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Counting on *IT*

MATHEMATICS AND SCIENTIFIC COMPUTING

Communicating the SS*f*M messages: Highlights of 2001-02

We have now completed the first year of the new Software Support for Metrology programme. This issue of *Counting on IT* covers many of the successes, but in addition, there have been other notable achievements in communicating the messages of the programme.

A programme brochure has been completed and distributed to all recipients of *Counting on IT*. This will be used throughout the remaining two years of the programme to inform people about the overall scope, objectives and anticipated benefits of the programme. It not only describes the technical themes of the programme and the main topics covered, but also highlights key outputs related to each topic and illustrates the benefits by giving potential good news stories that might arise from the programme.

We were also, as usual, active in promoting the programme's activities through conferences. Two conferences in particular had a major SS*f*M presence this year. The first was Algorithms for Approximation IV (known as "A4A4"), held in July 2001 at the University of Huddersfield. The programme sponsored this conference and organised two metrology sessions within it. This event was very successful, attracting over 100 attendees from approximately 30 countries. There were four SS*f*M presentations from NPL (one invited). NPL also chaired a number of sessions and took an active part in the generation and review of papers for the proceedings. A significant number of other SS*f*M contractors and SS*f*M Club members were present, and the SS*f*M programme had a stand at the conference. Contacts were made which led to new members joining the SS*f*M Club, including The MathWorks (the suppliers of MatLab), who subsequently made a presentation to the September Club meeting.

The second meeting of major importance for the programme was the National Measurement Conference at Harrogate in November. There, we helped to organise a session on numerical algorithm design and testing, another on models for metrology and their validation, and a double session on uncertainties. These involved a total of ten presentations, some from NPL, some from other SS*f*M contractors (University of Huddersfield and NAG Ltd), and some from collaborators (PTB, BMTA, UKAS and Rolls-Royce). In addition, Sira presented the SS*f*M best practice guide no. 9 on Laboratory Information Management Systems, and NAG had a stand in the exhibition.

The accompanying three-day British Electromagnetic Conference was very well received. Here, there were several presentations on remote calibration over the Internet, a topic now being taken up within the SS*f*M programme. Attendance stood at just over 400, which was lower than originally forecast, due to the downturn in various markets following 11 September.

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NPL
National Physical Laboratory

Separately tendered projects

The current SS*f*M programme, as originally approved, included nine projects to be competitively tendered. However, due to constraints on resources within the Department, DTI decided not to run competitions but rather to invite NPL to prepare proposals for each of these nine projects. NPL prepared proposals for all nine and these were submitted in three batches between November and February. NPL was required by DTI to ensure that the proposals provided the benefits of competitive tendering, as far as this was possible. Hence, very detailed proposals had to be produced, with a high degree of partnering with appropriate organisations, and cost savings against the guide prices.

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The following table indicates the current status of each of these projects:

No.	*Project Title*	*Partnering*	*Comment*
1.4	Continuous Modelling for Metrology	NPL & Heriot Watt University	Started May 2002
1.6	Data Fusion	NPL & NAG Ltd	Starts September 2002
1.8	Data Visualisation	NPL, Sira Ltd and NAG Ltd	Started April 2002
2.2	Testing Continuous Modelling Software	NPL, NAG Ltd & NAFEMS	Started April 2002
5.1.1	Internet Metrology: Protecting the Data	NPL, Gamma Secure Systems Ltd. & Baltimore Professional Services	Started March 2002. Focused on DC Electrical and Radiation Dosimetry applications
5.1.2	Internet Metrology: Demonstration of Technology	NPL & Photonics industry partner yet to be finalised	Started March 2002. Focused on Optical Time Delay Reflectometry application.
5.1.3	Internet Metrology: Promotion and Liaison	NPL & UKAS	Started March 2002. Focused on automatic network analysers and impedance application.
5.2	New Directions	NPL, NWML & LGC	Started April 2002
6.3	Newsletters	PPG Ltd & NPL	Started February 2002. Resulted in this issue of *Counting on IT.*

Partnerships in SS*f*M

One noticeable characteristic of the SS*f*M-2 programme is that NPL has entered into many more partnerships than it did in SS*f*M-1. On the main part of the programme, subcontracts have been established with:

- NAG Ltd.
- University of Huddersfield
- Adelard
- Sira Test and Certification Ltd.
- SignalsFromNoise Ltd.
- British Measurement and Testing Association

Further partnerships have been agreed for the separately tendered projects. See article above for details.

Additionally, Rolls-Royce and Glaxo Smith Kline are participating in the programme at their own expense. Partnerships of this kind are mutually beneficial, and we would welcome similar arrangements with other companies.

Industrial companies participating in an SS*f*M project benefit as the work of the project can be applied to an application that is directly relevant to the company. The programme benefits because such partnerships ensure that the work is industrially relevant, whilst protecting the principle that the results must be freely published.

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Generalised regression

Experimental data analysis is a key activity in metrology. The first stage involves building a mathematical model of the physical system in terms of mathematical equations that describe all the relevant aspects of the system. The model specifies how the system is expected to respond to input data.

At the second stage, the model solving or regression problem is: given measurement data, determine estimates of the model parameters by solving the mathematical equations constructed as part of the model, taking into account the error structure of the measurement data. In general, this requires the development of an algorithm to determine values of (and uncertainties in) the parameters that best explain the data. A common example of regression within metrology is the determination of the relationship between a control variable and a response variable, in the calibration of an instrument.

Regression problems can be classified according to the complexity of the error structure, and so-called "generalised regression" problems are those where there is correlation between the errors and/or where more than one measured variable is subject to error.

An example of a generalised regression problem occurs in the analysis of natural gas mixtures. Cylinders containing natural gas are prepared gravimetrically to contain known compositions of each of 11 constituent components. Given:

i) a number of primary standard natural gas mixtures containing known concentrations of one of the constituent components (e.g., CO_2),

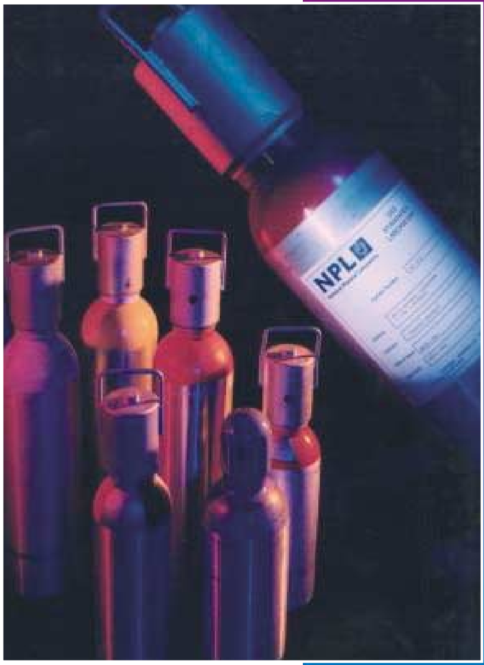
ii) the detector response for each mixture,

iii) the detector response for a new mixture,

we wish to determine the concentration of CO_2 in the new mixture.

