Report to the National Measurement System Policy Unit, Department of Trade & Industry

INTERIM STATUS REPORT ON FLOW MEASUREMENT

FROM THE SOFTWARE SUPPORT FOR METROLOGY PROGRAMME

BY RICHARD PATON

National Engineering Laboratory

November 1999

Software Support for Metrology

Interim Status Report on the Flow Area

by R Paton, NEL

November 1999

Abstract

This report describes the status of the mathematics and software used to support the Flow area of metrology, particularly as used within the NMS Flow 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 Flow programme projects applying SSfM outputs to specific problems in the Flow area.

ISSN 1361-407X

Authorised by Dr Dave Rayner,
Head of the Centre for Information Systems Engineering

National Physical Laboratory, Queens Road, Teddington, Middlesex, TW11 0LW

Contents

1. Introduction

The purpose of this interim status report is to provide an updated and extended report based on the initial report issued in December 1998. The report is to inform the NMS Software Support for Metrology (SSfM) Programme about the status of the mathematics and software used to support Flow Measurement, particularly what is used within the NMS Flow Programme. This and the companion status reports for the other metrology areas will provide the SSfM programme with further information and will help in the identification of best-practice to be disseminated, and suitable topics for case studies and feasibility studies. It should also lead to appropriate linkage between the Flow programme and the SSfM Programme and assist in the formulation of the future 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.

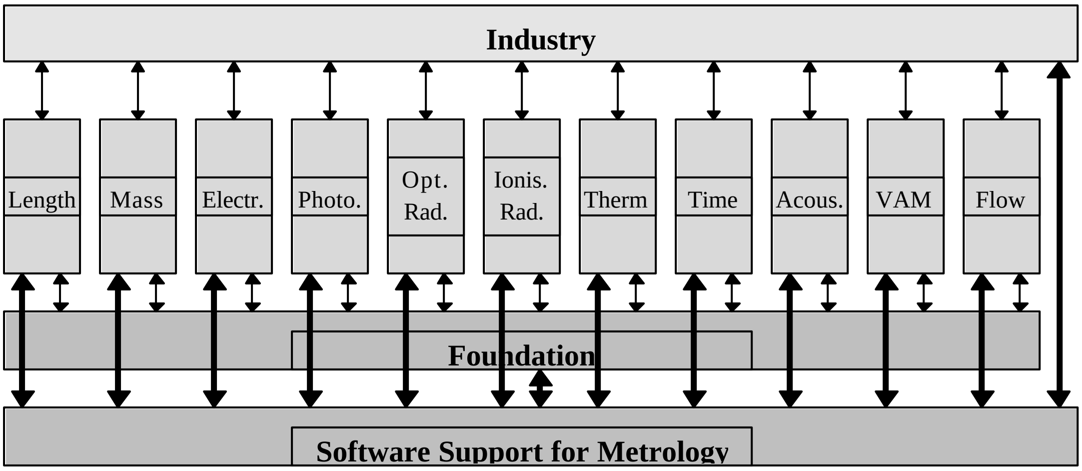


Figure 1. Relationship of SSfM to other NMS programmes and industry

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 Electrical 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 [3]. A summary of the differences from the initial Electrical status report is provided at the end of this report.

2. Scope of the Area Covered

NEL provides the UK National Standard for Flow Measurement through provision of the Flow Programme to NMSPU. NEL provides some of the most comprehensive flow measurement facilities and expertise in the world and disseminates this expertise to industry, Government and other parts of the National Measurement System. It also has contacts with National laboratories throughout the world through personal contacts, Standards committees, Euromet and CIPM. By its nature, flow measurement is a secondary standard, all measurements being traceable to primary standards of length mass and time. Unlike many areas of metrology the size and complexity of flow measurement facilities is significant. Hence the cost of calibration maintenance etc, is proportionally large.

