CANEUS

CANADA-EUROPE-US-JAPAN WORKSHOP 2002
August 25 to 30, 2002

Hosted and organized by CLS3 (Centre for Large Space Structures and Systems) of Montreal, Canada, held at the CSA (Canadian Space Agency)

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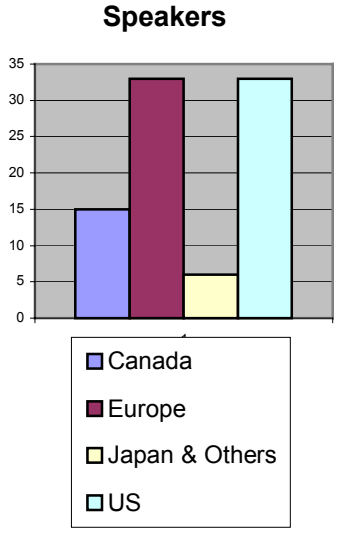
Report on the First Canada-Europe-US-Japan Workshop on Micro/Nano-Technologies (MNT) for Aerospace Applications

1. Executive summary

Canada, and in particular the CLS3 (Centre for Large Space Structures and Systems) in Montreal, together with the Canadian Space Agency and Canadian NanoBusiness Alliance several collaborating organizations from Canada, Europe, US and Japan, hosted and organized a historic and very successful CANEUS workshop.

The CANEUS workshop was a significant first step towards the creation of an international community of MNT developers for Aerospace applications. It has been long recognized that MNT promises what Aerospace applications need most: Low mass, size and power without loss of capability. However, Aerospace applications have not yet had the recognition they deserve from within the larger MNT community, in large part because of the perceived, relatively small market size.

Therefore, hand-in-hand with the creation of an Aerospace MNT community, a second major goal is the development of a coordinated strategy for international investment in MNT development for Aerospace applications. Thus, the first CANEUS workshop had the following objectives, which were met with, a great deal of success:



1. Assemble technical experts and programmatic decision makers from Canada, USA, Europe and Asia.
2. Catalyze research and development collaborations between the participating countries.
3. Identify and discuss strategies for focused MNT investment for Aerospace Applications.

Canada had the pivotal role, which it performed with tremendous skill, of bringing together researchers and practitioners from MNT and Aerospace organizations from across the world. The areas covered in the workshop were space, defense, aeronautics, geophysics and environmental control

Spanning a period of five days from August 25-30, 2002, the workshop covered 27 sessions with approximately 100 invited speakers from Australia, Austria, Belgium, Canada, France, Germany, Italy, Japan, Netherlands, Spain, Switzerland, UK, and the USA. In addition to these presentations, we were

fortunate to hear from two Nobel Laureates, Prof. Richard Smalley and Prof. John C. Polanyi.

With representation from over 200 of the world's leading authorities in aerospace and industrial R&D, as well as in the MNT research and investment sectors, the workshop provided a truly unique opportunity for technology exchanges and networking amongst participants and attendees representing a wide cross-section of industry, universities and government agencies. A series of outings, industrial tours and networking opportunities rounded out the event.

2. Technical topics

- **Devices & Systems**

  More than 10 papers were dedicated to Nanotechnology. Nanoscale materials production and characterisation methods as well as diverse applications of nanotechnology in electronics, space instrumentation, medicine and biology were presented in great detail. A large majority of the MNT presentations were given from the US and from Europe.

  An elegant definition of MNT was presented in a key-note address by NASA technologist, Dr. Minoo Dastoor, who stated: "MNT represents a bridge between classical and quantum physics". His point was that MNT is of interest not only because of the significant reductions in size that are possible, but mainly because one can now hope to exploit quantum mechanical effects in order to enhance device performance. For example, one could develop a new paradigm in microelectronics, taking the route of higher circuit complexity rather than pursuing further reductions in transistor dimensions. There was a very strong European contribution, with several papers in MEMS and MOEMS related topics: RF, gyroscopes, inertial platforms, bio-systems, optical devices, microthrusters and micropropulsion.