An approach to solving this problem is firstly to use the calibration data (relating to the primary gas mixtures) to calibrate the detector and, secondly to apply the new measurement to the calibration curve so constructed, to predict the concentration in the new mixture.

However the calibration data is known inexactly – the process of preparing the primary standards involves measurement error, and indeed the errors in the standards are correlated – for example, the gravimetric process used to prepare the standard mixtures involves comparing each standard mixture against calibrated masses selected from a common set of masses. The data returned by the detector (which is based on the analytical technique of chromatography) is also subject to measurement error. Consequently, in the data analysis we need to account for the inexactness of the measurement data, and to quantify the resulting uncertainty associated with the final measurement result.



Generalised regression provides better analysis of natural gas mixtures

Approaches for regression problems for errors in one variable (e.g. the response variable) are well known within metrology, whereas those for generalised regression are not. As part of the SS*f*M discrete modelling activities, algorithms and software for use by metrologists are being developed to solve such problems. The software will combine structure-exploiting linear algebra and numerically stable components, and it is hoped that metrologists will be able to use these routines with the same confidence and effectiveness that they currently enjoy with standard routines available in numerical libraries.

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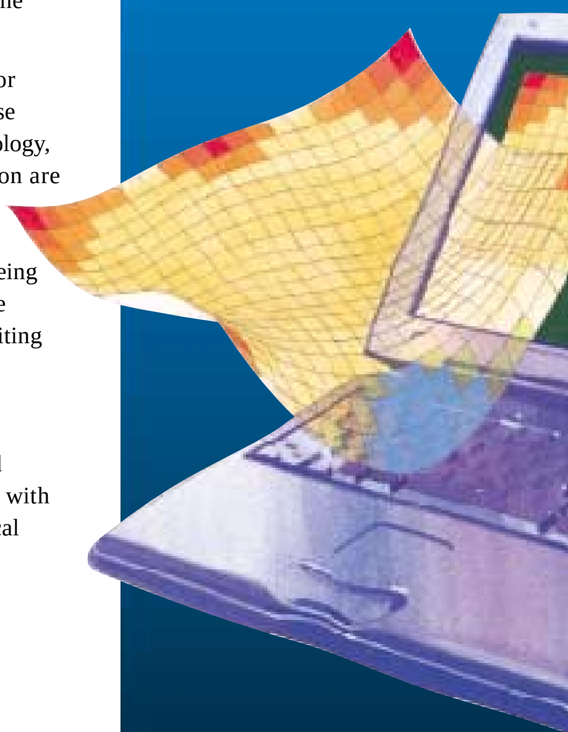

"We need to account for the inexactness of measurement data"

Jim Wilkinson

Numerical analysis awareness

Perhaps the only formula we are likely to remember from our school days is that for the roots of a quadratic equation: if $b^2 \geq 4ac$ then the function $q(x) = ax^2 + bx + c$ is zero at $x = \alpha$ and $x = \beta$, where

$$\alpha = \frac{-b + \sqrt{b^2 - 4ac}}{2a}, \text{ and}$$

$$\beta = \frac{-b - \sqrt{b^2 - 4ac}}{2a}.$$

The quadratic can be factored as $q(x) = a(x - \alpha)(x - \beta)$ from which we see that $a\alpha\beta = c$. Using a calculator or programming a computer to calculate the roots α and β would seem a straightforward task.

However, even for this computation, the way we organise the calculation, i.e., the algorithm we employ, can have a dramatic effect on the accuracy. Our initial approach may be to follow the formulae above: first calculate

$d = \sqrt{b^2 - 4ac}$ and then set,

$\alpha = (-b + d)/(2a)$,

$\beta = (-b - d)/(2a)$. Problems arise when b is large in magnitude relative to $4ac$ for in this situation d will be close to either b or $-b$ and subtractive cancellation error will occur in calculating one of the roots. For example if $a = 1$, $b = 1000$, and, $c = 1$ then b and d are the same to the first five digits so that there are five less digits available to store their difference $d - b$. In this case β is calculated accurately (there is no subtractive cancellation error) but approximately three digits of accuracy are lost in calculating α . A better algorithm is to calculate the root larger in magnitude first and then use the relationship $a\alpha\beta = c$ to calculate the other. So if b is positive we calculate $\beta = (-b - d)/(2a)$ and set $\alpha = c/(\beta a)$. Otherwise, we calculate α first and then β. Using this approach both roots are calculated accurately. (If we chose always to calculate β then α , we would lose approximately *six* digits of accuracy α for the case $a = 1$, $b = -1000$, and $c = 1$, for example.)

This simple example illustrates a number of points:

- numerical instability can occur in the simplest of calculations
- an algorithm stable for one set of inputs can be unstable for another
- it is not always obvious that an algorithm is likely to be unstable.

If an algorithm is discovered to be unstable, then we have the problem of how to replace it by a more stable one. In the early days of numerical computing the difficulties in analysing the numerical properties of algorithms led to a pessimistic view about achieving reliable computation in finite precision arithmetic. Pioneering work by Jim Wilkinson at NPL and others during the 1960's and 70's in the development of new error analysis methods made the problem much more tractable. Today we have access to a large number of numerical software routines, particularly for numerical linear algebra, that implement algorithms with proven stability properties.

The development and testing of reliable numerical algorithms is an important activity within the current SS*f*M programme and includes the development of a Best Practice Guide on Numerical Analysis for Metrology.

In honour of the contribution of Jim Wilkinson to numerical analysis, NPL, Argonne National Laboratory, Illinois, and NAG, Oxford, jointly award the *Wilkinson Prize for Numerical Software*. The next prize will be presented at the International Congress of Industrial and Applied Mathematics, Sydney, 7-11 July, 2003: www.iciam.org/.

For more details about the prize, contact wilkinson-prize@mcs.anl.gov.