Flow is a dynamic measurement. The interaction of the flowing medium with the artefact measuring it, and the variations of the flowing fluid through viscosity and density changes makes the measurement relatively imprecise compared with mass and length. Where other areas of metrology may talk of uncertainty in parts per million, the best flow measurement will be around 0.05%. Measurement of flow is a complex mix of quantity passed or collected, the time in which this is done and the stability of the fluid conditions during the measurement. Flow can be expressed as flowrate but across what time scale? Expressed as Quantity but is the rate steady? Flow can be measured dynamically using a flowmeter or dynamic pipe prover or statically by collecting quantity during a time. The testing of a flowmeter or a flow measurement device has to take place across a range of flowrates and conditions and a twenty flowrate test may take up to a day to accomplish. During this time, ideally, the fluid conditions must remain steady as the fluid interacts with the flowmeter but in practice it varies by 1C for NEL oil flow and more commonly by up 5C in other calibration facilities.

All of the above sets the scene to show the complexities of flow measurement and how software impinges on all aspects of flow measurement. The identified uses can be divided into a number of distinct areas:

Supervisory Control And Data Acquisition (SCADA) software designed to control and record data from a test facility used to calibrate flowmeters. Temperature, time, volume, pressure and weight can all be recorded along with the flowmeter output.

Processing software designed to take this data, process it and produce reports.

Statistical software to analyse data, produce curve fits and carry out uncertainty analyses.

Computational Fluid Dynamic Mathematical modelling software (CFD) used to predict flowing fluid behaviour and hence better explain and predict the performance of flow measurement devices.

Equations and algorithms used to predict the physical properties of fluids being measured.

Embedded software in commercial instruments and flow computers which must be understood, evaluated and possibly verified for industrial use.

This report has been compiled from a knowledge of NEL practice, practices in other UK NAMAS accredited laboratories and from industry. Euromet partners were also consulted and six countries responded with information of their practice.

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 1 b).
3. Hybrid measurement data composed of both discrete and continuous data sets.

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 Flow Programme and in flow measurement

The terminology, as used in the SSfM programme and defined above, was not recognised within the flow measurement community. This has not changed since the initial report. The terms seem to be recognised only by a small core of mathematicians but are used here for consistency with the other Status Reports in the SSfM programme and as a start to defining them within flow measurement.

In the measurement of flow, all models describing the calibration and assessment processes are based on discrete data. Measurement of time, mass, volume and meter output are all discrete data sets.

Analogue readings from meters or instruments are classified within the methodology of flow measurement as discrete data sets. This assumption is made as any analogue signal coming from a measurement transducer or transmitter is inherently averaged over a time period and this average result usually defines a discrete value in the subsequent model. This discrete value may be one averaged estimate attached to the test or a large number of discrete values taken during the test and used to show changes in the parameter, estimate random uncertainties, or averaged to provide a single discrete value for the following analysis model.

The models used to calculate the end result from these discrete data are all inherently simple. In calibration, the meter output is compared with a known volume (or mass) of fluid and the error defined. The mathematical models used mostly provide corrections to the volume or weight to account for differences in temperature and pressure between the reference standard and the meter being calibrated. The biggest corrections obviously lie in gas measurement where the fluid is highly compressible and temperature sensitive. In liquids the main corrections are applied to petroleum products, which are more sensitive to temperature expansion than water. This is especially in the case of light hydrocarbons.

It is in the definition of algorithms to define the volume correction factors for fluids where the application of software procedures comes in. Is this discrete or continuous was a question posed in the initial report and is no closer to resolution now. Many equations of state are complex continuous functions defining phase boundaries and density at variable conditions. The inputs of temperature and pressure may be discrete but the functions and algorithms are continuous and may form complex functions. The provision and verification of these equations of state and their application in a non-specialist world does need to be addressed. Other algorithms are derived from collected historical data, by compiling the data as tables and then providing algorithms to produce equations. Standardised procedures for rounding and data resolution are then applied which add uncertainty but ensure consistency of calculation.

The use of continuous data is probably confined to the research and modelling area of flow measurement. This assumes the definition of continuous encompasses the use of partial derivatives in equations to define the model. Computational Fluid Dynamics (CFD) uses the equations governing the behaviour of fluids to calculate velocity vectors and local pressure conditions within a fluid flow. CFD is not used for prediction or correction of measurements. The flow measurement community is very practically based and measurement of volume is the prime concern.

CFD is used extensively to predict the effect of changing flow conditions on measurement devices. It is in this area that continuous modelling techniques are used successfully to model and predict performance of measuring devices and to predict changes in performance in areas where testing would be impossible.

