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Report

to the National

Measurement System

Policy Unit, Department

of Trade & Industry

INTERIM STATUS REPORT ON THE ACOUSTICS METROLOGY AREA

FROM THE SOFTWARE SUPPORT FOR METROLOGY PROGRAMME

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Software Support for Metrology

Interim Status Report on the Acoustics Area

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Abstract

This report describes the status of the mathematics and software used to support the Acoustics area of metrology, particularly as used within the NMS Acoustics programme. This is one of a set of status reports produced for the NMS Software Support for Metrology (1998-2001) programme mid-way through the current programme to inform the formulation of the next SSfM programme (2001-2004). The different aspects of mathematics and software are reviewed under the headings of the themes and project topics of the current SSfM programme. The SSfM programme is identifying best practice where it exists and disseminating guidance on that best practice to other metrology areas. The outputs of the SSfM programme will be generic, applicable to more than one metrology area. This report, therefore, not only identifies problems to be tackled and best practice to be disseminated by the SSfM programme, but also if appropriate possible future Acoustics programme projects applying SSfM outputs to specific problems in the Acoustics area.

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Contents

1. Introduction

The purpose of this status report is to inform the NMS Software Support for Metrology (SSfM) programme (1998-2001) about the status of the mathematics and software used to support the **Acoustics** area, concentrating on what is used within the NMS **Acoustics Metrology programme**. This and the companion status reports for the other metrology areas will inform the formulation of the next SSfM programme (2001-2004). It may also lead to appropriate linkage between the Acoustics Metrology programme and the SSfM programme.

The SSfM programme is an underpinning programme that provides generic support in the use of software and mathematics to the NMS programmes for each metrology area. For details of the programme, its expected deliverables and the results already produced, see the SSfM web site: http://www.npl.co.uk/ssfm/.

The NMS programmes for specific metrology areas provide metrological support to industry. The SSfM programme in contrast has relatively little direct impact upon industry, although there is some as evidenced by the SSfM Club membership. This relationship is depicted in Figure 1. It is because of this relationship that the Status Reports concentrate primarily on the use of software and mathematics in the other NMS programmes.

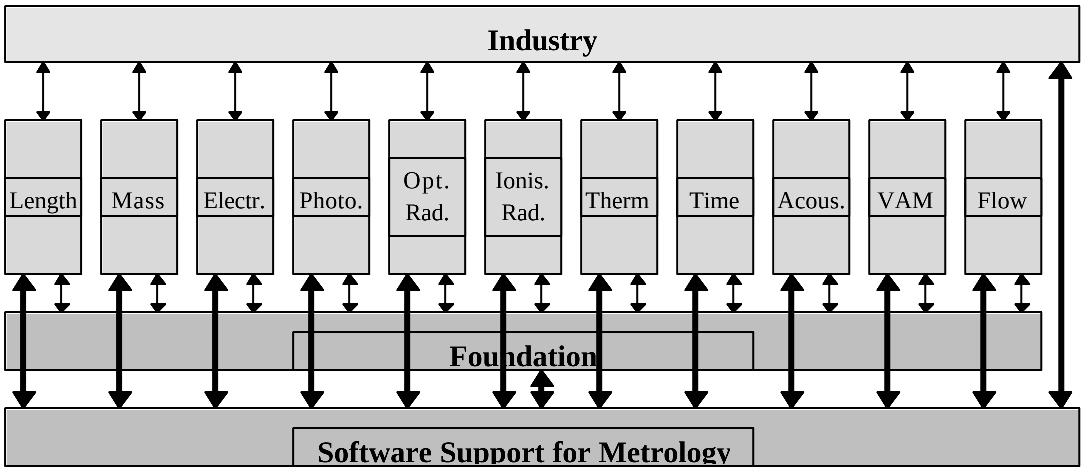

Figure 1. Relationship of SSfM to other NMS programmes and industry

In particular, this report addresses each of the themes within the SSfM programme and describes the status concerning the topics covered by each of the relevant projects. It also considers whether there are any important software or mathematics issues in the Acoustics area which are not addressed by the current SSfM programme or which need to be taken further in the next SSfM programme.

This report is an update of an initial restricted status report produced in November 1998. That initial report was one of a set of restricted status reports which were synthesised into an overall status report for all metrology areas [4]. A summary of the differences from the initial Acoustics status report is provided at the end of this report.

