SUPER-STRONG NANOTUBE CABLES

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A breakthrough during the 3rd International Conference on "Space Elevator, Carbon Nanotube Tether Design and Lunar Industrialization Challenges"

In cooperation with the National Research Fund of Luxembourg the European Spaceward Association has just held its 3rd International Conference *Space Elevator, Carbon Nanotube (CNT) Tether Design and Lunar Industrialization Challenges* in Luxembourg on Dec 5-6, 2009; the second author, Dr. Klettner, is the Conference Chairman. Experts on the space elevator system, CNT fibre research and Lunar Industrialization discussed latest results of their research work.
Consensus has been reached among the experts, that a space elevator can be built only if it will be based on the flaw tolerant design proposed by the first author, Prof. Pugno, published since 2006 (see [1] and the related news in Nature, 22 May 2006) in several papers [1-5], abandoning earlier unrealistic proposals, which ignored the role of defects and assumed a mega cable strength even larger than 100 GPa... In 2008 Pugno, presented as Top Speaker at the same conference, the flaw tolerant design of the mega cable assuming intrinsic fracture of the nanotubes, whereas in 2009, again invited as Top Speaker, he has completed the picture considering the complementary failure mode of the cable, that is nanotube sliding; for such a case, he has for the first time analytically calculated that single walled nanotubes with diameters larger than ~3nm will self-collapse in the bundle as a consequence of the van der Waals adhesion forces and that the self-collapse can enlarge the cable strength up to ~30%. This corresponds to a maximum strength of ~48 GPa, comparable to the thermodynamic limit for intrinsic nanotube fracture (see [3] and the related highlights in Nature 450, 6, 2007). These new findings, now published in the Journal of the Mechanics and Physics of Solids [6], have been reported in the related 2009 Conference Proceedings and will be discussed in details also in the Invited Talk at ICCE-18.
At least a 10 GPa strong mega cable is practically needed in order to be able to tackle a first prototype. Advance in the past 10 years has been such that the current primary hurdles are financial and political. However the whole endeavour needs a concerted effort. There may be already more than 300 researchers working on individual aspects of the space elevator system but they do not collaborate under a single coordinated framework and an appropriate funding. This provided a flaw tolerant mega cable may be already seen within the next 10 years. Implications for the design of the space elevator system are an increased taper ratio and a cable mass of two orders of magnitude larger. Even though the payload capacity of the first prototype will be accordingly lower a system of elevators using multiple cables and cars may allow highly profitable

operations. Higher expense for the construction will be compensated by a significant decrease in the costs of CNT's due to mass production on a large industrial scale.

Space elevators will need to be powered by ground based visible light lasers combined with adaptive optics. Existing technologies seem to be mature enough to become usable for space elevator power beaming within 10 years as well.

Concepts on clean Solar Power Satellites and HE3 mining of the moon will only be feasible with the kind of access to space that the elevator promises. Though NASA, ESA and JAXA have currently still no roadmaps that include the space elevator, the Japanese Ministry of Economy Trade and Industry (METI) has already realized the potential strategic value of this revolutionary space transportation system. In its long-term plan METI includes the space elevator and foresees CNT textiles with stretching strength of 10 GPa that may serve as a space elevator ribbon.

EuroSpaceward, recognizing Dr. Pugno's breakthrough in the ultimate design of high strength nanotube cables, has invited him to become the Vice-President Europe and Country Director (for Italy) of the Association.

This consensus, demonstrated by this joint paper, is vital for the space elevator project and community.

[1] N. Pugno, *On the strength of the nanotube-based space elevator cable: from nanomechanics to megamechanics.* J. OF PHYSICS -CONDENSED MATTER, (2006) **18**, S1971-1990.

[2] N. Pugno. *The role of defects in the design of the space elevator cable: from nanotube to megatube.* ACTA MATERIALIA (2007), **55**, 5269-5279.

[3] N. Pugno, *Space Elevator: out of order?*. NANO TODAY (2007), **2**, 44-47.

[4] N. Pugno, F. Bosia, A. Carpinteri, *Multiscale stochastic simulations for tensile testing of nanotube-based macroscopic cables*. SMALL (2008), **4**/8, 1044-1052.

[5] N. Pugno, M. Schwarzbart, A. Steindl, H. Troger, *On the stability of the track of the space elevator*. ACTA ASTRONAUTICA (2009), **64**, 524-537.

[6] N. Pugno, *The design of self-collapsed super-strong nanotube bundles*. J. OF THE MECHANICS AND PHYSICS OF SOLIDS (2010). **Available on line**.