Astrium Space Transportation
Operation Directorate

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NAONTECHNOLOGY SURVEY STUDY

Task 4.1
Technical Note – TN 4.1

Summary Report & Executive Summary

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Summary Report & Executive Summary

ABSTRACT

This document constitutes the Summary Report including Executive Summary of the Task group 4, This is the technical synthesis of the works performed during the whole project “Nanotechnology Survey Study”.

KEYWORDS

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ABSTRACT

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Summary Report & Executive Summary

This document constitutes the Summary Report including Executive Summary of the Task group 4, This is the technical synthesis of the works performed during the whole project "Nanotechnology Survey Study".

These works are done by following Consortium members:

- Astrium Space Transportation
- Astrium Satellites
- SPS (Snecma Propulsion Solide)
- Thales Alenia Space
- YOLE Development
- Sineurop.

Section Manager TEA 312

V. FORMOND

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1 INTRODUCTION

This document constitutes the Technical Note TN4 of the “Nanotechnology Survey Study”, related to WP 4000.1 & 2: Summary Report and Executive Summary.

This task led by Prime Contractor “Astrium Space Transportation”, in close collaborations with all sub contractors:

- Snecma Propulsion Solide (SPS)
- Astrium Satellites (Fr) and Germany
- Thales Alenia Space (TAS),
- YOLE Development
- SINEUROP Nanotech GmbH

This report gives the synthesis of the work performed during the whole project:

- Worldwide Nanotechnologies inventory, and particularly to know the real TRL levels of different available Nanotechnologies, European companies involvements and TOP 3 Suppliers. Three Data bases have been created
- Needs and Requirements for different space applications
- Ranking & Prioritisation
- Space activities and Road-mapping
- General Activity Descriptions (GADs) for different applications: Space Transportation, Satellites, Re-entry vehicles

2 PROJECT OVERVIEW

The objectives of this Contract are multiple:

- The first phase activity of the study is devoted to a worldwide inventory on Nanotechnology and produce a mapping of European capabilities on Nanotechnology
- The second phase is dedicated on « Identification of Space needs and requirements for different European Space applications » :
  - Space Transportation,
  - Satellites payloads, platforms
  - Probes for interplanetary exploration
- The third phase is dedicated on the final objectives :
  - Comparison of Nanotech benefits,

- Ranking & Prioritisation for space applications
- Road-mapping of Nanotechnology for space
- Establishment of GADs (General Activity Description) linked with Road- mapping

There are three major work packages:

- WP1: Nanotechnology Inventory by YOLE Development
- WP2: Space Needs and Requirements : inputs from four major Space End – Users: Astrium Space Transportation, Snecma Propulsion Solide (SPS), Astrium Satellites and Thales Alenia Space (TAS)
- WP3:
  - Comparison of Nanotechnology with existing solutions by YOLE
  - Ranking and Prioritisation and also Space Road-mapping with associated GADs by Space End – Users

FINAL PRESENTATION:

The final presentation meeting was organised on 1st September 2010 at ESTEC, Noordwijk.

Astrium ST (Prime) will send a CD Rom to ESA, with compilation of all Technical Notes of "Nanotechnology Survey Study" Contract.

PUBLICATIONS:

Astrium ST & Consortium members are presented some of the findings of this contract during 7th ESA MNT Round Table at Noordwijk – 13th to 17th, September 2010, related to Space road - mapping for Nanotechnology

3 DOCUMENTS DELIVERED

The consortium is delivered 9 Technical Notes under this contract.

Documents Delivered in Task 1:

- TN 1: European Nanotechnology Capabilities – final version is issued on 12/03/2009, TE612 n° 151 559.

Documents Delivered in Task 2:

- TN 2.1: Quantification of Possible Improvements – final version issued 16/12/2009, TAS – 09 – TAS – 1908
- TN 2.2.1 : Definition of Space needs and requirements for Space Transportations – final version issued 24/02/2010 – TE612 n° 153 073
- TN 2.2.2: Definition of Space needs and requirements for Satellites – Nanotechnology Materials – final version issued 22/02/2010 – 2189.NT.DH.09.0092.ASTR
- TN 2.2.3: Satellites needs and requirements – final version issued 13/12/2009 – TAS -09- TAS – 1922

Documents Delivered in Task 3:

- TN 3.1 : Comparison of the Nanotechnology expectations and limitations for Space Applications – draft version issued 12/02/2010 – TE612 n° 153 538, Final version delivered on 09/04/2010

- TN 3.2 : Ranking & Prioritisation : Final version issued on 25/09/2010, with reference – TE612 n° 154 135 ;

- TN 3.3 : Space Activities Road-mapping with GADs : Final version issued on 29/09/2010 with reference – TE612 n° 154 136;

Documents Delivered in Task 4:

- TN 4**:** Final Report is entitled as "Summary Report and Executive Summary", delivered on 22/10/2010 with reference TEA n° 154 769 dated 05/10/2010.

4 TECHNICAL OUTPUT HIGHLIGHTS

In this chapter, we present the technical summary of each work package.

4.1 HIGHLIGHTS OF WORK PACKAGE 1

This Work Package is organised in three steps occurred sequentially, with development of Data Bases:

- Database A – Description of nanomaterials worldwide
- Database B – European Suppliers by Nanomaterials group
- Database C – Details for top 3 European Suppliers

<u>Objective the database A:</u>

Map the nanomaterials activities in terms of: nanospecific properties and characteristics, advantages over conventional techniques, fabrication techniques, applications, state of the art of industrialization, future achievements, suitability for space, barriers to overcome and cost & markets.