- **Space Missions**

  Detailed mission plans were presented by American, Canadian and European Space Agencies. Dr. Thomas George from NASA/JPL proposed an efficient means of advancing the "space maturity" of MNT via the use of low cost, rapidly launchable, ultra-low mass satellites (below 1 kg). He proposed the use of these Low Earth Orbit demonstrations at the very early stages of MNT development. This would not only speed up the development of MNT-based devices and instruments for Space applications, but also "build in" robustness and reliability at a very early stage of development. Dr. Henry Helvajian from the Aerospace Corporation showed that a simple 100g pico-satellite can be produced out of glass in 75 minutes! There were also papers from Canadian and European participants, describing missions to perform complex measurements with spacecraft masses in the range of few kilograms.

- **Reliability**

  Reliability was considered the critical issue for the ultimate insertion of MNT in Aerospace application. A considerable amount of work has been done in the area of MNT reliability in both the USA and Europe. Several key presentations in the MNT reliability area were from Europe. Dr. Sammy Kayali of NASA/JPL described the primary frustration of MNT reliability researchers as being the lack of sufficient numbers of parts for testing. Papers describing MEMS reliability test vehicles, non-destructive tests and nano-robotics were presented.

- **Geophysics and Environmental Controls**

  These sessions were concerned with the various techniques and instrumentation required to evaluate fossil energy and water resources. Prof. Richard Smalley, Nobel Laureate in Chemistry, described energy and water utilization as the most important issues for human civilisation during his keynote address.

  Several measurement techniques needed for oil exploration were presented with some examples of MNT applications. Satellite and ground observations of moisture and water reservoirs are of prime importance for agriculture and every day life. Water resources both in the fragile environments of developing countries as well as the highly polluted conditions of industrialised world require immediate attention and the rapid development of reliable monitoring techniques on scales ranging from local observation of pollutants to regional, continental and global assessment of hydrological processes. Monitoring global environmental processes are also potentially important targets for MNT-based technologies. For example, the detection of out-diffused hydrocarbon (methane) from melting permafrost areas of the Northern Hemisphere is extremely important for the study of green house effects. Deploying highly distributed, fully autonomous, miniature monitoring systems over large areas is a long-term goal of environmentalists. It became clear that thus far the exciting potential of MNT has remained largely unexploited in this domain.

- **Aeronautics and defense**

  MNT has already made extensive inroads into the aeronautics and defense sectors. Although a large number of opportunities exist for novel MNT-based sensors and actuators in aircraft applications, there remains a considerable amount of work yet to be done, as described in the presentation by Dr. Hany Moustapha of Pratt & Whitney. Prospects for the

introduction of MNT into this highly demanding (in terms of functional and operational requirements) application area continue to be very bright.

- **Policy/Strategy and commercialisation**

  Strategic presentations were given by a number of speakers from the NASA and DARPA. Dr. Thomas George of NASA/JPL urged the participants to consider the fact that given a relatively small worldwide investment into MNT for Aerospace applications, the time had come to consider a coordinated, international investment strategy. However, such a strategy could only succeed on a foundation of inter-governmental agreements aimed at the free flow of Space MNT between participating countries. Thus, the coordinated investment strategy would involve targeting each nation's core competencies for focused, "critical mass" funding. Taken as whole, these core competencies would be complementary and allow for the creation of a technology "pipeline" for the rapid infusion of new MNT-based devices and instruments in Space. The European MNT scenario was described by Dr. Gaetan Menozzi. Dr. Menozzi described the role of MNT in the 6th Frame Programme, objectives of MINATEC, functioning of the EURIMUS/EUREKA Programme and the Nexus / User-Supplier Club goals.

3. Conclusion

In summary, the CANEUS conference was a great success. Not only did we achieve the stated primary objectives, but we went significantly beyond them by creating a unified MNT-for-Aerospace community across the USA, Canada, Europe and Asia. For its part, Canada can be proud of bringing together a truly historic gathering of technical experts and decision makers from across the various participating countries. It is recommended that the following future actions be taken by governmental policy makers from the participating CANEUS countries:

Recommended future policy actions:

1. Set up inter-governmental agreements that will serve as the basis for future collaborations and ensure the free flow of Aerospace MNT between participating countries.

2. Identify the areas of complementary, core expertise within each nation, which can be seamlessly integrated into the "technology pipeline" for Aerospace MNT.

3. Develop both a ground-based and space-based MNT reliability testing protocol that will benefit from the Space technology pipeline.

