



We Give the DNA of Motion for Earth and Beyond

*Houston, if you have a problem,
Icpe has the solution!*

Icpe, a Worldwide Brand and Best Romanian Electric Motor Developer and Manufacturer for High-tech Industry and Space



1950 - 2019



Icpe Team:

Ioana Ionica

Stefan Tanase

Ioana Maria Nicola

Carmen Beatrice Oprea

Andrei Cristian Covrig

Andrei Cristian Stancu

OEM

Professional services

R&D Electrical
Engineering

PRODUCTS
AND
TEHNOLOGIES

Innovative Efficient
Competitive
ECO Friendly



R&D

OEM

SERVICES

ALL
ELECTRIC
SHOP

Institutul de
Cercetări

Electrotehnice®

ISSN / ISSN-L: 1843-5912

<https://www.doi.org/10.36801/apme.2019.1.16>

Special electric motors
Servo control
Electric special cables
Electric apparatus

Metrology lab
Integrated Energetic
services
Consulting services
Publishing house

Electric cables
Electric Apparatus
PV systems
Solar panels kit

Research & Development

ICPE research department is a trustful partner in a wide range of areas having high expertise, capabilities and strategy.

We are carrying out:

- RDI support for companies
- Project management
- Studies
- New products and systems development
- Product design under customer's specification
- Electromagnetic /thermal/mechanic computation
- Prototype manufacture & demonstrative projects prototyping
- Product qualification including "in house" testing
- Technologies



- **Special electric machines**
- **Servo control**
- **Power apparatus**
- **Electric cables**
- **Electric vehicles and E-mobility**
- **Energy efficiency&Renewable energy sources**
- **Automation components**
- **Electro technologies**
- **Products testing**
- **New emergent domains**





- **lcpe** has gained a wide experience in Research and Development Projects.
- Based on an elite team, **lcpe** has been deeply involved in national and international projects in order to promote products and technologies for **sustainable development**.

- > **500+ RESEARCH PROJECTS** (2000-2019)

- > **20 ONGOING PROJECTS**

- ✓ *HORIZON 2020*
- ✓ *STAR / ESA*
- ✓ *MANUNET*
- ✓ *National projects*
- ✓ *EUREKA*
- ✓ *Norway Grants*



RESEARCH & DEVELOPMENT PRIZES AND AWARDS



lcpe

Research & Development For Space

Projects developed with:

- Romanian Space Agency – ROSA



- European Space Agency - ESA





Reaction Wheel for Spacecraft Attitude Control



<http://www.icpe.ro/projects/rwsac/>

Contract Duration: September 2017- December 2019

Partners: COMOTI
Institute of Space Science – ISS

The project RWSAC aims the development of a reaction wheel assembly for attitude control in spacecrafts by spinning-in proven technologies towards space applications.

Although having a relative simple operating principle, reaction wheels are intrinsically complex due to special restrictions imposed by their applicability to space missions: high reliability requirements, close to 100% duty cycle, mechanical wear, provisions for lubrication in vacuum, high precision for balancing at high rotational speed, mitigation of potential defects at launch etc.

Tackling this problems will increase the know how in the consortium beyond the product being developed, while expanding the existing abilities, skills, qualifications and methodologies applicable to most of the space related activities of the entities involved.



Advanced solar thermal propulsion system for increasing satellite operational life

www.icpe.ro/projects/strauss/

Contract Duration: September 2017- December 2019

Partners: COMOTI
University POLITEHNICA of Bucharest

The main objectives of this project is to research, design, manufacture and test an advanced/original solar thermal propulsion system for increasing of operational life of satellites by 2.5 times. The main objective will be reached through achievement of two secondary objectives:

- ❖ R&D of Special Equipment for Focusing of Solar Light (SEFSR),
- ❖ R&D of a high performance/ultra-light solenoid micro-valve and nozzles.



European Space Agency



Programme for New Member States (NMS) or Incentive Scheme

- Speed-up the identification and development of economic operators that may sustain a viable business case as a supplier for ESA projects.
 - Support the rapid introduction of the national economic operators in the European Space supply chain.
 - Contribute to bridge the geographical return gap occurring in the first years after a Country accession as a full-rights member of ESA.
- On Romanian Industry Incentive Scheme ESA Programme, lcpe gained contracts through which:
 - ✓ evaluated the suitability of its electric motors for the space sector (up to TRL 4-5);
 - ✓ developed a stepper motor needed in the space mechanism market (up to TRL 4-5);
 - ✓ developed a new Reaction Wheel using up-to-date technologies (up to TRL 3);
 - ✓ update the TRL level of the Reaction Wheel to TRL 4;
 - ✓ developed a limited angle torque motor for actuation system used in launchers (up to TRL 4-5);
 - ✓ directly respond to a market need revealed from a request by a space integrator (developing synchronous motors for LEO and GEO Applications).





Electric Motor Technology Spin Into Space - EMSIS

ESA EMSIS

www.icpe.ro/projects/emsis/

Partner: Institute of Space Science – ISS

EMSIS is a project through which Icpe was awarded a contract with ESA for evaluating the suitability of its electric motors for the space sector. EMSIS address this issue by spinning-in existing electric motor technology from the defense and aviation sector into the space domain.

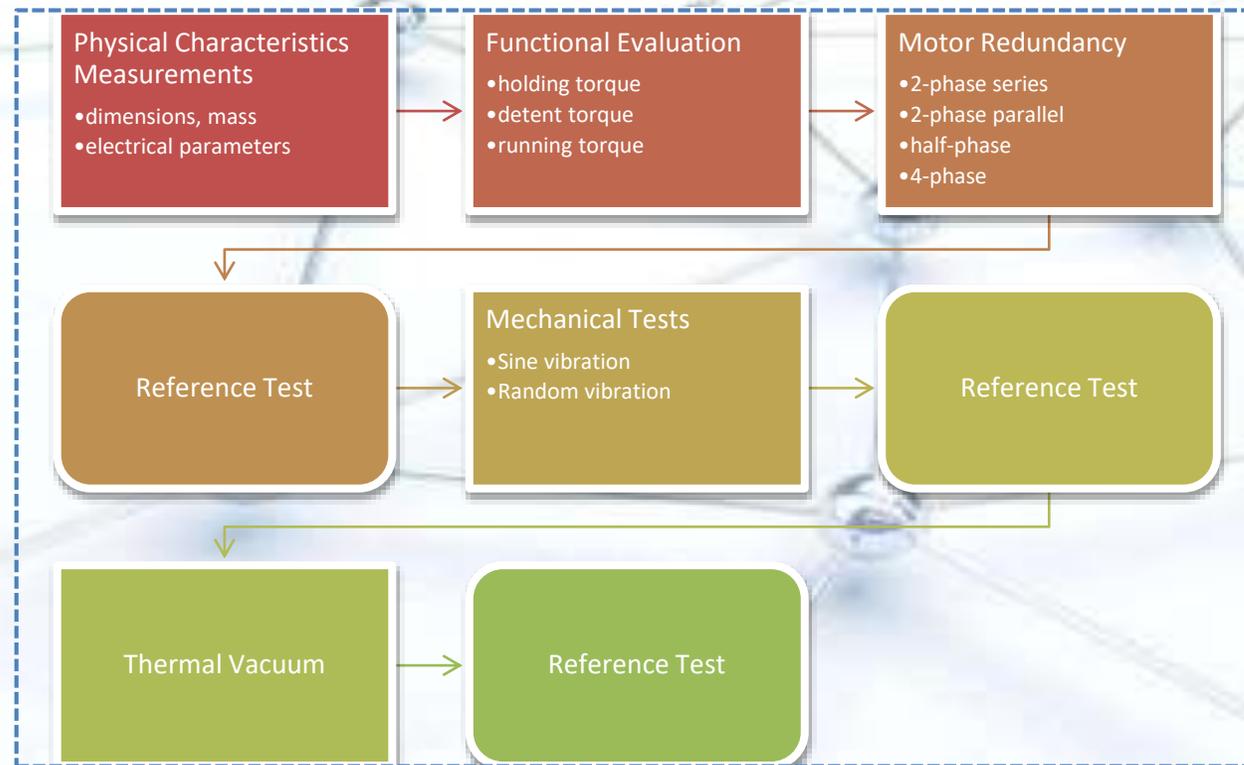


<https://phys.org/news/2015-05-mechanical-space.html>



■ Objective(s)

- Survey the space motors market and identify niches/needs;
- Research and characterize the space and launch environments;
- Spin-in the existing motor manufacturing technologies into the space components market;
- Certify the new motor and the new driver electronics manufacturing technology for space applications.



- In the previous flowchart is presented the Motor Test Campaign at the end of which, a hybrid stepper motor in frameless configuration was developed at EM level (TRL 5).



Stepper Motor for Space Mechanisms

<http://www.icpe.ro/projects/stepper-motor/>

Is a project through which Icpe was awarded with a contract with ESA for study and develop a new version of hybrid stepper motor.

The main objective of this project is to develop a new stepper motor for ESA space applications.

Currently, the project is at EM testing campaign. At the end of it, we aim to reach a TRL 5 with the hybrid stepper motor.

- **After EM completion, the Development Plan foresees the project continuation in order to reach TRL 8 for this motor.**



Development of a new Reaction Wheel using up-to-date technologies

www.icpe.ro/projects/new-reaction-wheel/

The **main technical objective** of this project is to develop a preliminary conception of a reaction wheel that will take maximum benefit of new technologies and to establish a detailed development plan for such product. The potential applications for the new reaction wheel are Earth observation satellites in Low Earth Orbit.

Main technical specifications:

- Angular momentum of 6 Nms;
- Reaction torque ≥ 0.2 Nm;
- Volume 200 x 200 x 90 mm³;
- Mass ≤ 5 kg;
- Exported forces due to micro-vibration lower than 0.5 N.

Break-throughs technologies:

1. Electric motor configuration based on a direct drive permanent magnet synchronous motor;
2. Digital control of reaction wheel with FPGA;
3. New technology for high precision balancing;
4. Hybrid bearings.

➤ At the end of the project, a Reaction Wheel at TRL 3 was developed.





- Design of a Torque Motor Unit (MoU) with applications in spacecrafts.
- The MoU produces a *torque proportional to supplied current*.
- **The design requirements are specific to space applications:**
 - *high reliability, high pressure resistance, adiabatic operation, operation under high vibrations.*
- **Currently, according to contract timeline the CDR Milestone was held together with ESA and Icpé's partner in the project and it was successfully closed.**



- **At the end of the project, the limited angle torque motor will reach EM stage (TRL 5).**



Synchronous Motors for LEO and GEO applications - SYMOLEG

The present project aims to directly respond to a market need revealed from an integrator from the space domain. At the same time it addresses the goal to diversify Icpce's portfolio of products for the space sector by developing synchronous motors for LEO and GEO applications. Icpce can enter on this new roadmap for these motors for space applications with minimal adjustments of its manufacturing technology since its portfolio already serves a wide range of applications in the aeronautics and defence industries; fields with similar technological and product/quality assurance requirements.

The main objective of the activity is the development of two types of synchronous motors, in frameless configuration at a TRL 4-5 (EM), starting from a Technical Specification from an integrator from the space domain.

The kick-off of the project took place on 29/10/2019.