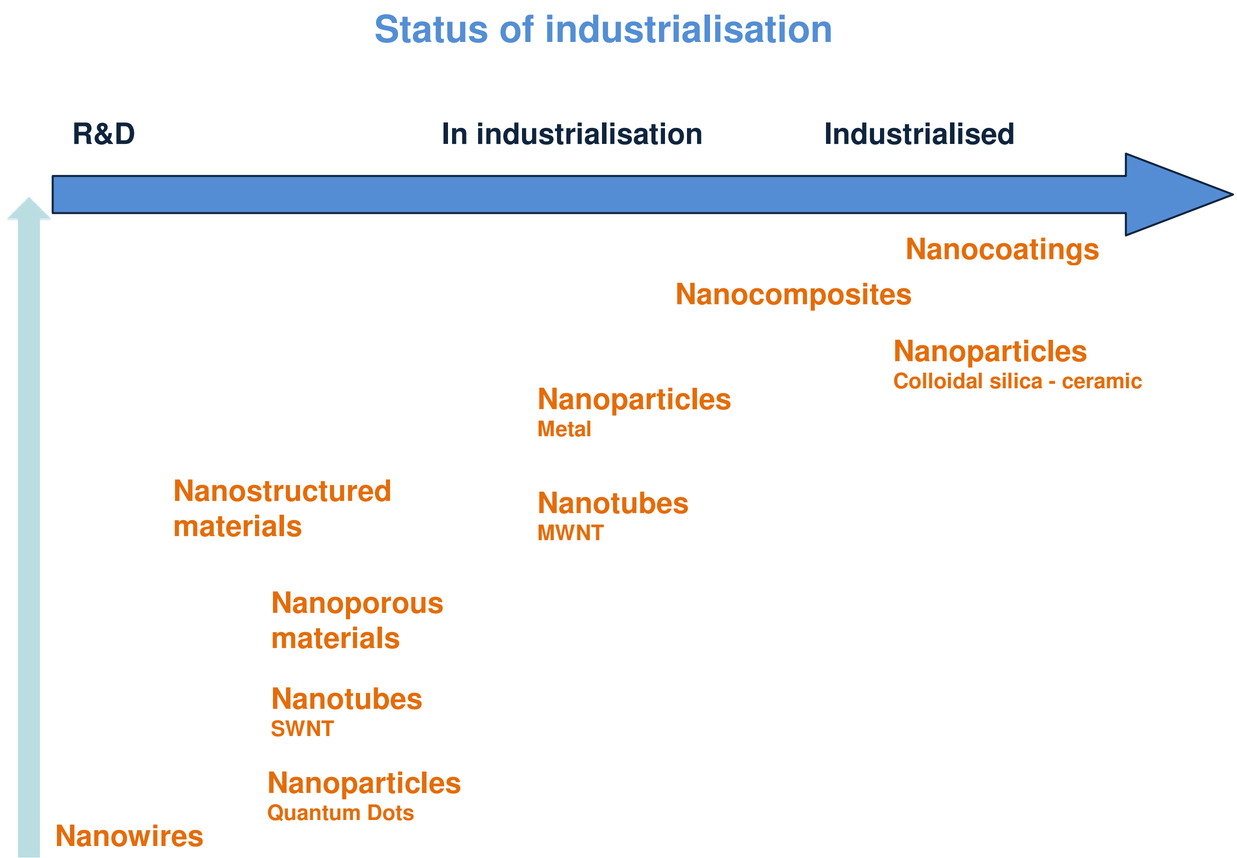
When available, performances of nanomaterials are provided, together with these results, the sources are mentioned and refer to documents that are enclosed in Technical Note (TN1).

The nanomaterials considered in the database are:

- Nanoparticles
  - Ceramics (ZnO, TiO2, CeO2, ZrO2, Al2O3…)
  - Metals (Ag, Au, Ni, Fe, Co)
  - Silicon dioxide (Silica)
  - Quantum dots
- Nanoclays
- Nanofibers
- Nanotubes
  - Multi Wall Carbon Nanotubes
  - Single Wall Carbon Nanotubes
- Nanocomposites
- Nanostructured materials / metamaterials
  - Metals
  - Ceramics
- Nanocoatings / thin films
- Nanowires
- Nanoporous materials

Subcategories have been defined for some of these products, since the properties among nanomaterials from a same family can notably differ, as well as their applications and level of industrialization.

The following chart represents the status of industrialization of the different nanomaterials studied, against their relative 2009 market size.



Objective the database B:

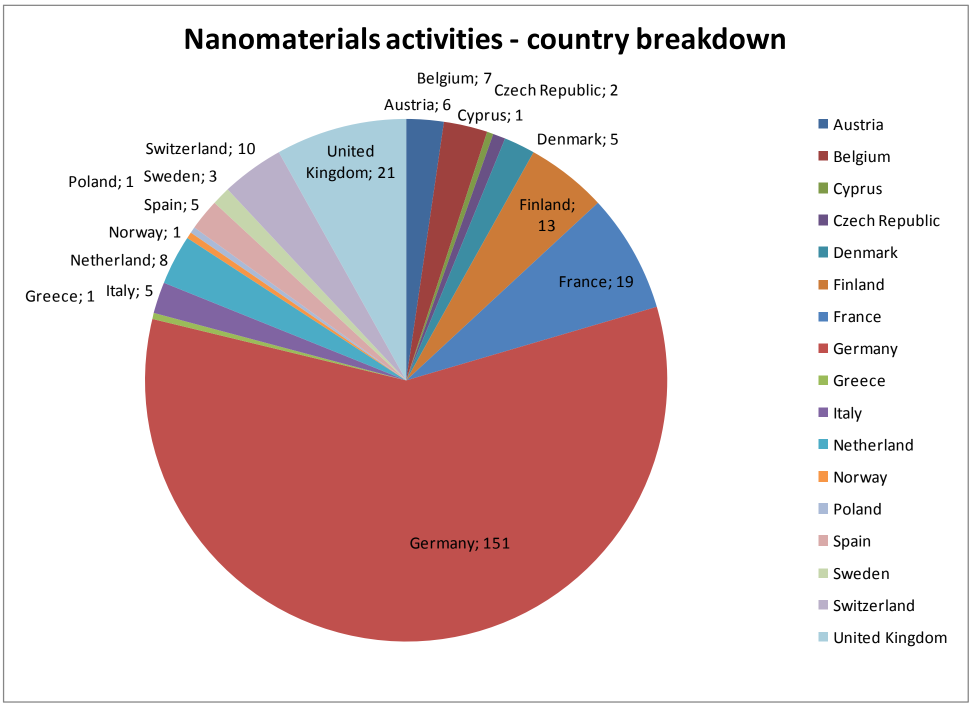
Database B is dedicated to European suppliers by nanomaterials group, with following informations:

- Build a list of European suppliers
- Analyze the supply chain
- Assess European capabilities and identify gaps

261 companies in Europe active in nanomaterials production have been listed in this database.

With the database it is possible to easily sort the producers of a specific category of a nanomaterial and check the fields of applications the companies are involved in.

This figure shows the nanomaterials activities breakdown per country in Europe in terms of number of companies. It shows that Germany has the largest share, with over 50% of nanomaterials companies in Europe being established in Germany.



The following table shows the repartition of nanomaterials activities according to nanomaterials types, as well as a country breakdown

	Nanoparticles			Nanoclays	Nanofibers	Nanotubes		Nanocomposites	Nanostructured materials / metamaterials		Nanocoatings / thin films	Nanowires	Nanoporous materials	TOTAL
	Nanoparticles - Ceramics	Nanoparticles - Metals	Nanoparticles - Silicon dioxide (Silica)			Nanotubes - MWCNT	Nanotubes - SWCNT		Metals Al, Mg, Ti, alloys	Ceramics				
Nb of occurrences	**49**	**22**	**13**	**7**	**7**	**17**	**8**	**33**	**3**	**2**	**109**	**2**	**8**	**280**
Austria	**0**	**0**	**0**	**0**	**2**	**1**	**1**	**1**	**0**	**0**	**3**	**0**	**0**	**8**
Belgium	**2**	**0**	**0**	**0**	**0**	**1**	**1**	**2**	**0**	**0**	**1**	**0**	**1**	**8**
Cyprus	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**
Czech Republic	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**2**
Denmark	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**3**
Finland	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**3**	**0**	**0**	**7**	**0**	**0**	**12**
France	**8**	**3**	**2**	**1**	**0**	**2**	**0**	**1**	**0**	**0**	**6**	**0**	**0**	**23**
Germany	**19**	**7**	**8**	**1**	**2**	**8**	**3**	**16**	**2**	**2**	**74**	**1**	**6**	**149**
Greece	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**2**
Italy	**3**	**2**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**3**	**0**	**0**	**9**
Netherland	**2**	**0**	**0**	**1**	**0**	**0**	**0**	**4**	**0**	**0**	**4**	**1**	**0**	**12**
Norway	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**
Poland	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**1**
Spain	**1**	**1**	**0**	**2**	**1**	**1**	**1**	**4**	**0**	**0**	**0**	**0**	**0**	**11**
Sweden	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**1**	**3**
Switzerland	**3**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**5**	**0**	**0**	**10**
United Kingdom	**9**	**8**	**1**	**1**	**0**	**1**	**1**	**2**	**0**	**0**	**2**	**0**	**0**	**25**

Nanocoatings and thin films are the category that shows the highest number of companies involved in Europe. Germany is especially leading this field. An explanation to that is that a lot of start-up companies have been created, as spin out of universities and research centres and their involvement in nanocoating directly leads to commercial products to be sold on the consumer market.

Objective the database C:

Database C is dedicated to the TOP 3 European suppliers for each nanomaterials category. And also contains information on the size of the company, the status of their respective development, the possible commercial availability, the expected time to market and the cost aspects.

4.2 HIGHLIGHTS OF WORK PACKAGE 2

The output of this Work package is divided in two parts:

- Quantification of possible improvements
- Establishment of Needs and Requirements for space

The End-Users have conducted a very large analysis of available public information on Nanotechnologies could lead to significant improvement for space: launchers, Satellites and Exploration. A tentative quantification of improvement brought by Nanotechnologies has been also presented, and this is much more "bottom-up" approach, driven mainly by available technologies.

Needs and Requirements:

Space Transportation:

The opportunities for space transportation systems are through thermal barrier and wear resistant coatings, sensors that can perform at high temperature and other physical and chemical sensors, sensors that can perform safety inspection more cost effectively, quickly, and efficiently than the present procedures, composites, wear resistant tires, and improved avionics.

For launchers the main application where these improvements could be of great interest in coming years (short term) is:

- Electrical conductivity
- Damage detection and Tolerance
- Thermal protection systems (C/C and C/phenolic)
- Structural composites (thermoplastic and thermoset based composites).
- Nanosensors

Satellites:

Astrium Satellites and Thales Alenia Space have presented their views on the potentialities of Nanotechnology with both "top-down" and "bottom-up" approach. They demonstrated the way for development and use of nanotechnology from satellite platform, payloads, earth observation, and telecom and to space exploration. Different Technical Notes (TN2.1, TN 2.2.2 & TN 2.2.3) have detailed the comparisons between classical technology and nanotechnology and also expressed the needs and requirements for each sector.

The use of nano-tubes to structure improvement appears of interest to target following performances enhancement:

- Better resistance to reduce structure mass, also taking into account thermal, electrical properties (conductivity), etc.

