The development of three segment magnetometer boom for the JUICE mission

Jiri Dokulil

The consortium of companies Frentech Aerospace, L.K. Engineering, SM, VZLU in Czech Republic has been working on the development of magnetometer boom for JUICE mission (JBOOM) in the frame of ESA contract No.4000113000/14/NL/JK.

JBOOM is a 10.6m foldable structure for the accommodation of magnetometer instruments intended for the challenging environment of JUICE mission. JBOOM consists of 3 HDRM systems mounted on the spacecraft interface and the stowed boom. The 3 limbs boom concept offers controlled deployment in the specified envelope and securing the fully opened boom by latching mechanisms. Our presentation describes overall design architecture and concepts.

The Development plan in frame of the contract consists of two major steps. The design and MAIT of the Demonstration model (DM) is focused on the verification of our initial design concepts and preparation of all critical building blocks. In the Qualification model (QM) all of the design features are already implemented and their performance is tested in the full scale configuration to demonstrate the full functionality under defined conditions.

The key innovative feature of our design is the integrated controlled boom deployment system driven by SMA material elements which allows various complex deployment strategies of multi segmented booms maintaining very low deployment shock. The current development status and some issues and achievements are presented.

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Qualification of a Low Shock Release Actuator

Florian GUENTHER

The company Space-Lock has successfully developed and qualified a new Release Actuator product, within ARTES. First, the development and de-risking were completed, including building and testing several hardware models to TRL 6. Then, a comprehensive qualification test campaign with 3 Release Actuator QMs and 10 Initiator QMs was performed. Qualification testing was successful, and the product has achieved TRL 7. All hardware was assembled on a production line which is capable of high-volume output, short lead time, and adequate traceability.

The qualified Release Actuator product has a preload capability of 35 kN, low generated shock, standard electrical interface, very high reliability, and a competitive price.

The presentation covers the key technical performances which were achieved, as well as an overview of the qualification test campaign. Furthermore, lessons learned are shared, and a short company overview is provided.

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Development and Qualification testing of a hinged Deployment Mechanism and Hold Down and Release Mechanisms for the Large European Antenna - LEA

Max Oswald

Deployment mechanisms are commonly used components to enable the usage of large, unfoldable structures like solar wings, antennas or booms and therefore part of hardly any satellite bus. Available European, deployment or hinge mechanisms are mainly focussing on small payloads or lightweight structure. The only mechanisms which are tailored to be very stiff and to deploy large structures are trade-controlled mechanisms from US companies. Given this dependence the development of European communication or Earth Observation Satellites relies on the availability of such rare hardware. As part of the ESA-ARTES program RUAG Space developed in 2018 a first technology demonstrator of a single-axis, self-actuated, ultra-stiff deployment and latching mechanism for large space structures called ABDM. This mechanism has been developed to deploy fragile tip masses on 5 m to 12 m booms up to 200° by a controlled sequence and to emit only a low shock during latching while creating an ultra-stiff connection between the booms or any other structure. This development was continued within the European non-dependence program Horizon 2020. As being part of the WeLEA consortium, RUAG space developed Hinge- as well as Hold down and release mechanisms up to Proto Flight Models for the Large European Antenna LEA. Giving the special requirements of this subsystem, the development of extremely stiff and reliable hinges as well as HDRMs for fragile but highly loaded components was not a build to print project. During the project, a technology readiness level of TRL 6 has been reached on mechanism level while a TRL of 8 is envisaged during the overall subsystem tests which are under progress and will finish until mid of 2021. The presentation gives details of the technology as well as the results of the environmental test. It will close with an outlook on currently ongoing activities during the Large Deployable Reflector for Earth Observation (LEOB) as well as on the future developments and the first flight mission of these mechanisms within the Copernicus Program on the Imaging Microwave Radiometer Mission CIMR.

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Development of Hexapod and Bipods with HDRM for the Athena Instrument Selection Mechanism.

