an anionic surfactant for superior dispersion and stability. Nanocyl's NC 7000 series of multiwall CNTs is produced in multi-tons via chemical vapor deposition (CVD). The company claims that the use of exclusive catalysts during production makes the product the most electrically conductive carbon nanotubes available. The company's Plasticyl range of CNT thermoplastic concentrates is used for applications requiring electrical conductivity or protection from electrostatic discharge (ESD). www.nanocyl.com

Nanoledge

The NANO IN™ base resins product line demonstrates third-party-validated improvements in strength, flexibility, toughness, conductivity and material fatigue. The NANO IN integrated nanoparticles create/improve conductivity, strength, flexibility, toughness, chemical resistance, compression & fatigue of materials. Main applications are in Sporting Goods, Wind Energy and Aerospace industries. www.nanoledge.com

Nemcel Ltd

Developing EMI/RFI shielding materials. www.nemcel.fi

Table 10: Global revenue estimates for the aerospace and aviation market impacted by carbon nanotubes

Chemark Consulting	Aircraft coatings market 2008 USA: $140 million
Lucintel	Aerospace composites market 2011: $2.5 billon Aerospace composites market 2017: $4.9 billion
ORNL	Aircraft de-icing: $5000 per aircraft
Materials World	Thermal spray coatings market 2010: $1.35 billion
Modumetal	Global thermal barrier coatings market 2011: $3.75 billon
Department of Energy	Maintenance, repair and overhaul of aircraft engines estimated to be $29.2 billion in 2018
Bharat	Global demand for EMI/RFI shielding options is estimated at about $4.5 billion in 2011 and is expected to increase to $5.2 billion by 2016
Ceresana Research	Global flame retardant market 2018: $5.8 billion
BCC Research	Global flame retardant market 2008: $4.1 billion Global flame retardant market 2014: $6.1 billion
Teal Group	Unmanned Aerial Vehicles (UAVs) global market 2012: $6.6 billion 2020: $11.4 billion
Smart Structures, Inc.	Total global aviation market 2010: $618 billion
Aviation benefits beyond borders	Total global aviation market 2010: $618 billion
TechNavio	Global Aerospace Composites market 2016: $3.95 billion
Invest Korea	Global aerospace market 2010: $400 billion
Deloitte	Global aerospace industry 2009: $382 billion