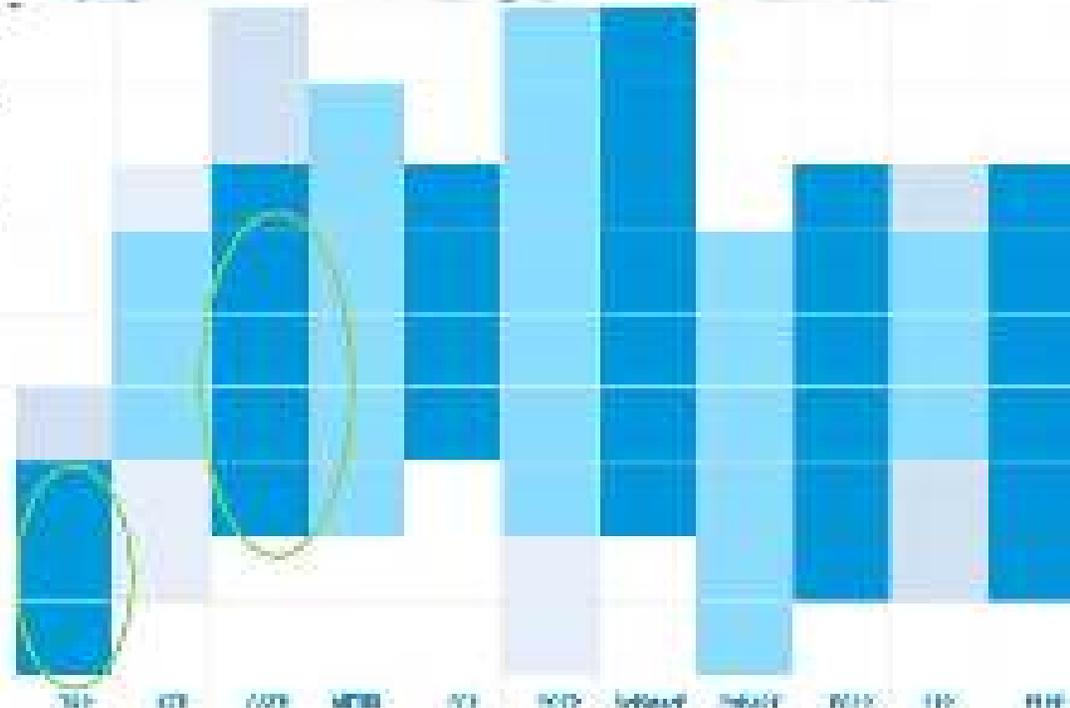


General Support Technology Programme (GSTP)

GSTP has the following objectives:

- **Enable missions** of ESA and national programmes by developing technology;
- Strengthen the **competitiveness** of European industry;
- Improve **European technological non-dependence** and the availability of European sources for critical technologies;

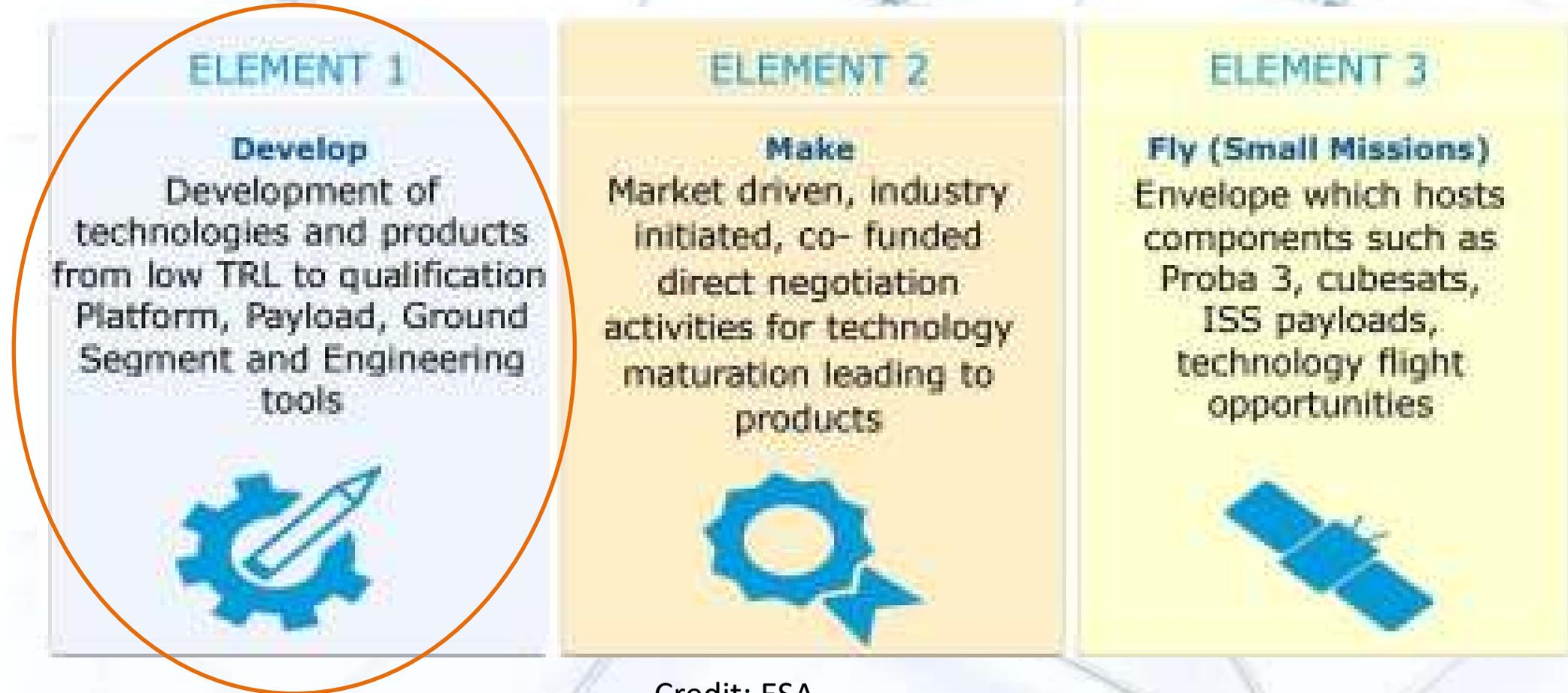
- TRP 1: Initial system of infrastructure and TRP 2: Initial system of infrastructure and infrastructure services
- TRP 3: Initial system of infrastructure and TRP 4: Initial system of infrastructure and infrastructure services
- TRP 5: Initial system of infrastructure and TRP 6: Initial system of infrastructure and infrastructure services
- TRP 7: Initial system of infrastructure and TRP 8: Initial system of infrastructure and infrastructure services
- TRP 9: Initial system of infrastructure and TRP 10: Initial system of infrastructure and infrastructure services
- TRP 11: Initial system of infrastructure and TRP 12: Initial system of infrastructure and infrastructure services
- TRP 13: Initial system of infrastructure and TRP 14: Initial system of infrastructure and infrastructure services
- TRP 15: Initial system of infrastructure and TRP 16: Initial system of infrastructure and infrastructure services
- TRP 17: Initial system of infrastructure and TRP 18: Initial system of infrastructure and infrastructure services
- TRP 19: Initial system of infrastructure and TRP 20: Initial system of infrastructure and infrastructure services
- TRP 21: Initial system of infrastructure and TRP 22: Initial system of infrastructure and infrastructure services
- TRP 23: Initial system of infrastructure and TRP 24: Initial system of infrastructure and infrastructure services
- TRP 25: Initial system of infrastructure and TRP 26: Initial system of infrastructure and infrastructure services
- TRP 27: Initial system of infrastructure and TRP 28: Initial system of infrastructure and infrastructure services
- TRP 29: Initial system of infrastructure and TRP 30: Initial system of infrastructure and infrastructure services
- TRP 31: Initial system of infrastructure and TRP 32: Initial system of infrastructure and infrastructure services
- TRP 33: Initial system of infrastructure and TRP 34: Initial system of infrastructure and infrastructure services
- TRP 35: Initial system of infrastructure and TRP 36: Initial system of infrastructure and infrastructure services
- TRP 37: Initial system of infrastructure and TRP 38: Initial system of infrastructure and infrastructure services
- TRP 39: Initial system of infrastructure and TRP 40: Initial system of infrastructure and infrastructure services
- TRP 41: Initial system of infrastructure and TRP 42: Initial system of infrastructure and infrastructure services
- TRP 43: Initial system of infrastructure and TRP 44: Initial system of infrastructure and infrastructure services
- TRP 45: Initial system of infrastructure and TRP 46: Initial system of infrastructure and infrastructure services
- TRP 47: Initial system of infrastructure and TRP 48: Initial system of infrastructure and infrastructure services
- TRP 49: Initial system of infrastructure and TRP 50: Initial system of infrastructure and infrastructure services
- TRP 51: Initial system of infrastructure and TRP 52: Initial system of infrastructure and infrastructure services
- TRP 53: Initial system of infrastructure and TRP 54: Initial system of infrastructure and infrastructure services
- TRP 55: Initial system of infrastructure and TRP 56: Initial system of infrastructure and infrastructure services
- TRP 57: Initial system of infrastructure and TRP 58: Initial system of infrastructure and infrastructure services
- TRP 59: Initial system of infrastructure and TRP 60: Initial system of infrastructure and infrastructure services
- TRP 61: Initial system of infrastructure and TRP 62: Initial system of infrastructure and infrastructure services
- TRP 63: Initial system of infrastructure and TRP 64: Initial system of infrastructure and infrastructure services
- TRP 65: Initial system of infrastructure and TRP 66: Initial system of infrastructure and infrastructure services
- TRP 67: Initial system of infrastructure and TRP 68: Initial system of infrastructure and infrastructure services
- TRP 69: Initial system of infrastructure and TRP 70: Initial system of infrastructure and infrastructure services
- TRP 71: Initial system of infrastructure and TRP 72: Initial system of infrastructure and infrastructure services
- TRP 73: Initial system of infrastructure and TRP 74: Initial system of infrastructure and infrastructure services
- TRP 75: Initial system of infrastructure and TRP 76: Initial system of infrastructure and infrastructure services
- TRP 77: Initial system of infrastructure and TRP 78: Initial system of infrastructure and infrastructure services
- TRP 79: Initial system of infrastructure and TRP 80: Initial system of infrastructure and infrastructure services
- TRP 81: Initial system of infrastructure and TRP 82: Initial system of infrastructure and infrastructure services
- TRP 83: Initial system of infrastructure and TRP 84: Initial system of infrastructure and infrastructure services
- TRP 85: Initial system of infrastructure and TRP 86: Initial system of infrastructure and infrastructure services
- TRP 87: Initial system of infrastructure and TRP 88: Initial system of infrastructure and infrastructure services
- TRP 89: Initial system of infrastructure and TRP 90: Initial system of infrastructure and infrastructure services
- TRP 91: Initial system of infrastructure and TRP 92: Initial system of infrastructure and infrastructure services
- TRP 93: Initial system of infrastructure and TRP 94: Initial system of infrastructure and infrastructure services
- TRP 95: Initial system of infrastructure and TRP 96: Initial system of infrastructure and infrastructure services
- TRP 97: Initial system of infrastructure and TRP 98: Initial system of infrastructure and infrastructure services
- TRP 99: Initial system of infrastructure and TRP 100: Initial system of infrastructure and infrastructure services



Credit: ESA



General Support Technology Programme (GSTP)



Credit: ESA



General Support Technology Programme (GSTP)

Assessments to prepare and de-risk technology developments

Objective: evaluate added value, address critical issues, orient follow-on activities

Activities include at least one of the following tasks:

- Analysis of specifications, assessment of development actions, schedule and cost
- Assessment of the benefits (performance, cost, lead time, risks...) and disadvantages of the potential solution with respect to the state-of-the-art
- Assessment of potential critical issues related to using a given technology for a specific application, using analysis/simulation and/or breadboarding and testing
- Duration maximum 9 months



Credit: ESA



SM2QM –Assessments to prepare and De-Risk Technology Developments

- Currently, we are at DML for QM level establishment including each material Reference File.
- Based on DPL at EM level, the processes for components manufacturing for its qualification were identified. The processes are separated between critical and non-critical.



<http://www.hytekaalborg.dk/en/handsoldering>

- For the critical processes, the personnel must be certified at ESA authorized schools for training and certification.
- Two critical processes were identified, adhesive bonding and soldering. At this moment, personnel from Icpce attended training courses at ESA authorized schools for training and certification for this two processes.
- At the end of the 9 months De-RISK phase, the subassemblies of the SM (stator and rotor) will be manufactured by certified personnel with qualified materials and processes in accordance with ECSS as stated in PA Plan.

SM2QM – Certificates for Personnel Qualification

ACTUALITĂȚI ȘI PERSPECTIVE ÎN DOMENIUL MAȘINILOR ELECTRICE - 2019





FLPP - Future Launchers Preparatory Programme

ESA's programme dedicated to the preparation of this future, the Future Launchers Preparatory Programme (FLPP), began in 2003. It oversees system studies and research activities to foster new technologies capable of delivering performance and reliability coupled with reduced operational costs.

- Promote reusability of existing and new technologies to reduce development costs globally.
- Perform system studies to assess evolutions of operational launchers, future launcher architectures, advanced concepts, select technology and elaborate technology requirements.



Credit: ESA



FLPP

Future Launchers Preparatory Programme Low Cost Actuation Systems



Is a project under the Future Launcher Preparatory Programme. Through this project divided in three phases, it is aimed to identify best solutions for low cost actuation systems including transfers of know-how from other sectors of industry, to evaluate their potential for space applications, characterize and enhance selected ones.