Michal Sidz

SENER

The ATHENA mission consists of an X-ray telescope designed to examine hot intergalactic medium and to search for supermassive black holes. It is a second L-class mission in ESA’s Cosmic Vision 2015-25 plan. SENER in Poland in frame of ATHENA mission was responsible for the design, manufacture and test of the Instrument Selection Mechanism (ISM) – Elegant Breadboard Model (EBM) to support and accurately position a mirror of about 2.5m diameter and about 1.5 tons mass. The ISM EBM consists of a hexapod mechanism and a bipod structure with Hold-Down and Release devices. This presentation will address the hexapod. The mechanism is made of a set of six drivelines with actuators responsible for moving and rotating the mirror. In this way the mirror can be pointed toward two instruments: a spectrometer and an imager. The final position of the mirror is based on the position feedback from angular sensors measuring the output shaft position of each of the actuators. The crucial part of the ISM testing campaign was functional testing during which the accuracy and repeatability of the mechanism was verified. The measurements were performed with the usage of laser tracker to monitor the position of the dummy mirror before and after commanded movements. In such way, a full calibration over the six degrees of freedom was realized. What is more, one driveline was submitted to life and motorisation tests. An approach to these tests and discussion of the results will be the subject of the presentation.

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Qualification testing of a Pin puller for Hold Down and Release Mechanisms

Kai Zajac

RUAG

Hold Down and Release Mechanisms (HDRM) are widely used for satellites to fix large deployable structures like antennas, solar arrays or deployable optical instruments during launch phase. The prime component of such an HDRM is a reliable release actuator. On the one hand frequently used devices are disposed by US American enterprise with International Traffic in Arms Regulations (ITAR) or Export Administration Regulations (EAR) and long lead times. On the other hand the level of reusability requires the need of full refurbishment or manual reset after dismounting. The objective of this project was to develop and test an easy to reset and cost-efficient fully European release device. The activity was supported by Germany’s national Space Program under the German “Komponenteninitiative” with administrative management of the DLR Space Administration.
During the finalized project, a compact, low weight, low shock and easy to reset release device based on a thermo-mechanical release mechanism has been developed, manufactured and successfully tested. With a new functional principle for such devices, this release device allows multiple resets with a minimum effort. The Pinpuller did undergo different qualification tests and analysis, especially environmental tests (thermal vacuum cycling, vibration), functional and release shock tests. Currently, the Pinpuller is able to generate a pull force of 200 N and withstand lateral forces of up to 500 N (pre-actuation) in an operational temperature range between -70°C and +100°C. The device is magnetically clean, has a mass of about 0.15 kg and is classified with a low shock response spectrum according ESA classification. On top, this small device, applicable for a wide range of space missions is absolutely free of ITAR or EAR regulations.

The presentation gives details of the technology and the design and will review the status and results of the environmental and release shock tests. Details disclosed include:

- Pinpuller concept overview and functional description
- Test results of environmental tests
- Test results of functional and release shock tests
- Lessons Learned

The presentation will close with an outlook on the future developments and future improvements of the Pinpuller like release sensors or in orbit demonstration with respect to New Space trends.

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A hexapod platform can be considered as a solution for space missions in which more-established isolators (e.g. viscoelastic mounts) are not adequate to achieve the required high-performance isolation. Nevertheless, these platforms are rarely actually integrated on a spacecraft due to several drawbacks they still present such as system complexity, considerable amount of added mass and potentially the need for control algorithm. For these reasons, extensive research has been carried out on one hand to investigate alternative damping methods to be embedded within the strut elements so to enhance the isolation performance, and on the other hand to improve the system dynamics which could be highly affected by improper boundary conditions or rattling effects within the joints.

Following these considerations, a team made by SSC, SSTL and CSEM has been working for two years on the design of a novel hexapod platform capable of providing high micro-vibration attenuation performance both at low and high frequency, while maintaining a system architecture that is relatively simple (e.g. no control algorithm, only flexure-based joints, cross-coupling between transferred forces and moments to be almost eliminated). In terms of damping method, the team has chosen to use Electromagnetic Shunt Dampers (EMSD), which is a technology developed by SSC and SSTL over the last 6 years. In particular, with the use of a negative-resistance converter, EMSDs have been proved to operate as semi-active dampers capable of combining the advantages of passive dampers (roll-off slope of -40 dB/decade) and active dampers (elimination of the resonance peak) without requiring either an active control algorithm or high input power. In a previous project, this technology was embedded in a 2-collinear-DoF strut where the mass of the magnet was made as an independent degree of freedom within the strut. This configuration has the advantage of having two levels of EMSDs due to the magnet bipolarity and its improved performance as a single strut or as a bipod system (two struts connected together and perpendicular with each other, as shown in Figure 1) was tested and verified.