2. Scope of the Area Covered

The NMS Acoustics programme includes noise, airborne acoustics, underwater acoustics and medical ultrasonics. The most common acoustics parameter which is measured is the acoustic pressure. This is generally sensed by a microphone (in air) or hydrophone (in water). The technology of acoustic sensors, including piezoelectric transducers such as hydrophones and parallel plate condensors such as microphones, which transform acoustic energy into electrical energy, is continuously developing. Although piezoelectric transducers and condenser microphones have been around for many decades, devices such as fibre-optic hydrophones are recent developments. In addition, the use of laser interferometry to measure acoustic parameters is less mature (NPL uses lasers to measure acoustic particle displacement and acoustic particle velocity) and some of the issues which arise here, such as the influence of the acousto-optic interaction in nonlinear fields on the measurements, are not well-understood.

Another sensor used in medical ultrasonics work is the thermocouple, which is used to measure temperature rises in tissue mimicking gels due to ultrasonic heating. NPL has been active in modelling these effects, e.g., using finite element analysis to model the errors which arise in thermal measurements from heat conduction by thermocouple wires.

Some of the work done on optical methods, e.g., the acoustic particle velocity laser, is not directly for NMSPU, but is covered by NPL's Strategic Research programme or third-party contracts.

In one case, an acoustic sensor is based on the principle of radiation force, i.e., for measuring acoustic power in ultrasonics, the transfer of momentum from the acoustic wave to a large target (either reflecting or absorbing) is the method by which the primary standard for acoustic power is realised.

In summary, the challenges lie in

a) improving the existing measurement capability (improving accuracy and reducing uncertainty),

b) extending the capability (e.g., to new devices and/or frequency ranges), and

c) delivering customised solutions to industry (particularly in respect of noise assessment).

In the Noise field, a further consideration is the performance of the human auditory system, whose response is non-uniform, e.g., in frequency and level. More importantly, Noise Section deals with psychoacoustics, i.e., human reaction to sound and hence the measurand is indirect: human perception of “annoyance” rather than direct measurements of sound pressure.

3. Modelling Techniques

3.1 Methods for Modelling Measurement Data

3.1.1 Types of data

There are three categories of measurement data sets:

1. discrete measurement data, which means:

   a) data obtained by sampling a discrete variable: e.g., a variable that may take only integer values such as in counting processes, and

   b) data obtained by sampling a continuous variable.

2. continuous measurement signal, which means an analogue signal prior to any analogue to digital conversion, which would result in data of type 1b).

3. hybrid measurement data composed of both discrete and continuous data sets.

The underlying phenomena being modelled are continuous in nature: acoustic intensity, acoustic pressure, diaphragm displacements, etc. However, practical measurements are discrete in nature, typically taking the form of digital signals.

3.1.2 Modelling

Types of model

There are three categories of model:

1. discrete models in which the outputs of the measurement system are related to measurements of its inputs by a system of algebraic equations;
2. continuous models in which the outputs of the measurement system are related to measurements of its inputs by a system of differential equations;
3. hybrid models in which the outputs of the measurement system are related to measurements of its inputs by a system composed of both algebraic and differential equations.

It is appropriate to distinguish here between the nature of the model and the approach to solving the model (which for a continuous model typically also involves solving algebraic equations).

Given infinite precision arithmetic, the set of equations derived from a discrete model can be solved exactly. This is not the case for a continuous model which typically requires approximations to be made, for example, in terms of domain discretisation.

Models used in the Acoustics Area

The type of modelling used in the Acoustics area comprises:

1. digital signal processing (mainly discrete data), and
2. continuous models of acoustic field parameters (continuous and/or hybrid data).

The two types of model are complementary: the continuous model is used largely for design and simulation, whereas the discrete model is used as part of the measurement services offered to laboratories and instrument manufacturers.

Novel techniques are required for some of the modelling problems encountered. For example, in underwater acoustics, methods are required to overcome the restrictions imposed by the finite size of the tanks in which calibrations are undertaken. This is done by windowing the measured signal to remove the transient behaviour of the calibrated devices, as well as the effect of echos, and then applying conventional signal processing techniques including the fast Fourier and discrete Fourier transforms. Recently, work has been undertaken to extend the windowed part of the measured signal to include the transient behaviour, and apply signal modelling techniques. There is an awareness that techniques such as time-delayed spectrometry and wavelet decomposition methods, in addition to traditional Fourier methods, may provide useful information.

