# ASTRIUM Satellites expriment about RTEMS On-Board Software Product :
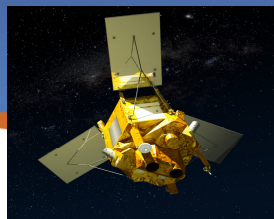# From an Open Source Software to an operational Satellite Real-Time Operating System

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Conférence L'Open Source pour les systèmes embarqués Temps réel
organisée par Open Wide au LAAS le 27 Avril 2012

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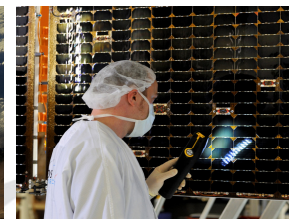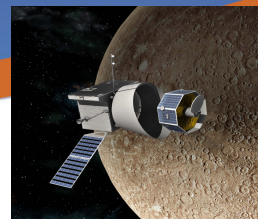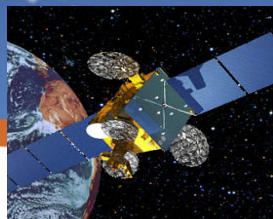
Agenda

- ASTRIUM
    - ASTRIUM company introduction
    - ASTRIUM Open Source Policy

- RTEMS: from Open-Source to Product
    - Motivation
    - RTEMS Open-Source Technical Definition & History
    - RTEMS Open-Source Risks analysis & Legal aspects
    - RTEMS Product
        - Definition
        - Qualification & Verification
        - Documentation
        - RTEMS on projects
    - One step beyond : Time & Space partitioning
    - Conclusion

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Astrium: part of EADS, a global leader in aerospace and defence

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Astrium's activities are based in three key areas

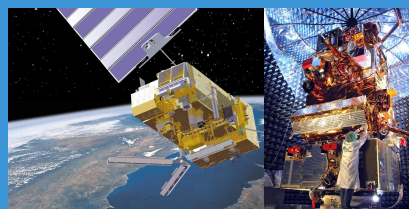## Astrium Space Transportation

The European prime contractor for space transportation and orbital infrastructure

Astrium Satellites

A world leader in the design and manufacture of satellite systems and ground segment

Astrium Services

A global provider of end-to-end solutions in satellite communications and geo-information services

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- In the frame of our prime core activities, Astrium is developing software in the following areas:

  - **Engineering tools and simulators** in support to Astrium industrial core processes to analyse, specify, verify, validate, qualify Space systems

  - **Ground Systems Software and Operational Software** that implement critical functions of Space systems operations

  - **Onboard Real Time Software** that are the recipient of a major part of system functional requirements, with many interfaces with onboard and ground subsystems

- Astrium policy is to have the full control of these software in order to master schedule, cost and quality of its Space system developments in the frame of European, National, Commercial and Export programmes.

- To support this policy, Astrium is continuously investing to improve its industrial engineering tools and simulators basis, and to develop re-usable Ground and Onboard Software building blocks.