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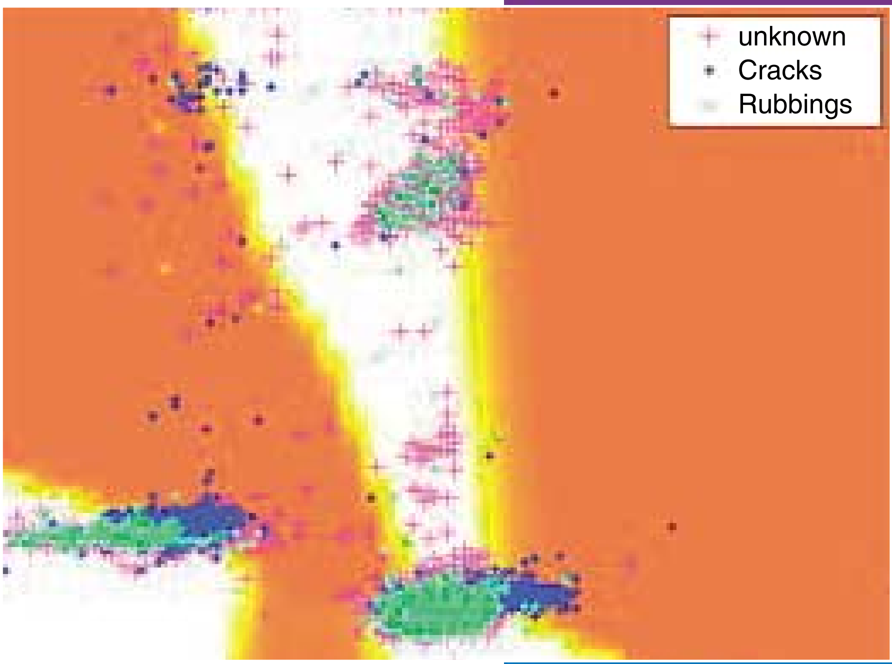
Data fusion in metrology

With the completion of the first round of flagship projects in the INTErSECT (INTElligent SEnsors for Control Technologies) Faraday partnership, we have strongly influenced the uptake of data fusion within the industrial companies involved in the scheme. We were unable to address fully the metrological requirements for data fusion in that programme of work, as it was directed at industrial control and sensors. We are fortunate now to have an opportunity to redress this as part of the SS*f*M programme.

Partnering with NAG Ltd, we shall be addressing two aspects of importance to metrology: classification of multi-dimensional data; and building models of measurement systems with many inputs where the uncertainty is poorly specified *a priori*.



Visualisation of acoustic emission events

The requirement to classify an event into one of a discrete set of classes is found in an increasing number of metrological areas — materials measurement being perhaps the most illustrative. We may be required to detect the number of cracks being heard emanating from a material under stress, but these could be masked by environmental noises. In the illustration, we have extracted two features (positions of spectral lines) from the sounds generated by corroded steel being stressed. Some of these we know to be associated with cracks, others with the noisy environment. However, we are ignorant about the vast majority of sounds. With just two features, we are not in a strong position to separate the events out into disjoint classes; but if we allow more features into the picture, we may stand a better chance of achieving separation. One of the purposes of the project is to examine how best to fuse multiple features to achieve reliable separation of data into classes. We will use case studies from the materials area and also from biotechnology (where there are analogous problems in trace-element measurement).

The other part of the project will be looking at general model building in metrology when we are faced with the prospect of having to model a system that has multiple inputs that are poorly understood in terms of uncertainty. For instance, laser tracking requires us to model the position in terms of angular and displacement offsets, and these are affected by material properties such as the refractive index of air. In a situation where we only have one input, it is straightforward to calculate an estimate of uncertainties after a number of experiments, but for technical reasons this does not carry over smoothly to the case when we are trying to fuse multiple data sources. The project will research methods to enable the estimation to be done correctly when we have multiple data sources.

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Uncertainties and standards

There is currently much activity in the "standards" world on producing guidance and procedures to support uncertainty evaluation.

For users of the Guide to the Expression of Uncertainty in Measurement (GUM), supplements are being produced concerning

- the propagation of distributions
- measurement models with more than one measurand
- the measurement modelling process
- the role of uncertainty within conformity and compliance

Work in the first area is the most advanced, with a major draft in place of a guidance document produced by Working Group 1 of the Joint Committee for Guides in Metrology (www.bipm.org/enus/2_committees/jcgm.shtml) concerned with maintaining the GUM. The propagation of distributions offers a more general capability than the law of propagation of uncertainty. It is relevant when the conditions for that law to apply do not hold or when there is doubt over whether they hold.

It is important to realise that it is not just for "complicated" models that guidance is needed. There are many problems where the model is (superficially) "simple", e.g., when it contains just one or two variables. For such "small" models, it cannot generally be expected that the central limit theorem will kick in to provide a normal distribution for the measurand. The reason is that the theorem requires there to be a "sufficiently large" number of quantities and other conditions to apply. In practice, the theorem often kicks in very early, but this cannot always be assumed.

A good example arises when converting the Cartesian co-ordinates of a complex-valued quantity, as occurs frequently in electrical, acoustical and optical metrology, into polar co-ordinates.

One of the operations involves forming the magnitude R from the real and imaginary parts X and Y using $R = (X^2 + Y^2)^{1/2}$. Even if X and Y are normally distributed, R will not be so. However, if the uncertainties in X and Y are small compared with the magnitudes of X and Y, R will be close to normal. If this is not the case, as arises when X and Y are close to zero, the distribution of R will be far from normal. As a consequence, a 95% coverage interval calculated for R based on the application of the law of propagation of uncertainty may not be realistic. Indeed, it may even include negative values, which cannot of course physically arise for a magnitude.

The figures indicate what might happen. Figure 1 is the distribution for R that results from the application of the law of propagation of uncertainty and Figure 2 that from the use of the propagation of distributions. The shaded regions correspond to the shortest 95% coverage intervals for R.

The SS*f*M Best-Practice Guide No. 6, *Uncertainties and Statistical Modelling*, available from the SS*f*M download page www.npl.co.uk/ssfm/download/bpg.html, gives further information. A new version of this guide will be produced during SS*f*M-2, containing further material and additional examples, especially relating to the above issue.

