Summer 2022

IAF MATERIALS AND STRUCTURES COMMITTEE

1. Introduction/Summary

The IAF Materials and Structures Committee was established more than three decades ago. The Materials and Structures Symposium, coordinated by the Committee, provides an international forum for recent advancements in materials and structures for space application. The applications classically concern space transportation, space vehicles and orbital infrastructure. The commercial use of the low earth orbit is more and more evolving and missions to Moon and Mars are the focus of today and future space missions. This continuous evolution of space activities requires new technologies which concern materials as well as structures. These structures include multi-functional structures and robotic systems for on orbit servicing. The Materials and Structures Symposium offers the unique international platform for exchange about recent advancements and future challenges for materials and structures for space applications.

Currently, the IAF Materials and Structures Committee is made up of about 40 members, among which more than 30 are strictly involved in the annual organization of the IAC conferences.

2. Latest Developments

Since its establishment, the Materials and Structures Symposium covers all the scientific aspects of the space sector:

- Launchers, space vehicles including their subsystems (mechanical, thermal, fluidic), components, their environmental and static, thermal and dynamic loading conditions as well as the verification and qualification on ground, in flight and on orbit.
- Deployable and dimensionally stable structures for orbital and planetary applications with a special focus on architecture, lightweight design, materials, mechanisms and dynamics. In recent years, space systems have been calling for large-scale structures to both improve performance (e.g. larger antennas aperture or solar panel size) and enable new applications (such as solar power stations). Therefore, new technologies are currently required to overcome the limitations imposed by launch systems in terms of mass and dimensions. Innovative deployable and/or foldable structures methods (such as origami techniques), as well as in-orbit modular assembly and manufacturing techniques, are the focus of the present and next challenges.
- Robotic systems for on-orbit servicing with a special focus on multi-body dynamics and control play a key role for the future use of the Low Earth Orbit

There is a clear tendency for commercial use of the low earth orbit. Cost-efficient, environment-friendly and sustainable space transportation solutions as well as in orbit manufacturing technologies will be a prerequisite for a commercial use of the LEO. Synergies between the definition of future orbital infrastructure, the in-orbit manufacturing and a potential reuse of launcher stages after completion of their missions will become important. There is a need of an end-to-end bidirectional space logistics approach, which covers not only the space transportation from earth to orbit, but also from orbit to earth.

The commercial use of the low earth orbit requires an evolution of the clean space initiative. Debris removal and on orbit servicing requires advancements in space robotics. Efficient structures, mechanism designs as well as the mastering of the multi-body dynamics and its control will be key for the commercial use of the low earth orbit.

It is the intention of the IAF Materials and Structures Committee to initiate a cooperation with IAF Astro-dynamics Committee (experts in the domain of control systems) for one of the upcoming IAC, potentially for the one which will take place in Milano in 2024.

Above applications require advanced and efficient materials, compatible with extreme environments. Therefore, specific sessions of the Materials and Structures Committee are dealing with these topics

- Advanced materials and structures for extreme temperature applications are needed for storage of cryogenic propellants. Applications for space transportation and for long-term storage require efficient thermal insulations.
- Applications in the hypersonic range of the re-entry need efficient high temperature resistant materials. This includes carbon-carbon and ceramic matrix composites, ultrahigh temperature resistant ceramics, ablative materials, ceramic tiles and other passive or active insulation concepts. These materials together with innovative structural concepts are enablers for propulsion systems, launchers, hypersonic vehicles, entry vehicles, aero capture and power generation. The full spectrum of material, design, manufacturing and testing aspects needs to be mastered.
- The realization of complex multifunctional structures, e.g. for engine applications, are produced by different types of additive manufacturing technologies. Continuous improvements of the technologies are ongoing w.r.t. to the qualification of new advanced materials for extreme temperature applications as well as the corresponding manufacturing process qualification, process simulation and in-process quality monitoring to detect defects at an early stage of production. Continuous improvements in materials and structural concepts are always needed to achieve extremely demanding goals in performance, reliability, and affordability of space components, especially in terms of greater accuracy/dimensional stability, longer life, and greater survivability to both natural and threat environments.
- Specialized material and structures technologies are explored in a large variety of space applications, both to enable advanced exploration and science/observation mission scenarios as well as to perform test verifications relying on utmost miniaturization of devices and highest capabilities in structural, thermal, electrical, electromechanical/ optical performances offered by the progress in nanotechnology. Examples are the exceptional performances at nano-scale in strength, electrical, thermal conduction of Carbon nanotubes which are experiencing first applications at macro-scale such as nano-composite structures, high efficiency energy storage wheels, MEMS and MOEMS devices. Molecular nanotechnology and advances in manipulation at nano-scale offer the road to molecular machines, ultra-compact sensors for science applications and mass storage devices.
- Considering the current international programs on the Moon and Mars, the study and characterization of the materials which constitute the surfaces of the Moon and Mars and their atmosphere will become important in the future. These are the materials that will be used for the habitats, but which require new technologies and new production processes. Our knowledge of them is still very limited.