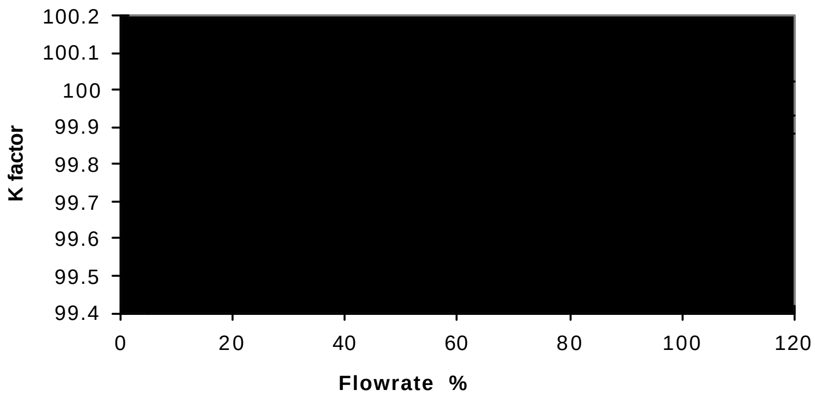
As continuous modelling is by nature a process by which a picture of the flow characteristics and interaction with the flow devices or containment is produced, little application in real time is possible. It is also clear that although the processes are becoming well understood, it is still vital to test models against experimental measurements and, even then, levels of agreement are still poor relative to experimental calibration of flow devices. The techniques are however very useful in predicting and explaining trends and shifts in flow device performance and to indicate levels of performance change. This allows extrapolation of experimental data and significant cost reduction compared with experiment where facilities may not exist for the conditions of interest.

Hybrids of discrete and continuous data types are almost non-existent in flow measurement especially in the standards and calibration area. Within industry the advent of intelligent flowmeters where the performance is dependent on a microprocessor measuring a flow dependent parameter and then calculating and correcting this measurement to derive an accurate output of flow or quantity across variable conditions may include hybrid algorithms. For example an ultrasonic flowmeter measures time differences of a sound pulse crossing a pipe. The time difference is proportional to the velocity of the fluid. The average velocity across the pipe is dependent on the flow profile, which is in turn proportional to the viscosity, which can only be determined by the temperature and knowledge of the fluid properties. The speed of sound is related to the density and hence the velocity, pipe area, flow profile and density can give rise to the mass flow through a number of different complex algorithms built into the meter software.

For the flow calibration laboratories in the National Measurement System a knowledge of the software algorithms within a meter is not required as the meter is normally tested as a 'black box'. If any understanding of the results from the test or prediction of performance away from the test conditions is required, a knowledge of the existence and operation of these complex calculations is required. This is especially true if testing yields inconsistent results when compared with expectations from the representatives of the meter companies.

Other simple models are sometimes used to predict flowmeter behaviour over a range of temperatures, viscosities and pressures. In general these are very crude models based on experimental data and apply only to the meter tested. Owing to the extreme sensitivity of flowmeter performance to fine manufacturing tolerance, even the most sophisticated models find it difficult to fully account for generic behaviour. Depending on the fluid, performance curves of many meters vary in magnitude, slope and shape. This makes extrapolation between the calibration curves at different conditions very difficult to carry out accurately and nearly always assumptions are made. As far as can be ascertained little mathematical work has been carried out to provide easy to use tools for this purpose.

A graph of 'ideal' performance of turbine meters at different viscosities are given below to illustrate the problem. The graph shows the top curve for water the second for kerosine (2 cSt) and the third for gas oil (7 cSt).



Generally calibration laboratories represent meter performance curves by showing the data only. Occasionally curve fits are employed. A number of techniques are used for this. For some meters, the data are first manipulated to plot against a function of the measured parameter. For instance Reynolds number is used to express a physical representation of flowrate accounting for viscosity and density. Secondly the required parameter may be plotted against the square, square root or other function of the reference to allow a straight line linear regression to be used to model the performance. As can be seen from the above figure, choosing a function to fit one data set is not easy; to fit functions to the different data sets and allow uncertainty analyses and a relationship to viscosity is very difficult to achieve mathematically.