4. Implement low cost, rapid launch space testing opportunities that can advance Space MNT development far more rapidly than is currently the case. In this way, there is a dual benefit of realizing the Return-on-Investment (ROI) quicker as well as "building in" reliability and robustness into Space MNT at a relatively early stage of development.

Proposed Future CANEUS Events

Year	Event	Conference Site
2004	CANEUS II Conference	California, USA
2006	CANEUS III Conference	France
2008	CANEUS IV Conference	Asia

4. Appendix

a. Workshop Program

The CANEUS workshop had 32 sessions, which included:

- Overview sessions: 2 sessions summarizing MNT developments in Canada, US, Europe, and Asia. The overall vision and strategies for focused worldwide investment was addressed.

- Devices & Systems - 11 sessions covering topics which included MEMS devices, precision MEMS sensors and gyroscopes, optical MEMS devices; MEMS-based smart materials and structures, and MEMS-based systems for space applications; nanoelectronics, nanomaterials, nanodevices and nanosensors; photonics and bio-nanotechnology

- Space Missions - 3 sessions describing current and future missions utilizing MNT-based devices and instruments, as well as technology development for sensing, communication, and propulsion.

- Reliability - 4 sessions on MNT reliability issues including the effects of radiation and mechanisms of failure.

- Aeronautics - 1 session

- Geophysics and Environmental Controls - 2 sessions

- Defense / Policy - 1 session

- Policy/Strategy - 3 sessions and 2 work groups

- Commercialization - 3 sessions covering topics which included investing in nanotechnology, intellectual property related to nanotechnology, the business of nanotechnology, and profiles of nanotechnology companies

b. Alphabetical list of speakers:

- ***Ajayan, Pulickel M.*** (RPI, USA): "*Nanomaterials synthesis",* focused on the directed assembly of multiwalled carbon nanotubes on planar substrates into highly organized structures that include vertically and horizontally oriented arrays, ordered fibers and porous membranes.
- ***Arney, Susanne*** (Lucent Technologies, USA): "Reliability of Optical MEMS Devices".
- ***Assemat, David*** (CNES, France): " MEMS and Microtechnology Microtechnology for Space Applications : CNES Policies and Strategies".
- ***Astrium, Germany*** : "MST space qualification approaches".
- ***Astrium, Germany***: MST technology roadmap and MST in-orbit verification 2000-2001
- ***Ayazi, Farrokh*** (Georgia Tech, USA) : "Enabling Technology (HARPSS) Which Can be Used to Make Both High Precision Gyroscopes and MEMS Resonators" described the applications of the HARPSS process to integrated RF, sensory micro-electro-mechanical systems and the latest results on application of this technology to RF and MEMS sensors***.***
- ***Bawa, Raj***: (Bawa Biotechnology Consulting and RPI) : "Patenting Nanotechnology Inventions: Big Business in Small Technology"
- ***Borzi, Raffaella*** (IMEC*,* USA): "Micro-NanoTechonology Collaboration Strategies for Businesses and Governments, between Europe, USA and Other Countries".
- ***Brown, Simon*** (University of Canterbury, New Zealand: "Nanowires and Control of Nanoparticle Deposition Via Percolation".
- ***Coumar, Oudea*** (EADS-LV, France): "Space Radiation Sources and Effects on MEMS Technologies and Devices".
- ***Cox, Kenneth J.***(NASA JSC, USA): "Nanotechnolgy for Space: NASA Vision".
- ***Dardalhon, Muriel*** (CNES/EADS-LV / LIRMM, France): "Reliability Analysis of CMOS MEMS Structures Obtained by Front Side Bulk Micromachining".
- ***Dastoor, Minoo*** (NASA, HQ, USA): "Convergence of Bio and Nano Technologies: NASA Perspective".
- ***Dommann, Alex*** (Interstate University of Applied Science, Switzerland): "Accurate Microscopic Method to Investigate the Aging of Micromachined Silicon Actuators".
- ***Drevonon, Claude on behalf of Olivier Vendier*** (Alcatel Space Industries, Europe): "RF MEMS Use Within Space Telecom Payload", portrayed on-going actions - in collaboration with European labs and companies –through internal studies and different contracts from European Community, French Minister of Industries and agencies (ESA, CNES).
- ***Falbel, Gerald*** (Optical Energy Technologies, USA): "Attitude Control and Solar Power for Pico, Nano, and Microsatellites", described available technology for attitude sensing, control and solar power for low cost, low weight pico, nano, and micro-satellites.
- ***Ferrer, Carlos*** (CNM, Spain): "Circuit & System integration of MNT devices" explained a methodological plan of circuit and system integration of nanodevices and microdevices in order to develop new to the aerospace applications***.***
- ***Garcia, Ernest*** (Sandia National Laboratories, USA): "RF MEMS use within space telecom payload".
- ***George, Thomas*** (NASA JPL, USA): "MEMS for Space Applications: A Vision and Strategies for Focused Worldwide Investment" addressed the challenge facing developers of MNT for Space Application, namely, bridging the TRL gap between new concepts and mature space technologies.