- Higher stability for high performance applications like optical,
- Radiation shielding
- Batteries could benefit from CNT electrodes to improve the energy to mass ratio

Most of the technologies are still low TRL level (between 1 & 2), they of-course require further dedicated investigation to have a proper assessment of their benefit in the space domain. The space industry could however benefit of spin-in R & D from other domains with large volumes.

4.3 HIGHLIGHTS OF WORK PACKAGE 3

This work package is dedicated on three different tasks:

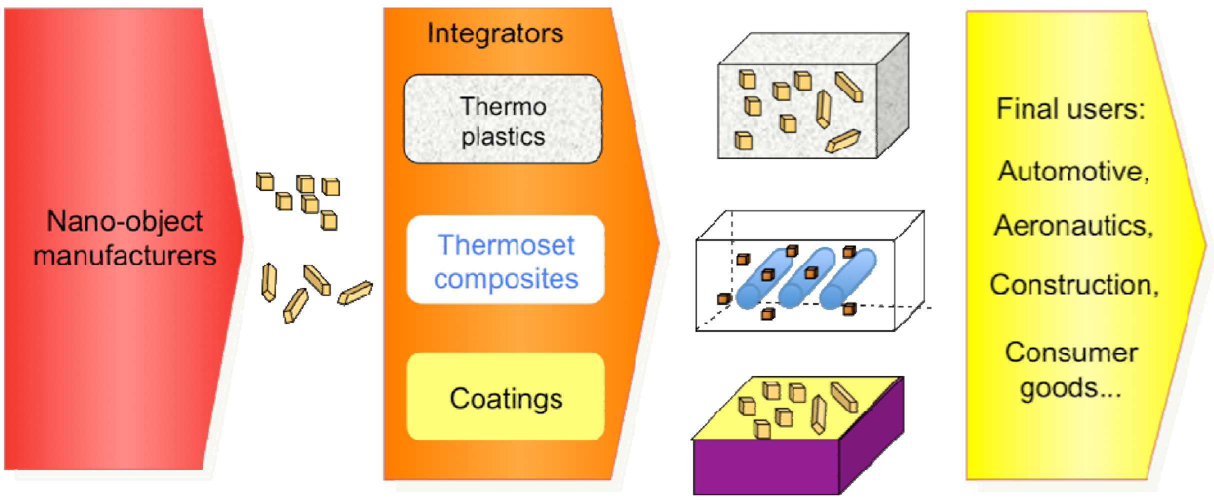
- Expectations and limitations for space applications
- Ranking and Priority
- Road mapping associated with GADs

Supply Chain:

Nanomaterial supply chain is an integrated approach

The figure illustrates three main manufacturing steps in the supply chain:

1. nano object manufacturing
2. nano objects integration into a matrix to make nanocomposites
3. nanocomposites processing to obtain final parts.



The integrators players can be traditional material players (thermoplastics, thermoset composite or coating manufacturers) or new companies specialized in the nano objects integration by making a special treatment (Ex: Amroy for CNT). **Integration step is the biggest challenge for the Nanomaterial supply chain.** There is still a lot to do in this area to improve the dispersion and the compatibility between the nano objects and the matrix.

Important barriers & challenges:

- o Nanomaterial quality is dependant from the supplier source, and not always constant from batch to batch.
- o Nanomaterial performances may vary significantly when switching from lab samples to industrial quantities samples.
- o There is a need to define standards for the measuring tests. In the same time, the measuring techniques are not reliable today (especially to measure the nanoparticles dispersion in nanocomposites) and those techniques must be improved to be chosen as a reference.
- o Each application requires often a customization of the nanomaterial => nanomaterial development cost is important.

General barriers & challenges for the development of nanomaterials for the space domain are:

- to adopt an integrated supply chain approach: a good collaboration between the different supply chain players (nano object manufacturers, integrators, final users) is a key success factor.
- to pay attention to a good cost/ added value ratio: general high cost of nanomaterial can be a bottleneck if the added value is not as high as the cost.
- to develop integration technologies and skills: chemical functionnalization or others techniques to fully benefit from nano size properties.
- to further assess the health & safety issues
- to develop measuring techniques and standards
- to Improve nanomaterial production consistency over time

Priority, Ranking and Road mapping:

The End-users are established the “Ranking & Prioritisation” for Space transportation, Satellites and Explorations. And based on Priorities, Nanotechnology Roadmaps have been are established for different applications (see chapter 5 for details).

Space Transportation:

The Roadmaps are established for the following topics, as considered in Priority in two domains like Materials and Process. In particular for Space Transportation, we have distinguished two steps to judge the TRL levels; one is based on Nanotechnology materials intrinsic properties and second related to the process for large and acceptable production: i.e. reproducible quality to manufacture a given Nanomaterial.

Here are the domains, where Nanotechnolgy could play a major role in coming years:

- For Composite structures (OMC – Organic Matrix Composite modified with nano fillers)

  - Electrical Conductivity
  - Damage Tolerance
  - Damage Detection
  - Mechanical Damping
- For thermal protection modified with nano fillers:
  - Internal Thermal Protection
  - C/phenoloic based material
- For Propulsion:
  - SRM (Solid Rocket motor) TVC
- For Sensors:
  - Gas detection
  - Sensors miniaturization
  - Transmission (Wireless)
- For Coatings
  - Conductive coatings

<u>Satellites:</u>

<u>Thales Alenia Space:</u>

The Roadmaps are established for the following topics, as considered in Priority by Thales Alenia Space:

- Structural materials for ultra-stable structures
- Harness and Electrical interconnects for RF & DC
- Heat sink
- Nanomaterial characterization
- Energy storage (battery)
- Electricity generation (thermoelectrics)
- Structure PF, P/L and equipment
- Radiation Shields
- Communication P/L

Astrium Satellites:

The Roadmaps are established for the following topics, as considered in Priority by Astrium Satellites:

- CNT filled - CFRP (polymer composites)
- CNT Ceramic Composites for Thermal Protection
- CNT Ceramic Composites for Optical Structures
- CNT Ceramic Composites for Hot Bearings
- CNT Metal Composites for Mechanical Applications (Fasteners)
- CNT Metal Composites for Thermal Applications (Heat Management
- CNT Metal Composites for Tribo Applications
- CNT modified Elastomers
- CNT modified Polymer Films for Thermal Control
- CNT Ceramic Composites for Electrodes
- CNT Structure in Electrolyte (Actuator Function)
- Gas Sensors (Metallized CNT Structures)
- Mechanical / Thermal Sensors (Neurons)
- Nano Coating
- Nano Filled Propellants
- Nano Based Gas Storage

5 MAJOR CONCLUSIONS OF SPACE ROAD-MAPPING

This chapter recalls the major conclusions of Ranking and Prioritisation, associated with Space road-mapping and related GADs of different Nanotechnology activities for European Space applications.

5.1 SPACE TRANSPORTATIONS

This table is summarize the space Road mapping, Ranking & Priority with related GADS for Space Transportation. Astrium ST with SPS has established 14 GADs for TRP activities.

Field of Application	Benefit of Properties (Needs /Nano)	Need	Expected (<5years)	estimated TRL	Ranking - Priority P0 = highest P2 = lowest	targeted TRP TRL 2014	targeted GSTP TRL 2017	GAD
Composite Structure								
Structural parts	Electrical Conductivity	4	5	2	0	3	6	7
	Damage Tolerance	5	2	2	1	3	5	1
	Damage detection	4	1	2	1	3	5	2
Elastomeric damper	Mechanical Damping of Low frequency Vibrations	3	3	2	1	3	5	3
Thermal Protection								
Internal Thermal Protection (elastomeric)	Ablation & Thermomechanical performances	5	1	2	0	3	5	4
Thermal Protection system (C/phenolic)	Ablation & Thermomechanical performances	5	4	2	0	3	5	6
Propulsion								
SRM TVC (flexseal concept)	Stiffness	4	3	1	1	3	5	11
	Mechanical performances	4	3	1	1	3	5	11
Sensors								
Gas Sensors	High sensibility to detect gases: H, He, .. ⇑	5	3	2	0	3	6	12
SHM (Structural Health Monitoring)	Miniaturization, e. g. for Sensor technology for integration in the structure ⇑⇑	4	3	2	1	3	5	13
Telemetry	Miniaturization, e. g. for Sensor technology for distributed architecture with wireless communication ⇑⇑	4	3	2	1	3	5	14
Surface functionnalization								
Conductive coatings	Higher surface conductivity	4	4	2	0	3	6	8

5.2 SATELLITES

5.2.1 TAS

Thales Alenia Space:

This table summarizes the space Road mapping; Ranking & Priority with related GADS for Thales Alenia Space for Satellite activities, TAS has established 11 GADs for TRP activities.

Field of Application	Benefit of Properties (Needs /Nano)	Need	estimated TRL	Accessibility	Feasability	Ranking - Priority P0 = highest P2 = lowest	Related GADs
Ultra-stable Structure	Stability with temperature	5	2	4	4	**0**	TAS GAD 2
	Mechanical performances	5	1	3	4	**1**	
	Electrical Conductivity	4	1	4	5	**0**	
Harness& electrical interconnects	high current capability	3	1	?	1	**2**	TAS GAD 1
RF & DC	low density	4	2	1	2	**0**	
Heat sink	High thermal conductivity and low CTE	4	3	3	4	**0**	TAS GAD 3
Nanomaterial characterization	characterisation means for high thermal conductivity nanostructured film	4	2	1	3	**1**	TAS GAD 4
Energy storage (battery)	higher capacity	5	1	1	4	**0**	TAS GAD 9
Electricity generation (thermoelectrics)	Improved Electrical efficiency	4	1	1	2	**1**	TAS GAD 7
Structure PF, P/L and equipment	Density	5	2	4	3	**0**	TAS GAD 5
	Thermal conductivity	5	2	3	2	**1**	
(low CTE)	Electrical conductivity	5	2	4	4	**0**	
Radiation shields	Density	5	2	2	3	**0**	TAS GAD 8
	Improved Radiation efficiency	3	1	1	1	**2**	
Communication P/L : Integrated RF Isolator	Integration, miniaturization Improved performance	5	1	1	2	**0**	TAS GAD 11
Communication P/L : new high linearity components (Nanogap)	fast (<100 ns) electromechanical systems	4	3	1	4	**0**	TAS GAD 6
Communication P/L : reconfigurable component	Low loss reconfigurable materials	4	2	3	3	**1**	TAS GAD 10
(Functional oxide)	Temperature stability	4	1	3	2	**2**	

5.2.2 Astrium Satellites

Astrium Satellites:

The following three tables summarize the space Road mapping; Ranking & Priority with related GADS for Astrium satellites for Satellite activities has established 9 GADs for TRP activities.