Nevertheless, through that previous project it became clear how the boundary conditions can severely affect the overall performance. In particular, despite using the all-spherical-joint boundary conditions (widely used in literature), the test campaign demonstrated that such joints produce an inherent limitation for micro-vibration mitigation at high frequency due to the inertia of the struts (unavoidable in a real scenario). In fact, as shown in the ADAMS simulation reported in Figure 2, the strut inertia causes a plateau in the force transfer function that would cancel the high-frequency benefit of the damping method. The project team has then worked to modify the overall hexapod geometry and to come up with new boundary conditions that could restore the desired high frequency performance provided by the EMSDs. The new boundary conditions consist of a combination of a universal joint (providing 2 rotational DoFs) and a newly designed planar joint (capable of providing 2 translational DoFs and a rotational DoF about the strut longitudinal axis). Both these joints are placed on top of the strut as shown in Figure 3. This configuration minimizes the moving mass that was responsible of the plateau effect. Figure 4 shows an example of the expected force transfer function, which is characterized by a maximum amplification of 8dB and a minimum of -50dB attenuation between 60Hz and 370Hz within the operational temperature range of -20C to +50C. The proposed technology is capable of operating in the aforementioned temperature range without any active compensation but in a complete passive fashion it will adapt to the operational temperature. The final design of the breadboard hexapod platform which suspends a cluster of 4 reaction wheels can be seen in Figure 5. However, the advantage of this technology is that it could be easily adapted for a larger payload (e.g. a telescope) by increasing the base diameter but without the need to change the strut dimensions.

The key element for maintaining similar isolation performance would be to place the center of mass of the suspended payload on the top plane of the hexapod (i.e. the plane containing the 3 points of intersection of the 2 struts of each bipod). The fully assembled hexapod mounted on top of the triangular dynamometric table can be seen in Figure 6. On the figure the input is along Z, the mini-shaker needed to be centered with the top dummy wheel. The hexapod was tested as well with input along X, Y, Mx and My, Mz moment was difficult to achieve, therefore it was not tested. Couple of configurations were tested: a case with the coils in open circuit and so no damping (ND), a case in which the coils were connected to the negative resistance converter (WD) a case with the coils in short-circuit conditions (SC) and couple of partial failure conditions. The test results for the Z input can be seen in Fig. 7. The comparison with the Simulink model shows good correlation with this complex system at least up to 200Hz.

The presentation will cover the evolution of the final hexapod design, the completed performance analysis and the several lessons learned while investigating its dynamics. This will include: the considerable reduction of undesired secondary modes, the analysis of safe operative conditions both in orbit and at launch, the evolution of the flexure-based joints and the design of a novel planar joint. The highlights of the test results carried out on the single struts and on the fully assembled hexapod will be presented in the paper together with practical lessons learned on the delicate conditions in assembling a device with stringent dimension and angular tolerances.
Improvements in computer hardware, software algorithms and sensor technologies have stimulated new ideas and given some additional prospect for testing, monitoring & maintaining spacecraft equipment. Reaction Wheels (RWs) are critical components of spacecraft attitude control subsystems. In various ESA missions, for instance XMM-Newton and ROSETTA, reaction wheels showed some forms of anomalous behaviour, which were manifested by erratic changes of the RW friction torque and increased micro-vibration levels (when actually monitored). RW operation as interesting case study and data from relevant space missions were the main subject of this work for studying how advanced software solutions can aid spacecraft operators and technical experts in testing, monitoring and maintaining important assets. The investigation covered a wide range of analysis methods and algorithms, from finding simple statistics to Deep Learning Auto encoders. The most promising algorithms and use cases were then selected, further refined and implemented as two stand-alone pieces of software (namely, the 'Telemetry Data Module' and the 'Micro-vibration Data Module') intended as experimental test platform for further development of the overall idea and concept. Experimenting with different use cases and technologies demonstrated that Machine Learning algorithms could be useful for determining changes and trends in signals, which might go unnoticed when dealing with large amounts of data. At the same time, it was demonstrated that the specific knowledge by technical experts is very valuable in Machine Learning projects, where simple heuristics might outperform advanced algorithms.

