SPACE TRANSPORTATION

NANOTECHNOLOGY ROADMAP FOR SPACE APPLICATIONS

Contract N°: 21668/08/NL/EM

Astrium ST (Fr) : C. OUDEA, J-M. DUPILLIER, G. LARNAC

SPS (Fr) : M. BOURGEON

Astrium Sat (GmbH): H. WULZ

TAS (Fr) : O. VENDIER

All the space you need

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NANOTECHNOLOGY ROADMAPPING FOR SPACE APPLICATIONS

OUTLINES

- Introduction
- Potential applications in Space
- Ranking & Prioritititisation:
  - Space Transportation
  - Satellites
- Roadmapping :
  - Space Transportation
  - Satellites
- Conclusions

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Technical Officer ESA/ESTEC : F. FILHOL
Technical Officer EADS-Astrium ST : C. OUDEA

Project Team (End-Users)

- **Members of Consortium**
  - **EADS - Astrium Space Transportation : Prime**
  - **Sub Contractors:**
    - **Astrium Satellites (GmbH & Fr)**
    - **Thales Alenia Space, Toulouse (Fr)**
    - **Snecma Propulsion Solide (SPS)**
    - **YOLE Development (Fr)**
    - **SINEUROP Nanotech (GmbH)**

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Snecma Propulsion Solide
SAFRAN Group

ThalesAlenia Space
A Thales / Finmeccanica Company

- **SPACE TRANSPORTATION**
- **SATTELITES**

YOLE DÉVELOPPEMENT

SINEUROP Nanotech GmbH

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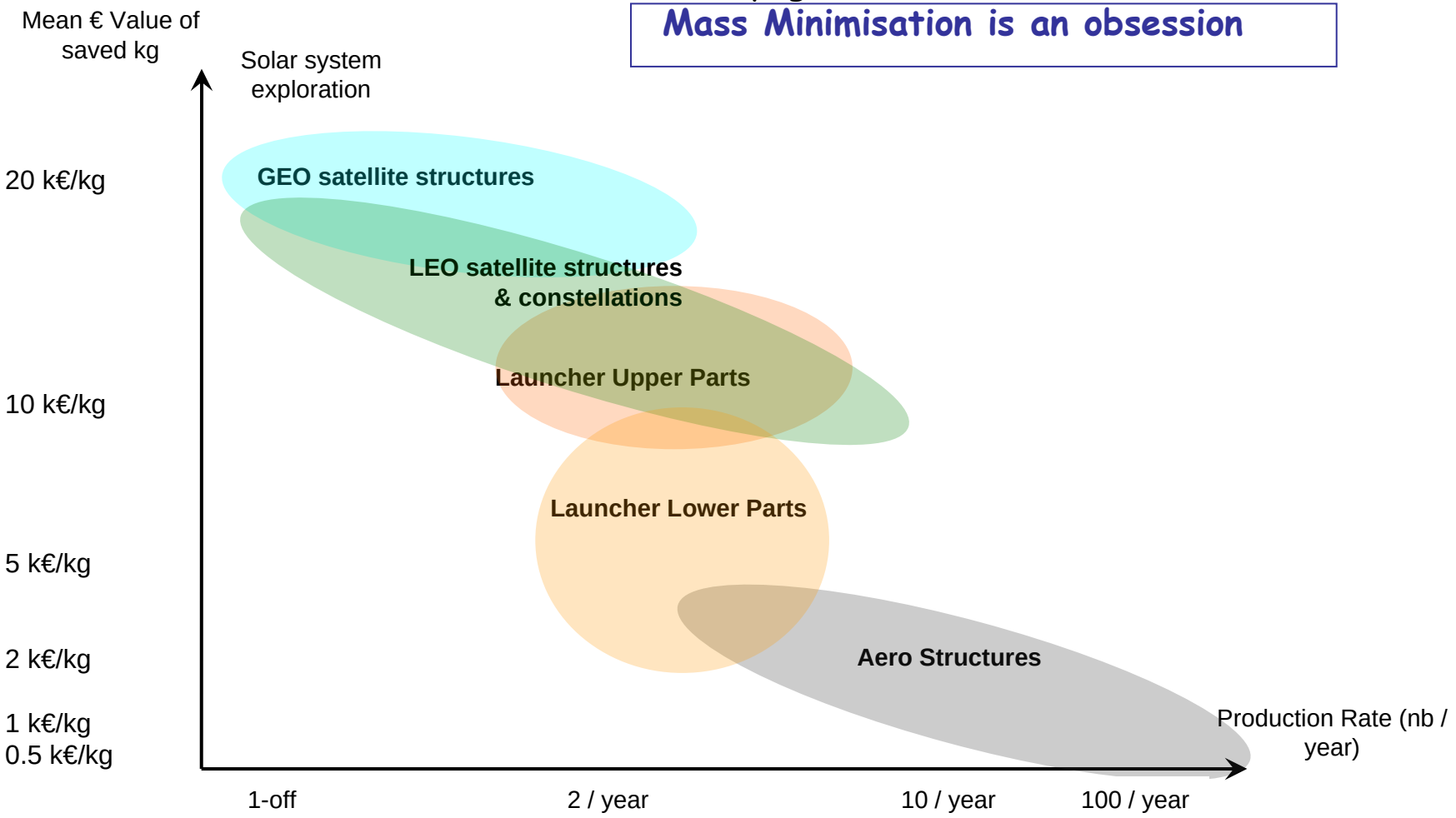
Materials for Space industry : a small market with high exigencies