- ***George, Thomas*** (JPL-NASA, US): " Policies and Needs for Potential Governmental Agreements for Free flow of Aerospace Based MNT Between Member State Organizations"
- ***Giacomazzi, Eugenio*** (Universita di Roma La Sapienza, Italy):"Chemical Microthrusters: Effects of Scaling on Combustion" showed how the effects of miniaturizing rocket engines can be estimated in advance, thus avoiding (costly) mistakes. In particular, the attention was focused on combustion physics, i.e., quenching, flame thickness and turbulence length scales.
- ***Gimzeski, James*** (UCLA, USA): "The Nanoarchitectonics of Molecular Systems and Molecular and Bimolecular Machines".
- ***Gordon, Neil*** (Canadian NanoBusiness Alliance, Canada): "Commercialization of Nanotechnology – A Canadian Perspective".
- ***Gratton, Daniel*** (CSA, Canada): "MEMS Development Programs at the CSA".
- ***Helvajian, Henry*** (Aerospace Corporation, USA): "The fabrication and missions of the Aerospace COSA (Co-orbiting Satellite Assistant)".
- ***Hodgins, Diana*** (ETB Codicote Innovation Centre, UK): "A solid state gyro, a 3 Axis Accelerometer, and a Pressure sensor Devices and Instruments for Space Applications" described 3 physical MST sensors that ETB are currently developing with partners, that utilize this core expertise, and would be suitable for certain space applications.
- ***Huff, Michael*** (MEMS Exchange, USA): "MEMS Exchange Collaboration Program".
- ***Jha, Virendra*** (CSA, Canada): "Micro / Nano Technology for Aerospace Applications, Perspective of the Canadian Space Agency"
- ***Jiang, Xin Xiang*** (CSA, Canada): "CSA's Perspective on Nano-Materials Research and its Potential Impact On Space Technologies".
- ***Jin, Zhonghe*** (Zhejiang University, China): "Design of the MEMS-Pico Satellite".
- ***Kayali, Sammy*** (NASA JPL, USA): "Reliability and Qualification of Advanced Microelectronics for Space Applications" provided a discussion of the subject and an approach to establish a reliability and qualification methodology to facilitate the utilization of state-of-the-art advanced microelectronic devices and structures in high reliability applications.
- ***Klocke, Volker*** (Klocke Nanotechnik, Germany): "Nanorobotics for the International Space Station / Nanomotors for RF technology".
- ***Krotz, Gerhard*** (EADS-CRC, Germany): "Aerospace Applications of Mass Market MEMS Products".
- ***Krotz, Gerhard*** (EADS-LV, Germany): "MEMS for Aircraft Applications in Europe".
- ***Kruzelecky, Roman*** (MPB, Canada): "The Application of Thin-film Smart coatings for the Miniaturization of Space Systems".
- ***Liu, Lerwen*** (ISAS, Japan): "Overview on the Asia Pacific Nanotechnology Initiatives and Developments" provided the latest update on the Nanotechnology government programs and industry policy in the Asia Pacific region including Australia, China, Hong Kong, Korea, Japan, Singapore and Taiwan.
- ***Liu, Lerwen*** (nAbacus, Japan): "Nanotechnology Global Policies.and APEC Collaboration Strategies".
- ***Maebius, Stephen; Herrera, Stephen; Monty, Greg; Von Ehr, Jim; Modzelewski, Mark; and Harper, Tim; were co-panelists with Bawa, Raj*** for the IP and commercialization issues at the workshop.
- ***Malhotra, Sandeep*** (Nanotechnology Investments,Ardesta , USA) focused on commercialization of nanotechnology, being developed at leading universities and research labs in North America and Europe, through the formation of start-ups as well as investments in early-stage companies.