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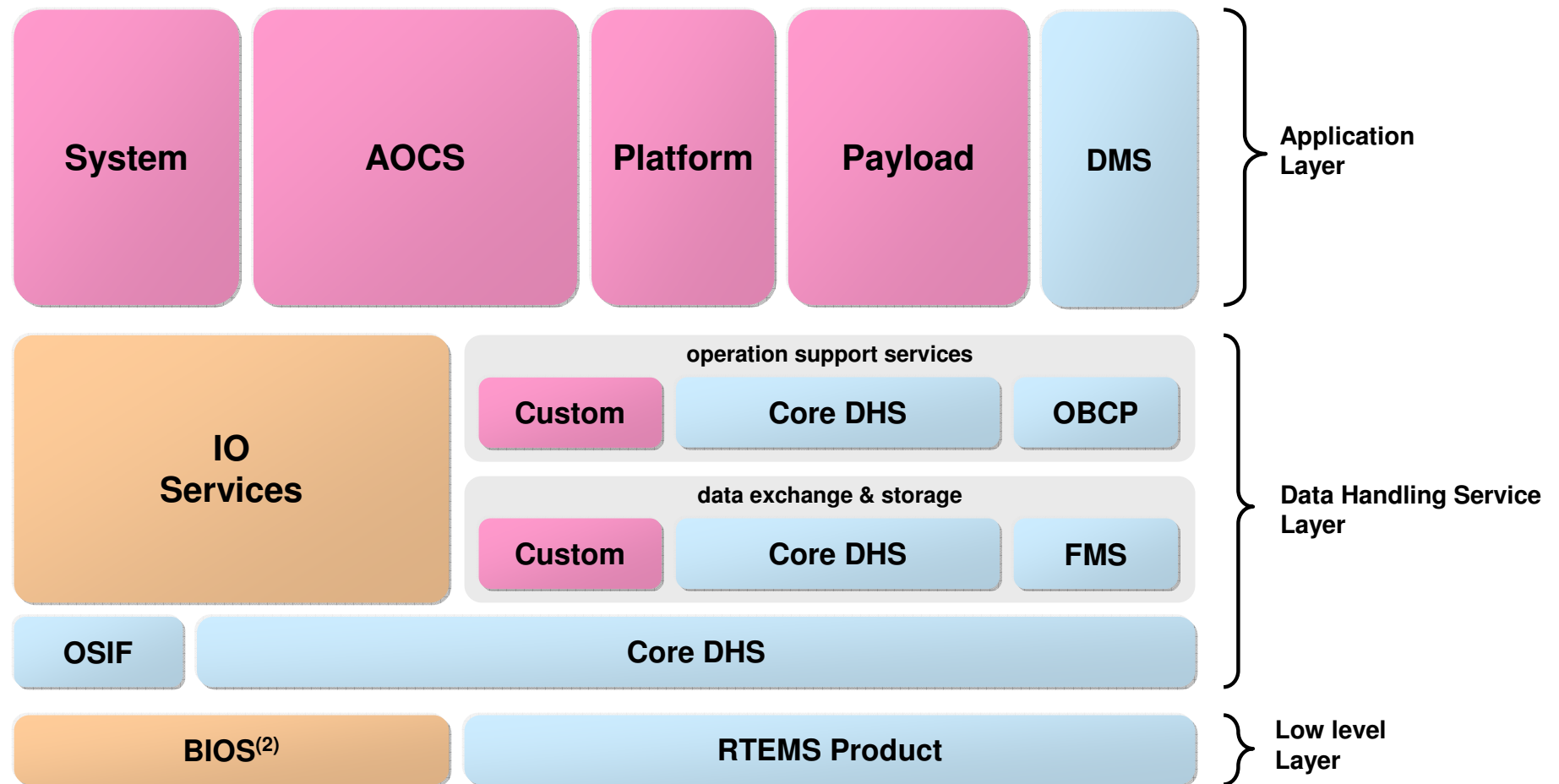
Astrium Position on Open Source Software

- Astrium is successfully using and developing OSS (e.g. SPIS, Eclipse, RTEMS, Linux, J-Synoptic, etc.) in the frame projects under development and for operational software.

- The selection of OSS is done on a case-by-case basis and depends first on quality and long term stability criteria.

- As OSS is a complex subject in terms of IPR and legal aspects (many OSS license types, contamination issues, etc.), Astrium has defined an internal OSS Policy to manage the usage of OSS.

- Astrium participates to the OPEES ITEA project and POLARSYS Eclipse Industrial Working Group to evaluate the feasibility and the opportunity to support an OSS business model, in collaboration with other industries for an enlarged user community.

- However, Astrium does not consider the OSS approach as applicable to software where sensitive know-how is involved (e.g. industrial know-how and/or national restrictions on dissemination).

ESA is defining its own OSS Policy & Licence

Debate is open between Agencies & Space Industry about OSS for Space

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Satellite On-board software architecture
Standard layers & Criticality level

System	AOCS	Platform	Payload	DMS

Application Layer

IO Services

operation support services

Custom	Core DHS	OBCP

data exchange & storage

Custom	Core DHS	FMS

Data Handling Service Layer

OSIF	Core DHS

BIOS[2]	RTEMS Product

Low level Layer

- ASTRIUM Products
- Project / Mission dependent software
- HW / OBC dependent software

Satellite On-Board Software criticality level is B or C

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- With new programs using ERC32 microprocessor in both platform and payload computers, a Real Time Operating System is required.

- In the frame of mission critical software for **unmanned** space programs, EADS Astrium selected C language in order to benefit from the large choice of available development tools and from the large user-base.

- Both VxWorks (Commercial solution) and RTEMS (Open source solution) were evaluated and it was chosen to qualify RTEMS and make it available for all EADS Astrium flight software projects.