- The **main objective** of this contract is to develop a **low-cost actuation system**.
- Icpe is in charge with evaluation, design, a demonstrator manufacturing & measuring the functional characteristics of a DC Brushless motor. This variant must be low cost compared with the one for AC Brushless motors, that necessitates an expensive driver.
- Establishment of the detailed requirements will be done till the first milestone of the project, SRR.
 - *Kick Off Meeting was held on the middle of this year, together with ESA.*
 - *In accord with contract timeline, currently we are at the detailed design stage of the BLDC Motor.*



New Orbital Infrastructure Programmes

- The programmes for New Orbital Infrastructure represents another development direction on which Icppe together with COMOTI are already involved.
- In this direction there are major requirements regarding International Space Station – ISS.



Credit: ESA



The Journey of a Motor used in Space Applications





- 1. Requirements and Documentation**
- 2. Breadboard (BB) and Engineering Model (EM) - Design stage and simulation results**
- 3. BB and EM Manufacturing technology roadmap towards the space sector. Product manufacture and test bench philosophy**
- 4. Breadboard (BB) and Engineering Model (EM) - Test campaign overview**
- 5. Product Assurance**
- 6. Product documentation**



Lessons learned



Key Take-Aways





➤ Study on market needs and potential niches in space applications

- Study on existing electric motors serving the aerospace market
- Study on market needs and potential niches in space applications in order to establish the particularities from the electric motors' point of view
- Survey's online and offline versions were being distributed to potential partners
- Entities operating in the space sector were contacted to provide information on their use of electric motors and specific requirements

1. Requirements and Documentation



➤ Study on market needs and potential niches in space applications

1. Requirements and Documentation

- The main focus was developing a product for operations in space, with applications directed towards LEO or GEO orbits, together with the adaptation of its technology/processes imposed by the Space requirements
- Space applications of electric motors require conformance from the following points of view:
 - Launch and associated mechanical loads;
 - Thermal and vacuum operations;
 - Space compatibility of materials and electronics



1. Requirements and Documentation

➤ **ACTUALITĂȚI ȘI PERSPECTIVE ÎN DOMENIUL MAȘINILOR ELECTRICE - 2019**
There are many factors affecting and limiting the design that are not mandatory requirements or contained in Specification:

○ External environment:

Solar radiation (UV/VUV)



[ESA Academy – PA&S Training Course 2017]

▪ Radiations

▪ Vacuum

▪ No convection. This means that it is necessary specific designs for heat dissipation.

▪ Outgassing

▪ Extreme temperatures

▪ Mechanical



[ESA Academy – PA&S Training Course 2017]



1. Requirements and Documentation



Example outgassing values

Material	Typical TML
PVC plastic	20-30%
Superglue	15%
Marking ink	10%
Conformal coating	1-2%
CRP	<1%
Silicone	0.1%
Kapton	0.1%
Metals	<0.01%

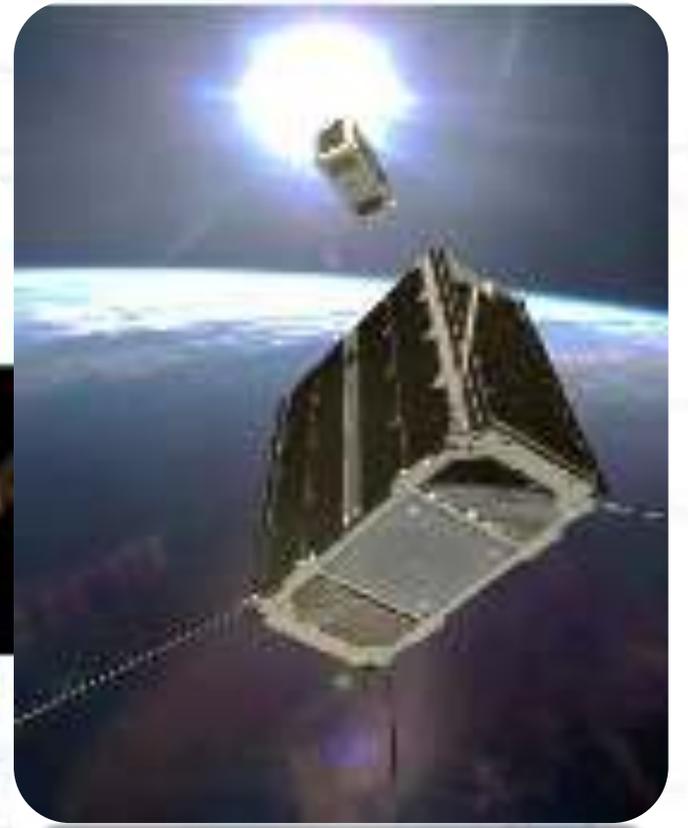
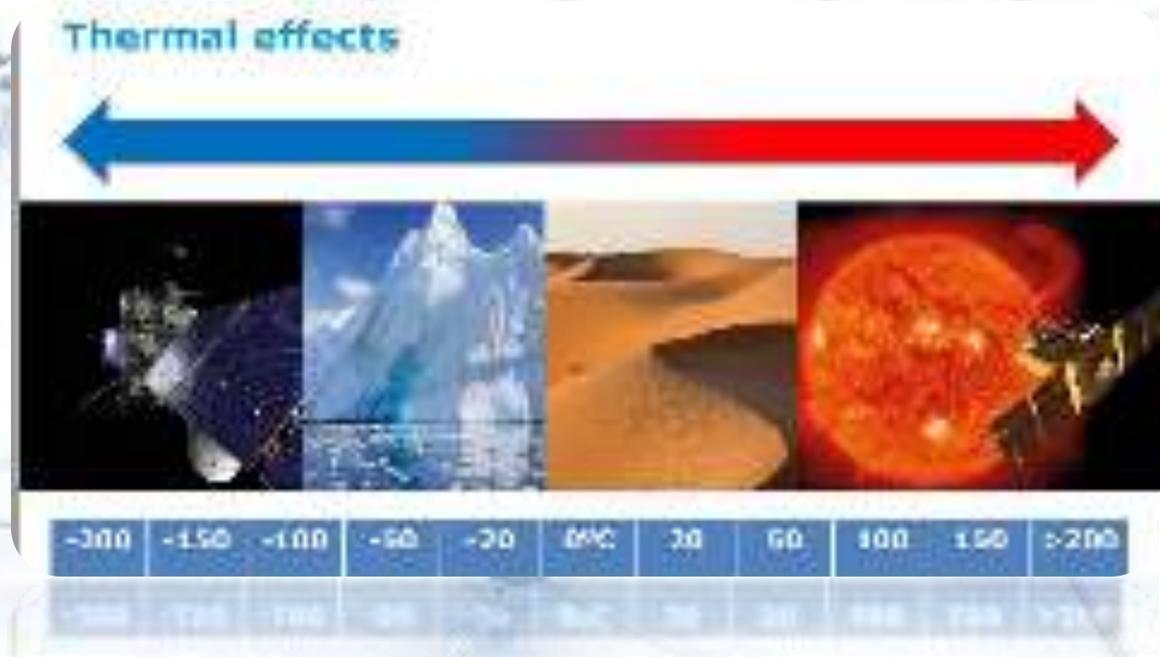


[ESA Academy – PA&S Training Course 2017]



Rate depends on orbit e.g. 1 cycle every 90 minutes for some Low Earth Orbits

1. Requirements and Documentation



[ESA Academy – PA&S Training Course 2017]

Temperature can vary over wide range e.g. -150°C to +150°C



[ESA Academy – PA&S Training Course 2017]



[ESA Academy – PA&S Training Course 2017]

1. Requirements and Documentation

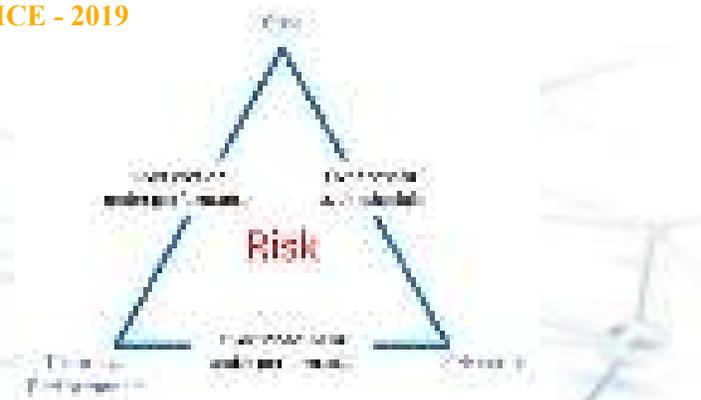
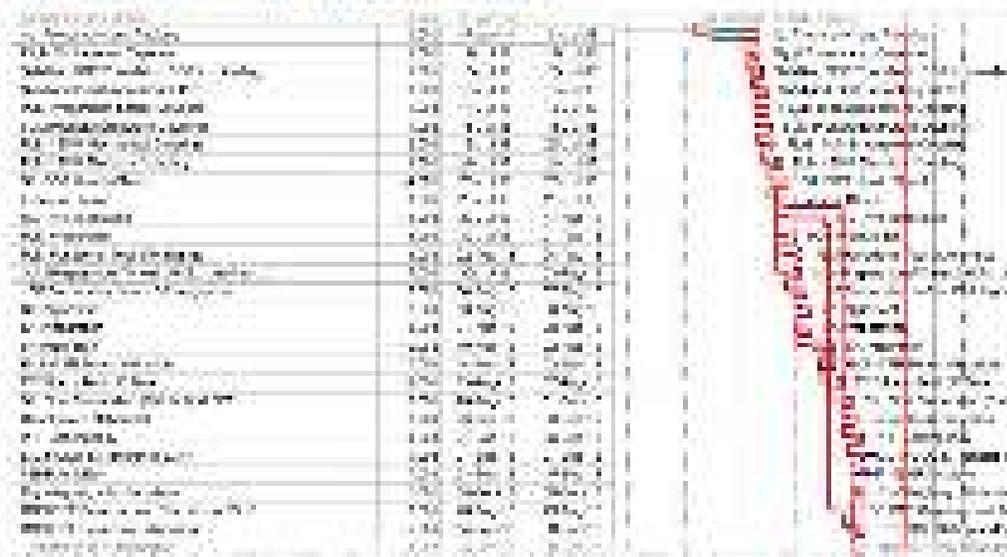


1. Requirements and Documentation

ACTUALITĂȚI ȘI PERSPECTIVE ÎN DOMENIUL MAȘINILOR ELECTRICE - 2019

- Cost Analysis:
 - risk analysis
 - schedule analysis

Schedule – the GANT chart



	Low	Medium	High	Very High	Critical
1	Low	Low	Medium	High	Very High
2	Low	Low	Medium	High	Very High
3	Low	Low	Medium	High	Very High
4	Low	Low	Medium	High	Very High
5	Low	Low	Medium	High	Very High

ES&P Item	Risk Impact	Preparation Action
ES&P Item 1	High	Conduct a risk analysis plan and ensure that the risk analysis is completed and approved by the project manager and the risk management team.
ES&P Item 2	Medium	Conduct a risk analysis plan and ensure that the risk analysis is completed and approved by the project manager and the risk management team.
ES&P Item 3	Low	Conduct a risk analysis plan and ensure that the risk analysis is completed and approved by the project manager and the risk management team.
ES&P Item 4	Very Low	Conduct a risk analysis plan and ensure that the risk analysis is completed and approved by the project manager and the risk management team.

[ESA Academy – PA&S Training Course 2017]

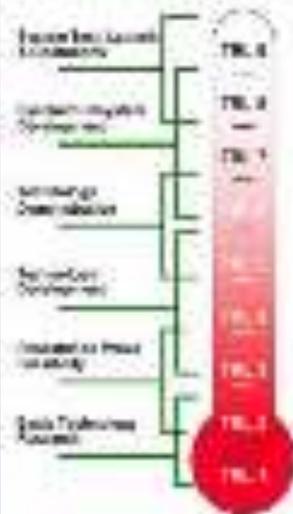


ACTUALITĂȚI ȘI PERSPECTIVE ÎN DOMENIUL MAȘINILOR ELECTRICE - 2019

- Cost Analysis:

- Technology Readiness Level - TRL (low TRL)
- dependence of critical resources (test facilities)
- no repair/servicing (quality measures, analyses and testing).