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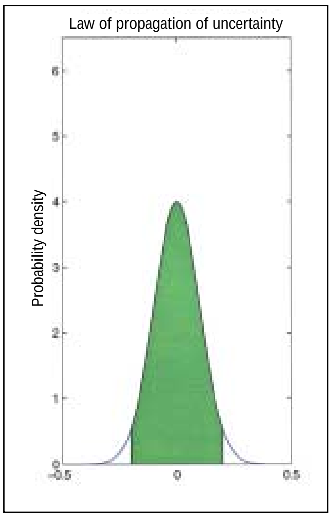

Figure 1

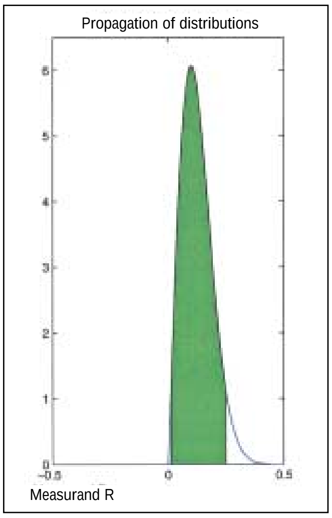

Figure 2

Industrial methodology for uncertainty

The Guide to the Expression of Uncertainty in Measurement (GUM) describes an internationally agreed method for evaluating and reporting uncertainty. As such, it should and does have an impact on industrial measurement procedures. But do its methods bring as wide a benefit as possible? In the SS*f*M project on industrial methodology, NPL are looking, in collaboration with a selection of SS*f*M club members, at the next directions for application of GUM-like approaches.

One industrial area that is an obvious target for a rigorous application of uncertainty analysis is that of statistical process control. In this discipline, a process is monitored and controlled by tracking the measurand with respect to a band, and if the measurement value transgresses this band, either a warning or an alert is given, and action should be taken to return the measurand to the permitted band. The process is said to be in or out of statistical control if the value is in or out of the band respectively.

There are also issues of reproducibility and repeatability in industrial measurements. The former term relates to the ability of a measurement scientist using the same measuring equipment to achieve compatible results over a short period of time; the latter refers to the achievability of compatible results by different experimenters using different instruments over significantly extended periods of time.

Clearly, the GUM is relevant both to statistical process control, and reproducibility/repeatability; but the uptake of the approaches in the Guide is not as widespread as it might be. The project is addressing this issue in two ways, by

- ensuring that the technical disciplines are compatible from a mathematical perspective
- phrasing results in terms familiar to those involved in statistical process control, in order to ease the uptake of GUM-like approaches by industrial measurement scientists.

How certain can we be when we automate process control?

Both Rolls-Royce plc and Glaxo Smith Kline plc are participating in this project. The participation of other companies would be welcome.

We would encourage others with an interest in these areas to contact the author so that their views and requirements can be incorporated into the approach being developed.

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Spectral characteristic modelling

A study has been undertaken of the spectral characteristics of sources and detectors in optical radiation metrology. As a result of this work, new mathematical models have been developed for describing these spectral characteristics. In particular, it has been demonstrated that classes of spectral characteristics of sources can be well represented by the product of a Planck function and an empirical correction term. Encouraging results have also been obtained for detectors using a combination of empirical functions and the exponential decay behaviour observed in practice.

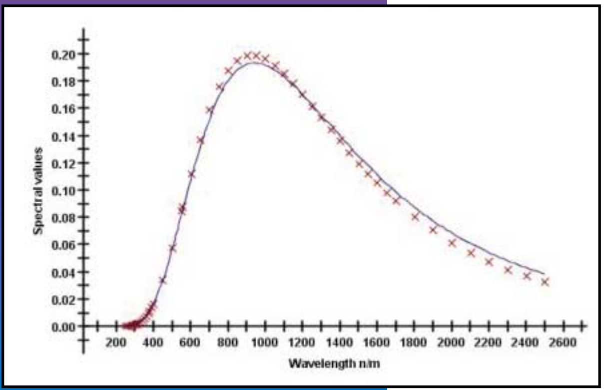

Figure 3: Polynomial with weights : FEL196.dat Order : 1 Temperature : 3064.47 K

Figure 3 shows the modelling of the spectral irradiance of a lamp by the Planck function. The value of the colour temperature for this source (and a normalisation constant) is determined to give the closest match to the irradiance data, accounting for the data uncertainties. The deviations of the Planck model from the data provide an indication of the departure of the lamp from behaving as a perfect black body source.

Figure 4 shows a model for the data that consists of the product of the Planck function, with the determined colour temperature, and an empirical correction function containing parameters that were adjusted optimally in terms of their number and their values. This hybrid model is typical of a class of models that are useful in representing sources.

Benefits of the approach are:

- Smoothly interpolated values at intermediate wavelengths can be obtained as a consequence of modelling the data in a manner that respects its provided uncertainties.
- Derived quantities involving, say, integrals containing the spectral irradiance model can be formed.

Using splines in metrology

Empirical models are important to metrology in cases where the knowledge of the underlying physics for a measurement system is insufficient to characterise it completely. For empirical models depending on one variable, polynomial and particularly polynomial *spline* curves, when used with care, are generally very satisfactory for representing data. A polynomial spline curve is composed of a sequence of polynomial curves joined together at points called *knots*, and in such a way as to ensure smoothness of the complete curve. An example of a spline curve composed of four cubic polynomial pieces joined so that the curve and its first and second derivatives are all continuous is shown in Figure 5.

Spline curves provide a flexible class of functions that are effective for representing a wide variety of shapes. The knots, however, generally have no physical meaning for the metrologist, and yet the effectiveness of a spline representation can depend critically on their number and positions. Consequently, metrology users require assistance with knot placement via appropriate algorithms and software. NPL and the University of Huddersfield are undertaking work as part of the SS*f*M programme to provide this assistance.

Automatic knot placement is a very difficult problem. A number of knot placement strategies [1] are available, however, to help the user select a *sensible*, if not necessarily optimal, set of knots. Some of these strategies work by sequentially *inserting* knots in order to maximise the improvement in the spline fit (measured, for example, in terms of the root-mean-square residual value); others work by *deleting* knots in order to minimise the change in the quality of the fit. Figure 6 shows the effect on the root-mean-square residual of a spline fit to experimental data resulting from the application of a knot insertion algorithm followed by the application of a knot deletion algorithm.

- Uncertainties, both in the form of an uncertainty swathe centred on the characteristic, and as an uncertainty matrix, that permit the uncertainties associated with any derived spectral quantity to be evaluated.

A further feature of the work is a study of the effects of the finite instrument slit bandwidth. The results of this study are used in monochromator design, and also permit the indicated measurements to be corrected to those that would have been obtained with a slit of zero width.

