Consultative Committee for Acoustics, Ultrasound and Vibration (CCAUV)

President: Dr Takashi Usuda Executive Secretary: Dr G. Panfilo

1. Executive summary

The CCAUV covers quantities in the field of Acoustics, Ultrasound and Vibration, all of which concern mechanical waves in various media (air, water and solids) and in structures (machine components, vehicles, buildings, and even human tissues and bodies). Although the measurement units that the CCAUV supports are not fundamental units of the International System of Units (SI), they have a direct relationship with public safety, health, and security as these phenomena are experienced in everyday life. Clear routes for future planning of the activities of the CCAUV have been identified through the strategic planning process, which revealed the importance and priority of acoustics, ultrasound and vibration (AUV) to our stakeholders.

2. Scope of the CC

The remit of the CCAUV is to advise the CIPM on all scientific matters and issues that influence metrology in the fields of mechanical waves: acoustics (A), ultrasound and underwater acoustics (U) and vibration (V). It identifies and organizes Key Comparisons (KCs) in these four fields to establish global compatibility of measurements and traceability to the SI. The CCAUV also acts as the focus and network for this diverse community, to discuss the results of latest research to support emerging areas, and to develop common aims and collaboration between national metrology institutes and designated organizations in Member States of the BIPM or with other relevant bodies.

3. Strategy

In 2017, the CCAUV reviewed its strategy to illustrate the present and future metrological needs for applications in AUV. The BIPM does not carry out any activities in these fields; as a result the planning uniquely covers NMIs, DIs and their stakeholders. The published CCAUV Strategic Planning document gives a detailed analysis of each separate discipline.

The CCAUV has now reached the stage where repeats of KCs are being carried out in addition to considering new ones. The comparison phase within all four fields has matured and is dominated by repeats. Additionally, these repeat KCs are characterized by broadened scopes, spanning increased frequency ranges, which reflect the changing demands of users.

To achieve the highest efficiency and quality, the CCAUV is supported by its three Working Groups (WGs): the Working Group on Strategic Planning (CCAUV-SPWG) oversees revision of the CCAUV strategy and associated documents on a regular basis, it maintains a watching brief on developments and evolution in relevant scientific fields. The Working Group for RMO Coordination (CCAUV-RMOWG), among other things, works to resolve any obstacles to the review of inter-RMO calibration and measurement capabilities (CMC) and to harmonize intra-RMO CMC review processes. The Working Group for Key Comparisons (CCAUV-KCWG) reviews protocols, reports of international key comparisons and coordinates with the RMO KCs in order to assure the quality of published data.

The CCAUV follows developments in adjacent fields and applications, such as the work on the new definition of the kelvin and materials metrology in terms of acoustic wave propagation. It maintains close interaction with the Technical Committees of the International Electrotechnical Commission (IEC) and the International Organization for Standardization (ISO), both of which have a liaison status within the Committee. The CCAUV has started dialogue with the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) concerning infrasound and low-frequency vibration traceability for its International Monitoring System (IMS).

4. Activities and achievements since the last meeting of the CGPM

The CCAUV has met twice since the 25th meeting of the CGPM (2014). As recommended by the CIPM *ad hoc* Working Group on Governance in 2012, the RMO TC-AUV chairs were invited to the CCAUV meetings, as well as to participate in the Key Comparison and Strategic Planning WG meetings.

The CCAUV has taken part in the revision of the CIPM MRA. The application of the recommendations made by the CIPM *ad hoc* Working Group on Implementing the Recommendations from the Review of the CIPM MRA has been one of the main activities of the CCAUV and its WGs.

Guidance documents are provided by the KCWG for carrying out KCs within the framework of the CCAUV.

The List of Service Categories has been updated in agreement with the CCM, introducing force measuring chain and force transducer for mechanical impedance and mobility measurements or modal testing.