High exigencies : Every gram in orbit costs ≈ 20 € ,so …

Mass Minimisation is an obsession



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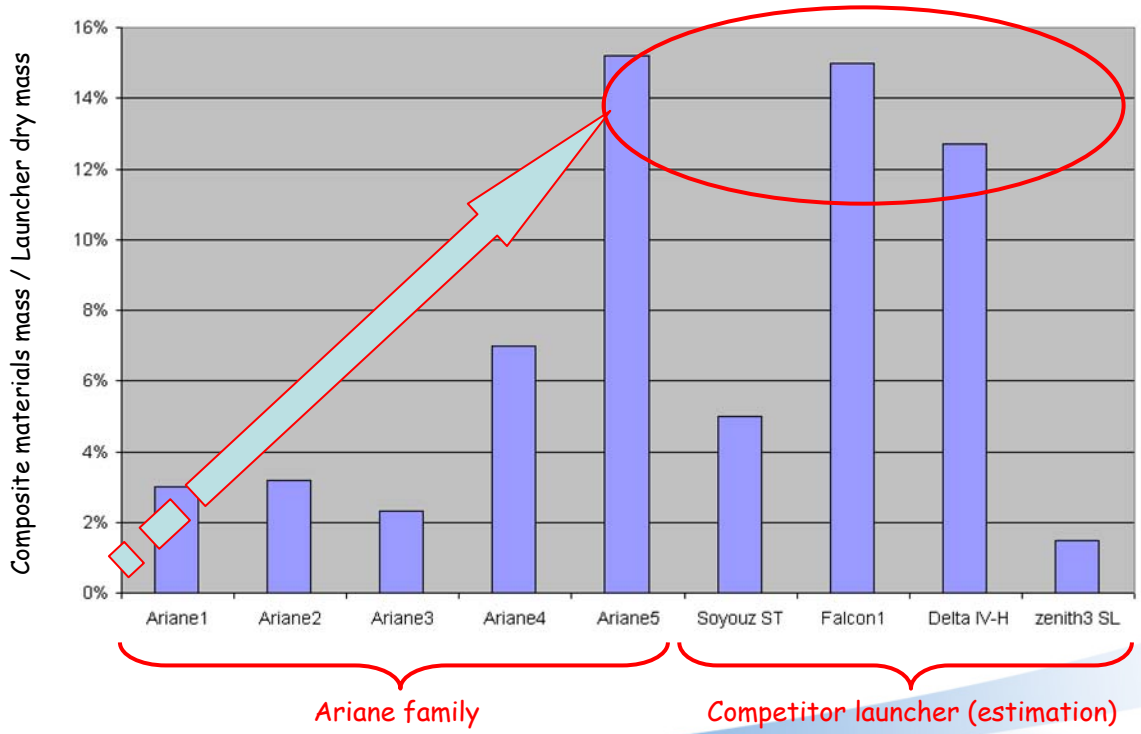
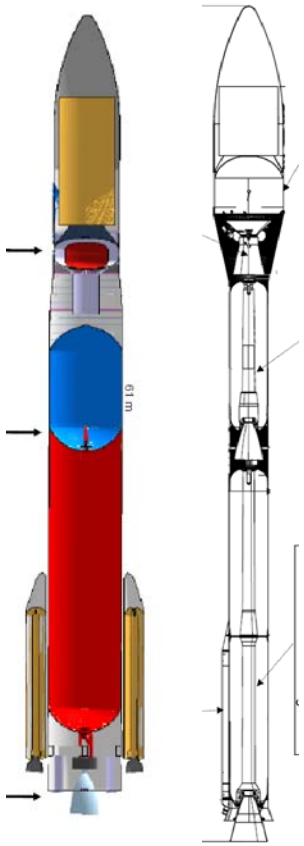
NEEDS FOR LAUNCHERS

Estimated composites materials mass ratio for launchers

the use of composite is increasing with the different versions of Ariane



NEEDS FOR LAUNCHERS



Where to use composite materials on future launchers

	A5ME	ARIANE 6
Heatshield (not structural)		
Rear bay 1st stage (ETF)	Dutch Space	
Liquid 1st stage	EPC (AST)	(3) (2)
Solid 1st stage	EAP (AST)	
Intertank skirt		
Interstage 1/2	Casa	
Rear bay 2nd stage (ETF)		
Liquid 2nd stage	Cryo upper stage (AST) (2)	(2)
VEB	Casa	
S/C adapter	AST	
Fairing	Contraves	
Solid strap-on		
Liquid strap on		
Strap-on nose cone	SABCA	