A primary standard method used for calibrating both microphones and hydrophones is the reciprocity method. This method requires the use of three devices at least one of which must be a reciprocal transducer, i.e., its transmitting and receiving sensitivities are related by a constant factor, termed the reciprocity parameter which depends upon the geometry of the acoustic field. The devices are paired off in three measurement stages, at each of which one device is used as a transmitter and the other as a receiver. For each pair a measurement is made of the ratio of the voltage across the terminals of the receiving device to the current driving the transmitting device. Using the reciprocity principle, the sensitivity of any one of the devices can be determined from the purely electrical measurements described above with traceability to standards of electrical measurement (the ohm and ampere).

Calibration of membrane and probe hydrophones at frequencies of greater than 500 kHz is based on the primary standard of optical interferometry and is traceable to primary standards of length via the wavelength of the laser light. Another interferometer based system, a laser pistonphone, is used to provide primary standard pressure calibrations of microphones at low audio frequencies.

In all the above calibration methods, care is taken with the experimental design to minimise errors, e.g., wherever possible the calibrations consist of measuring voltage ratios incorporating the use of calibrated attenuators to equalise the voltages, thus minimising errors due to gain and linearity of the measurement channel. In many of the methods, assumptions are made regarding the nature of the acoustic field, e.g., plane-wave or spherically-spreading, and these must be verified.

A number of mathematical models are used in ultrasonics work. Ultrasonics in water generally involves high frequencies and high amplitudes, and both linear and nonlinear acoustic propagation algorithms are needed to validate the calibration methods. The requirement for high frequencies requires fine meshes in PAFEC simulations. Consequently, there are performance issues, and trade-offs to be made which need to be validated.

Linear acoustic theory is generally well-understood following the pioneering work of Rayleigh. A number of approaches to nonlinear propagation exist in the literature of which some have been implemented at NPL.

Analysis of acoustic *systems* (as met in practice) can be difficult, and hence there can be discrepancies (a) between theory and practice, and (b) between practitioners. NPL has started to look at acoustic cavitation phenomena and is continuing to study nonlinear behaviour (wave propagation, interactions, etc.) in general. NPL's work on nonlinear ultrasonics began in the early 1980s and underlies an existing UKAS-accredited hydrophone calibration service.

3.1.3 Summary

The Acoustic Area uses mathematics and software widely, and in modelling terms this use is relatively advanced. Both discrete (FFT and regression methods) and continuous (Finite Element Analysis) modelling is performed. The main areas of concern relate to:

1. modelling the entire system,
2. removal of assumptions in continuous models, e.g., to include nonlinear wave phenomena,
3. extracting more information from signals by the application of novel analysis methods, and
4. statistical modelling, particularly of correlated and/or complex-valued quantities.

3.2 Uncertainties and Statistical Modelling

Levels of accuracy vary widely across acoustic metrology, with an overall uncertainty of several percent for a primary standard in ultrasonics and underwater acoustics whereas an equivalent primary standard in air acoustics may typically be an order of magnitude smaller.

The ISO Guide to the Expression of Uncertainty in Measurement (GUM) [1] and UKAS M3003 [2] are widely used in this area of metrology. Some problems with these documents are identified, including

1. the need for more and/or better examples, e.g., on the use of the Welch-Satterthwaite formula, and where uncertainty components vary with frequency when measurements are taken in the time domain, and

2. the “Type A and B” distinction is not as convenient as that between “random” and “systematic”.

Not all metrologists have received formal training in uncertainty estimation, but all are familiar with these Guides, and it is accepted that a knowledge of uncertainty estimation is essential, particularly for understanding and hence controlling sources of uncertainty.

Generally, an assumption is made that the input quantities are uncorrelated and each is drawn from a Gaussian distribution. It is accepted that this assumption is not always tenable, as in the application of reciprocity calibration methods. Furthermore, many of the quantities encountered in the area are complex-valued, and there are concerns about

1. the independence of the errors in the real and imaginary parts of these quantities, and
2. the choice of suitable distributions to model the associated magnitude and phase of these quantities.