Nano-Modified Structural Materials (Space Structures)					
Nano Material	**Field of Application**	**Benefit of Properties**	**Priority /estimated TRL**	**Ranking** P0 = highest P1 = medium P2 = lowest	Related GAD
CNT filled - CFRP (polymer composites)	•Large Antennas •Satellite Central Structures •Mounting Panels •Primary Structures for Manned Vehicles	Mass reduction w.r.t. alu ⇑ Thermal conductivity orthogonaly to fibers ⇑⇑ Electrical Conductivity ⇑⇑ Fatigue and interlaminar shear⇑⇑ Avoidance of EMD ⇑⇑ Stiffness (TBC)	High need for space platforms to save mass and launch & operational cost TRL 4	0	GAD 1
CNT - CMC (ceramic composites)	•Heat Shields Hot Structures • Hot instruments and antennas •Leading Edges	Toughness ⇑ Heat Rejection ⇑⇑ Electrical conductivity ⇑⇑	High need for improved heat shields and leading edges TRL 2	1	GAD 2
CNT - MMC (metallic composites)	•High strength fasteners, joining and attachment systems	Strength ⇑ Tolerance to Microcrack ⇑ CTE reduction ⇑	High-strength Fasteners with suited CTE, Isostatic Mounts, TRL 2	2	GAD 3
CNT - CMC (ceramic composites)	•Optical Components, optical Benches and Supports	Very High Stiffness ⇑ Toughness ⇑ Microcrack resistivity ⇑ Fatigue ⇑	High need for improvement of toughness of ceramics and electrical conductivity, TRL 2	2	GAD 2
CNT – reinforced plastics (polymer composites)	•Large Antennas •Satellite Central Structures •Mounting Panels	Electrical Conductivity ⇑⇑ Thermal conductivity orthogonaly to fibers ⇑⇑	High need for space platforms to save mass and launch & operational cost TRL 2	2	

Nano-Modified Functional Materials (Thermal Control, Electrodes, Energy Storage)					
Nano Material	**Field of Application**	**Benefit of Properties**	**Priority /estimated TRL**	**Ranking** P0 = highest P1 = medium P2 = lowest	Related GAD
CNT - polymeric Films & Foils	•Electrically conducting & optical transparent Films for thermal control	Electrically conducting, optical transparent films Mass saving ⇑⇑⇑	High need for lightweight electrical conductive foils TRL 3	**0**	GAD 4
CNT - CMC (ceramic composites)	•Electrodes	High Surface Area ⇑⇑⇑	Need for improved electrical energy storage (super capacitors TRL 3	**1**	
aluminium wires with CNT coatings	•High conductivity electric wires ,i.e. for current return.	50% mass reduction w.r.t. pure alu wires ⇑⇑⇑	High need for lightweight electric wires to save mass and launch & operational cost TRL 3	**1**	
CNT - MMC (metallic composites)	•Metallic tribo composites filled by lubricant particles	Friction ⇑ Wear ⇑⇑⇑	Need for hot bearing (200 - 300°C) with improved friction and wear TRL 3	**1**	GAD 5
CNT - CMC (ceramic composites)	•Hot Bearings	Very High Stiffness ⇑ Toughness ⇑ Microcrack resistivity ⇑ Fatigue ⇑ Tribology/Friction ⇑⇑⇑	Need for improved very hot bearings for re-entry purposes (1000 - 1200°C) TRL 1	**2**	GAD 2
CNT - MMC (metallic composites)	•Thermal management for high-dissipative electronics & instruments	Improvement of heat transfer at contact interface ⇑⇑⇑	Need for improved thermal management of highly-dissipating temperature stabilized instruments (microwave generators, lasers) and densely packed electronics) TRL 2	**2** (conventional MMC better than CNT-MMC)	
CNT - Elastomer	•Mech. Damping Materials	Mechanical Damping of Micro-Vibrations ⇑	Passive micro damper, e. g. AOCS TRL 1	**2** (active damping seems better solution)	GAD 6

Nano-Sensors & Actuators					
Nano Material	**Field of Application**	**Benefit of Properties**	**Priority /estimated TRL**	**Ranking** P0 = highest P1 = medium P2 = lowest	Related GAD
CNT-Felts in Electrolyte	•Highly efficient actuators	Low voltage, high displacements ⇑⇑	Adaptive Structures, Deployment Mechanisms TRL 2	**1**	GAD 7
CNT - felts & papers with specific surface metallization	•Gas Sensors	High sensibility to special gases ⇑	Miniaturization for probes, rovers and robotics TRL 3	**2**	GAD 8
CNT Fibers in polymer matrix	•Strength Sensors •Temperature Sensors	Miniaturization, e. g. for MEMS technology ⇑⇑	Neurons for structural health monitoring, TRL2	**2**	GAD 9

6 CONCLUSION

This document constitutes the Technical Note TN4 of the "Nanotechnology Survey Study", related to WP 4000.1 & 2: Summary Report and Executive Summary.

This report gives the synthesis of the work performed during the whole project:

- Worldwide Nanotechnologies inventory, and particularly to know the real TRL levels of different available Nanotechnologies, European companies involvements and TOP 3 Suppliers. Three Data bases have been created
- Needs and Requirements for different space applications
- Ranking & Prioritisation
- Space activities and Road-mapping
- General Activity Descriptions (GADs) for different applications: Space Transportation, Satellites, Re-entry vehicles

APPENDIX 1 Executive Summary

Executive Summary

This contract "Nanotechnology Survey Study», is managed by Prime Contractor "Astrium Space Transportation", in close collaborations with European major End-Users and Nanotechnology Experts:

- Snecma Propulsion Solide (SPS)
- Astrium Satellites (Fr) and Germany
- Thales Alenia Space (TAS),
- YOLE Development
- SINEUROP Nanotech GmbH

This Executive summary gives the work performed during the whole project:

- Worldwide Nanotechnologies inventory, and particularly to know the real TRL levels of different available Nanotechnologies, European companies involvements and TOP 3 Suppliers. Three Data bases have been created.
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Nanotechnology Inventory:
A worldwide Nanotechnologies inventory has been done, and particularly to know the real TRL levels of different available Nanotechnologies, European companies involvements and TOP 3 Suppliers. Three Data bases have been developed:

- Database A – Description of nanomaterials worldwide
- Database B – European Suppliers by Nanomaterials group
- Database C – Details for top 3 European Suppliers

The nanomaterials considered in the database are:

- Nanoparticles
    - Ceramics (ZnO, TiO_2, CeO_2, ZrO_2, Al_2O_3…)
    - Metals (Ag, Au, Ni, Fe, Co)
    - Silicon dioxide (Silica)
    - Quantum dots
- Nanoclays
- Nanofibers
- Nanotubes
    - Multi Wall Carbon Nanotubes

    - Single Wall Carbon Nanotubes
- Nanocomposites
- Nanostructured materials / metamaterials
    - Metals
    - Ceramics
- Nanocoatings / thin films
- Nanowires
- Nanoporous materials

Subcategories have been defined for some of these products, since the properties among nanomaterials from a same family can notably differ, as well as their applications and level of industrialization.