4.1. Main activities

The CCAUV meets every two years. The group of metrologists within these areas represent a sparse and geographically-dispersed community. Therefore, in addition to covering cooperation via comparisons, CCAUV meetings also provide a global forum to describe the latest research and demonstrate progress in the relevant fields; they allow the creation and maintenance of contacts with other specialists; and they facilitate discussions on current issues. The meetings also provide an opportunity for scientific exchange and thematic presentations on current leading-edge AUV metrology topics.

There is no significant workload for the CCAUV with regard to reviewing CMCs so far but it plans to pursue a risk-based assessment approach towards reviewing them in the future. The planning process for KCs involves careful deliberation to optimize resource requirements needed to respond to the needs of its stakeholders.

Some mature KCs have reached the stage where repeats of CC KCs, normally conducted on a 10-year cycle, are being carried out to assess them as well as to extend their calibration range. Long-term timetables and repetition periods were defined in the updated strategy document. The CCAUV has implemented the approach of limiting participation in CC KCs that use sequentially travelling standards. Typically, 10 to 15 (2 to 3 per RMO) participating laboratories take part in CC KCs for a period of 1 year.

An *ad hoc* WG reviewed the expression of CMCs (for example units, uncertainty ranges) to achieve better consistency and reported its findings to the KCDB manager.

The CCAUV decided that comparison pilots should include paragraphs in the KC documents to act as proposals for KCWG approval and to give a general indication on "how far the light shines”. This will allow KCs and SCs to be interpreted as widely as is reasonably applicable to indicate coverage of CMCs.

CMS/ITRI (Chinese Taipei) became an Observer and METAS (Switzerland) became a Member of the CCAUV in 2016.

4.2. Challenges and difficulties

Contrary to many other Consultative Committees, the CCAUV does not maintain a base unit; the units that it uses are either derived (composed by several different base units), or represented by the dimensionless unit “decibel”. For this reason, there is a need in the AUV areas to provide traceable measurements in a wide range of units.

Although the planned redefinition of four SI base units does not have an immediate impact on AUV metrology, it will ensure that future requirements for increases in accuracy have been addressed. A coherent metric system among the mechanical and electro-magnetic quantities is indispensable for improving inertial sensors that are based on Microelectromechanical System (MEMS) calibrations.

Comparisons that are designed to accomplish traceability are carried out by circulating travelling standards, such as microphones, hydrophones or accelerometers, between participants. This unavoidable method of working in the AUV field is often time consuming, whereby the next participant must wait for the previous, and where the conservation of artefact quality can critically affect the outcome of a global comparison. Unfortunately, transport problems are regularly encountered and are often exacerbated by national customs procedures. This can be particularly problematic for the sensitive and fragile instruments involved.

5. Outlook in the short and long term

Environment Monitoring

Future developments in the area of metrology for airborne sound (sound in air) can be grouped under four main headings within emerging technologies: a) metrology infrastructure, sensors and instrumentation; b) hearing assessment and conservation; c) product and machinery noise; d) environmental noise assessment. In all of these areas, the common denominator is the goal to better understand and mitigate the impact of noise on humans, and their environment.

Each line of development has a significant impact on the human population, industrial activities, industrial design, urban planning, health, safety, security, and environmental protection. There are several cases where the positive applications of sound and strategies for the mitigation of noise are intertwined. The benefits of environmental monitoring extend across all areas of society, from urban to rural populations.

A further aspect to be considered is the monitoring of highly dynamic events such as seismic activity and controlled explosions such as mining and demolition of man-made structures. Such events have an impact on the environment, and in some cases these sound sources may be of vital importance to global security. In this context, a subset of the environmental monitoring activities, which have applications to support the monitoring of the international treaties for banning nuclear testing, will require the establishment of acoustic traceability at very low frequencies.

Underwater acoustic techniques are chosen for most marine applications that require remote imaging, communication or mapping in sea water. Techniques based on electromagnetic waves are not suitable for such applications because they suffer from a limited range due to high levels of absorption.