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This project de-risked the technology for a novel iteration of the reaction wheel, which aims to have improved performance and significantly more accurate control over the reaction wheel speed. The resulting wheel will serve the CubeSat missions of the future which have stringent pointing requirements. A custom built reaction wheel motor, in which the reaction wheel flywheel is the rotor, was developed in two iterations. Both prototypes were functional. The second prototype showed in first analysis to deliver significantly higher power efficiency than existing compact reaction wheels. Two high resolution sensor solutions were selected, implemented and tested. The sensors can be fit in an integrated reaction wheel and have speed measurement accuracy below 1 RPM. A reaction wheel speed control loop was implemented in a simulation environment and tested with Monte Carlo simulations. The control loop is stable and greatly improves performance in steady state and with disturbances.

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The primary objective of the activity was to develop the technology needed to produce reaction wheels with optimized magnetic signature. Therefore Astro- und Feinwerktechnik Adlershof GmbH with support of Magson GmbH and CSEM developed a magnetically clean reaction wheel. The activity started with a phase to identify and characterize magnetic and magnetization sources in the reaction wheel design, and reaction wheel production and test processes. Afterwards the results were assessed and trade-offs on possible design optimization were performed. Based on the trade-off results, the design was optimized with respect to the magnetic signature and an active compensation mechanism was designed. The design and development activities were supported by extensive magnetic modelling, magnetic testing and breadboarding. Afterwards an engineering model (EM) based on the new design including the active compensation was produced and tested.

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Today, satellites provide geospatial insights, relay information, or defend (inter)national interests against threats. To accomplish their mission, satellites require agility to manoeuver (changing spatial orientation). However, only > 1-ton
satellites (e.g. Pleiades, WorldView) use the state-of-the-art agility technology named Control Moment Gyroscope ("CMG"). Most satellites (99.5%) use traditional technology (reaction wheels) and remain inefficient as they lack the agility to re-point quickly for high resolution (<70cm GSD) Earth observation, rapid in-space/on-ground threat evaluation or optical ground station rapid downlink.
Veoware Space increases the agility of small satellites (50kg to 300kg) using its proprietary miniaturized modular & scalable control moment gyroscope. This paper presents the results of the DE-RISK activity. In this activity, the team started from identifying the basic requirements that a micro-CMG needs to compete with reaction wheels in the smallsat market. Based on this analysis, Veoware reached out to customers to validate such requirements and ensure that any development would find a proper need. The team then initiated the design exercise and developed a breadboard model of such CMG (the "BBM"). The BBM was tested at sub-assembly and assembly level, successfully demonstrating the compliance to performance, mass, and volume requirements. This presentation finally concludes on the key challenges encountered by the team and the way Veoware will continue its development in the future.

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### MREP Mechanisms at low temperatures, test results from 3 lifestests at -5/-80 deg on grease and solid lubricated harmonic drives.

**Andreas Merstallinger**

The aim of the activity was to develop a concept to lubricate a locomotion gear for Martian environment based on a combination of a planetary gear (PG) and a Harmonic Drive gear (HD). The activity is a CCN to the project “Mechanisms that work at low temperatures”. This presentation will set focus on the HD, since more optimisations and adjustments were done and the PG showed overall suitable performance and less wear during the life tests. During the core contract several lubrication concepts were explored, including fully solid lubricated, fully fluid lubricated and some “hybrid” concepts in a temperature range of -5 to -80 °C (operating) and -125 to +125 °C (non-operating). All tests were done in a CO2 atmosphere at a pressure of 15 mbar. Finally, the best performance was achieved with a hybrid lubrication, i.e. lubrication was selected independently for the interfaces in the HD. However, severe wear was found after the life tests, especially at the HD toothing. Hence, the CCN targeted to explore the effect of a surface treatment on the toothing of a HD to overcome the wear problem, hence also guarantying a proper lubrication capacity. The Life tests were recently finalised and preliminary test results will be presented. With a starting efficiency of about 90%, an efficiency of about 70% after reaching EOL – including some efficiency decrease to 50% after non-operational cycles and restart – it can be stated, that a significant performance increase was reached during the whole life test. The “hybrid” concept shows promising results in combining sufficient efficiency during low temperature operation without the need of additional heating – which leads to an overall saving of electrical power – while also guarantying a longer life than fully dry lubricated concepts.