- ***Manzoni, Giulio*** (Mechatronic GmbH, Austria): "Austrian-Italian Micropropulsion R&D for Nanosatellites".
- ***Marchand, Laurent*** (ESA, Europe): "MNT Based Missions an ESA Perspective".
- ***Marchand, Laurent*** (ESA, France): "MNT programs and Strategies within the ESA".
- ***Masson, Patrice*** (Sherbrooke University, Canada): "MEMS for Engines".
- ***Matsuo, Hiroki*** (ISAS, Japan): "MNT Developments: An Asian Perspective".
- ***Mehrez, Hatem*** (Harvard University, USA):"Theoretical Modeling of Electronic Transport Through Nano-Structure Devices"gave some details of the recent experimental data, explained the theoretical model, showed numerical predictions and compared them with the experiment.
- ***Menozzi, Gaëtan*** (MINATEC, France): "The New Center of Competences for Micro and Nano Technologies in Grenoble".
- ***Menozzi, Gaëtan*** (NEXUS, France): "Overview of the European Program on MNT" gave an overview of the European R&D programs on MNT from EU IST with the next plan in the upcoming 6th FWP Framework program, EURIMUS the strategic Eureka programs for the development of MEMS products and NEXUS the European network of Excellence for Microsystems.
- ***Menozzi, Gaëtan*** (NEXUS, France): "MEMS in FRANCE, An overview of trends and products for Aeronautic & Defence applications", presented a basic road map, areas of expertise in MEMS sensors for navigation such as accelerometers, gyrometers, pressure sensors. Examples from major defense companies were shown.
- ***Merrill, Walt*** (Glennan Microsystems, USA): " Harsh Environment Microsystems - The Glennan Microsystems Initiative".
- ***Meunier, Michel*** (Ecole Polytechnique Montréal): "Laser Micro-Nano Engineering of Materials".
- ***Meyyappan, Meyya*** (Center for Nanotechnology, NASA): "An Overview of Recent Developments in Nanotechnology " talked about recent developments, opportunities and challenges in various areas of nanotechnology including carbon nanotubes for electronics, structural and sensor applications; nanostructured materials, molecular electronics; and bio-nano fusion.
- ***Moustapha, Hany*** (Pratt & Whitney, Canada): "CRIAQ and Canadian Aerospace Collaboration in MEMS"
- ***Orban, Jacques***(Schlumberger OFS, France): "Oil & Gas / Geophysics & Well optimization: Status & Trend in Measurements & Controls".
- ***Packirisamy, Muthukumaran*** (CRAIQ, Canada): "MEMS Based Gas Turbines Control and Monitoring Systems - a Brief on the CRIAQ Project" discussed CRIAQ priorities, which are set based on industry interests.
- ***Pasmanik, Guerman*** (Passat, Canada): "Adaptive Transmission of Eyesafe laser Emission from Minisatellite to Ground Vehicles".
- ***Pimprikar, Milind*** (CLS3, Canada): "CANEUS Overview – Background and Proposals for the Future".
- ***Polanyi, John C.*** (Nobel Laureate: University of Toronto, Canada): "Science, Technology and Humanity" talked about the links between science and technology, using his own past and recent experience to illustrate examples. He then warned against over-reliance on technology to solve humanity's major problems.
- ***Pomrenke, Gernot*** (AFOSR, USA): "MNT for Aerospace Activities within AFOSR".
- ***Pressecq, Francis*** (CNES, France): "Quality and Reliability Issues for MEMS and Microtechnology Use in Space Systems".
- ***Ramesham, Rajeshuni*** (NASA JPL, USA): "MEMS Reliability: Review of the Present and Vision for the Future" discussed the fabrication

aspects of a sensor device that is based on a sputter deposited multilayer giant magnetoresistive (GMR) sensor.