261 companies in Europe are active in nanomaterials production and detailed informations have been given in databases.

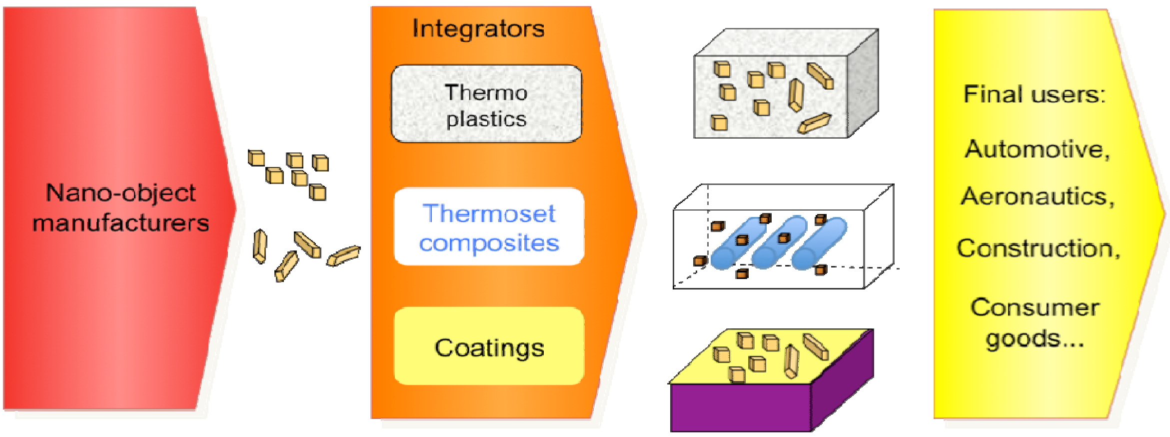
Nanocoatings and thin films are the category that shows the highest number of companies involved in Europe. Germany is especially leading this field. An explanation to that is that a lot of start-up companies have been created, as spin out of universities and research centres and their involvement in nanocoating directly leads to commercial products to be sold on the consumer market.

Supply Chain:

Nanomaterial supply chain is an integrated approach

The figure illustrates three main manufacturing steps in the supply chain:

4. nano object manufacturing
5. nano objects integration into a matrix to make nanocomposites
6. nanocomposites processing to obtain final parts.



The integrators players can be traditional material players (thermoplastics, thermoset composite or coating manufacturers) or new companies specialized in the nano objects integration by making a special treatment (Ex: Amroy for CNT). **Integration step is the biggest challenge for the Nanomaterial supply chain.** There is still a lot to do in this area to improve the dispersion and the compatibility between the nano objects and the matrix.

Important barriers & challenges:

- Nanomaterial quality is dependant from the supplier source, and not always constant from batch to batch.
- Nanomaterial performances may vary significantly when switching from lab samples to industrial quantities samples.
- There is a need to define standards for the measuring tests. In the same time, the measuring techniques are not reliable today (especially to measure the nanoparticles dispersion in nanocomposites) and those techniques must be improved to be chosen as a reference.
- Each application requires often a customization of the nanomaterial => nanomaterial development cost is important.

General barriers & challenges for the development of nanomaterials for the space domain are:

- to adopt an integrated supply chain approach: a good collaboration between the different supply chain players (nano object manufacturers, integrators, final users) is a key success factor.
- to pay attention to a good cost/ added value ratio: general high cost of nanomaterial can be a bottleneck if the added value is not as high as the cost.
- to develop integration technologies and skills: chemical functionnalization or others techniques to fully benefit from nano size properties.
- to further assess the health & safety issues
- to develop measuring techniques and standards
- to Improve nanomaterial production consistency over time

Priority, Ranking and Road mapping:

End-Users have presented a wide range of Ranking and Priority for different space sectors:

- for Space Transportations in following major domains for on going and future programmes like Ariane 6, etc.:
    - launcher structures
    - re-entry vehicles
    - propulsions
    - nanosensors

- for Satellites part 1 (Astrium Satellites, Friedrichshafen and Toulouse) in following major domains for on going and future programmes:
    - Structural materials for space structures
    - Functional materials for Thermal control, Electrodes and Energy Storage
    - Nanosensors and Actuators
    - Nano-coatings
    - Nano-filled propellants

- Nano based Gas storage

- for Satellites part 2 (Thales Alenia Space, Toulouse and Cannes) in following major domains for on going and future programmes:
  - Structural materials for ultra-stable structures
  - Harness and Electrical interconnects for RF & DC
  - Heat sink
  - Nanomaterial characterization
  - Energy storage (battery)
  - Electricity generation (thermoelectrics)
  - Structure PF, P/L and equipment
  - Radiation Shields
  - Communication P/L

Space Transportation:

The Roadmaps are established for the following topics, as considered in Priority in two domains like Materials and Process. In particular for Space Transportation, we have distinguished two steps to judge the TRL levels; one is based on Nanotechnology materials intrinsic properties and second related to the process for large and acceptable production: i.e. reproducible quality to manufacture a given Nanomaterial.