Another key driver for environmental monitoring is the concern over exposure of marine life to noise pollution. The impact of acoustic noise emanating from human activities poses unprecedented risks for the sustainability of key marine species, biodiversity, ecosystems and the overall health of the oceans. This increasing concern has led to the introduction of regulations.

Oceanic studies related to climate change use acoustics as a tool to probe the oceans, for example to monitor changes in acidification, detection of methane seepage, or to detect CO_2 leakage from sub-seabed Carbon Capture and Storage (CCS) sites.

Medical and diagnostics

Medical and diagnostic applications span all stages of life, from birth (in the form of neonatal screening) into old age (hearing conservation).

Hearing impairment can lead to severe degradation of the quality of life. Hearing loss can lead to social isolation, family tensions and employment challenges for adults. In children, it can affect communication ability, literacy, educational achievement, as well as social and psychological development. Consequently, national healthcare programmes invest heavily in both hearing diagnostics (through screening programmes) and rehabilitation (hearing aids).

The metrological underpinning of ‘objective audiology’ is a vital prerequisite for the extended use of this technology, which has the potential to become the standard diagnostic technology for audiology in the future. Improved methods for the determination of reference values of the ear with regard to hearing thresholds requires new calibration methods that are traceable to national standards and the investigation of the relationship to behavioural hearing thresholds, which have to be determined for the new earphones.

Therapy and Diagnostics: After x-rays, ultrasound is the second most commonly used imaging technique in medicine. There are 250,000 diagnostic ultrasound instruments world-wide and 250 million examinations are performed each year. In the developed world, most foetuses will be the subject of at least two obstetric examinations during normal pregnancy. Safety-sensitive diagnostic applications will drive the continued development of improved metrological tools and prediction models. A number of these applications involve generating higher acoustic output.

Novel therapeutic applications of ultrasound will continue to emerge, supporting drug delivery concepts based on high-power ultrasound or cavitation and more extensive use of High Intensity Focused Ultrasound (HIFU) or High Intensity Therapeutic Ultrasound (HITU). Exploitation of the clinical potential of these methods requires the development of metrology for both existing and emerging dosimetric quantities. To unlock the potential of therapeutic ultrasound and to better assess safety in diagnostic applications, metrology is essential for the development and validation of methods to determine ultrasound dose.

Key factors in assessing the safety of medical ultrasound applications lie in methods of estimating *in vivo* ultrasound levels, and its implications in terms of bio-effects. The ability to make such measurements is likely to find increasing application, for example in the evaluation of protein solutions, or assessment of nanoparticles.

Engineering and production

Sensors, and the instrumentation used to produce meaningful outputs from them, underpin all acoustic measurements, starting with the realization and dissemination of the primary standard and finishing with hearing assessment, noise measurement or a description of sound quality. In many cases, the drivers for developments in acoustic instrumentation can be addressed through innovation in sensors and instrumentation. In this respect there is great potential to exploit synergies with the consumer product sector, where the demand for microphones now exceeds 2 billion units each year. With the proliferation of low-cost sensors, there is now scope for active management of the acoustic performance of sophisticated items and wireless, autonomous and intelligent operation. For example condition monitoring of machinery, vehicles, rail infrastructure and even domestic appliances could be implemented to maintain the acoustic performance designed into products, optimizing operating efficiency or simply monitoring the level of noise produced. These applications demand new metrological techniques, such as remote self-calibration of sensors and sensor networks, acoustic signature recognition and decision making based on multiple parameters.

Industrial applications of ultrasound are extensive, where it is commonly applied as a means of bringing about macroscopic changes in materials, either within the bulk or at surfaces. Ultrasonic cleaning is the most widespread application of industrial ultrasound and such technology is used for the cleaning of surgical and dental instruments. There is a need for broadband measurement methods capable of spatially resolving non-uniformities in acoustic field distributions, and to underpin improved understanding of influencing factors. This will enable high-power ultrasound to be further applied in an economically viable way in a wide range of technical fields in industries such as food (crystallization control, pasteurization), pharmaceuticals (particle size control) and biofuel production.