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### New Electrical Contacts material selection and assessment for electrical sliding contact applications

**Roland Holzbauer**

Aim of the project "New electrical contact materials selection and assessment for sliding electrical transfer applications - ECM" was to identify, select and test the novel European material pairs that could be used for future sliding electrical contact applications. Within 3 loops a wide range of brush and slipring materials was tested using a novel setup to simulate experimentally the slip-ring-contact, but also to access the friction and load forces online, together with the contact resistance.

Although the project is not yet fully finalised, some first interim results will be presented. That covers plots of resistance and contact forces over lifetime but also some findings on the contact surfaces by SEM/FIB.

The new setup was found to be a proper tool for investigation of the performance within the regular frame but also for simulation of contamination and arcing in the electrical contact.

The presentation will explain some investigation methods and give some interim results of the tested materials.

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### Ongoing and Future Tribology Activities in ESTL for 2021

**Simon Lewis**

This presentation will provide a brief overview of a selection of ongoing tribological R&D activities together with those planned for ESTL in 2021, to highlight the ways in which ESTL can support industry and the easiest ways to access the results of our work.

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### Mechanisms of Transfer Film Production in Bearings

**Adam Wade**

This presentation aims to update the community on recent work done at ESTL in exploring the mechanism for transfer film formation in solid lubricated bearings. Results from the advanced bearing test rig will be discussed with supporting evidence from other tribometers. The results presented include a comparison of PGM-HT and Tecasint 8591 self-lubricating composite materials.

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### Ongoing Investigations into Hybrid lubrication

**ESTL**

**Rachel Bingley**

Recent advances in the understanding of hybrid lubrication have enabled the development of a hypothesis for the mechanisms by which the successful extension of MoS2 dominated tribological behaviour is achieved. The ideal lubrication scenarios to replicate this advantageous behaviour will be presented along with some initial lessons learned about the inherent difficulties in successfully achieving this.

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### Hard coatings for Anti-Wear Surfaces and Extension of Solid Lubricant Life

**ESTL**

**Greg Kelly**

Previous work by ESTL has identified a range of hard coatings for applications in which a high friction force is required, there was also found uncertainty on the interaction between such coatings and MoS2 for applications where low friction and minimal wear is the target. This work consisted of both reciprocating and unidirectional pin-on-disc (PoD) tests with the aim of determining the "best" hard coating from amongst a selection of coatings which were evaluated. Life-tests were also conducted on MoS2 lubricated discs to determine what synergy there is between the hard interlayer coating and MoS2 performance.

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## Latest Developments in Bearing Modelling Using CABARET

**ESTL**

**Achilleas Vortselas**

CABARET is a numerical code, freely available to users in Europe, which can be used by mechanism engineers to
design, select or optimise ball bearing systems for use in spacecraft mechanisms. Whilst originally developed some
years ago for turbopump bearing applications, today its latest release (CABARETv.3) provides a much improved state of
the art analysis capability which can be used for a range of more general space mechanism applications. Now ported
into Matlab and employing a fully updated user interface, CABARET v.3 has a number of new features which will be
highlighted in this presentation:

- Workflow using a new GUI and new Bearing Library.
- Fluid lubricant traction and bearing torque calculation.
- Cage stability and wear modelling.
- Bearing stiffness calculation.
- Bearing thermal conductance modelling.

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## Euro SMG Development of a stepper motor gear box targeting SADM application

**Reliance Precision Ltd**

**Rik Stewart**

Following completion of the third and final phase of the EuroSMG rotary actuator development, this presentation
reflects on a number of technical lessons learnt from 2012-2021

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## Elegant Breadboard model of an Encoder

**MICOS**

**Roman Schoenbaechler and Brian Wood**

The objective of this activity was for the development and test of an Elegant Breadboard model of an Encoder that has
been designed and developed under this contract using a baseline design from CSEM in Switzerland and that which was
developed under the previous DANOE C16 by Micos Engineering GmbH.