When comparing against tolerances, particularly in medical ultrasound and similar critical measurement applications, metrologists are aware of the approximate nature of the uncertainty statements made and, hence, the uncertainties quoted tend to be conservative. A major concern relates to statistical tolerancing, in particular the uncertainty of meeting a specification. The OIML guidance on conformance to specification is to have four results: the artefact passes, probably passes, probably does not pass, or does not pass, and this requires explanation for users.

In intercomparison exercises, problems are identified including how to

1. include the uncertainty of the measuring laboratory, and
2. deal with outliers. In particular, guidance would be useful addressing how and when to include/exclude observations, and what robust methods are suitable.

Generally, software for uncertainty estimation software is developed (in-house) at NPL but, nevertheless, metrologists would welcome reliable generic uncertainty estimation software and/or tools. Similarly, there is an appetite for more information concerning uncertainty estimation, perhaps through case studies.

The level of confidence used in deriving confidence intervals for acoustic parameters is generally 95%.

3.3 Visual Modelling and Data Visualisation

Data visualisation is used where possible to display input and output quantities (signals and/or parameters). Some quantities require three dimensional plotting. Quiver plots, for example, are used for the visualisation of sound power output.

Visualisation invariably relies on the use of third-party graphical software. The continuous modelling package PAFEC provides colour graphical output, but the graphs are not truly dynamic.

Generally, data visualisation has not been extensively integrated with modelling software to investigate, for example, how certain parameters of interest vary as other parameters are modified. But it is seen that this integration would be valuable for design purposes and may also enable service staff to check instruments.

Clearly, there is scope to extend the use of visual modelling in this area of metrology.

3.4 Data Fusion

Different analysis techniques are used over different regions of the frequency scale. Generally, there will be some range of overlap, which eases the task of smoothly fusing the data. One method of doing this is to take account of the relative uncertainties and use weighted means to combine the data.

A further use of data fusion is in characterising noise in terms of various measured attributes. The statistical package SPSS is used to analyse the individual data streams and fuse them into a perception of noise.

Finally, intercomparison exercises are undertaken to assist in validating the UK's acoustic measurement capability against its peers.

Although there is little evidence that this has happened yet, it might be possible to *integrate* predictive data from (continuous) models with measured data, using updating strategies based on powerful statistical techniques, in such a way that the overall uncertainty is reduced. There would appear to be scope for such activity in the Acoustics area.

There is some awareness of INTErSECT (particularly of the Sensors theme and of AESAD) but little appreciation of how the Data Fusion theme might impact on the Acoustics area.

4. Validation and Testing

Typically, a known electrical signal, sometimes prescribed by a relevant Standard, is used to test software as a black box. Cost of testing is a main concern, particularly as the number of operating options associated with measuring instruments grows.

4.1 Spreadsheets and Other Mathematical Software Packages

Spreadsheets are used throughout the Acoustics area. Although attractive to users, the policy is to discourage the use of spreadsheets, because of the difficulty of configuration control of spreadsheet solutions. It is noted that spreadsheets are difficult to make generic (which militates against re-use), but easy to alter. Spreadsheets are often used for prototyping only, but are sometimes used for uncertainty budget calculations and simple data analysis and display.

Other third-party packages used in the Acoustics area include:

1. MathCAD (for general mathematics and including symbolic manipulation),
2. MatLab (for discrete modelling, data and signal processing and visualisation),
3. SPSS (for more advanced statistics),
4. PAFEC (for continuous modelling), and
5. the NAG library (which is a general-purpose numerical subroutine library).

In addition, software packages developed by other groups in NPL are used, including:

6. NPLFIT (for calibration curve fitting), and
7. IDES (for integral and differential equations, and associated calculations, e.g., evaluation of Bessel functions).

The first of these was developed under NPL's quality system and is registered as production software; the second was developed prior to introduction of the formal quality system, but is from a reliable source and has been validated in use.

The Acoustics area also includes "home-grown" software, e.g., the beam calibration software written in Forth and now being re-implemented in Delphi, and many routines written in FORTRAN using subroutine libraries (such as NAG and IDES) on the NPL mainframe. There are also many instrument drivers etc., written in

1. LabWindows (data acquisition, instrument design and control package),
2. HT-Basic (data acquisition and control package) and
3. LabVIEW.

There is some awareness of software deficiencies, to the extent that a defensive strategy is followed in respect of measurement system design, i.e., a key requirement of an acceptable system is that the software should be as simple as possible. Hence, software is viewed as forming part of the traceability chain and a risk minimisation strategy followed.