1. Requirements and Documentation



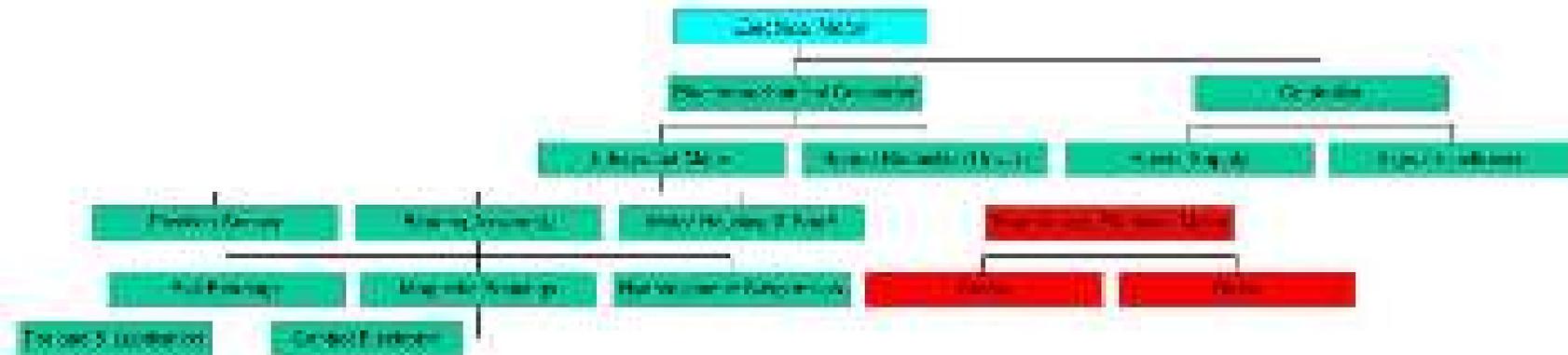
[ESA Academy – PA&S Training Course 2017]



➤ Study on market needs and potential niches in space applications

- The usage scenario most likely involves actuators for deployment and pointing of various equipment.
- The target product lifetime should be the same with the operational lifetime of the satellite: more than 10 years. This is in line with requirements for more than 15 years of operation.
- The reliability is one of the most important design demands.
- This requirement results also from the emphasis for the thermal vacuum tests option and it also can be correlated with performance tests and trend analysis.
- Based on Survey conclusions, the motor requirements are established.

1. Requirements and Documentation



- The next step was spinning Icpes' existing motor design and manufacturing technology towards space applications.

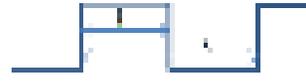
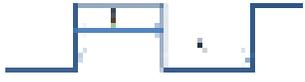


2. Breadboard (BB) and Engineering Model (EM) - Design stage and simulation results

- ✓ Having the requirements, BB (Breadboard) stages and an EM (Engineering Model) were considered.
- ✓ FEM based numerical modelling was largely used to allow us to optimize the geometry and to obtain the required characteristics according to Specification.
- ✓ Several BB variants, different from materials and geometry point of view were realized until the requirements stated in the Technical Specification are fulfilled.



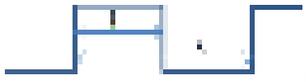
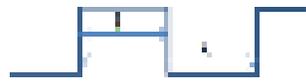
BB1 - Geometry characteristics

Sator	Rotor
Rectangular	Rectangular
 $t/\lambda=0.5$	 $t/\lambda=0.5$

Sator	Rotor
- Iron Silicon lamination	- Neodymium type Permanent Magnet - Two semi-armatures made of Steel 416
	

EM - Materials

EM - Geometry characteristics

Sator	Rotor
Rectangular	Rectangular
 $t/\lambda < 0.5$	 $t/\lambda < 0.5$

Sator	Rotor
- Iron Cobalt lamination	- Two Samarium Cobalt type Permanent Magnets - Two semi-armatures and one armature made of magnetic iron
	

2. Breadboard (BB) and Engineering Model (EM) - Design stage and simulation results

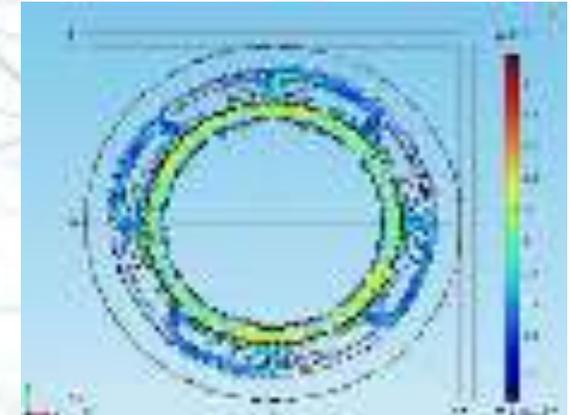
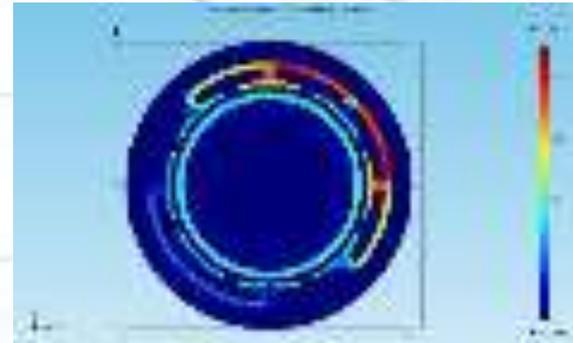
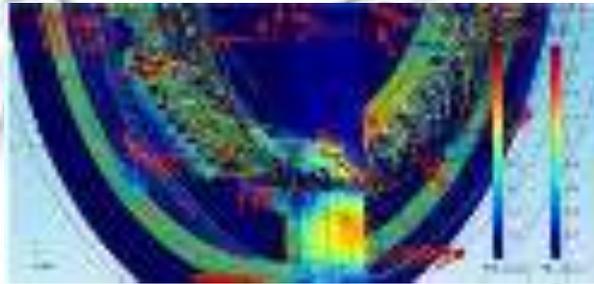


ACTUALITY & PERSPECTIVE IN DOMENIUL MAȘINILOR ELECTRICE - 2019

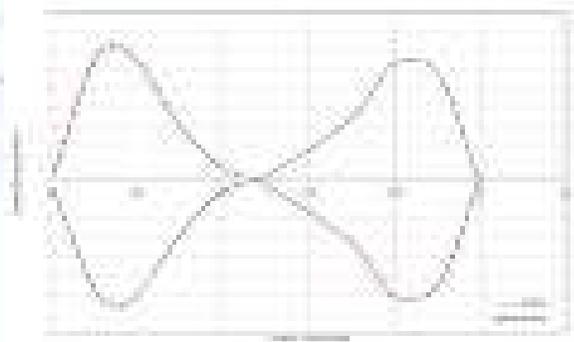
➤ **Electromagnetic Model**

- Detent Torque
- Holding Torque

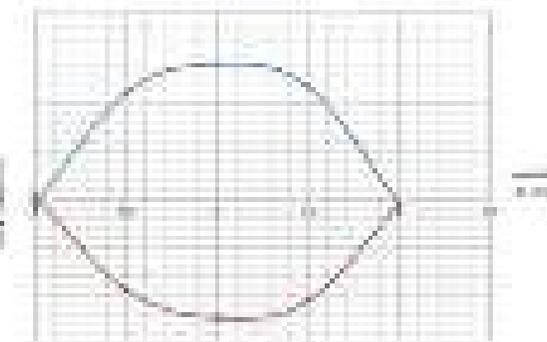
**2. Breadboard (BB)
and
Engineering
Model (EM) -
Design stage
and simulation
results**



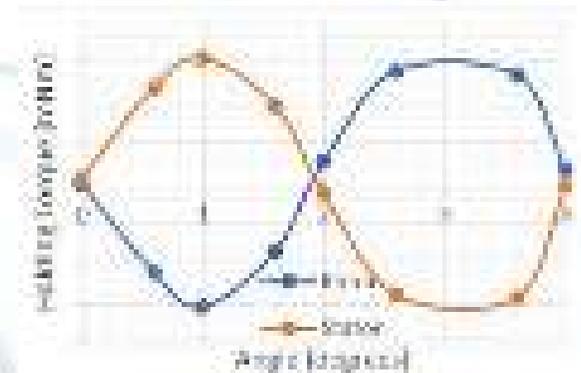
Magnetic flux density



Calculated detent torque characteristic



Calculated holding torque characteristic - Half-phase option





2. Breadboard (BB) and Engineering Model (EM) - Design stage and simulation results

➤ Thermal Model

- Several constructive solutions including shaft and case were also considered in numerical modeling.
- The simplified thermal model was realized for two variants. The first variant considers the motor not fully embedded (only for stator stack length) and the second variant considers the motor fully embedded (with a case, higher than the length of winded stator).

Support structure	Assembly condition	Temp. point	Maximum temperature at Top 10	Temp. point	Maximum temperature at Top 10
EM model not fully embedded	Motor not fully embedded	Motor winding	111.1	15	81
		Surface of stator insulation	112.7	8	104.4
		Surface of rotor insulation	112.8	8	107.5
	Thermal process	EM 100%	112.8	8	107.5
		EM 50%	112.8	8	107.5
		EM 20%	112.8	8	107.5
EM model fully embedded	Motor fully embedded	Motor winding	111.1	15	81
		Surface of stator insulation	112.7	8	104.4
		Surface of rotor insulation	112.8	8	107.5
	Thermal process	EM 100%	112.8	8	107.5
		EM 50%	112.8	8	107.5
		EM 20%	112.8	8	107.5
The case fully embedded	Motor fully embedded	Motor winding	111.1	15	81
		Surface of stator insulation	112.7	8	104.4
		Surface of rotor insulation	112.8	8	107.5
	Thermal process	EM 100%	112.8	8	107.5
		EM 50%	112.8	8	107.5
		EM 20%	112.8	8	107.5

- With the increase of epoxy resin surface emissivity, the temperature decreases, meaning that the assembly cools down more efficient.

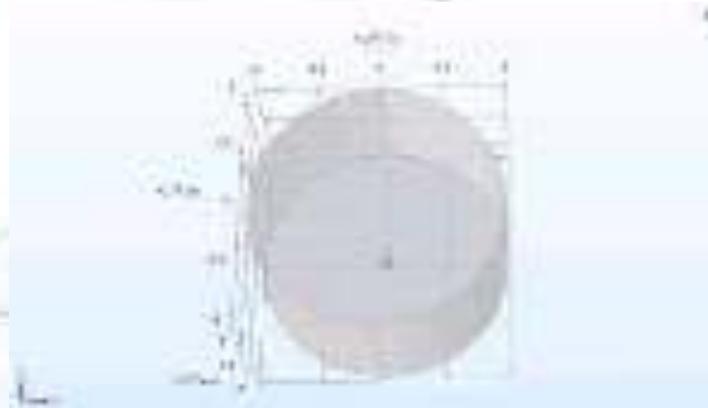


➤ Magnetic moment

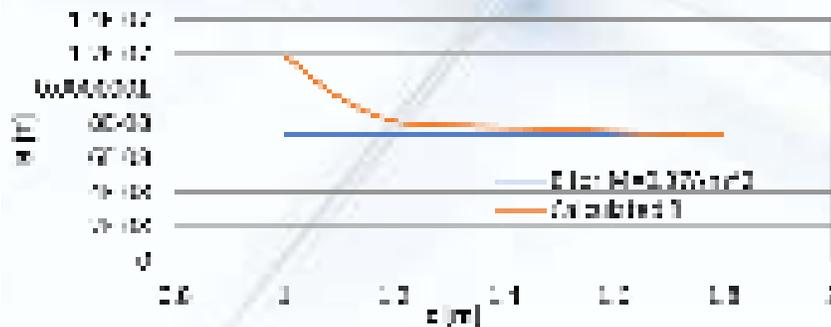
- The dipolar moment 'M' was calculated and the conditions of FEM analysis are:

Property	Value
Analysis type	2D Static Magnetic
Element type	Linear
Number of elements	6811632
Boundary condition	The air domain surrounding the motor is fixed to ground. The motor is fixed to ground.

Magnetic flux density color map



Analysis model of the stepper



$$M = \frac{1}{2 \cdot 10^{-7}} \cdot B \cdot r^2 [A \cdot m^2]$$

Where:

- B[T] is calculated magnetic flux density, at a distance 'r = 1000mm' from the unit;
- r[m] is distance separating the motor from the calculated point.