The outcome of the DANOE C17 development phase was to reach a technology readiness level of TRL3 with respect to
the DANOE Imager (EZV Ruby) and the electronics design while establishing an Elegant Breadboard Model (EBB) to allow
the demonstration of design adequacy and performance in representative environment for the mechanical structure to
reach TRL5. The performance of the EBB was assessed based on a semi-commercial electronics developed by CSEM.

Part of the scope of the C17 development phase was to identify a design for the electronics for the DANOE Encoder to
ensure that the performance can be achieved and the operation of the encoder meets the requirements of future
spacecraft applications.

Most notably, the electronics used in the EBB was an improvement from phase C16, but was based on semi-commercial
electronics. As well, due to budgetary and scope constraints, it was possible to customize the semi-commercial
electronics to the representative imager, as the focus was to advance the thermomechanical design of the encoder to
TRL5, while the electronics and imager maturity was gauged at TRL3 within the Statement of Work. Due to financial
constraints, it was not possible to adapt the semi-commercial electronics a redesign activity would have been required.

There are elements of the performance that have not been verified and will need to be performed in the future. All other
objectives were reached during the development.

Based on the constraints during the development phase C17 (workflow, budgets), the de-risking activities on imager
were possible only on a very limited batch, and due to EZV management of their distributor the components delivered
where from two batches, greatly reducing the representativeness of the available residual components. Nevertheless,
the imager is qualified according to JESD JEDEC G47 and, a part of radiation verification and annealing can be performed
at batch level. A more commercial approach can be undertaken, to qualify the overall encoder electronics is qualified as
a single product but only after having achieved sufficient confidence and having undertaken de-risking on the critical
components. The encoder performance can only be assessed with the correct encoder architecture and with the
finalized electronic.

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### Expanding our Understanding of Fluid Lubricated Applications

**Anthony Kent**

This presentation summarises work in three areas relating to fluid lubrication. We will present latest data on the friction and tribo-lifetime of a selection of new-to-market or potentially overlooked fluid lubricants, comparing performance in spiral orbit tribometer tests over a range of temperatures with more familiar products. Also provided is a summary of work to assess the efficacy of creep barriers stored beyond their nominal shelf life, a task which aims to provide a methodology for “re-lifing” such products to extend shelf life. Finally, we present results of a study aimed at a further examination of the so-called auto-catalytic effect relating to PFPE oils.

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### Guidelines for Safe Use of Hybrid Ceramics

**Dominic Bailes-Brown**

Hybrid ceramic ball bearings offer great promise and are increasingly used in vacuum applications. Such bearings offer the potential for long life and low torque noise due a combination of chemical inertness, high hardness and the extremely smooth surfaces produced in ceramic balls. However there persists the common misconception that these materials do not require lubrication to perform adequately. This opinion arises principally from the belief that adhesion between ceramics and steels is weak, such that the likelihood of cold welding is reduced, which in turn minimises adhesive wear and friction in vacuum. This presentation shall address this misconception, and present guidelines for the safe use and lubrication of hybrid ceramics (including fluid lubricants, thin-film solid lubricants, and SLM transfer films) in space mechanism applications.

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### Alternative Cage Materials for Fluid Lubricated Bearings

**Matthew Holland**

It is known that, due to the complex porous nature of the material, cotton phenolic ball retainers (cages) used in ball bearings require initial impregnation with oil to minimise their uptake of free oil in the bearings. However the phenolic itself can be variable in nature, while the impregnation process is both costly and rarely achieves a complete saturation of the material. Therefore phenolic cages may continue to absorb free oil from the bearings, even after impregnation with the risk that bearings stored pre-launch, in hibernation during flight or even operating for a long period after lubrication may experience oil starvation during operation. This presentation shall discuss the recent activity performed by ESTL to identify and evaluate the performance of candidate alternative cage materials (not requiring impregnation) which could replace phenolic for use in fluid lubricated bearings.

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### Ka-band medium-gain antenna and pointing mechanism for smallsats

**RUAG**

**Presenter(s)** contact

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RUAG Space has been contracted by ESA to develop a novel antenna pointing mechanism (APM) for LEO-to-Earth communication in the frame of a dedicated ARTES project. A dual horn antenna concept was chosen to deliver high RF performance in the Ka-Band range.