(2) HP tanks

(3) Trade off still possible for the tank

Parts already in composite on A5 — No new development foreseen for this part

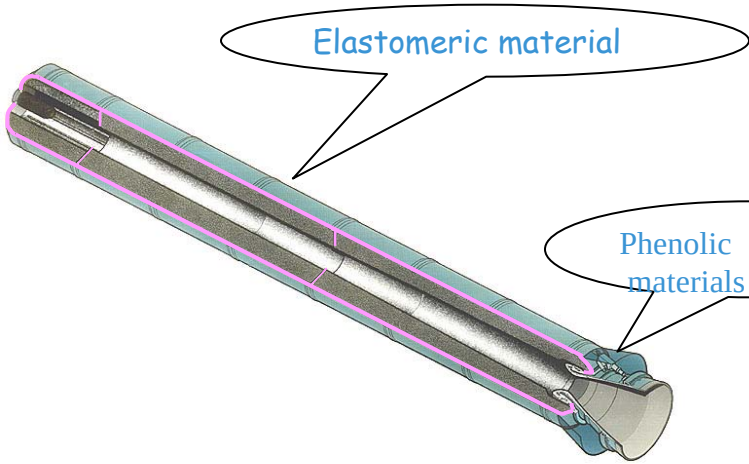
New development possibly based on new techno

Parts metallic on A5 Trade off metallic/composite still possible — New development based on A5 existing techno

New development based on new techno

Parts metallic on A5 — No new development foreseen for this part

Not applicable for the launcher



Except low pressure cryogenic tank, all structures could be concerned

Advantages brought by composite to increase the launcher performance, This trend will probably be confirmed through the development of the next generation of launcher, i.e Ariane 6

In a solid rocket motor as Ariane 5 boosters a first great challenge consists to reduce strongly the mass of inert of Internal Thermal Protections (ITP) to win in payload

Satellites: Selection of potential applications & benefits of nano-technologies

- Following axes are identified as potentially taking benefit of nano-technologies:
  - Structure – thermal
    (➔ Nano-structured ceramics, Metal Matrix Composites, CNT)
    - Mass savings of supporting structures (primary, housings …)
    - High performance (stability & thermo-elastic) for optics supporting structures (incl. X-Ray)
    - Improved thermal interface
    - Multifunctional substrate and coating ➔ Ex : Radiation shielding & EM transparent
    - Radiation shielding (High LEO, MEO, Jovian Exploration, GEO)
  - Power Subsystem
    - High energy to mass ratio storage ➔ Ex : Li-Ion with SiNT or CNT
    - High power to mass (& Surface) ratio solar cells ➔ Ex : Coatings, Quantum dots GaAs Solar Arrays
    - « Green » energy ➔ Ex : thermo-electric power generation
    - Harness mass reduction ➔ Ex : CNT based Wires

Satellites: Selection of potential applications & benefits of nano-technologies

Following axes are identified as potentially taking benefit of nano-technologies:

- Communication
  - Mass savings of supporting structures with improved thermal interface (primary, housings …)

    ➔ Ex : replacement of Aluminum by nanostructured alloys/nanocomposites
  - When possible substitute active device by passive device

    ➔ Ex : functional oxides
  - Improved efficiency EMI EMC shielding ➔Ex : Thin film RF absorbers
  - Cost decrease : low temperature processes, Organic technology keeping performance of high temperature processes

ESA Missions

- Following ESA Missions could be enhanced (/enabled) by introduction of nano-technologies:
  - **JGO** – Jovian Ganymed Orbiter [B2: 2013 / Launch: 2020]
    - High Radiation
    - Mass impact

    → Low Mass shielding structure

    → Global Mass Minimisation:
    - Structure
    - Power & Harness
  - **MSR** – Mars Sample Return Orbiter [B2: 2015 / Launch: 2022]
    - Mass Reduction to cope with largest launcher

    → Global Mass Minimisation:
    - Structure
    - Power & Harness
  - **IXO** – International X-Ray Observatory [B2: 2014 / Launch: 2022]
    - Structural Mass reduction to cope with Ariane V launcher
    - X-Ray Optical supporting stable structure

    → Structure Mass Minimisation:

    → Highly stable structure
  - **GEO-OCULUS / GEO-HR** (resolution 20 to 10m) [B2: 2015 / Launch: 2022]
    - Launch affordability ➔ SOYUZ compatibility
      ➔ Severe mass reduction
    - Very high stability of « optical benches »
      to achieve resolution

    → Highly stable structure

Potential nanomaterial applications comparison based on space community expectations (mass savings and other drivers)