2. Breadboard (BB) and Engineering Model (EM) - Design stage and simulation results



- Having the Stepper Motor Specification and the existing reviews of Icpe`s commercial motors, the next step was spinning Icpe`s existing motor design and manufacturing technology towards space applications.

2. Breadboard (BB) and Engineering Model (EM) - Design stage and simulation results



Manufacturing technology

- Having a new design and very demanding requirements in the “Stepper Motor Technical Specification” impacted the design phase where more rigorous analysis needed to be made before the first iteration of the manufacturing.
- The permanent magnet stepper motor, produced in the past by Icpe has speed up the development of the required stepper motor.



CNC machines type DMG MORI CLX 450



CNC 4 axes milling machines – Mynx Daewoo Dosan

**3. BB and EM
Manufacturing
technology
roadmap
towards the
space sector.
Product
manufacture
and test bench
philosophy**



**3. BB and EM
Manufacturing
technology
roadmap
towards the
space sector.
Product
manufacture
and test bench
philosophy**

Technical features of the equipment :

Industrial cutting speed up to 400 mm²/min
Fast improvement of the surface quality (three cuts)
Fast threading : 20" spark to spark
Traveling speed 3 m/min secured by a proven collision protection
Taper-Expert smart module for best taper accuracy



Electro-erosion machines type AgieCharmilles CUT 200 Sp

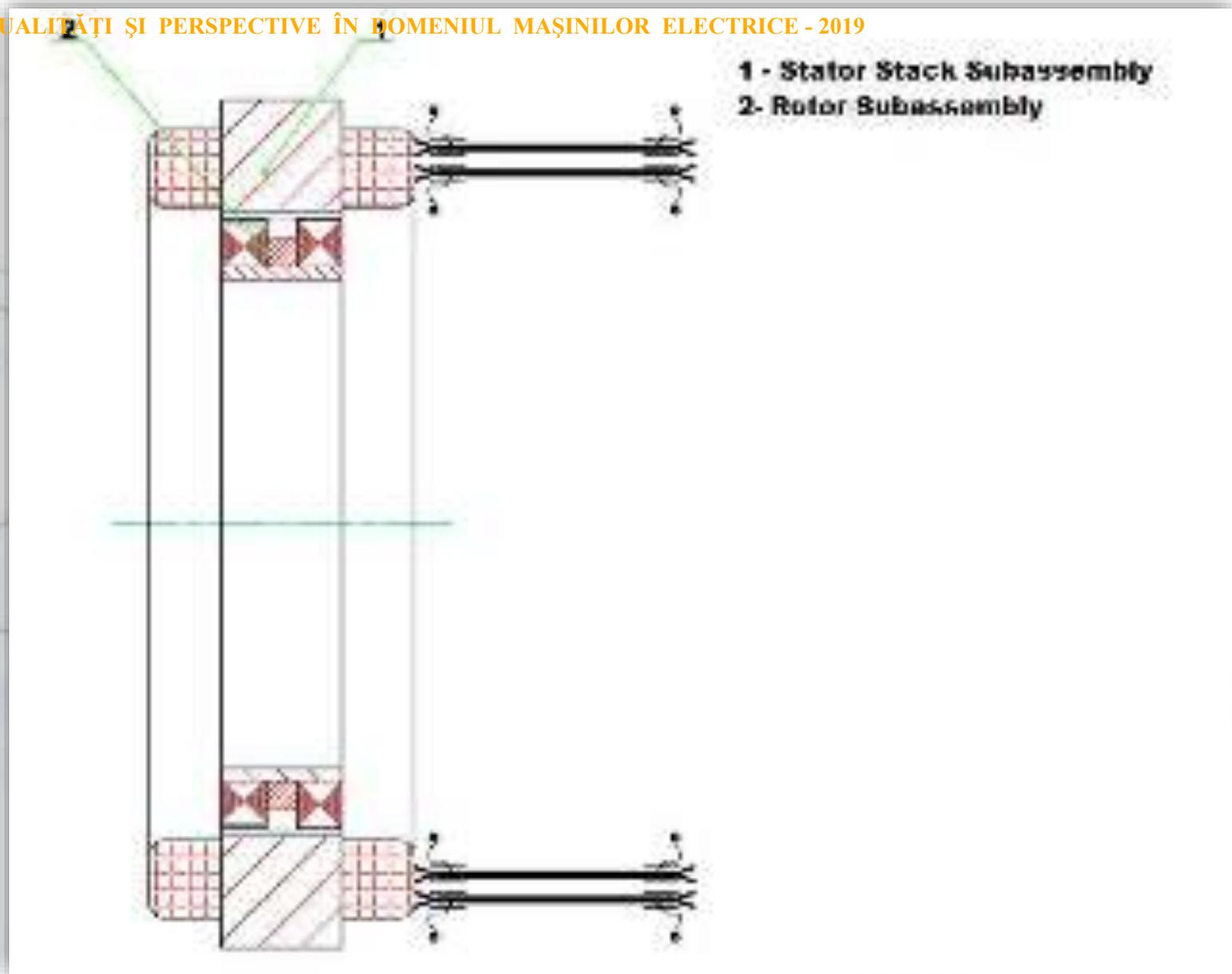
- Positioning Accuracy according to ISO 230-2
- Accuracy of positioning in X/Z Axes < 5 μmm
- Accuracy of positioning in C Axes < 20 arc sec



Machining Center type DMG MORI CLX 450



**3. BB and EM
Manufacturing
technology
roadmap
towards the
space sector.
Product
manufacture
and test bench
philosophy**





- This frameless becomes functional after it is integrated into an actuator or mechanism.
- In order to be integrated, these components must be manufactured in accordance with the manufacturing documentation.
- All these conditions are imposed by the specific operating characteristics of the stepper motor that require the critical size of the 0.1 mm air gap.

**3. BB and EM
Manufacturing
technology
roadmap
towards the
space sector.
Product
manufacture
and test bench
philosophy**



Automat dimensional measuring system in coordinates type Wenzel XOrbit 55



Stator verification process

**3. BB and EM
Manufacturing
technology
roadmap
towards the
space sector.
Product
manufacture
and test bench
philosophy**

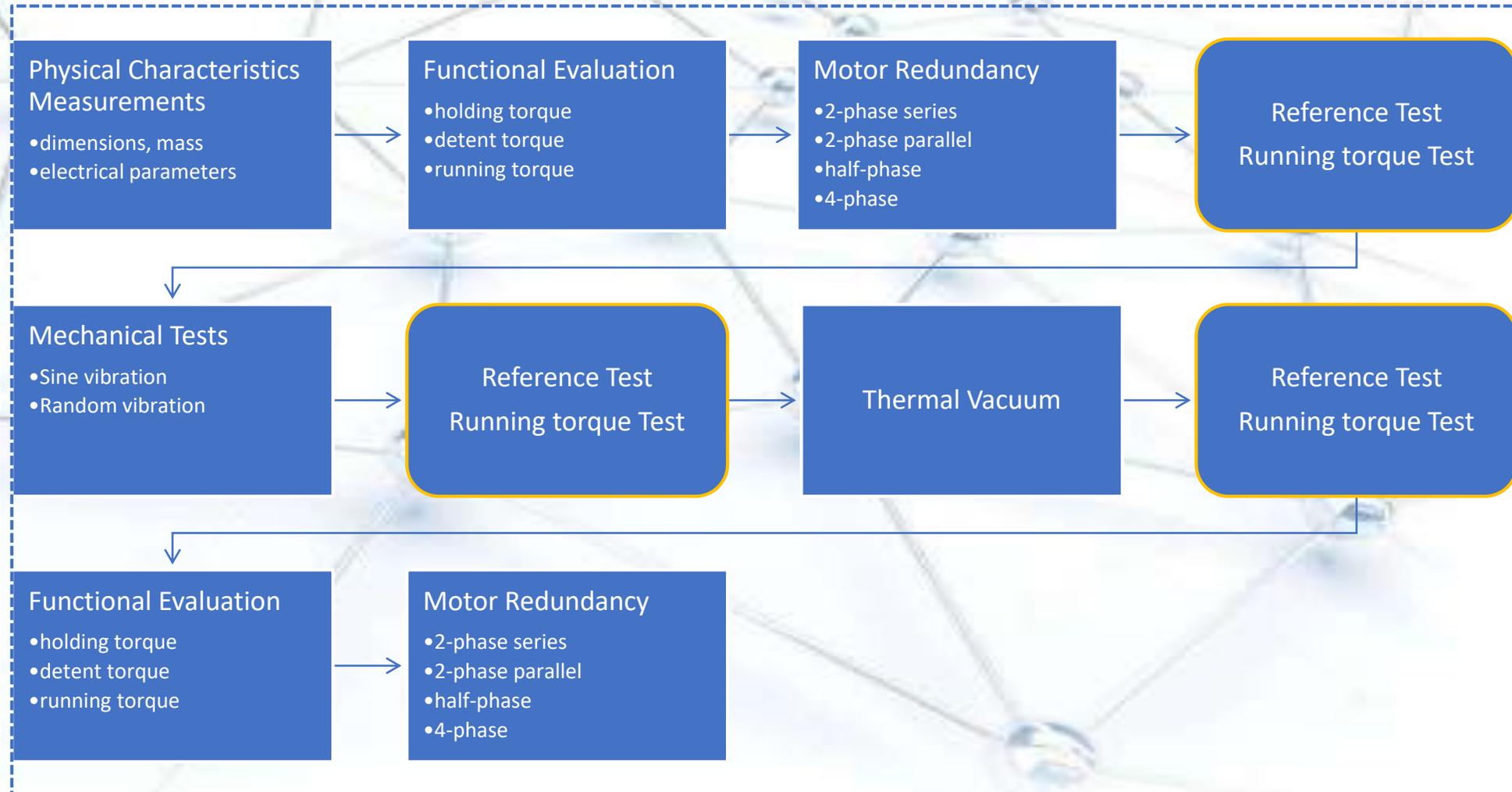


Rotor verification process



- In the following flow chart is presented the motor test campaign at the end of which, a hybrid stepper motor in frameless configuration was developed at EM level (TRL 5).