Generally, the claims of package suppliers are accepted without further formal testing. However, this is changing. Recently, some enhancements to PAFEC have been commissioned, and a test plan has been drawn up such that these extensions to the functionality of PAFEC will be accepted only when they pass the tests at NPL.

Reference data files for reciprocity calibrations were developed jointly between NPL, DTU/DPLA and PTB as a Euromet project.

4.2 Model Validation

Model validation principles are generally well-understood in the Acoustics area. In the case of continuous models, model validation is undertaken by comparing different approximations and testing whether quantities such as energy are conserved. For discrete models, testing is performed in an "evolutionary" fashion, by three methods:

1. inputting extreme data and checking robustness,
2. providing data with "known" results and checking accuracy, and
3. verifying behaviour of the complete system and checking reliability.

Other examples include choosing when to truncate a (slowly-converging) series expansion, or to use a specific calibration model. Common methods include comparison with ideals such as point sources, ideal pistons, etc., which have analytical solutions, though not always in closed form.

Transfer impedance can be measured and the corresponding transmission line model derived with help from model validation techniques.

4.3 Measurement System Validation

As stated before, the measurement system is chosen to reduce sensitivity to all sources of error, including software. Traceability/validation is available for the simplest instrument functions, but research-based activity requires more functions, which are often difficult to validate. As an example of such "defensive" design, where possible the key calibration is based on voltage ratios, whence the measurement system is more robust.

Embedded software is common: calculations are built into the hardware, including FFTs and spectrum analysis. The perception is that they are generally easy to test. As an example, in Noise and Audiometry, embedded software is used and supplemented by off-line calculations in a bought-in package which implements the relevant ISO Standard, with prescribed validation procedures.

These procedures are often based on inputting a known signal and testing against predicted output. Indeed, this is seen as part of the measurement audit process. As an example of this process, microphones with a full calibration history can be validated experimentally with new data.

Positioning systems can be open- or closed-loop; the latter use feedback control to correct for problems. In the case of the former, it was discovered that a certain linear position encoder had a problem, which was identified by validating against a geometric model. Benefit was obtained in this instance from links with NPL colleagues in Dimensional Metrology.

Generally, the analysis software is validated separately using existing data and results. Measurement system validation also benefits directly from modelling. It is often beneficial to analyse and test an equivalent electrical system and determine its calculable response. This idea has proved very successful.

Regular EUROMET comparisons (with DPLA and PTB) provide further measurement system validation.

Concerns about measurement system validation relate largely to the “black box” nature of embedded firmware, hence lack of visibility at the required level of detail. For example, firmware upgrades can have subtle consequences in respect of timing, etc., which may compromise consistency.

4.4 Validation of Simulated Instruments

Considerable simulation is undertaken, particularly in Underwater and Medical Ultrasound. However, no attempt has yet been made to simulate a whole class of instruments, as was the case of the Virtual CMM in the Length metrology field.

In the Acoustics area, (continuous model) simulations tend to focus on key features such as the diaphragm and piston. The details of the design have a profound effect on the measurement results. This is in contrast to the generic parametric error models of CMMs, which are typically discrete models, with many parameters, but lower conceptual complexity.

Perhaps the work on calculable response systems could be developed into simulated instruments.

5. Metrology Software Development Techniques

5.1 Software development methods

In Air Acoustics, most of the software developed is used for instrument control. It is integral with the measurement system and is mainly developed in-house, because of the need to understand the underlying instrument. The software comprises libraries for instrument control (LabWindows, not LabVIEW).

The measurement services parts of Underwater and Medical Ultrasound are similar in respect of use of software. Software development for design and simulation is based on refining a prototype.

The software packages used have been listed elsewhere. Languages used include HP-Basic (where there is much legacy code), HT-Basic (for PCs), Visual Basic (mainly by consultants), C (very little), FORTRAN (to link with IDES, NAG library and PAFEC), Pascal, Delphi (to modernise the Pascal and Forth software), Forth (beam calibration software written by a consultant) and LabWindows (for instrument control). LabVIEW is also starting to be used.

Traditional software development techniques (the V- or "specify, design, write, test" model) is used to develop software. Software development is in accordance with NPL's QMS which meets the TickIT requirements for software. The perception of managers is that the NPL QMS, as applied to software development, introduces several problems:

1. the design stage is made unnecessarily cumbersome, to the extent that fewer options are tried,
2. developers are reluctant to change software, hence they live with software bugs, and
3. stringent requirements for regression testing soak up resources.