The work also supports the determination of key comparison reference curves for spectral quantities and the efficient industrial re-calibration of sources and detectors by industrial laboratories.

This work was carried out jointly with the NMS Optical Radiation Metrology programme.

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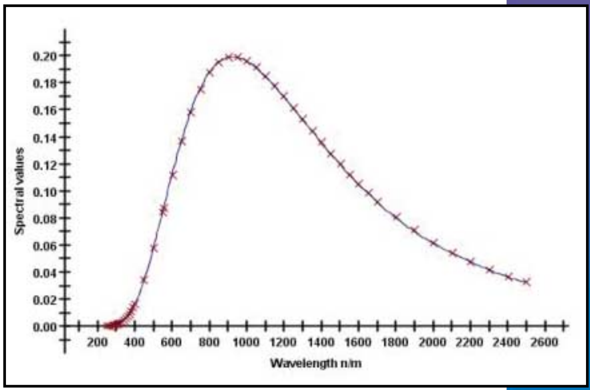


Figure 4: Polynomial with weights : FEL196.dat
Order : 10
Temperature : 3064.47 K

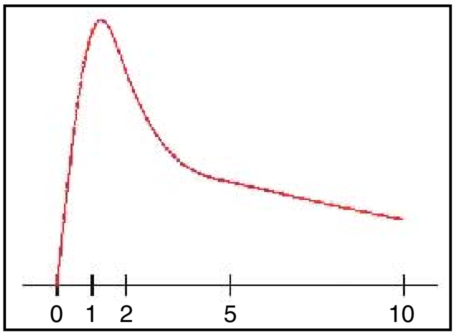


Figure 5: A cubic spline curve s(x), $0 \leqslant x \leqslant 10$, with interior knots at x = 1, 2 and 5

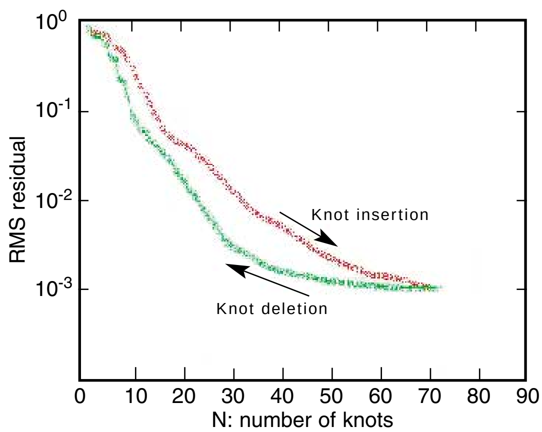
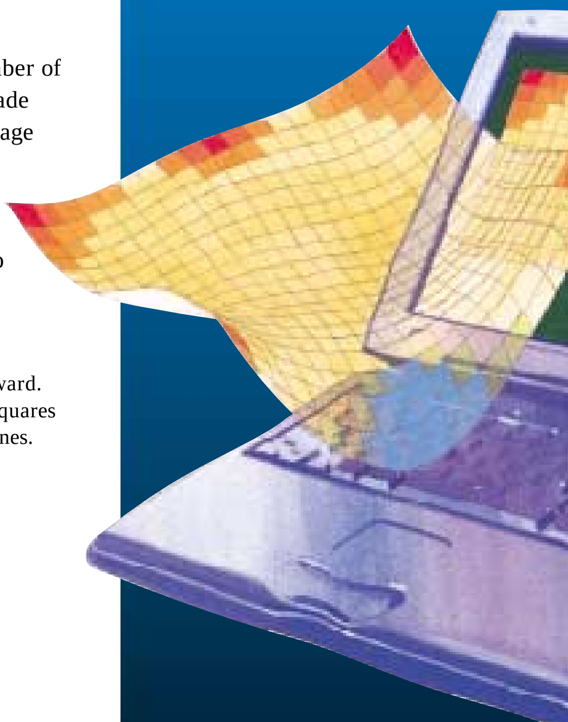


Figure 6: Effect on the root-mean-square residual of a spline fit to experimental data of knot insertion and knot deletion

A software package, containing a number of knot placement algorithms, is to be made available through METROS. This package will act as a pre-processor to NPLFit; software developed by NPL for modelling experimental data using polynomial and spline curves, and also available through METROS.



Reference

[1] M.G. Cox, P.M. Harris and P.D. Kenward. Fixed- and free-knot univariate least-squares data approximation by polynomial splines. Proceedings of Algorithms for Approximation IV, University of Huddersfield, July 2001.

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Use of the Internet to support Metrology

Measurement instruments need to be calibrated to check that they are continuing to measure correctly. Calibrating such instruments is a core activity at NPL, and it enables them to be compared with definitive primary standards maintained by the laboratory.

Traditionally, instruments have been transported to a laboratory for calibration, which incurs downtime while the instrument is out of use.

NPL is leading the world in developing Internet Calibration services where the instruments are calibrated remotely, with control applied over the Internet. In some Internet Calibration services, a calibrated artefact can be sent by NPL to be measured by the client's instrument. In other services a measurement instrument, which has been calibrated at NPL, can be sent to the client to measure their calibration artefacts. In either case the server at NPL controls the process and the remote measurements are processed by NPL software.

Internet Calibration (or more accurately "Internet enabled Calibration") is just one way of exploiting the Internet to support measurement. Other examples of Internet (enabled) Metrology are giving access over the Internet to NPL software for specific measurement calculations, and to NPL databases of physical properties.

Internet Calibration Systems at NPL

*i*PIMMS: impedance measurement

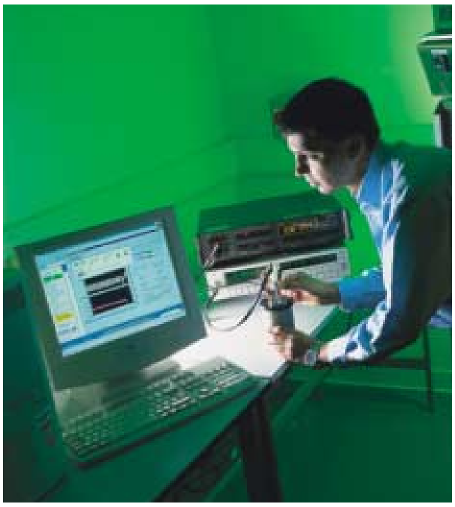
The first Internet Calibration service (in the world) is the *i*PIMMS system developed by NPL in collaboration with BAe Systems. This service works by connecting the client's Automatic Network Analyser (ANA) to NPL via the client PC's Internet browser and following procedures described in web pages displayed on the browser.