4. Breadboard (BB) and Engineering Model (EM) - Test campaign overview





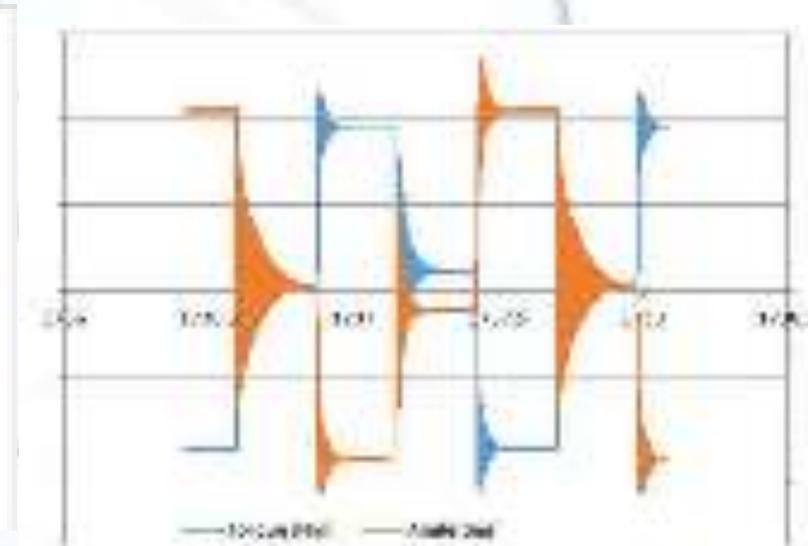
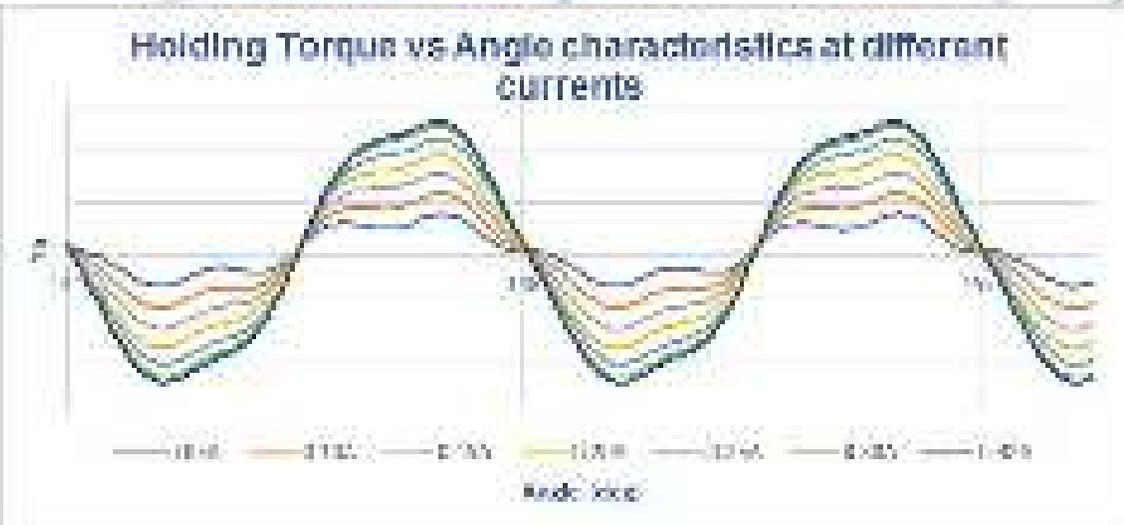
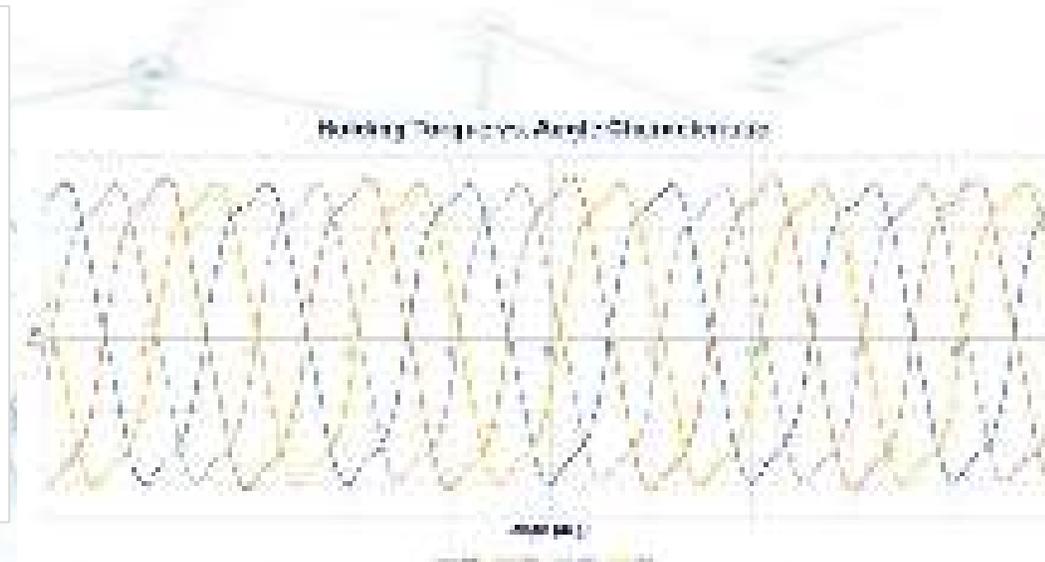
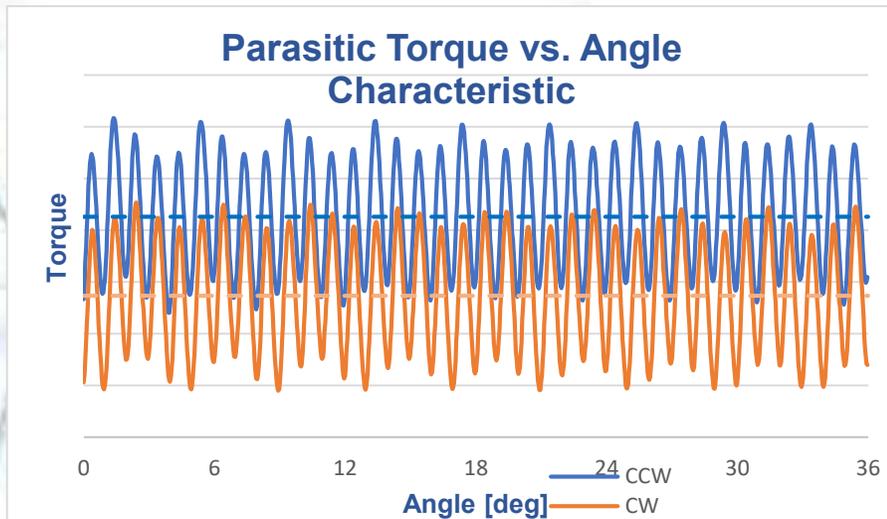
4. Breadboard
(BB) and
Engineering
Model (EM) -
Test campaign
overview
-
LABORATORY
TESTS

- The test campaign states laboratory and environmental tests. The laboratory tests (BB & EM) are made in house using Icpe`s designed and manufactured test benches.
- Each performance of the motor is measured using a certain configuration of the test benches, stated in ***Motor Test Plan and Procedures***. All the test benches are developed by Icpe, one being presented in the picture.





4. Breadboard (BB) and Engineering Model (EM) - Test campaign overview - LABORATORY TESTS





- Before the vibration tests, the motor's functionality was verified at Icpe with the device mounted on the test bench.
- The motor under no load configuration was commanded to perform a 360 steps rotation at the minimum supply voltage.
- The angular displacement of the mark on the head of the device shaft was monitored.
- The device shaft stopped with the mark in its starting position.

4. Breadboard (BB) and Engineering Model (EM) - Test campaign overview - LABORATORY TESTS



Est@r-II TV vibration test- on computer MB (Credit: ESA)



https://twitter.com/ESA_History/status/1159736787604058112 (Credit: ESA)



Vibration tests

- The motor is in a frameless configuration.
- Rotor and stator mounting adapters to shaker mounting interface were made.
- The vibration test was conducted in accordance with Motor Test Plan & Procedure using in house facilities.
- The tests results and conclusions have been included in Motor Mechanical Test Report.



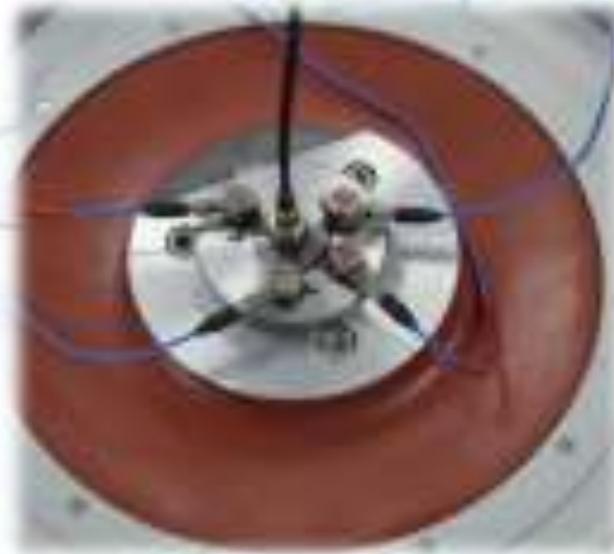
4. Breadboard (BB) and Engineering Model (EM) - Test campaign overview - ENVIRONMENTAL TESTS



Vibration tests

- Rotor radial: Dimensions Measurement → Low Sine → Sine → Low Sine → Random → Low Sine → Dimensions Measurement
- Rotor axial: Dimensions Measurement → Low Sine → Sine → Low Sine → Random → Low Sine → Dimensions Measurement

**4. Breadboard (BB)
and
Engineering
Model (EM) -
Test campaign
overview
-
ENVIRONMENTAL
TESTS**



Rotor on shaker (axial)



Rotor on shaker (radial)



**4. Breadboard (BB)
and
Engineering
Model (EM) -
Test campaign
overview
-
ENVIRONMENTAL
TESTS**

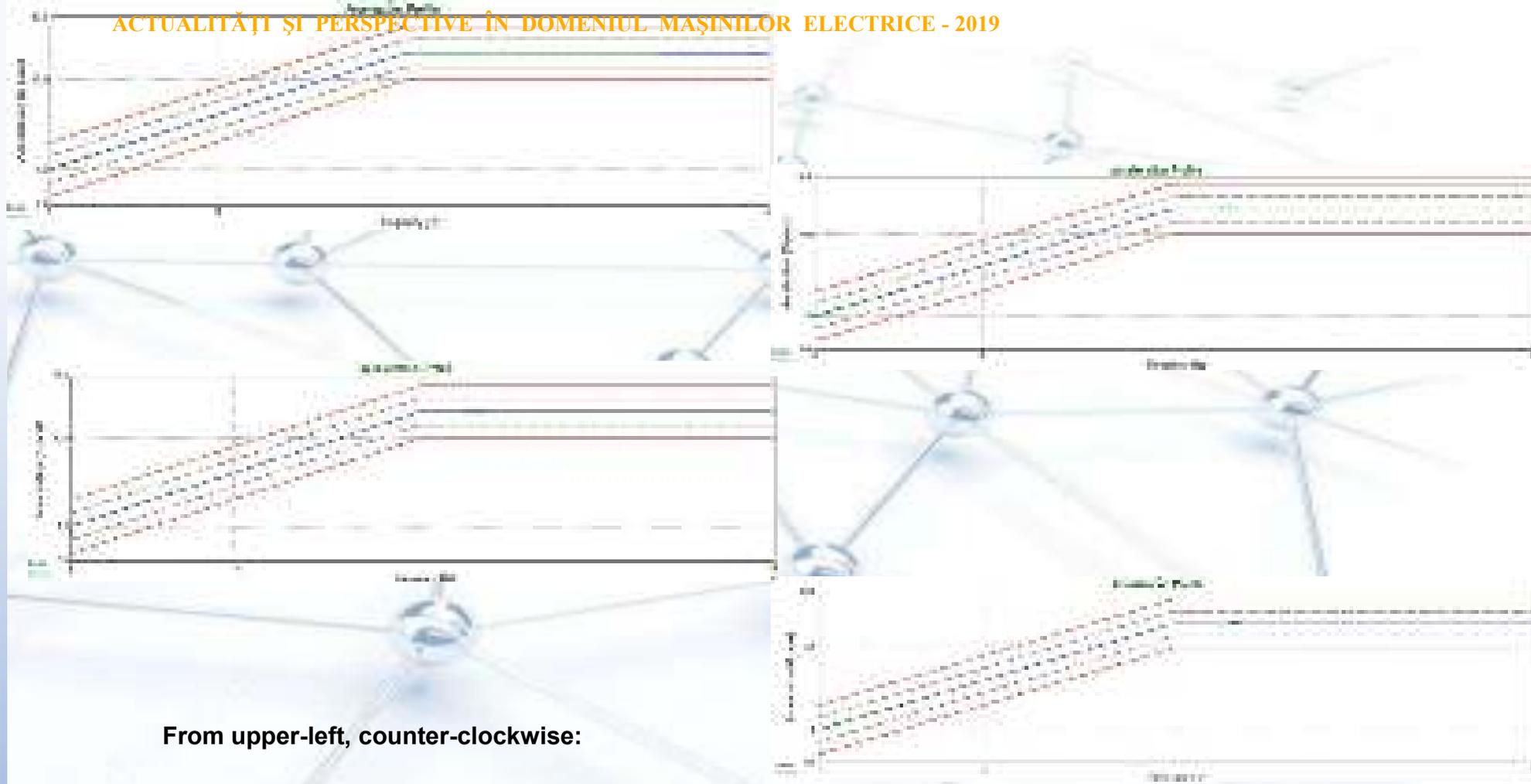
- Stator radial: Dimensions Measurement
→ Low Sine → Sine → Low Sine →
Random → Low Sine → Dimensions
Measurement
- Stator axial: Dimensions Measurement →
Low Sine → Sine → Low Sine → Random
→ Low Sine → Dimensions Measurement



Stator on shaker (radial)