The management perception is that NPL's model imposes these constraints on the assumption that the software writer abandons the software, whereas most developers at NPL are also users. As implemented, the NPL quality requirements for production software give rise to the need for lots of retrospective effort, with little apparent added value. It is agreed, however, that much had been learnt from implementing ISO 9001 [3]. It is worth noting that other parts of NPL find it possible to take a more pragmatic approach to interpreting the quality requirements and hence do not report the same problems.

There are particular problems with regard to the NPL computing infrastructure in that good software such as the IDES library and similar software is available only on a central computing system and is not well-integrated with the PCs recording the data.

Summarising, there are concerns about cost of software development, particularly balancing the potential cost of software failure (which could be enormous, harming NPL's reputation for reliable primary standards) against the actual cost of developing the software.

Contractors have been successfully used in the past in some areas, with the advantage of providing additional resources and software skills. However, it is considered absolutely essential to maintain adequate software capability, particularly since an understanding of acoustics assists in devising test and validation strategies.

5.2 Software reuse

Instrument control software is reused where possible, by adding to a common repository of LabWindows instrument drivers. This is a formal library, with a specific procedure for its maintenance and a software manager appointed to ensure that all this is co-ordinated across the twelve or so machines using LabWindows. Staff would welcome more information on what software is available across NPL, but they would need to check its compatibility and quality. The repository is not extensive, since there are relatively few National Instruments cards suitable for the Acoustics area.

The Y2K problem is being addressed by replacing PCs which fail to pass millennium compliance tests, but the problem is expected to have little direct impact, since the Acoustics area generally does not use dates in a mission-critical fashion. The assumption is that external systems will continue to work normally.

In terms of software development techniques, procurement of a replacement to the HP9000 series 300 workstations is difficult, since it may prove difficult to reuse existing software. Therefore, not all software is reused, i.e., some software is being re-engineered: the beam calibration software is now being converted from Forth to Delphi; inherited Pascal software is being replaced by Delphi or MatLab where appropriate. Even the LabWindows instrument drivers sometimes require customisation. Another form of re-engineering occurs when a prototype version is reimplemented in a different language, e.g., a MathCAD program was written to simulate beam calibration, though the beam calibration was implemented in Forth.

Mixed language programming occurs when GUIs (typically written in Visual Basic) are added to existing software.

The general principle is to re-use where possible, but this is not enforced strictly.

5.3 Virtual Instruments

LabVIEW and the virtual instruments concept has not been used in the Acoustics area until recently. However, LabWindows (a conventional set of modules with a similar functionality) has been in use for ten years.

Some initial observations are that:

1. a disadvantage is that the virtual instrument concept implicitly assumes only one instrument of a given type is attached to the control PC, but this is often not the case at NPL,
2. an advantage is that software design is difficult to separate from system design, hence the virtual instrument concept is a good fit with measurement software in the Acoustics area, and
3. training in the development of virtual instruments would be welcome.

6. Support for Measurement and Calibration Processes

6.1 Automation of Measurement and Calibration Processes

At present, the acoustic measurement service is administered manually via paper forms. This is probably adequate in that it is relatively low-volume but any efficiency savings would be welcome.

The Acoustics area is reviewing the use of LIMS and awaiting developments elsewhere at NPL. The key requirement of a LIMS system is that it should issue *traceable* calibration certificates. A secondary requirement is that it should be sufficiently easy to use so that errors should not be introduced.

6.2 Format Standards for Measurement Data

Transferring data from one service to another is subject to internal consistency checks. The medium, whether internally (with colleagues or with other software packages) or externally (e.g., with customers, or where reporting results in intercomparison exercises) is generally (a set of) ASCII files, backed up with paper copies.

Generally no formal format standards are used. The main concern relates to extracting and interpreting manufacturers' data, rather than sharing measured or processed data.

7. Suggestions for Future Activities

7.1 Expected Benefits of the SSfM Programme

Generally, the Acoustics area makes sophisticated use of mathematics and software. It has particular strengths in modelling and measurement system validation, each of which could provide exemplars of existing good practice.

The direction of technology transfer might well be reversed in the case of

1. visual modelling,
2. data fusion,
3. validation of simulated instruments,
4. virtual instruments, and
5. automation of measurement and calibration processes.