Nanomaterial application field	Nanomaterial application	Satellite platform sub system mass breakdown	Potential final mass savings on the spacecraft with nanomaterials	Other important driver for nanomaterial	Total interest
Structures	Satellites and launcher' basic structure	Mechanical and thermal functions: 30 to 60% of the total mass	●●●●●		●●●●●
	Launcher (structures and motors) and re-entry thermal structures		●●●●●		●●●●●
	Satellites' optical structures		●●	●●	●●●●
	Tribology for satellites structures		●●	●●	●●●●
	Thermal protection foil		●●	●	●●●
Propellant	Solid propellant		●●●		●●●
Coatings	Corrosion protection		●	●●●●	●●●●●
	De icing coating for launchers		●		●
	Black coating		●		●
	Radiation protection coating		●●		●●
	EMI et lightning strike protection		●●		●●
Electronic/electric devices	Microwave devices	Avionics and communication functions: 20 to 30%	●●●		●●●
	Packaging & interconnexion		●●		●●
	Interface material		●●		●●
	Electric wiring		●●●●		●●●●
Sensors and actuators	Sensors		●	●●●	●●●●
	Actuators		●		●
Energy storage & generation	Thermo electric decentralized sources	Power functions: more than 30%	●●●		●●●
	Solar array		●●		●●
	Super capacitors		●●		●●
	Lithium batteries		●●●		●●●
	Fuel cells		●		●
	Hydrogen storage		●		●

●●●●●: High level of interest
●: Low level of interest

Other important drivers for nanomaterials : this can be the need to suppress Cr, in coatings, or the need for miniaturized sensor networks, or the need to improve technical performance of optical or tribological structure…

Nanomaterial categories under development for all space applications

Nanomaterial application field	Nanomaterial application	Nano object – Nano surface	Nanocomposites			Nano Structured materials	
			OMC	MMC	CMC /C-C	Ceramic	Metal
Structures	Satellites and launcher basic structure		●	●			●
	Launcher(structure and motors) and re-entry thermal structures		●		●		
	Satellites' optical structures			●	●	●	
	Tribology for satellite structures			●			
Propellant	Solid propellant	●		●			●
Coatings	Corrosion protection		●				●
	De icing						●
	Black coating		●				
	Radiation protection coating						
	EMI and lightning strike protection		●				
Electronic/ electric devices	Microwave devices	●					●
	Packaging & interconnexion	●		●			
	Interface material	●	●				
	Electric wiring	●	●				
Sensors and actuators	Sensors		●				
	Actuators		●				
Energy storage & generation	Thermo electric decentralized sources	●					
	Solar array	●					
	Super capacitors		●				
	Lithium batteries		●				●
	Fuel cells						●
	Hydrogen storage		●				

OMC nanocomposites are the most popular nanomaterial, especially with CNT

CNT are the most popular nano objects, used in OMC, CMC, MMC, nano surfaces

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Ranking & Priority

For the "Ranking & Prioritisation", we have taken in to account the following criterias:

- Actual space community needs and requirements
- Nanotechnology offer with level of maturity
- Nanotechnology (processors /integration) feasibility with composite materials

The chance of success based on experiences from other Nanotechnology projects (NACOMAT : Nano Coposites Materials), etc,… :

- accessibility
- required investment,
- time needed for demonstration, etc.

Ranking & Priority
Space Transportation (1)

Field of Application	Benefit of Properties (Needs /Nano)	Need	estimated TRL	Ranking - **Priority** **P0 = highest** **P2 = lowest**
Composite Structure				
Structural parts	Stiffness	5	2	**2**
	tensile strength	5	2	**2**
	Electrical Conductivity	4	2	**0**
	Fatigue	3	1	**2**
	Damage Tolerance	5	2	**1**
	Damage detection	4	2	**1**
	Avoidance of EMD	2	2	**2**
	Fire resistance	2	2	**2**
Elastomeric damper	Mechanical Damping of Low frequency Vibrations	3	2	**1**

Ranking & Priority
Space Transportation (2)

Field of Application	Benefit of Properties (Needs /Nano)	Need	estimated TRL	Ranking - **Priority** **P0 = highest** **P2 = lowest**
Thermal Protection				
Internal Thermal Protection (elastomeric)	Ablation & Thermomechanical performances	5	2	**0**
Thermal Protection system (C/phenolic)	Ablation & Thermomechanical performances	5	2	**0**
Propulsion				
SRM nozzle (C/C)	Ablation	3	1	**2**
SRM TVC (flexseal concept)	Stiffness	4	1	**1**
	Mechanical performances	4	1	**1**
Propellant	Energy density	5	1	**2**
	Better ignition	4	1	**2**
	Green propellants	4	1	**2**

Ranking & Priority
Space Transportation (3)

Field of Application	Benefit of Properties (Needs /Nano)	Need	estimated TRL	Ranking - **Priority** **P0 = highest** **P2 = lowest**
Sensors				
Gas Sensors	High sensibility to detect gases: H, He, .. ⇑	5	2	**0**
SHM (Structural Health Monitoring)	Miniaturization, e. g. for Sensor technology for integration in the structure ⇑⇑	4	2	**1**
Telemetry	Miniaturization, e. g. for Sensor technology for distributed architecture with wireless communication ⇑⇑	4	2	**1**
Surface functionnalization				
Metal Corrosion Protection	Replacement for cadmium and chromium based oxidation protection	5	1	**2**
Conductive coatings	Higher surface conductivity	4	2	**0**

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Roadmapping
Space Transportation (1)

- For Space Transportation, Roadmapping are established in the following topics as considered in Priority in 2 domains like **Materials and Process**:

⇨ For Composite structures (CMO modified with nano fillers) :Electrical Conductivity, Damage Tolerance, Damage Detection and Mechanical Damping

⇨ For thermal protection modified with nano fillers:Internal Thermal Protection and C/phenoloic based material

⇨ For Propulsion: SRM (Solid Rocket motor) TVC (Thrust Vector Control)

⇨ For Sensors: Gas detection, Sensors miniaturization

⇨ For Coatings : Conductive coatings

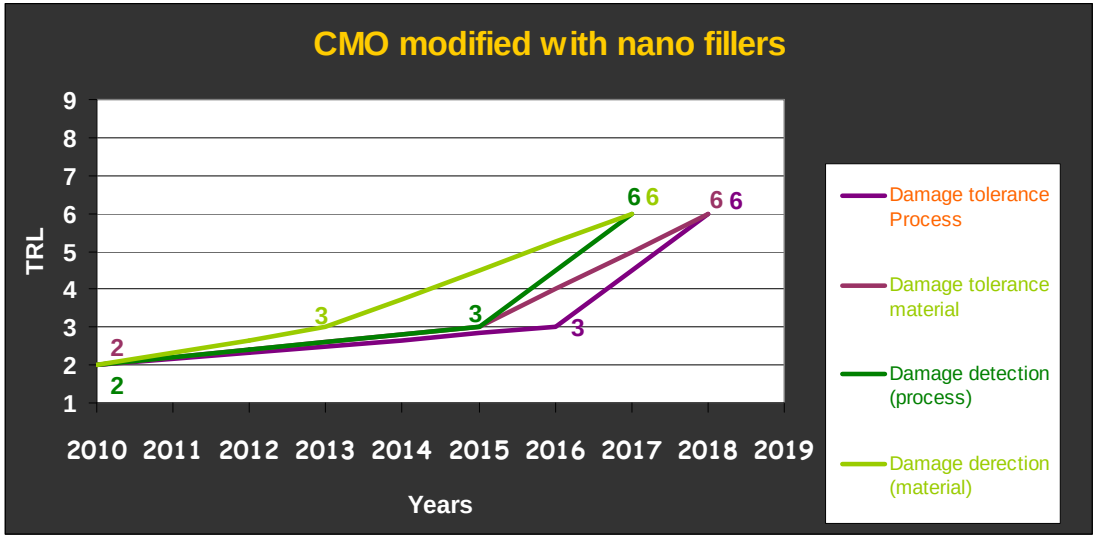
Roadmapping
Space Transportation (2)

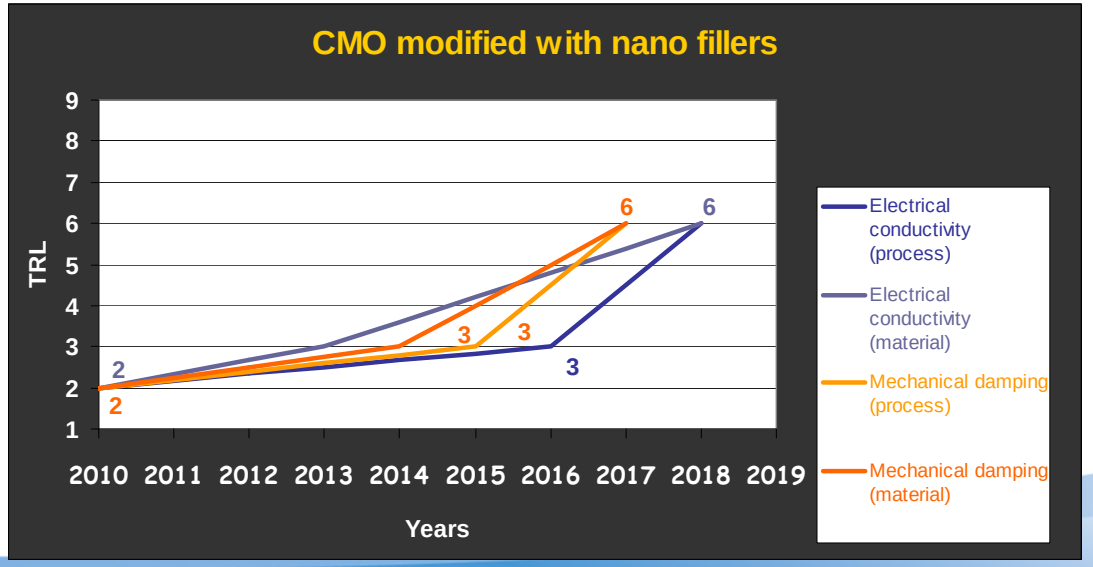
Field of Application	Benefit of Properties (Needs / Nano)	Need	Expected (<5years)	estimated TRL	Ranking - Priority P0 = highest P2 = lowest	targeted TRP TRL 2014	targeted GSTP TRL 2017	GAD
Composite Structure								
Structural parts	Electrical Conductivity	4	5	2	0	3	6	7
	Damage Tolerance	5	2	2	1	3	5	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

Roadmapping
Space Transportation (3)