The APM is based on a crossed-axis gimbal kinematic providing a pointing range of up to +/- 65° per axis. This is especially important for the use in LEO when elevation angles between G/S and satellite become very small. The underlying kinematic concept is not susceptible to the key-hole problem (e.g. in contrast to azimuth-elevation APMs). RUAG has designed this APM to provide high pointing agility (more than 1°/sec at output stage) in order to be compliant with high agility demands when tracking ground stations. Two RSA high detent torque NEMO stepper motors with 3-stage planetary gear reductions are used to drive the mechanism and prevent back driving in unpowered condition.

An innovative dual-horn antenna concept was developed for this application by experts from RUAG Space Sweden. These horn antennas provide an effective gain of >23dB, leading to an overall HF gain of >20dB (incl. RF cables & connectors), satisfying the needs for high bandwidth Ka-Band communication. To lower recurring product cost and to reduce mechanism complexity, RSA implemented two key features in this APM design:

1. No HDRM is needed, because the APM has a mechanically balanced design (thus also providing low disturbances towards satellite platform during pointing),
2. The RF path is made of a coax-only solution (avoiding the use of RF rotary joints).

The presentation will provide a brief design, development and verification overview of the built and tested APM and summarizes the main performance parameters with emphasis on the results achieved during the test campaign.

### Development of secondary mirror pointing mechanism for cryogenic telescope applications.

**RUAG**

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In the frame of a dedicated study initiated by ESA, RUAG Space has been contracted to develop a high precision secondary mirror focusing and alignment mechanism (M2M) for cryogenic telescope applications like EChO, ARIEL or SPICA.

The developed M2M is formed of universal cryogenic linear actuator building blocks – Nano Struts – which can be combined in Hexapod configuration for a 6-DoF mechanism, in tripod configuration for a 3-DoF mechanism, or used as a self-standing high resolution single DoF actuator. For the purpose of the hardware phase a 3-DoF tripod configuration (tip/tilt & focus) without HDRM was chosen as baseline design for a dedicated EQM to be built and tested.

The Nano Strut is a linear stage with high resolution (65 nm) at high stroke (0.9 mm), high load capability in axial and lateral direction, high stiffness and high Eigenfrequency within restricte envelope and low mass. Each Nano Strut comprises a RSA NEMO high detent torque stepper motor, a 4-stage planetary gear with integrated hard end-stops and a 2-stage flexure-based kinematic reduction. The kinematic reduction converts the rotational output of the planetary gear into a linear motion with high resolution.

For the tripod configuration three identical Nano Struts are combined and connected wrt each other via lower and upper I/F frames towards the S/C and mirror and via 3-off identical side frames for lateral stability. The connecting framework as well as the main parts of the Nano Strut flexure kinematic levers are made from Invar 36 material. The effective CTE of the mechanism matches Invar 36 to achieve minimized cool-down drift.

The specified in-orbit operating temperature (<20 K) and the associated demanding pointing performance and accuracy requirements formed several design and verification challenges which have been successfully resolved, e.g. application of MoS2 dry lubrication on gears and bearings of the geared actuator, development of a cryogenic environment compatible high accuracy interferometric pointing measurement system, use of a high accuracy reference switch compatible with the cryogenic environment.

The presentation will provide a brief design, development and verification overview of the built and tested M2M EQM, summarize the main performance and accuracy parameters with emphasis on the results achieved during performance and life testing in cryogenic environment as well as the respective lessons learned.
De-risk activity: adaptation and testing at 40 K of an existing actuator of a mirror pointing mechanism.

<table>
<thead>
<tr>
<th>Main requirements of the actuator are:</th>
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<td>- Overall stroke ± 350 μm</td>
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<td>- Resolution shall be better than 0.1 μm</td>
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<tr>
<td>- Accuracy shall be kept below +/- 2 μm</td>
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<tr>
<td>- Withstand mass of the mirror during launch</td>
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<tr>
<td>- Full performances to be demonstrated at 40K</td>
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<tr>
<td>- Verification of the life cycles requirements</td>
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The following activities were performed:
- Required design modifications based on GAIA and EUCLID M2M Actuators
- Manufacturing of one actuator
- Test verification of one actuator in relevant environment

The actuator was submitted to a complete test campaign. Difficulties and lessons learnt found for the demonstration of the performances and successful outcomes will be presented:
- Verification of functional performances and life testing were performed at ambient temperature inside low humidity chamber.
- Vibration test was performed as preconditioning for life testing inside the TV Chamber.
- Preparation of the cryostat to achieve the required 40K in the actuator while the operation of the actuator is monitored.
- Verification of the functional performances of the actuator during the life cycle testing until failure.
- Dismounting of the actuator an investigation of the possible reasons of the premature failure of the actuator.