Taking these in turn:

1. Noise and Audiometry would be expected to benefit from visual modelling, e.g., determining the spatial or temporal distributions of sound. Usability of packages such as PAFEC would be improved if the user could *interact* visually.
2. There is a lot of scope for data fusion, e.g., from arrays of microphones and when combining historical data with measurements.
3. The simulation of parts could be integrated to simulate entire measurement systems, including the effect of introducing different artefacts, generating example data, etc.
4. The Acoustics area is relatively new to virtual instruments and might benefit from the experience of others.
5. The same applies to LIMS, where it would appear that the full potential of LIMS has yet to be appreciated in physical metrology.

7.2 Case Studies and Feasibility Studies

Case studies might include:

1. modelling of devices, such as hydrophones,
2. uncertainty evaluation, for correlated and complex-valued quantities,
3. validating finite element models,
4. simulating acoustic measurement systems, and
5. updating software and moving platforms: estimating and controlling the project time and cost.

7.3 Future SSfM Topics

Approximation methods taking account of scale information: Perhaps the next technological step to be taken is to realise that traditional approximation techniques fail to take direct account of data scaling in the independent variable. As an example, PAFEC uses traditional basis functions and hence has difficulty in representing short-scale information such as that which is associated with high spatial frequencies. The result is very fine discretisation and computational cost. *Multigrid methods* offer an alternative set of basis functions which use controlled extrapolation to reduce the computational effort.

Awareness of scale can also improve discrete modelling. For instance, traditional time series analysis methods fall into two categories: time-based and frequency-based. Some signals e.g., those that are nonstationary, are best represented in a mixed format. *Wavelet methods* utilise a flexible set of basis functions which can be tuned to relatively economical representations of signals which are not easily represented by other methods.

Intelligent technologies, or *soft computing techniques*, may well provide in the future a useful set of tools for certain metrological applications, for example in the soft measurement of noise quality. Generic activity to explore such techniques can be expected to underpin specific applications of these techniques, as well as to promote their wider use.

7.4 Future Acoustics Programme Topics

There are a number of SSfM topics that are expected to benefit the Acoustics programme: these are detailed in Sections 7.1, 7.2 and 7.3. The topics could be progressed either in the Acoustics programme, in the current or future SSfM programmes, or perhaps more usefully as combined activity between the Acoustics and SSfM Programmes.

8. Summary of Changes

The principal changes from the initial restricted status report on the Acoustics area are as follows:

- the scope of the area covered by the Acoustics programme updated,
- the awareness within the Acoustics area of INTErSECT updated to include the AESAD project,
- the list of mathematical software packages used within the Acoustics area updated to include LabVIEW,
- the addition of soft computing as a future SSfM topic,
- the addition of future Acoustics programme topics.

9. Acknowledgements

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Appendix 1: Glossary of Abbreviations

Abbreviation	Expansion
ASCII	American Standard Code for Information Interchange
CISE	Centre for Information Systems Engineering
CMAM	Centre for Mechanical and Acoustic Metrology
CMM	Co-ordinate Measuring Machine
DPLA	Danish Primary Laboratory of Acoustics
DTU	Technical University of Denmark
FDA	US Food and Drug Administration
FEA	Finite Element Analysis
FFT	Fast Fourier Transform
GUI	Graphical User Interface
GUM	Guide to the expression of Uncertainty in Measurement [1]
IDES	Integral- and Differential-Equations software library
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
LIMS	Laboratory Information Management System
NAG	Numerical Algorithms Group
NMI	National Metrology Institute
NMS	National Measurement System
NMSPU	National Measurement System Policy Unit
OIML	Internal Organisation for Legal Metrology
PC	Personal Computer
PTB	Physikalisch-Technische Bundesanstalt
QMS	Quality Management System
SSfM	Software Support For Metrology
UKAS	United Kingdom Accreditation Service
Y2K	Year 2000 (millennium bug)

Appendix 2: Bibliography

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4. Rayner, D., *Initial Report on the Status of Software and Mathematics in each Metrology Area*, NPL Report CISE 18/99, February 1999.

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D Rayner	CISE, NPL	
P Harris	CISE, NPL	
G Torr	CMAM, NPL	
M Goldsmith	CMAM, NPL	
File	ISE/XSP/51A	