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- R.T.E.M.S is an open-source software developed by On-Line Applications Research Corporation (OAR). It is distributed by OAR Corporation. RTEMS C language source code is available on web site : http://www.rtems.com
- RTEMS is an Operating System composed of a kernel and a set of optional features.

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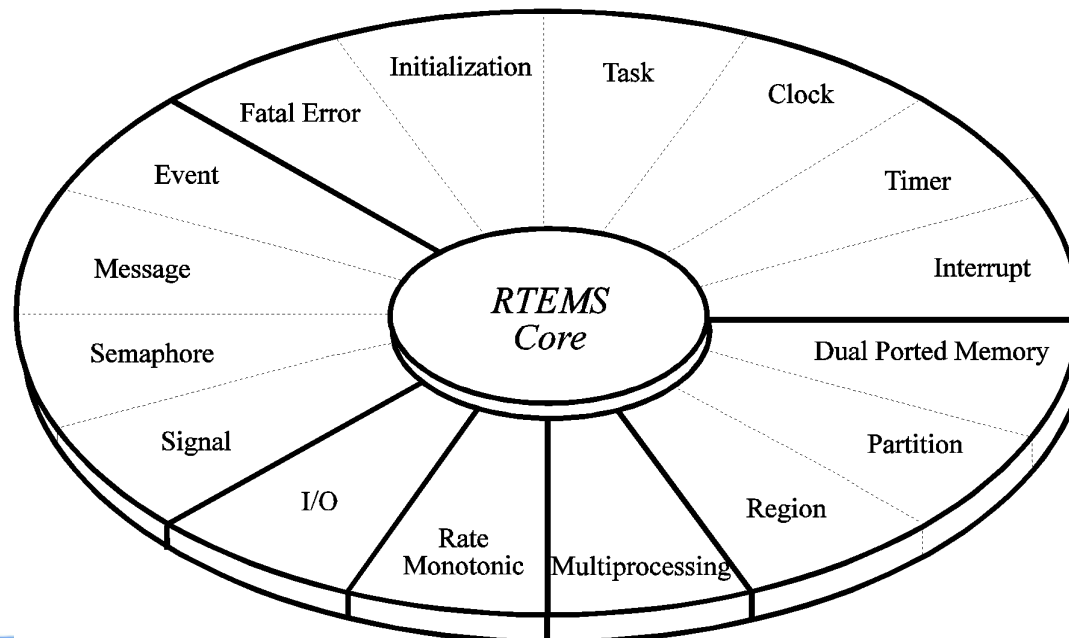
- RTEMS (Real Time Executive for Multiprocessor Systems) dates back until late 1980s. It was originally developed for the United State Army and gained support from ESA in 1995.

- RTEMS development timetable :

  - 1988 : initial development,

  - 1992 : release 2.0.1 (uses GNU toolset),

  - 1993 : release 3.0.0 (support for Ada added),

  - 1995 : release 3.5.0 (support for ERC32 added, sponsored by ESA),

  - 1998 : On-Line Application Research (OAR) becomes primary distributor of RTEMS.

  - 2000 : release 4.5.0

  - 2004 : release 4.6.1

  - 2006 : release 4.6.6 - SPARC LEON3 BSP submitted by Gaisler Enterprises

  - 2008 : releases 4.7.2, 4.8.0 and 4.9.1

  - 2009 : releases 4.9.2 & 4.9.3 - Herschel and Planck launch with RTEMS

  - 2010/2011 : release 4.10.x

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- Legal Risks : OSS licence & copyrights

  - We involved Contract & Legal departments

  - ASTRIUM tried to mitigate the legal risk with US lawyer consultancy.

- Human risks :

  - ASTRIUM internal On-Board Software experts preferred VXWORKS: we decided to make a pilot project.

  - Trans-national teams (France/Germany/UK) & projects : a unique RTEMS product cell organisation was settled, some training sessions were prepared and organised, some local focal points were nominated.

- Technical risks :

  - A qualification against Space standards ECSS was mandatory for application on projects (ESA & National Agencies, Commercial customers)

  - For long term maintenance issues, a dedicated RTEMS product cell organisation was settled.

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- Customer risks : resistance / opposition (neither flight proven, neither Space qualified)
  - External customers ➔ we involve ASTRIUM projects leaders & ASTRIUM management in decision process.
  - Internal customers ➔ we involve ASTRIUM Management & Internal On-Board Software Experts in decision process.