It is as well worth mentioning the increase in scientific collaboration between the various committee members. This has allowed the development of new research activities between different countries, e.g. between the La Sapienza University of Rome in Italy and the Moscow Aviation Institute in the Russian Federation.

3. Breakthroughs

One of the most significant trends that have been observed in recent years is linked to the possibility of being able to produce and assemble mechanical components of spacecraft in orbit. It is known, large reflectors, large antennas and solar panels are difficult to assemble and test on the ground. Due to the need to make them very light to reduce launch costs, these subsystems are unable to withstand static and / or dynamic loads associated with Earth's gravity. In-orbit production will make it possible to overcome these limits. This requires studying and inventing new techniques and methodologies of automated mechanical assembly in orbit. The verification of the mechanical integrity and the validation of the functionality of the structure components and of the assembled large structures in orbit are prerequisite for their subsequent use and maintenance during their operating lifetime.

The reduction of space transportation costs is an important point when considering the evolutions of Mega Constellations, the increase of use of the Low Earth Orbit and for missions to Moon and Mars. This cost reduction requires besides improvements of the propulsion systems efficiency and the increase of reusability of launcher stages, the increase of the performance through even more efficient structural materials and designs. The efficiency of structures is often expressed in the structural index. This is the most important index, but efficient thermal insulations will reduce propellant boil-off losses and by this increase the P/L performance as well. This is an important aspect especially for missions with long ballistic phases. Composite applications for cryogenic propellant tanks are seen as a game changer for future launchers. Tightness of the LH2 propellant tanks and

LOX compatibility as well as new failure criteria to be mastered, are some of the main challenges of application of CFRP as material for cryogenic propellant tanks. Structural health monitoring will become more important for reusable launchers.

These seemingly very difficult challenges will require greater synergy among different disciplines of applied space engineering. Materials science, construction techniques, based for example on on-orbit additive manufacturing and the ability to assemble large structures in orbit, together with mechatronics and a better knowledge of the space environment will have to be an integral part of future aerospace industries that want to play a leading role in the new space economy. Therefore, in the coming years, the developments in material technologies and in the design techniques of structures for space applications will have to face these new challenges both, from fundamental research and industrial research point of view. It is also worth mentioning the possible use of AI techniques to control robotic manipulators for autonomous in-space structure assembly in the context of future lunar missions.

4. Action plan for the year

Proposed activities for the committee:

1. Possible cooperation with IAF Astrodynamics Committee (experts in the domain of control systems) -> in discussion
   Organizing a joined session addressing the topic of Control/Structure Interaction for spacecraft and launchers, aimed at discussing possible solutions and new approaches to innovative techniques and applications
2. Organization of the 2022 Santini's Memorial Lecture (during Session C2.4) -> done for IAC 2022
   Invited speaker: Prof. Andrè Preumont (Expert in Mechanical and Aerospace Engineering)
   Université Libre de Bruxelles (Belgium)
   More info:
   https://research.com/u/andre-preumont
3. Organization of an online Round Table -> in discussion The round table exchange shall be related to a specific topic relevant for the Materials and Structures Committee. The topic can be proposed by members of the Committee, and the envisioned panel of speakers could be composed of three to four experts (either members of Committee or external invited speakers). The Round Table initiative is thought to be open, so to be attended by a wide public with the twofold objective of both rising interest in the Committee's activities, and allowing especially young professionals to get an insight into the trends and developments of the materials and structures technologies.
   A format would be defined in terms of event duration (for example, two hours at max), event agenda (presentations, discussion on some open questions for the selected topics and final Q&A session) and platform to be used: a possible suggestion is to organize the event with an online platform (such as Zoom, Streamyard). Also, cooperation with SGAC (Space Generation Advisory Council) can be proposed to advertise the event among young professionals.
4. Organization of an online 1-day online Workshop -> in discussion
   The objective is to give the members of the committee the space to present their activities to the committee, so to foster possible cooperation and to exchange ideas and discussions on several topics related to materials and structures.