	CMO modified with nano fillers							
	Electrical conductivity (process)	Electrical conductivity (material)	Damage tolerance Process	Damage tolerance material	Damage detection (process)	Damage derection (material)	Mechanical damping (process)	Mechanical damping (material)
2010	2	2	2	2	2	2	2	2
2012	2,3	2,7	2,3	2,4	2,4	2,7	2,4	2,5
2013	2,5	3	2,5	2,6	2,6	3	2,6	2,8
2014	2,7	3,6	2,7	2,8	2,8	3,8	2,8	3
2015	2,8	4,2	2,8	3	3	4,5	3	4,0
2016	3	4,8	3	4,0	4,5	5,3	4,5	5,0
2017	4,5	5,4	4,5	5,0	6	6	6	6
2018	6	6	6	6				
2019								
2020								

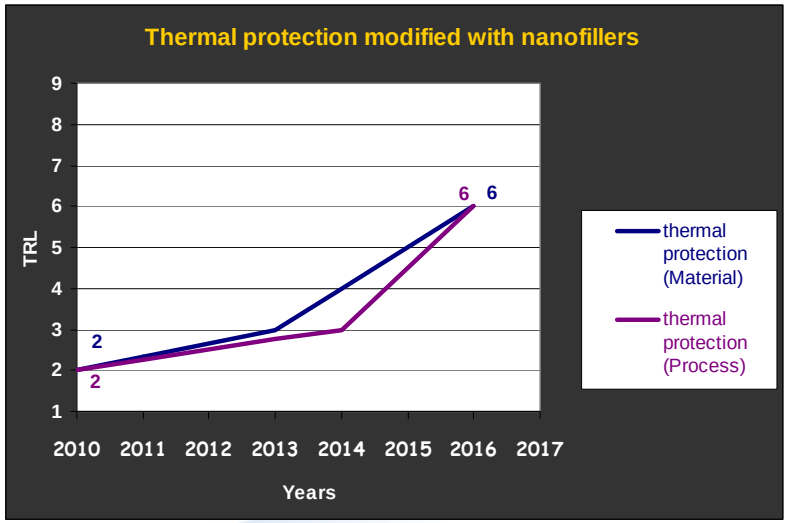
Roadmapping
Space Transportation (4)





Roadmapping
Space Transportation (5)

	thermal protection modified with nano fillers			
	thermal protection (Process)	thermal protection (Material)	thermal protection (Process)	thermal protection (Material)
	internal thermal protection (elastomeric) Process	internal thermal protection (elastomeric) Material	C/phenolic based material (Process)	C/phenolic based material (Material)
2010	2	2	2	2
2011	2,3	2,3	2,3	2,3
2013	2,8	3	2,8	3
2014	3	4,0	3	4,0
2016	6	6	6	6
2017				
2018				
2019				
2020				



Roadmapping Satellites (1)

For Satellites, Roadmapping are established in the following topics as considered in Priority :

Thales Alenia Space :

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

Astrium Satellites:

- CNT filled - CFRP (polymer composites)
- CNT based Ceramic composites for Thermal protection, Optical structures, Hot bearings
- CNT based Metal Composites for Mechanical (Fastners), Thermal (Heat Management), .
- CNT modified Elastomers
- Gas Sensors (Metallized CNT Structures)
- Nano Filled Propellants
- Nano Coating

Ranking & Priority TAS Satellites (1)

Field of Application	Benefit of Properties (Needs / Nano)	Need	estimated TRL	Accessibility	Feasability	Ranking - Priority P0 = highest P2 = lowest
Ultra-stable Structure	Stiffness	5	2	4	4	0
	Mechanical performances	5	1	3	4	1
	Electrical Conductivity	4	1	4	5	0
Harness& electrical interconnects	high current capability	3	1	?	1	2
RF & DC	low density	4	1	1	2	0
Heat sink	High thermal conductivity and low CTE	4	3	3	4	0
Nanomaterial characterization	characterisation means for high thermal conductivity nanostructured film	4	2	1	3	1
Energy storage (battery)	higher capacity	5	1	1	4	0
Electricity generation (thermoelectrics)	Improved Electrical efficiency	4	1	1	2	1
	Density	5	2	4	3	0
Structure PF, P/L and equipment	Thermal conductivity	5	2	3	2	1
(low CTE)	Electrical conductivity	5	2	4	4	0