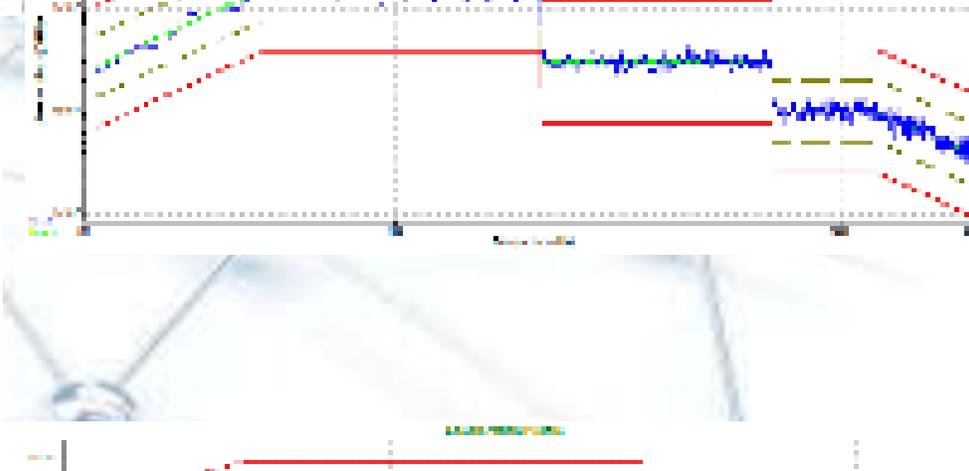
Stator on shaker (axial)



**4. Breadboard (BB)
and
Engineering
Model (EM) -
Test campaign
overview
-
ENVIRONMENTAL
TESTS**

From upper-left, counter-clockwise:

- Sine vibration – rotor mounted for radial excitation,
- Sine vibration – rotor mounted for axial excitation,
- Sine vibration – stator mounted for radial excitation,
- Sine vibration – stator mounted for axial excitation



4. Breadboard (BB) and Engineering Model (EM) - Test campaign overview

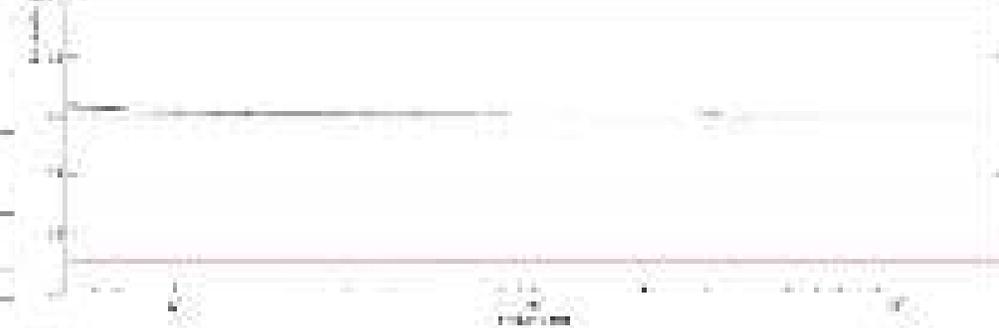
ENVIRONMENTAL TESTS

From upper-left, counter-clockwise:

- Random vibration – rotor mounted for radial excitation,
- Random vibration – rotor mounted for axial excitation,
- Random vibration – stator mounted for radial excitation,
- Random vibration – stator mounted for axial excitation



- Low level sine vibration – rotor mounted for radial excitation,
- Low level sine vibration – stator mounted for axial excitation,



- Low level sine vibration – stator mounted for radial excitation,
- Low level sine vibration – rotor mounted for axial excitation.

Before and after test were measured:

- Dimensional measurements;
- Electrical parameters measurements;
- Post-test functional evaluation – On-load torque measurement, parallel configuration and comparing with the test results before the vibration test. The difference between the two values is less than 1.5%).

4. Breadboard (BB) and Engineering Model (EM) - Test campaign overview - ENVIRONMENTAL TESTS



4. Breadboard (BB) and Engineering Model (EM) - Test campaign overview - ENVIRONMENTAL TESTS



<https://apod.nasa.gov/apod/ap091130.html>



<https://sputniknews.com/world/201506231023726282/>

- Thermal – vacuum (TV) cycling tests were conducted in accordance with Motor Test Plan & Procedure.
- These tests were performed at a Romanian institute, Institute of Space Science - ISS.



4. Breadboard (BB) and Engineering Model (EM) - Test campaign overview

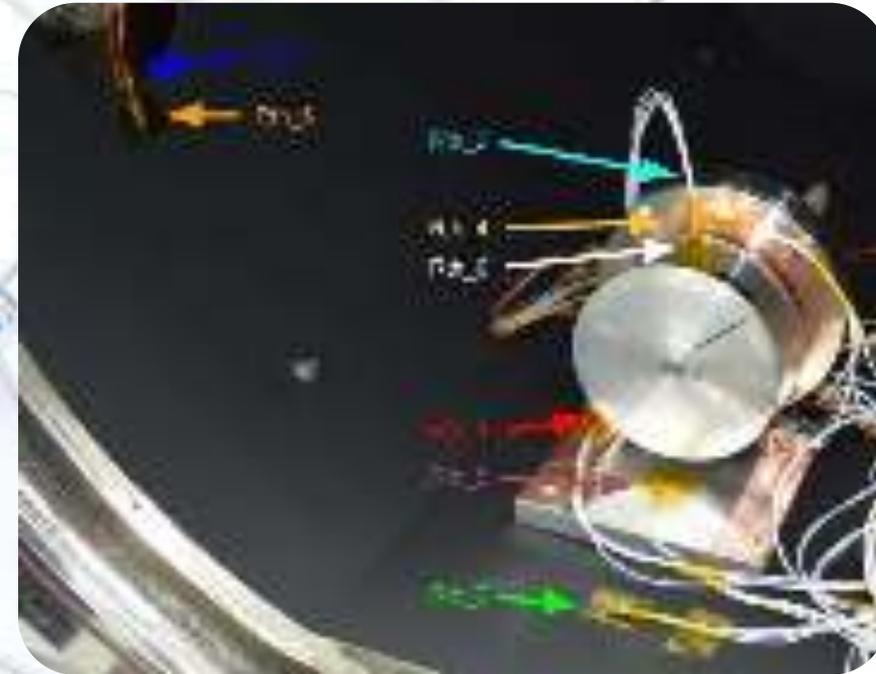
-

ENVIRONMENTAL TESTS

- The motor and the stator were loaded in the custom designed chassis manufactured at Icpe. For the purpose of the test, the ball bearings used were degreased in order to minimize the amount of outgassing during the test.
- An aluminum mounting plate was manufactured to serve as a mechanical and thermal interface between the shroud of the thermal chamber and the motor.



- Temperature inside the thermal chamber was logged during the cycles using 8 PT100 thermistors connected to the data acquisition board in a 4-wire configuration.
- The TRP for the procedure was thermistor channel Rth_0 mounted on the chassis stator frame.



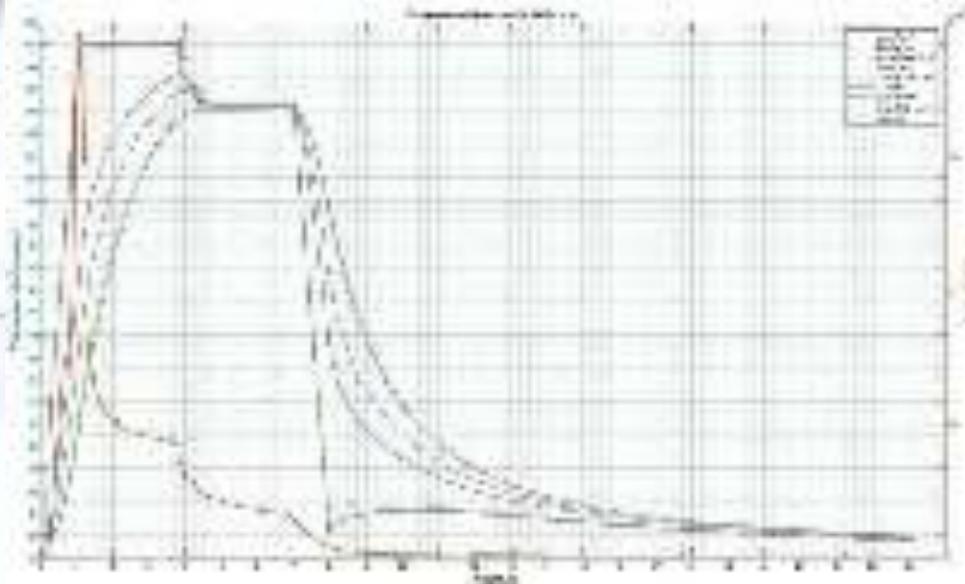
**4. Breadboard (BB)
and
Engineering
Model (EM) -
Test campaign
overview
-
ENVIRONMENTAL
TESTS**



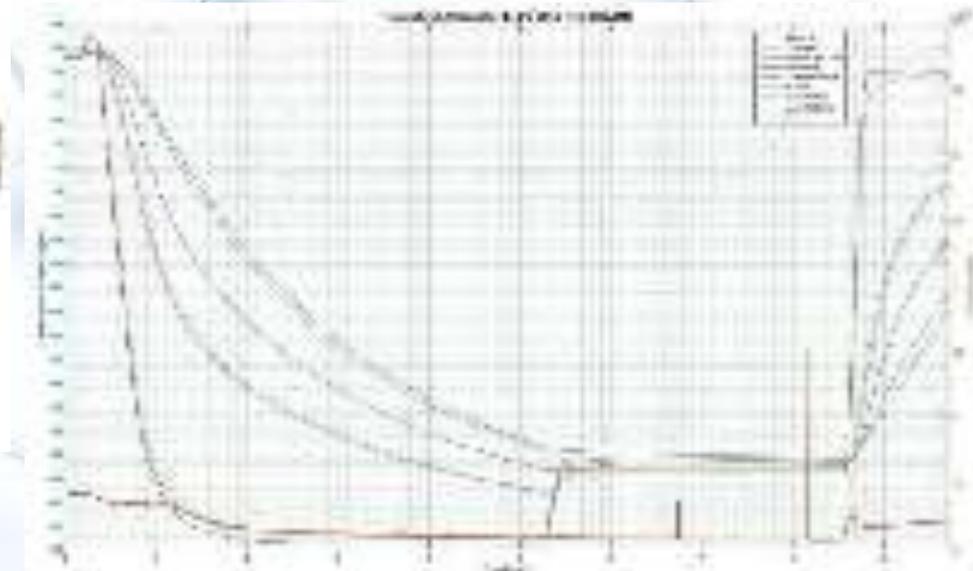
- The test consists in:
 - First step, two intercalated stages: hot-cold storage (at +120°C and -60°C).
 - Second step, two intercalated stages: hot-cold functional (at +100°C and -40°C).

4. Breadboard (BB) and Engineering Model (EM) - Test campaign overview - ENVIRONMENTAL TESTS

Hot Storage test

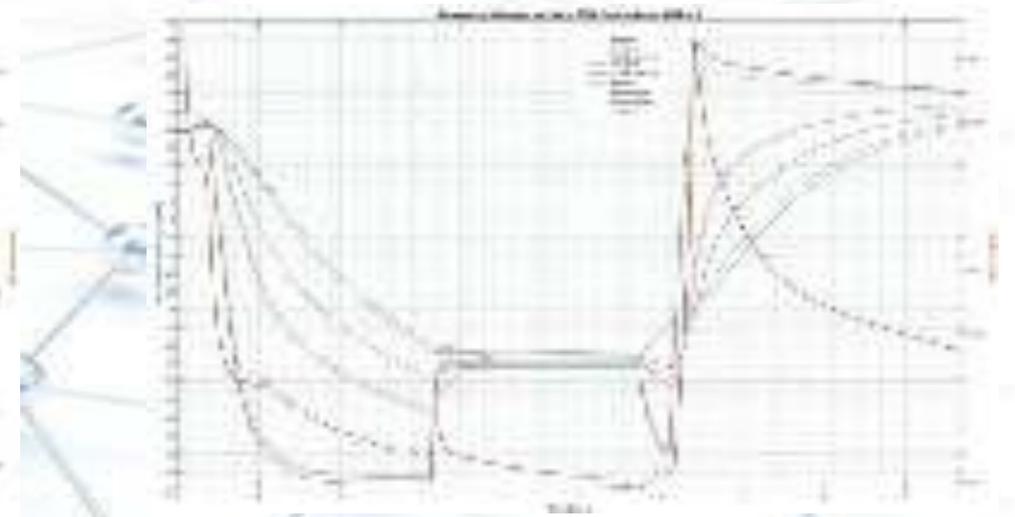
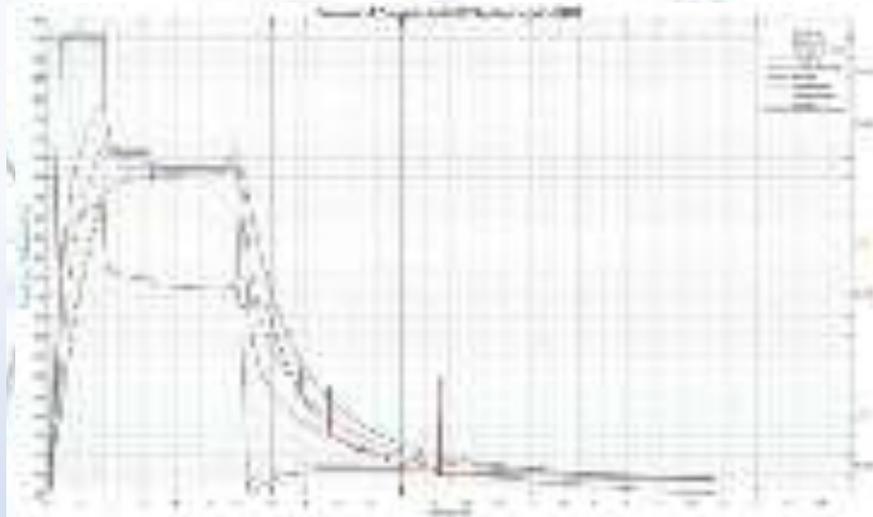


Cold Storage test



Functional cycle – hot stage

Functional cycle – cold stage



Post TVAC results

After the TVAC campaign, the functionality of the motor was also verified at ICPE without a load. No issues with these operations were observed.