Here are the domains, where Nanotechnolgy could play a major role in coming years:

- For Composite structures (OMC – Organic Matrix Composite modified with nano fillers)
  - Electrical Conductivity
  - Damage Tolerance
  - Damage Detection
  - Mechanical Damping
- For thermal protection modified with nano fillers:
  - Internal Thermal Protection
  - C/phenoloic based material
- For Propulsion:
  - SRM (Solid Rocket motor) TVC
- For Sensors:
  - Gas detection
  - Sensors miniaturization
  - Transmission (Wireless)
- For Coatings

- Conductive coatings

Based on Ranking, Priority and Road mapping, Astrium ST and SPS have established 14 GADs for TRP activities for launchers

- Astrium ST GAD 1: Development of a more damage tolerant structural composites by nano reinforced
- Astrium ST GAD 2: Development of impact damage detection systems based on Nanotechnology
- Astrium ST GAD 3: Development of a nano-reinforced elastomeric damper for launcher equipment supports.
- Astrium ST GAD 4 : Development of Low ablative nanoreinforced elastomers for Internal or External Thermal Protection in future Solid Rocket Motors
- Astrium ST GAD 5 : Development of a functionalized adhesive
- Astrium ST GAD 6: Improvement of ablative properties of phenolic composites used as ITP in solid rocket nozzle by nanoreinforcement.
- Astrium ST GAD 7: Improvement of electrical conductivity of Composite structures.
- Astrium ST GAD 8: Development of conductive coatings with nano technologies for space and launchers structure application and Evaluation of CNT produced by Arc discharge for composite properties increase.
- Astrium ST GAD 9 : NanoRAD (Nanotechnology sensitive to Space Radiation)
- Astrium ST GAD10 : NanoTPS (Nanotechnology for Thermal Protection Systems)
- Astrium ST GAD 11 : Development of a nano-reinforced mechanical elastomeric materials for launchers
- Astrium ST GAD 12 : Gas sensors
- Astrium ST GAD 13 : SHM – Structural Health Monitoring
- Astrium ST GAD 14 : Telemetry sub system based on MEMS/NEMS

Satellites:

Thales Alenia Space:

The Roadmaps are established for the following topics, as considered in Priority by Thales Alenia Space:

- Structural materials for ultra-stable structures
- Harness and Electrical interconnects for RF & DC
- Heat sink
- Nanomaterial characterization
- Energy storage (battery)
- Electricity generation (thermoelectrics)
- Structure PF, P/L and equipment
- Radiation Shields
- Communication P/L

TAS (Thales Alenia Space) has established eleven GADs as listed below:

- TAS GAD 1 : CNT based wire or CNT coated Al wire for application to low density DC harness or RF Cable
- TAS GAD 2 : MNT doped CFRP for stability applications (optical benches)
- TAS GAD 3 : Dedicated thermal characterization methods for high thermal conductivity (>200 W/m°C) interface based on nanostructured materials

- TAS GAD 4 : High thermal conductivity (>400 W/m°C) nanocomposite or nanotructured metal alloy for application to heatsinking for RF power module (CTE low 4-6 ppm/°C)
- TAS GAD 5 : Low CTE nanocomposites and nanostructured alloys as a replacement to Aluminum for space satellites
- TAS GAD 6 : Ultrafast (<100 ns) actuator using nanogap technology to realize very high linearity mixer for future generation of frequency convertors
- TAS GAD 7 : Characterization of thermoelectric materials doped with nanoparticles
- TAS GAD 8: Low density nanostructured material for high efficiency space radiation shield, application to electronic equipment
- TAS GAD 9 : Nanostructured electrodes for space Li-Ion battery
- TAS GAD 10 : Very low loss, temperature compensated ferroelectric varactors for future reconfigurable microwave front-ends
- TAS GAD 11 : High integration planar isolator based on nanocomposite for application to microwave electronic equipment

<u>Astrium Satellites:</u>

The Roadmaps are established for the following topics, as considered in Priority by Astrium Satellites:

- CNT filled - CFRP (polymer composites)
- CNT Ceramic Composites for Thermal Protection
- CNT Ceramic Composites for Optical Structures
- CNT Ceramic Composites for Hot Bearings
- CNT Metal Composites for Mechanical Applications (Fasteners)
- CNT Metal Composites for Thermal Applications (Heat Management
- CNT Metal Composites for Tribo Applications
- CNT modified Elastomers
- CNT modified Polymer Films for Thermal Control
- CNT Ceramic Composites for Electrodes
- CNT Structure in Electrolyte (Actuator Function)
- Gas Sensors (Metallized CNT Structures)
- Mechanical / Thermal Sensors (Neurons)
- Nano Coating
- Nano Filled Propellants
- Nano Based Gas Storage

Astrium Satellites has established nine GADs in the following domains:

- Astrium Satellite GAD 1 : Hyper-Light-Weight Space Structure Demonstrator of CNT-Composite Material
- Astrium Satellite GAD 2 : CNT Ceramic Optical Space Structure Prototype
- Astrium Satellite GAD 3 : CNT Metallic Attachment System Demonstrator

- Astrium Satellite GAD 4 : Optical Transparent and Electrically Conductive CNT Films/Foils for Application in Space
- Astrium Satellite GAD 5 : Tribology at Elevated Temperatures by Application of Novel Metallic Composite Materials ("Tribo Composite" with incorporated nano particles & lubricants)

- Astrium Satellite GAD 6 : 3D Carbo Nanofiber Network / Elastomer Composite for Damping of Mechanical Micro Vibrations
- Astrium Satellite GAD 7 : Buckypaper / Electrolyte Actuator for Space Applications
- Astrium Satellite GAD 8 : Gas Sensors based upon metalized Carbon Nano structures
- Astrium Satellite GAD 9 : Neurons for based upon Carbon Nano structures embedded in a Polymer matrix