The emerging metrological activity in the field of dynamic measurement of mechanical quantities, like force and torque, has revealed a whole new area where linear and angular acceleration become base quantities for traceability of the derived quantities. One well known area is automotive crash testing for which dynamic measurements are essential. Although widely accepted international standards exist, the results are in many cases not strictly comparable due to the lack of appropriate calibrations and an in-depth understanding of the dynamic metrology. The metrology infrastructure currently in place for dynamic mechanical quantities, namely vibration and shock, lags a long way behind that established for acceleration measurements.

Emerging applications in MEMS sensors

Requirements for traceability in shock acceleration measurements are generated in research, industry, medicine and the military. The challenge is to cover the wide range of applications with a small number of efficient methods and calibration techniques. MEMS accelerometers made their debut in the automotive applications of crash sensing and airbag control. Here, the accelerometer continuously measures acceleration of the car. The acceleration curve is integrated to determine if a large change in velocity has occurred and, if it exceeds a predetermined threshold, the airbag is fired. The decision to fire the airbags must be made in the order of milliseconds, yet the operation must be extremely reliable since errors can result in loss of life and limb. Automotive applications for accelerometers also include vehicle dynamic control, rollover detection, antitheft systems, electronic parking brake systems, and vehicle navigation systems. Since human life is at stake if these systems malfunction, these accelerometers are all tested and calibrated, as well as undergoing extensive reliability testing.

The development of autonomous vehicles is advancing rapidly. As of 2018 no fully autonomous cars were yet permitted on public roads. Accelerometer specifications for inertial guidance of an autonomous vehicle will be the strictest compared to the other applications discussed above, since in the event that a GPS signal is lost the position of the vehicle must be determined by the inertial guidance system over a period of time that might span tens of minutes. The current designs for capacitive MEMS-based accelerometers and gyroscopes may never meet requirements for fully autonomous driving, and may have to move towards optical-based systems instead of capacitive-based systems.

Society and Occupational Safety

Noise produced by a variety of sources such as transportation (road, rail, air), industrial plant and wind farms, neighbourhood noise, sports and entertainment venues, is detrimental to the environment and quality of life.

Requirements for traceability and mutual recognition of measurement results are needed for workers' safety. The human response to mechanical vibration, where a dose concept is applied, represents one issue, and hearing is commonly put at risk from excessive exposure to man-made noise. Measures to reduce these hazards impose huge expenses annually. The widespread screening of work-force or personal noise dose-monitoring will demand new approaches and innovative instrumentation.

Low-frequency vibration transducers are widely used for monitoring earthquakes. The demand for earthquake monitoring systems has increased following a number of major seismic incidents. Special sensors provide traceability to thousands of seismometers and hundreds of observation stations in the Global Seismographic Network, which provide an immediate alert to the population, demanding calibrations at ultra-low-frequencies.

Annex: CC Data

CCAUV set up in 1998

President: T. Usuda	Executive secretary: G. Panfilo
Membership:	18 members, 2 liaison and 12 observers
List of CCAUV members and observers:	http://www.bipm.org/en/committees/cc/ccauv/members_cc.html
Meetings since the 24th CGPM meeting:	25-27 November 2015 / 20-22 September 2017
Full reports of the CCAUV meetings:	http://www.bipm.org/en/committees/cc/ccauv/publications_cc.html
Three Working Groups: Key Comparisons (CCAUV-KCWG) RMO Coordination (CCAUV-RMOWG) Strategic Planning (CCAUV-SPWG)	http://www.bipm.org/en/committees/cc/ccauv/working_groups.html

CCAUV Comparison activity	Completed	In progress	Planned
CCAUV key comparisons (and supplementary comparisons)	15	3	13
RMO key comparisons (and supplementary comparisons)	26	2	-
BIPM comparisons	0	0	0
CC pilot studies	4	0	5
CMCs	1174 CMCs in 51 service categories registered in the KCDB		