First, measurements at the client's site are made of reference artefacts sent by NPL. From these measurements, and the known values of the artefact, correction coefficients for the ANA are calculated at NPL. Then, the ANA is used to make real measurements required by the client. These are sent to NPL where the corrections are applied, and the corrected measurements are sent back for use by the client.

"NPL is leading the world in developing Internet Calibration services"

*i*VR: voltage and resistance measurement

NPL is currently developing, in collaboration with Adelard and Fluke, an Internet Calibration service for measuring DC electrical quantifies: voltage and resistance. In this service, an instrument (the Fluke 4950) has been fully characterized by NPL and will be sent to the client. The 4950 is connected to NPL via a PC (sent with the 4950). Measurements are made of the client's voltage and resistance standards (artefacts) and the data is sent to NPL.



NPL's internet calibration system for resistance measurement

The calibration process is controlled by instructions sent from the NPL server and the process is observed by a web camera as well as temperature and humidity monitors. The web cam pictures are recorded at key points, to demonstrate that the correct procedures were followed; they can also be used for real-time "trouble shooting". At NPL, corrections for the standards are calculated and sent back to the client, and a calibration certificate can be issued, either electronically or on paper.

*i*Colour: Remote monitoring/calibration of spectrophotometers using the Internet

The Optical Radiation Measurement group at NPL, in collaboration with Datacolor International, has undertaken a case study into the Internet Calibration/monitoring of spectrophotometers, specifically with regard to reflectance and colour measurements. This project builds on expertise gained during development of *i*PIMMS.

There are many potential benefits of this type of QC/traceability mechanism to the spectrophotometer user community including:

- Real-time remote conformance checking of instruments within a supply chain, with built in failure alarms.
- Ease of use, the remote operator being guided through the calibration process by the software running at NPL
- Storage of results in a database, accessible by users during servicing and audits. 'Data warehousing' would also provide long term access to calibration history, and provide robust, paperless audit trails
- The sharing of data in a common file format throughout an organisation, or network of organisations
- The standardisation of a monitoring/ calibration system for a worldwide network of instruments
- Real-time on-line analysis of results with uncertainties, using proven routines and algorithms developed at NPL
- Direct traceability to national scales held at NPL would be achieved through the provision of NPL calibrated artefacts to the system users. (Typical calibration artefacts include: Colour tile sets, Neutral Density filters, wavenumber standards, and Infrared transmittance standards)
- Manufacturers of spectrophotometers connected to the system could be given limited access to the history of the instruments, allowing them to improve preventative maintenance, and to judge what parts and servicing might to be required during service visits

Spectrophotometric measurements are an essential part of processing and characterisation processes in a wide range of industries

Internet Metrology in SS*f*M

In order to support Internet Metrology in the National Measurement System, three new SS*f*M projects have started. These will address security issues, generic software, and accreditation of Internet Metrology, and will help to demonstrate and disseminate the possibilities of Internet Calibration.

Protecting the data

One important aspect of traditional calibration is that it must be possible to trace the measurements given by a calibrated instrument back to the primary (or national) standard. One risk in Internet Calibration is that this traceability will be lost if assurance cannot be given that the measurement data has been unchanged in transmission over the Internet. This project will assess the security mechanisms used by Internet Calibration services, and will recommend appropriate security measures to be taken.

It is usual to keep records of calibrations, so that instruments and the calibration process itself can be monitored. Internet Calibration will store calibration histories in a database. The integrity of the measurement data held in the database is just as important as its integrity during transmission. The project will investigate and report on the data warehousing issues of storage and retrieval of measurement data kept in databases.

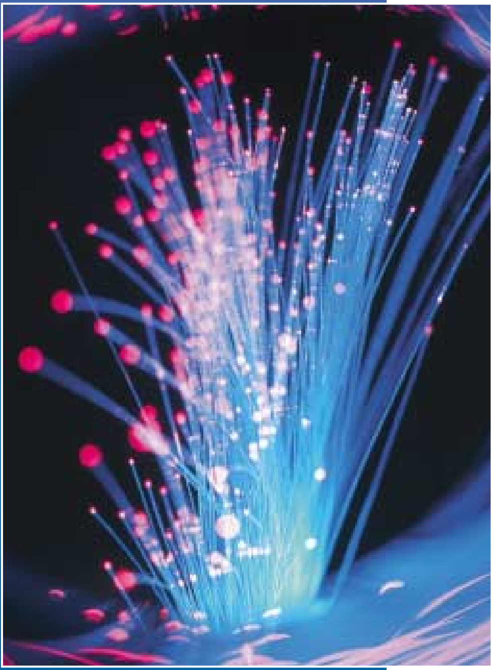
Internet Metrology services will have to operate through a firewall both at the client

"Internet Calibration service providers would like to issue electronic certificates"

and the service provider. Ensuring that the service can operate through a firewall may preclude the use of novel technology in implementing the service. The project will produce a report on these issues.

Internet Calibration service providers at NPL would like to issue electronic certificates to increase the accessibility of the data; but there are security issues involved in proving that a certificate was issued by NPL. The project will investigate generic solutions that can be employed by any organisation that produces calibration certificates.

Demonstrating the technology



Optical time domain reflectometers are used to measure the properties of optical fibres

This project will produce a further demonstration of Internet Calibration technology by developing a service based on Optical Time Domain Reflectometers in the Photonics area. OTDRs are used to measure the properties of optical fibres, and accurate measurement is important to fibre manufactures and their customers in the Telecoms industry.

The project will investigate different models of operating an Internet Calibration service and the benefits that can be expected.

Promotion and liaison

This project aims to ensure the take up and acceptance of Internet Metrology in the measurement community, in the UK and internationally. Presentations and company visits will be made to explain Internet Metrology. The project will also ensure that Internet Metrology services can be operated to the satisfaction of accreditation bodies, by producing, with UKAS, a guide for assessors of Internet Metrology services.

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What is safe measurement?

Measurement systems that use software are hard to qualify for use in safety systems, since they can fail in ways that hardware-only systems cannot. The NPL Best Practice Guide has been updated to provide guidance for the development of such systems, which, if followed, would allow for their certification for inclusion in safety systems.

Two years ago a general standard for safety *systems* was published (IEC 16508) and this has been used as a framework for the revised Guide.