Conclusions of the test campaign

- The motor has passed the test successfully without any issues observed during and after the thermal cycling.



4. Breadboard (BB) and Engineering Model (EM) - Test campaign overview - ENVIRONMENTAL TESTS



5. Product Assurance

During regular product development, ICPE already has a strong commitment to QA as it holds certificate No. 1 of 31 October 1997 for the SR EN ISO 9001 standard issued by the Romanian Society for Quality Assurance. ICPE has the Integrated Management System: Quality - Environmental - Occupational Health and Safety, in accordance with the requirements of the reference standards: ISO 9001 / 2015, ISO 14001 / 2015 and OHSAS 18001 / 2008. This system is documented, supervised, maintained and improved continuously by CERTIND accreditation.

All projects will be developed as part of a department where the personnel always carries out its work in accordance with the above mentioned standards, elaborating the PA/QA documentations.

The implementation of the projects shall have procedures classified into three categories:

- Icpe General Procedures List;
- Department List of Procedures / Instructions / Technological Notes;
- Specific to motor - Procedures List for motor.



All the ESA Standards for Product Assurance can be found below:

5. Product Assurance

A screenshot of the ECSS (European Cooperation for Space Standardization) website. The header features the ECSS logo and the text 'European Cooperation for Space Standardization'. A navigation menu includes 'HOME', 'ORGANISATION', 'STANDARDS', 'Handbook and Info', 'SUBSCRIBE', 'CONTACT US', 'Reliability', and 'Links to other sites'. Below the menu is a search bar with the text 'Search' and a 'Search' button. The main content area is titled 'Active Product Assurance standards' and includes the text 'The following standards can be downloaded in PDF or MS Word format.' Below this, there is a list of standards, with the first one partially visible as 'ECSS-Q70-01'.

<https://ecss.nl/standards/ecss-standards-on-line/active-standards/product-assurance/>

For each project an effective PA Program shall be established and implemented by Icpe compatible with contract requirements and ECSS Standards.



5. Product Assurance - Requirements



PA & Safety Training Module 3: Overview of Product Assurance in the Space Business



The Program shall be described in Product Assurance Plan and should cover the following:

- Design Assurance (e.g. reliability, selection of the materials and processes);
- Quality Assurance (among others, including procurement and control of the materials and processes, contamination control and verification of conformance for applicable requirements);
- Management to ensure adherence to the schedule and on-time product delivery.

5. Product Assurance - Requirements





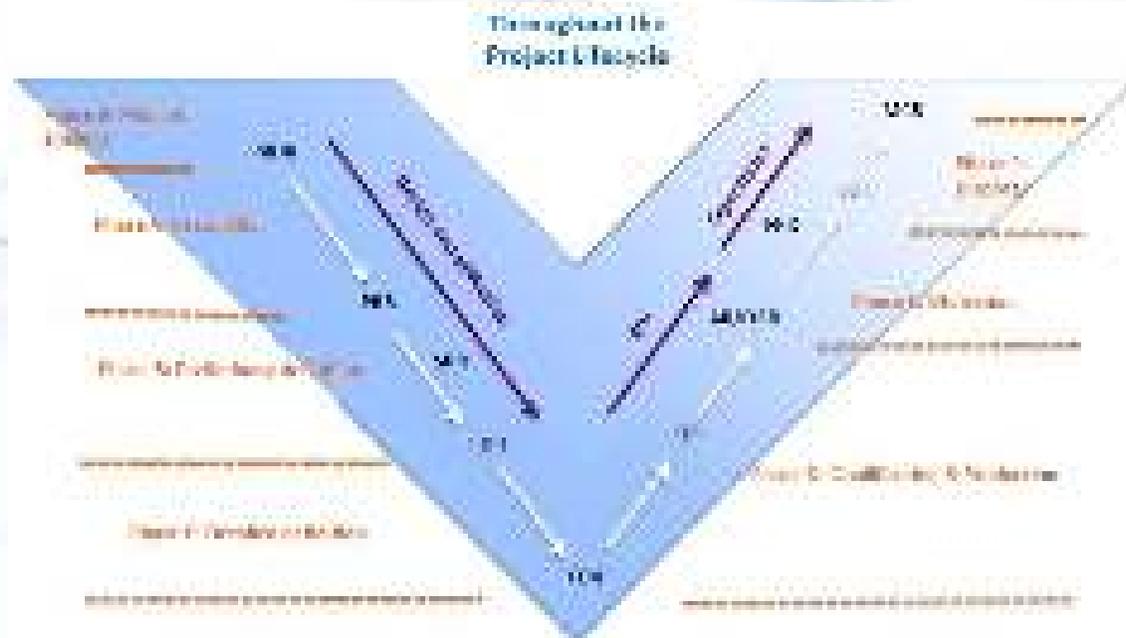
Space Projects

- Safety of life aspects (when fuelled)
- Reliability/availability key factors
- Impact of radiation exposure on parts and materials
- Redundancy of key functions



http://www.esa.int/Safety_Security/Protecting_our_Pale_Blue_Dot

5. Product Assurance - Scope



Management Support

- Risk assessment
- Configuration control
- Procurement (requirements)

Engineering

- Design review process
- Verification completeness
- Qualification and Acceptance

Production/AIT

- Inspection
- Training
- Facilities/machines/testing



A plan which prepare, implement and follow-up PA / QA management system according to PA requirements from Technical Specification.

5. Product Assurance - Activities



PA & Safety Training Module 3: Overview of Product Assurance in the Space Business, ESA Course 2017



5. Product Assurance - PA Documents





DML – Declared Material List At QM level

ACTUALITĂȚI ȘI PERSPECTIVE ÎN DOMENIUL MASINILOR ELECTRICE - 2019

5. Product Assurance - DML

- The purpose of the DML is to present all the materials used in motor's components breadboarding process.
- The data in the DML make possible to assess whether the materials are suitable for a specific application, at the supplier and the customer levels (in the approval status column by ESA).
- In order to fulfill the DML lines, for each material a Reference file must be prepared.

Qcda	Volume
Item	Minu
Routing number	Cost
Item Number	Com Ref
Material Identification	SOE
MaterialStd	SOE Ref
ChemicalName	Flam
Product Type	Flam Ref
Manufacturer Distributor	Offget
Supplier Name	Offget Ref
Procurement Spec	Offget
Prod Spec Issue	Offget Ref
Prod Spec Rev	Supplier Justification
Prod Spec Date	Supplier Comments
Summary of Process	Supplier Approval Status
Equipment	Customer Approval Status
SubSystem	Customer Comments
Line	Spec1
Line used	Spec2
Has used LV Axis	Dirv Amp Input
Ambiance	Wtd Dirv Input
Temperature	Date last change
Area	Wtd last change

DPL – Declared Process List at QM level

- The purpose of the DPL is to present all the processes used in motor's components breadboarding process.
- The data in the DPL make possible to assess whether the processes are suitable for a specific application, at the supplier and customer levels (in the approval status column by ESA).

1	2	3	4	5	6	7	8	9	10
1	2	3	4	5	6	7	8	9	10

5. Product Assurance

-
DPL





Request for approval (RFA)

The objective of an RFA is to enable the supplier to request from the customer permission to use a critical mechanical part, material or process.

- For each process a RFA is fulfilled and then it's send to ESA for approval.
- For each material that do not comply with application requirements a RFA is fulfilled and then it's send to ESA for approval.

5. Product Assurance

-
RFA

ECSS-Q-ST-70C Rev.1

The image shows two pages of a Request for Approval (RFA) form. The form is structured with multiple sections and tables. The left page contains a header section with fields for 'Project', 'Part Name', 'Material', and 'Process'. Below this is a large table with columns for 'Description', 'Quantity', 'Unit', and 'Material'. The right page continues the form with sections for 'Approval', 'Comments', and 'Signatures'. The form is filled with text and tables, indicating it is a detailed document used for quality assurance in the aerospace industry.



Nonconformance

- When a nonconformance is detected, the project PA representative analyses it to identify its extent and cause.
- In addition, immediate actions are taking to prevent unauthorized use of the nonconforming item.
- The nonconformance is documented on the NCR (nonconformance report) form and submitted to the internal NRB (nonconformance review board).

The image shows two forms side-by-side. The left form is titled 'Nonconformance Report' and contains various fields for reporting a nonconformance, including sections for 'Description of Nonconformance', 'Cause', and 'Action'. The right form is titled 'Nonconformance Report Construction Sheet' and is a large, mostly empty table with several columns and rows, likely used for tracking the construction or resolution of the nonconformance.

5. Product Assurance

-
NCR



5. Product Assurance

-
RFW &
RFD

➤ Request for Waivers (RFW)

- Waivers requested for the reported non-conformances. This document asks customer permission to use a material or process where as a result of inspection etc. a non conformance has been identified.

➤ Request for Deviation (RFD)

- Authorization, granted prior to the manufacture of a component, to change a particular performance or design requirement of the specification, drawing or other document.

The form is divided into several sections:

- IDENTIFICATION:** Includes fields for 'PROIECT / PROIECTE', 'SERIE / SERII', 'MATERIAL / MATERIALE', 'CANTITATE / CANTITĂȚI', and 'CANTITATE / CANTITĂȚI'.
- DESCRIȚIE:** Contains a large text area for 'DESCRIȚIA DETALIATĂ A NECONFORMANȚEI / A DEVIĂRII'.
- CAUZA / CAUZE:** A section for identifying the cause of the issue.
- REZOLUȚIE / REZOLUTII:** A section for detailing the proposed solution or deviation.
- APROBARE:** A section with multiple rows for signatures and dates, including 'INGINEERUL / INGINERUL', 'SERVICIUL / SERVICIUL', and 'CĂȘTIGĂTORUL / CĂȘTIGĂTORUL'.
- REZULTAT:** A table with columns for 'CANTITATE / CANTITĂȚI', 'SERIE / SERII', 'MATERIAL / MATERIALE', and 'CANTITATE / CANTITĂȚI'.



6. Product Documentation - Requirements





6. Product Documentation - Drawings





6. Product Documentation
-
Assembly Integration and Verification



Key Take-Aways

- The environment requirements and constraints are crucial.
- Very few materials restricted, but need to show that they are fit for purpose over the lifetime of the mission.
- Select materials from preferred lists where possible. Identify critical materials and processes early, and validate effectively.
- Test as you fly, fly as you test. Trade-off must always be performed, taking into account the criticality of the application and heritage.
- Prediction of materials behavior in the space environment is not an exact science, especially for long term degradation – aim is to minimize risk.
- Knowledge of the environmental effects, sound engineering judgment and experience is required to make the final assessment.
- The unique space and launch environment, the limited number of items produced, the cost of the launch services and the impossibility to repair are driving the costs and development time of space projects.



6. Product Documentation - Lessons Learned



- Thank you for your attention!



ICPE

313 Splaiul Unirii, 030138 –

București, ROMÂNIA

Tel.: +4021 589 34 09 |

Fax: +4021 346 72 90

www.icpe.ro