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### SADM Demisability study (modelisation, analysis, test campaign, design for demise improvement)  
**KDA**  
**Njord Eggen**

Internationally accepted guidelines and standards limit the casualty risk related to each atmospheric re-entry to 1:10,000. To avoid having to perform a controlled re-entry at End-of-Life (EoL), it is possible to design missions such that they are compliant to re-enter uncontrolled. This is called the Design for Demise (D4D) approach. Most activities in the field of D4D aim at maximising the exposure of components to the flow, or minimising the energy needed to ablate components.

The main focus for D4D activities is recurrent units on spacecraft which appear to be critical for the casualty risk. Solar Array Drive Mechanisms (SADM) have been identified as a promising candidate for which an improved demisability could help platforms perform an uncontrolled re-entry. As a designer and manufacturer of SADMs, Kongsberg Defence & Aerospace (KDA) is aware of the increasing importance of sustainable space activities. For this reason, the Demisable SADM project was initiated in late 2019 as an ESA TRP contract, and involving partners Hyperschall Technologie Göttingen (HTG) and Deutsches Zentrum für Luft- und Raumfahrt (DLR).

The activity aimed at assessing the demisability and fragmentation phenomenology of KDA’s baseline KARMA-4 TG in a high-fidelity reentry simulator, and comparing results to a Plasma Wind Tunnel (PWT) campaign using a simplified model of the SADM. In addition, iterations of D4D with demisable screws were simulated to assess the possibility to further decrease the release altitude from the spacecraft for which a full demise could be achieved. Furthermore, simulations were performed to increase the confidence in results by investigating locally the impacts of modelling simplifications, by using the different relevant databases for material properties, and by using different trajectories for the parent spacecraft.

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### Development and test of a compliant mechanism having the function of a rotation reducer and manufactured through additive manufacturing technologies  
**CSEM, Almatech**  
**Lionel Kiener**

The current status of the development of a Compliant Mechanism based on Additive Manufacturing (COMAM) will be presented. This GSTP project is done in partnership with Almatech (CH) and 3D Precision (CH).

The new geometric possibilities offered by Additive Manufacturing (AM) have allowed us to develop, build and test innovative concepts for compliant mechanisms with almost no support structure under the flexure blades. Bringing together CSEM’s experience in the design and development of high-performance flexural elements and mechanisms for more than 30 years has opened the doors to new opportunities.

The design for AM, topology optimization, manufacturing, followed by the 3D metrology will be presented to highlight the complete development flow of this compliant rotational reducer mechanism. The functional, performance and environmental test results will be detailed. Several lessons learned and future perspective for compliant mechanisms built by Additive Manufacturing will be highlighted.

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### Development and test of a compliant mechanism having the function of a rotation reducer and manufactured through additive manufacturing technologies  
**RUAG**  
**Melzer Christian**

Compliant mechanisms are used in space applications, where high reliability, accuracy and demanding requirements to contamination are valid. Their high complexity normally requires sophisticated and expensive manufacturing methods. The use of Additive Manufacturing could allow developing space compliant mechanisms with a higher design freedom, leading to novel manufacturable complex geometries compliant for new applications.

In the frame of the “Development of a Compliant Mechanism Based on Additive Manufacturing” ESA activity, a compliant mechanism was developed, manufactured using powder bed fusion with titanium alloy Ti-6Al-4V, followed by thermal and surface post-processing on sample and demonstrator level under relevant environment. This allowed demonstrating the possibility of using additive manufacturing to produce dynamically loaded flexible items. Also, important knowledge regarding the fatigue behaviour of Ti6Al4V flexible additive manufactured mechanism was gathered.

The kinematic design, manufacturing and post-processing of the compliant mechanism were proven challenging and lessons have been learnt for the definition of a dedicated end-to-end development process for additive manufactured compliant mechanism, which can serve as a basis for further innovative designs, where high performance can be achieved with monolithic designs reducing machining costs and integration efforts.

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