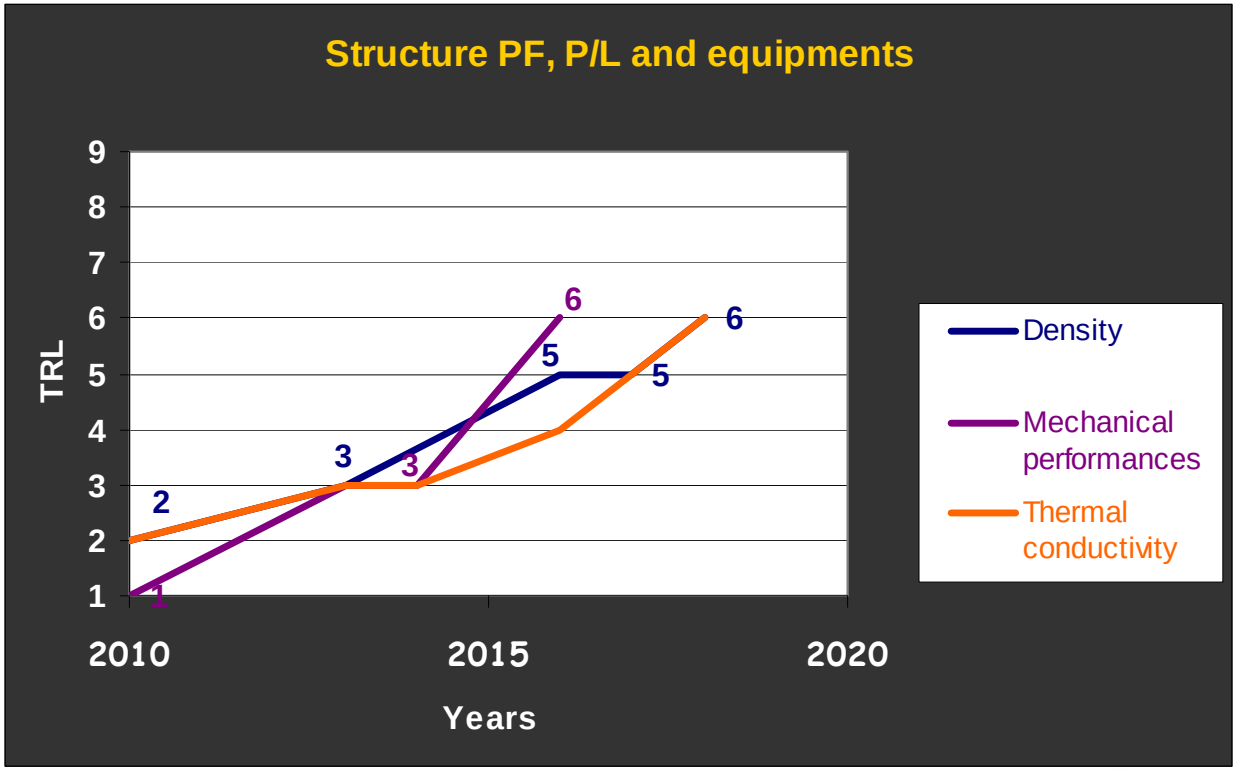
Ranking & Priority TAS Satellites (2)

Radiation shields	Density	5	2	2	3	**0**
	Improved Radiation efficiency	3	1	1	1	**2**
Communication P/L : Integrated RF Isolator	Integration, miniaturization	5	1	1	2	**0**
	Improved performance					
Communication P/L : new high linearity components	fast (<100 ns) electromechanical systems	4	2	1	4	**0**
(Nanogap)						
Communication P/L : reconfigurable component	Low loss reconfigurable materials	4	2	3	3	**1**
(Functional oxide)	Temperature stability	4	1	3	2	**2**