- Financial risks (expenses profile) :
  - ASTRIUM decided to invest initially.
  - Return of Investment was achieved after three projects.

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- **RTEMS source code includes copyrights :**
  - Copyrights OAR (all modules)
    - ➔ <u>License</u> GNU GPL Version 2 or later version accompanied with a special exception.
  - Copyrights ESA (Sparc specific modules)
    - ➔ No explicit license information

A risk analysis is conducted to evaluate/reduce following risks :
  - Risk to be sued by anybody claiming financial compensations for illegal copies of a proprietary software.
  - Risk that the application software becomes free software.

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Legal aspects

➢ The lawyer consulting office Clifford Chance in New-York confirms that we can use RTEMS. The copyright and contamination rules are not applicable except if EADS-Astrium distributes it to others companies.

➢ An information has been requested to ESA about its copyrights. ESA confirms that no financial compensations will be claimed by the Agency.

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- Derive from the RTEMS 4.6.1 basis a qualified RTOS for ERC32 usable within EADS Astrium programs with minimum costs. This RTOS is called **RTEMS Product**.

1. RTEMS Product includes a single selection of RTEMS optional features. The selection shall comply with typical needs of mission critical software for unmanned space programs.

2. RTEMS Product shall own a qualification status compliant with ECSS-Q-80-B requirements applicable to « Re-used software » .

3. An RTEMS product maintenance cell provides RTEMS community activity monitoring and bug fix and re-qualification for RTEMS product users.

4. RTEMS Product shall, as far as possible, not diverge from distributed RTEMS in order to benefit from RTEMS user community activity.

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Optional feature selection

- 10 among the 17 RTEMS optional features have been selected for inclusion in RTEMS Product. They comply with the typical needs of the targeted flight software class.

- The RTEMS Product library only contains the selected features in order to prevent the use of non qualified features.

- RTEMS Product also includes a generic ERC32 Board Support Package derived from the standard ERC32 one.

  This BSP was modified to move all target specific aspects in configuration files in order to make the qualification activities **independent from the target hardware**.

initialization	task
interrupt	clock
timer	semaphore
message queue	event
signal	partition
region	dual ported memory
I/O	fatal error
rate monotonic	Multi-processing
User extension	

Selected

Not selected

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Files identification

- The complete RTEMS 4.6.1 was downloaded from RTEMS web site and put under configuration control.

- It contains almost 9000 files representing more that 380000 lines of code. In order to narrow the scope of RTEMS Product qualification it was necessary to identify the source files that are included in RTEMS Product.

RTEMS 4.6.1
392500 loc
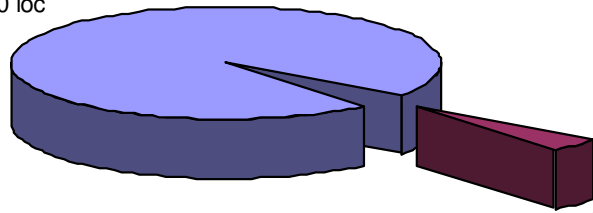
RTEMS Product
4%

File category	Number of files	Lines of code
C source files	153	7500
C header files	120	9000
Assembly files	4	600

- RTEMS Product includes around **4%** of RTEMS 4.6.1 (in terms of lines of code).

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Product library

- When building a complete flight software, RTEMS Product is seen as :
    - a set of C header files used to compile the application software (these header files contain the declarations needed to use RTEMS Product),
    - a library that is linked with the user Application software.

- The linker will only include the modules that are strictly necessary in the complete flight software. This depends on RTEMS Product usage at Application software level.

- This reduces the size of the embedded code to a minimum and avoids to include unused code in the flight software.

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- In order to reach qualification objective, the following activities have been performed on RTEMS Product :

  - **Source code verification**: in order to assess the quality of the code with respect to reliability and robustness criteria.

  - **Testing**: to assess its functional conformity, performance, robustness and measure code coverage.

  - **Documentation**: produce a complete qualification documentation set (from product specification to qualification status and software configuration item data list).

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Source code verification

- Source code verification was performed using the Telelogic Tau RuleChecker tool using a set of 43 coding rules derived from MISRA C coding standard.

- Verification results are:
    - 13 rules violated (30 not violated),
    - 641 violations (more than 400 related to coding style),
    - An exhaustive analysis of the violations showed no evidence of poor coding or design.