Of course, the Guide only covers the software aspects, whereas the industry requirement is to be able to purchase off-the-shelf measurement subsystems that can be incorporated into safety systems.

It seems that around half the metrology industry supplies equipment having a safety role. For the Guide, this presents a problem since it is clearly necessary to cover non-safety applications as well.

NPL would welcome comments on the Guide. It is to be revised to cover the more demanding safety systems, and hence views on this area would be particularly welcome.

The draft guide SS*f*M Best Practice Guide No. 1: Measurement system validation: Validation of measurement software - Revision for safety systems: Draft for review) is available at: www.npl.co.uk/ssfm/download/#ssfmbpg1_draft

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Ultrascan equipment is a medical example of a measurement system where safe measurement is a concern

Revision of the software best practice guides

The first SS*f*M programme produced ten best practice guides covering all the themes of the programme. As part of ongoing work in various themes in the current programme, new best practice guides are being developed, and there is a project for the revision of the software best practice guides. The most significant output from this project will be a new best practice guide on Test and Measurement Software, combining the three existing best practice guides on the development of virtual instruments (BPG 2), the development of software for metrology (BPG 3), and mixed language programming (BPG 8). The objectives of the revision are to address feedback from users of the existing guides (providing guidance on different languages, and meeting timing and usability constraints), and to recast the guides in a consistent style and format.

The new guide (BPG 12) will be based on the virtual instruments guide, which had the most positive feedback of the software best practice guides. This guide focuses on languages and issues for virtual instruments; but much of the material is also applicable to measurement software produced by single person developer-users, or small teams. The general editorial style of the virtual instruments guide will be retained, with a three-part structure consisting of an overview, general guidance, and technology-specific guidance. The general guidance will cover development, testing and verification, and validation. This section will include material from BPG 3, making it less abstract, using the material on “mini-projects” to augment the guidance on rapid application development (RAD) lifecycles. The technology-specific guidance will include material from BPG 8 on languages not covered by the virtual instruments guide, and material from both guides on the same languages (e.g. Visual Basic and LabView) will be merged.

The existing virtual instruments guide is eighty eight pages long, and the additional material will make it substantially longer. The full text would be unwieldy, so we intend to provide the electronic version of the new guide with check boxes so the readers can tailor it to their needs by selecting the topics or languages they are interested in. The guide will still be printable, but the tailoring will be organised to produce at most a hundred pages. Adelard is currently working on the new guide. A draft will be produced in July 2002 and the final version will be ready by the end of September 2002. We would welcome comments on the approach we are taking, and on the draft, when it is produced: comments can be sent to either author.

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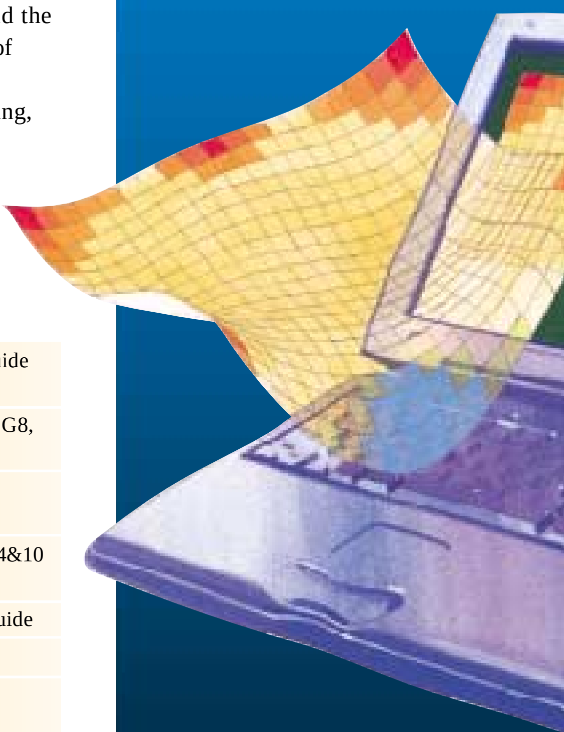
The current status of all the best practice guides developed under SS*f*M-1 or proposed under SS*f*M-2 is summarised in the table

No.	Subject	Source	Work under SSfM-2
1	Measure System Validation, including Safety-Critical systems	NPL	Maintenance of Guide and extension of Guide to “safe measurement” (to meet IEC61508)
2	Development of Virtual Instruments	Adelard	To be revised to incorporate BPG3 and BPG8, and form the basis of the new BPG12
3	Development of Software for Metrology	Logica	To be incorporated into Part 2 of the new BPG 12
4	Discrete Modelling	NPL	Maintenance based on the composite BPG4&10 as appears in the Roadmap CDROM
5	Guide to METROS	NPL	Maintenance to produce a METROS user guide
6	Uncertainty and Statistical Modelling	NPL	Maintenance
7	Development and Testing of Spreadsheet Applications	NPL	Maintenance
8	Mixed Language Programming	NAG	To be incorporated into Part 3 of the new BPG 12
9	Selection and Use of LIMS	Sira	No revision planned under SS*f*M-2
10	Discrete Model Validation	NPL	To be maintained as part of BPG4, see above
11	Numerical Analysis	NPL	To be developed
12	Test and Measurement Software	Adelard	Revision of BPG2, incorporating BPG3 and BPG8



MetroNet – A european network on SS*f*M topics

During the previous SS*f*M programme IMGC (the Italian National Metrology Institute (NMI)) coordinated the organisation of two Euro-conferences on *Advanced Mathematical and Computational Tools for Metrology*. These provided much needed networking between European and other international organisations.

IMGC, with the support of other European NMIs including NPL, made a proposal under framework 5 for support for further networking and conferencing, and a three year project has been approved: an EU thematic network called "SofTools_MetroNet", or "MetroNet" for short.

IMGC is the network coordinator, and there are three work package leaders: the German (PTB), Dutch (NMi) and UK (NPL) NMIs. NPL is leading a mathematics and statistics work package, largely concerned with making metrology-relevant mathematical and statistical algorithms and software known through METROS, re-badged for MetroNet.

The initial membership of MetroNet consisted of 12 organisations, mostly NMIs. In addition, CERN and BIPM, are non-funded partners and members of the steering committee. The Commission wishes to see the membership increase to 24 funded members plus additional unfunded partners. Most of the new members should be industrial companies, and several Universities should be included among the partners.