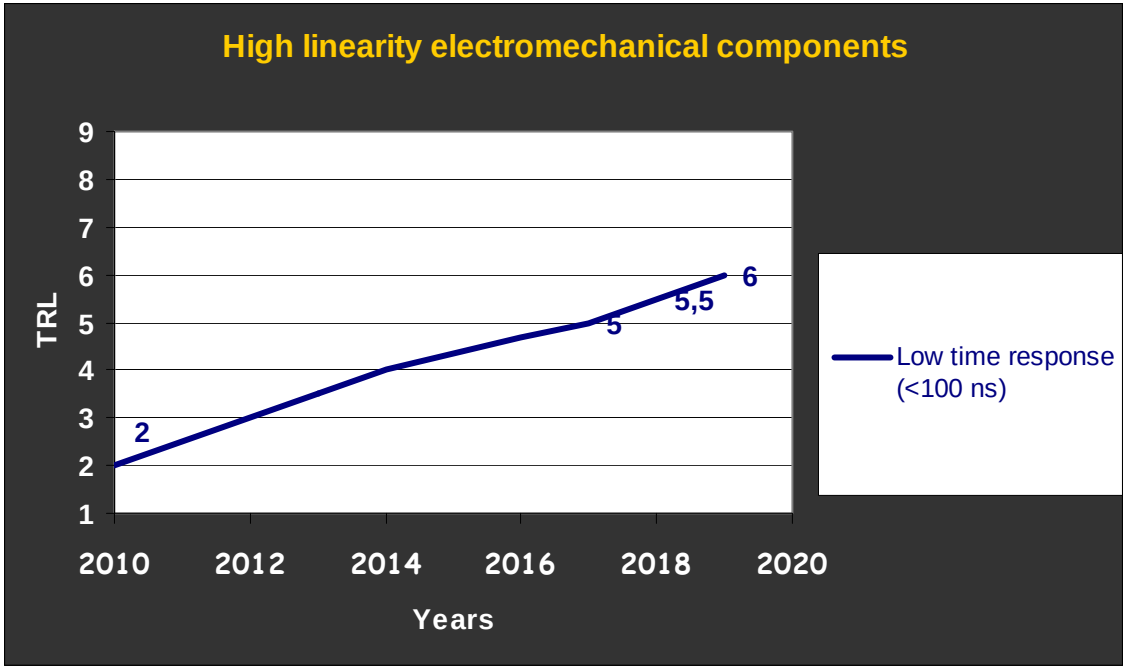
Missions & technologies

Field of Application	Benefit of Properties (Needs / Nano)	Ranking - Priority P0 = highest P2 = lowest	targeted TRP TRL 2014	Missions JGO	MSR	IXO	GEO-OCULUS GEO-HR	Other Missions
Ultra-stable Structure	Stiffness	0	3			X	X	
	Mechanical performances	1	3					
	Electrical Conductivity	0	4					
Harness& electrical interconnects	high current capability	2	3	X	X	X		
RF & DC	low density	0	4					
Heat sink	High thermal conductivity and low CTE	0	5					
Nanomaterial characterization	characterisation means for high thermal conductivity nanostructured film	1	5					
Energy storage (battery)	higher capacity	0	3	X	X		X	
Electricity generation (thermoelectrics)	Improved Electrical efficiency	1	3					Near Sun Exploration X
Structure PF, P/L and equipment	Density	0	5	X	X	X	X	
	Thermal conductivity	1	4					
(low CTE)	Electrical conductivity	0	5					
Radiation shields	Density	0	4	X			X	
	Improved Radiation efficiency	2	3					

Nano-composite, nano- alloy for PF, P/L and equipment structure



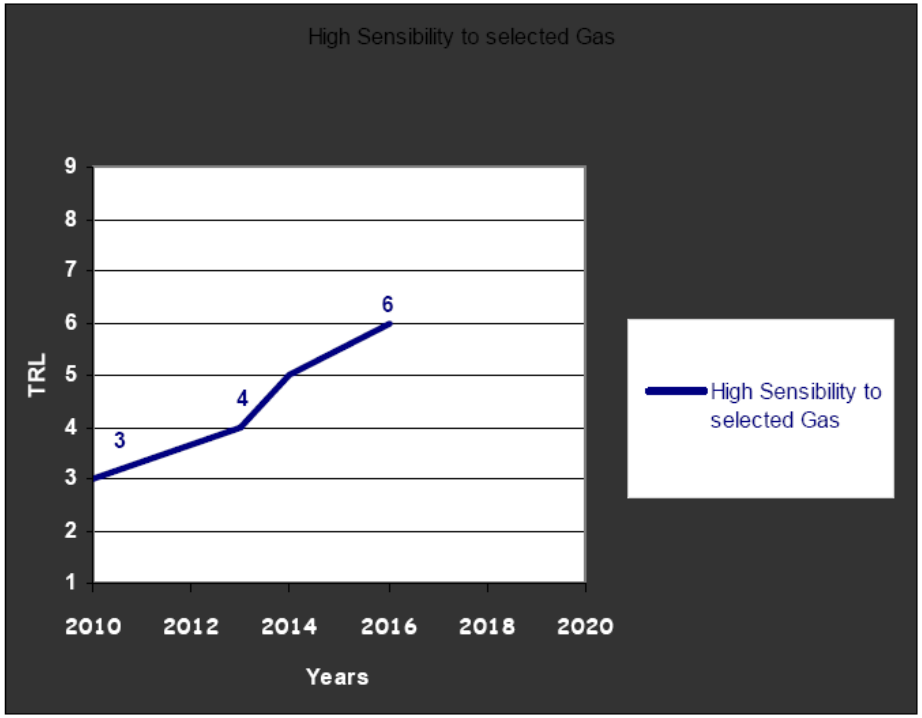
Ultra-fast electromechanical components (high linearity)



Gas Sensors based upon metallized CNT Structures (Astrium Sat & ST)

- Objectives: Demonstrate performance of Gas sensors based upon specifically metallized (depending on gas to be detected) Ccarbon nano structures (felts, papers, 3D networks..) :
  - Hydrogen, Helium, …

- Estimated TRL : 2/3
- Target TRL (TRP) : 3 - 4
- Target TRL (GSTP) : 6



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Conclusions

- Among the available Nano technologies priority have been put on physical properties to be improved for future and also accessibility
- Proposition of Nano technologies activities are in line with Space Transportation & Satellite systems needs
- Development roadmaps have been presented for best candidate technology
  - Established according to consortium sources, international WGs sources or when available, public document or advertizing
- End Users need definition have shown the potential impact for space of Nano technologies but despite the technical activities, some barrier need to be overcome
  - TRL are still low (2 to 3) for these technologies ➔ Improvements are still to be confirmed through Space R&D, but could benefit from Spin-In into other sector
  - Industrialization of the process, production of the nano-objects : which performance compared to lab demonstration ?
  - Impact to health, relevant protection standards ?
- MNT technologies are moving fast outside Europe, where no barriers to development are set….

THANKS

- **SPACE TRANSPORTATION**
- **SATTELITES**