- Conclusions:
    - RTEMS Product code is rather homogeneous indicating that it was initially developed by a small team over a short period of time.
    - Violations analysis indicate that readability and maintainability criteria were not taken into account at the same level as in our usual quality systems.
    - It also shows that violations do not question reliability and robustness of RTEMS product.

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- **Testing activities objectives detail as follows:**

  - **Functional tests**: cover 100% of the requirements that apply to RTEMS Product. If a requirement can not be covered by test it can be covered by an analysis of RTEMS Product design and code.

  - **Performance tests**: measure the timing of each individual service of RTEMS Product. Evaluate the CPU load associated to internal mechanisms.

  - **Robustness tests**: activate RTEMS Product in more complex and stressful situations than the functional tests that are dedicated to a specific feature.

  - **Code coverage**: cover 100% of the branch and simple decision of the code. Complete the test suite to improve coverage. Analyse and justify all non-covered code.

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- The RTEMS Product validation plan includes 91 cases whose results are:

Case category	Number of case	Functional coverage	Tests code coverage
Functional	80	100%	C code 85%

Assembly code 100% |
Analysis	1		
Coverage	4	-	
Performance	2	-	
Robustness	4	-	

- 3 bugs were found during the test campaign:
  - 1 was corrected to make the corresponding test OK,
  - the 2 other bugs do not impact RTEMS Product usability have not been corrected. Usage restrictions have been traced in RTEMS Product user's manual.

- An **exhaustive** analysis of the code corresponding to the branches and decisions not covered by tests has been performed and tracked in the RTEMS Product qualification status.

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- RTEMS Product documentation includes :

  - RTEMS Product development and maintenance plan

  - RTEMS Product user's manual

  - RTEMS Product validation specification

  - RTEMS Product qualification report

  - RTEMS Product SCIDL

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- A specific RTEMS behaviour verification activity is performed in the frame of global / stress testing of the software.

- Based on the timings (task switching and Interrupt handlers) collected on a real hardware using SIF.

- Performed together with the measurement campaign used to consolidate CPU budget reports and Schedulability analysis.

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- After the completion of qualification activities, RTEMS Product 1.0 was released in 2005.

- Evolutions where performed on the 4.6 branch by RTEMS community up to 4.6.6.

- In 2007, the critical PR#1237 was raised
    - it was decided to update RTEMS Product to correct this bug and other less critical bugs.

- RTEMS Product 1.0.1 based on RTEMS 4.6.6 + correction of PR#1237 has been released in 2008.
    - All tests have been re-run on the new version (one new test has been added).
    - Coverage analysis of the new version has been updated.

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Status today

- Since 2008 an update of RTEMS Product status is delivered to projects every 4 to 6 month including:

  - The analysis of all the problem raised

    - By RTEMS Product users,

    - By RTEMS users (from OAR managed bugzilla).

  - Workarounds or checks to be implemented on projects to ensure that identified problems do not occur.

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Version used by projects

- RTEMS Product 1.0 is used by:

  - TerraSAR X, GIOVE-B, Pleiades, SMOS Instrument (ERC32, PR#1237 does not apply to these projects)

- RTEMS Product 1.0.1 is used by:

  - Galileo IOV, Aeolus, Lisa PF, Gaia, Bepi Colombo, Sentinel 2, Earthcare (ERC32).

  - Alphasat Payload Controller (Leon2/Astrium MDPA ASIC)

  - Spot 6, Spot 7, Seosat, KRS, Sentinel 5P, CSO (Leon3/Astrium SCOC3 ASIC)

  - Exomars Rover (Leon2)

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One step beyond : Time & Space partitioning

- Establish a spin-in from aeronautical domain of the TSP/IMA technology for space applications:
  - Define, develop and demonstrate an "IMA for Space" system built on ARINC653.
  - Based on Time & Space Partitioning and Hypervisor technologies compatible with LEON2/3 based space computers and RTEMS Operating System.
  - Several solutions COTS and OSS are evaluated on several use case applications.

pikeOS	COTS	Aeronautics (A350)	Port to Leon	ARINC653
XtratuM	OSS	Space (SVOM)	Developed for Leon	ARINC653
AIR	RTEMS	Space (R&D)	Developed for Leon	ARINC653

RTEMS Product in all ASTRIUM SAT projects France/Germany /UK is a success and give us a competitive advantage.

Positive ROI was achieved after 3 projects.

External & Internal customers are satisfied.

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Thank for your attention.
Any question ?

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