- ***Rigo, Sebastien*** (CNES, France): "Determination, with a Nanoindentor, of the Stiffness of the Structures Used in the Microswitch".
- ***Rooij, Nico F. de*** (Institute of Microtechnology University of Neuchâtel, Switzerland): "Swiss Activities in MNT for Space".
- ***Rossi-Bazin, Carole*** (LAAS Laboratory, France): "The Development of Solid propellant uRockets forSpace Applications" portrayed solid propellant microrocket devices for micropropulsion needs, which is based on the high rate combustion of one single propellant stored in a combustion chamber.
- ***Ruggiero, Eric on behalf of Daniel J. Inman*** (Virginia Tech, US): "Active Dynamic Analysis and Vibration Control of Gossamer Structures Using Smart Materials".
- ***Sagman, Uri*** (C Sixty Inc., Canada): "Nanomedicine: Fullerene and Nanotube Biology".
- ***Sargent, Daryl*** (Draper Lab, USA): " Inertial MEMS for Aerospace Applications".
- ***Smalley, Richard*** (Nobel Laureate:Rice University, USA): "Fullerenes, Space, and the World's Energy Challenge" With his trademark flourish of science lecture laced with references to poetry and philosophy, he explained that he aims to prove that nanotech can help save the world.
- ***Snelling, Martyn*** (Astrium, UK): "Adding Value by Removing Mass"
- ***Snyder, Rick*** (Ardesta, USA): "Small Tech Commercialization: A Pragmatic Perspective" discussed key commercial issues in the Small Tech field, the outlook for its various sectors, and what is needed to build a successful company.
- ***Songlin, Feng*** (Shanghai Institute of Metallurgy, China): "MEMS and Pico-Satellite in Chinese Academic of Science"
- ***Srivastava, Deepak*** (NASA Ames, USA): "Computational Nanotechnology of Nanomaterials and Devices" described the role of computational nanotechnology in advancing the possibilities and knowledge base in nanomaterials, electronics, sensors and machines through use of carbon nanotubes and fullerenes in these areas.
- ***Stansfield, Barry*** (INRS, Canada): "Carbon Nanotubes".
- ***Stewart, Duncan*** (HP Research Labs, USA): "Molecular Electronics: the H-P Way" outlined their work on architecture, defect tolerance and fabrication of nanowires by epitaxial growth, catalyzed CVD growth and imprint lithography as well as molecular efforts on ab initio modeling, monolayer film deposition and electrical device fabrication.
- ***Subramanian, Venkat R.*** (University of Saskatchewan, Canada): "MEMs/Nanotech Facility at the Canadian Light Source Synchrotron".
- ***Suski, Jan*** (Aerospace and Geophysics Club, NEXUS, and Schlumberger RMS, France): "Overview of Aerospace, Geophysics and Environmental Control".
- ***Tadigadapa, Srinivas*** (Pennsylvania State University, USA): "MEMS Package Reliability for Space Applications".
- ***Takahashi, Koji & Yasaka, Tetsuo*** (Kyushu University, Japan): "Microthruster Development and University Miniature-Satellite Program in Japan" stated of microthruster development in Japan is reviewed and the problems that they are confronted with are discussed.
- ***Tang, William*** (DARPA, USA): "MNT for aerospace and defense Programs at DARPA".
- ***Teillet, Philippe M.*** (Centre for Remote Sensing, Canada): "Towards Integrated Earth Sensing: From Space to In Situ" described a new initiative called the In Situ Sensor Measurement Assimilation Program - ISSMAP, with the goal of developing new data acquisition strategies and systems for an

integrated Earth sensing approach to monitoring remote environments, hazards, disasters, and natural resources.

- ***Tucholka, Piotr*** (University Paris XI, France): "Major challenges For Environmental Studies", described the growing necessity for progress in qualitative and quantitative solutions for major and fast changes in global, regional and local environment due to increasing effects of human activity.
- ***Van Hoof, Christiaan*** (IMEC, Belgium): "Engineering and Flight model development at IMEC" gave an overview of key ongoing space microelectronics activities at IMEC in the areas of technology, flight hardware development and design.
- ***Vancauwenberghe, Olivier*** (Schlumberger Doll Research, USA): "Resonant MEMS Microsensors for the Measurement of Fluid Density and Viscosity".