MetroNet will sponsor various international meetings, including annual meetings of the network. NMi in Delft hosted the first of these on 15-17 May 2002. An open workshop focusing on *Internet Metrology and Self-Calibrating Instruments* was held on the first day. During 2002, NPL and PTB are hosting two other MetroNet sponsored events. The first is a pair of BIPM/NPL workshops to be held at NPL on 16-18 and 19 September 2002. The first of these will be on *The Impact of IT on Metrology*, of which one day will be devoted to Internet Metrology. The second workshop will be on *Key Comparison Statistical Analysis*, and this topic will also be the subject of the PTB event, to be held in December 2002, largely for a German audience.

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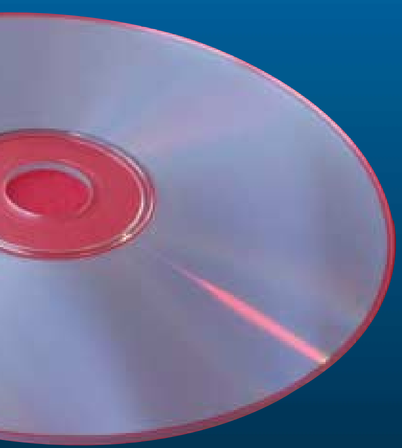
SS*f*M CDROMs available from NPL

The SS*f*M programmes' outputs are available from the SS*f*M website (www.npl.co.uk/ssfm/), and this has proved a successful and popular dissemination method for the programme. However there are reasons for NPL to use other ways of distributing outputs from the programmes. For example, downloading large documents over the Internet can be slow and not everyone has Internet access from their desk or workbench, in particular those working in “sensitive” industries. NPL needs to manage the access to items such as software, so we can organise new releases. We have started to use CDROMs and we currently have two available.

The Roadmap CDROM (Version 1.1) contains the outputs of the first SS*f*M programme, and navigation to locate the appropriate documents. It contains all the best practice guides developed under the first programme, and many other technical reports; 45 documents in all. The documents are provided in PDF: so they can be viewed on screen, linked to by other documents, and printed. The CDROM opens to the Roadmap navigation pages, showing the main topics of the documents. There is also a contents page that lists all the projects and milestones, and the documents they produced. The index pages provide fine-tuned access to the documents, based on the keywords/concepts used in the documents. The CDROM is free to full club members and is also available for purchase, priced £50 net, via the NPL e-store at www.npl.co.uk/e-store/ index_search.php?search_term=roadmap.

The NPLFit CDROM (Version 1.2) contains software developed at NPL for fitting calibration curves and other experimental data. The package includes the fitting of polynomials and splines, and includes software for the standard



Updates to METROS

The METROS website (www.npl.co.uk/ssfm/metros) will be central to the delivery of algorithms, software, testing and guidance from the SS*f*M programme. While these are being developed in the current programme, existing NPL software has been added to METROS.

The latest version of NPLFit (Version 1.2) is available through METROS to SS*f*M club members (see article "SS*f*M CDROMs available from NPL" below). The NPL Data Approximation Subroutine Library (DASL) is a precursor of NPLFit containing functions for a wider range of models. METROS now includes the DASL functions that are not in NPLFit: functions for fitting surfaces and parametric and/or periodic splines. There is also now a function (T1GRE) for generalised polynomial regression (see article "Generalised Regression" page 3). The NPLFit FORTRAN routines have been augmented by equivalent functions in Matlab that call the corresponding FORTRAN routines. Finally, there are functions for least-squares fitting of geometric elements in Matlab, implementing the various circle_fit, sphere_fit, etc. key functions.

There have been other extensions to METROS: the reference data sets have been extended to an on-line data set generator, which will generate data sets with user-supplied test results. This system is currently available for review by SS*f*M club members (at www.npl.co.uk/ssfm/members_only/rds/) and it will ultimately be an automatic on-line testing service, producing certified test reports. There are also plans to add more of the NAG library to METROS.

We are pleased to announce that METROS is now supported both by a EUROMET project and by the MetroNet thematic network. Appropriate acknowledgement of this will be added to the site.

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uncertainties of fitted values in accordance with the Guide to the Expression of Uncertainty of Measurement (published by ISO) and UKAS Document M3003. The software consists of a graphical user interface to access the functions, and dynamically linked libraries to make the functions available to other software. The libraries implement a number of the METROS key functions. The software is currently used within NPL and is available (on CDROM) for evaluation by SS*f*M club members (see www.npl.co.uk/ssfm/members_only/nplfit). The evaluation period extends to September, at which point we expect to make the software more widely available.

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SS*f*M Club News

A very successful autumn Club meeting was hosted by Rolls-Royce in Derby on October 4th 2001. There were 37 attendees. The presentations covered safety-critical software validation, numerical software testing, and uncertainty evaluation. The uncertainties session was especially highly rated, with five industrial talks of the very highest quality. Discussions in the breaks were very lively and led directly to very constructive Rolls-Royce participation in a Length formulation meeting the next day at the University of Huddersfield. Discussions also identified several opportunities for collaborations with NPL to tackle serious industrial problems.

On February 28th 2002 the spring meeting was held at NPL. On this occasion, the themes were standards and regulation, and modelling. Meetings are for members only, and the club gained several new members because of this meeting, bringing the number of attendees to 35. Feedback was most encouraging.

Membership categories and fees were revised in April 2001. There will be no increase in fees for the year 2002/3. The UK membership fee is £120 + VAT, but UK Organisations numbering fewer than 250 people may join at a preferential rate (£90 + VAT) as SME (small & medium enterprise) members. The rate for Non-UK members is £180 + VAT. It is now possible to pay on-line by e-commerce. SS*f*M collaborators in other NMIs and members of NPL or NMSPU enjoy free club membership.

Membership is for a named person, but members and collaborators may nominate any number of persons from their organisation to become associate members, who can join free of charge, but who must pay to attend club meetings unless they are standing in for the named member.

There are currently 42 full members, 53 collaborators, 67 associates, and 91 NPL/NMSPU members, all of whom have access to the private area of the club website.

For full details of benefits and fees see the club website: www.npl.co.uk/ssfm/club. We look forward to welcoming you as a member if you have not yet joined.

This year has seen an extra benefit for members: a copy of the SS*f*M Roadmap CDROM containing all the outputs of the first SS*f*M Programme is sent free of charge. This includes ten Best Practice Guides, and other reports. For full details see article on page 14.

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SS*f*M website: www.npl.co.uk/ssfm

If you have a general enquiry or do not know who you should contact please call our general enquires number and we will be pleased to help you.

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For enquiries to NPL outside the scope of CMSC, please use:

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