The most common technique beyond linear regression is curve fitting by polynomial regression or splines; the former is most often used in the UK but other European laboratories frequently employ splines. Unfortunately the nature of most flowmeter performance curves does not lend itself to polynomial curve fits and extrapolation is very dangerous. Sometimes different curve fits are applied over different parts of the characteristic to follow the data better but this must be considered an undesirable practice.

3.2 Uncertainties and Statistical Modelling

Uncertainty in flow measurement has been governed historically by ISO 5168. The standard used over many years has been withdrawn and a revised version issued as a technical report (BS ISO 5168 TR[1]). As this revision is based on the separate derivation of systematic and random uncertainties it was only allowed to be issued as a technical report until a further revision brings it in line with current recognised practice. The original standard has served flow measurement very well, and the move to the concepts of the ISO Guide to the expression of Uncertainty in Measurement (GUM) [2] based on statistical approaches has not been well received by the flow measurement community. Calibrating a flowmeter is a slow, time consuming and hence expensive business. Systematic uncertainty could be calculated by established methods, and random components from the flow test rigs could be assessed using the very best of meters and operators. Subsequent calibrations span a wide flow range, and repeatability or random uncertainty is established at only a few points. Five test points is the norm at any one flow to establish random uncertainty. This is not conducive to good statistics. As even good laboratories can only manage 30 test points on a meter in a day, and this is spread over a ten or twenty to one turndown on flowrate, statistical methods of uncertainty have not been found easy to apply with adequate rigour.

Most laboratories have now adopted the approaches given in the GUM and reassessed the uncertainty of their operations. In UK almost universal agreement has been reached on expressing the uncertainty of the quantity of fluid passing through the meter under test as the prime uncertainty given. Further uncertainties are then given for any secondary instruments measuring the flowmeter output (eg pressure, pulse counts, milliamps etc). Having achieved this consistency in the expression of uncertainty, the flowmeter calibration laboratories are now about to embark on the next stage of how, consistently, to give the uncertainty on the measured parameter of the flowmeter. This is not a trivial task. Consistency between laboratories is the first objective to ensure the customers can understand and compare uncertainties. Secondly the problems of how to express uncertainty from the different number of test points, the different flow rates at which repeat points are taken, and the weaknesses of curve fits and expressing uncertainty of curve fits have all to be addressed. UKAS, following EAL instruction are now requiring uncertainty of calibration to be given. No agreement is currently in place as to how this should be addressed.

If this change in presentation is achieved an estimate of the uncertainty the client can expect by taking the meter from the laboratory to his process may be possible.

This is the future approach in UK. As most laboratories in UK and Europe now use Excel as the prime analysis tool, no other identified statistical tools are used. Some laboratories do use MathCAD but no obvious advantages are shown. No attempts have been seen in any laboratory to explore or account for the distribution of results either as the inputs to the process or the output from the process. In fact most input parameters to the calibration process, being results from calibrations themselves, tend to be taken as rectangular distributions based on acceptability criteria and not derived from the calibration results directly. This approach provides good prudent uncertainty budgets and saves costs by avoiding constant changes or corrections to software and procedures.

It is a recognised fact that the expected uncertainty from flow measurement as seen from intercomparisons between laboratories, is larger than the uncertainty calculated within any individual laboratory unless very pessimistic estimations are used. From experience over many years it is thought the best European laboratories agree within 0.15% but their internal uncertainties are around 0.05%. Another intercomparison just completed shows agreement within 1% for facilities with claimed uncertainties of 0.1%

Confidence limits of k=2 or 95% are universally employed.

Software support for uncertainty is very poor, and this is an area for the programme to address.

Easy-to-use curve fitting routines for complex functions are few and far between and, if they were to become available, would ease flowmeter performance and uncertainty analyses greatly.

In industrial applications different approaches to uncertainty analyses need to be applied depending on the application. Tracing through uncertainty for an oil transfer by following a traceability route requires a different approach to that of a water distribution network.

An exciting development in uncertainty estimation is being introduced within some areas of the oil industry. This approach uses statistical Monte-Carlo simulation. The effectiveness of this may be discussed in a future report. This technique has been employed by one service company and uses standard statistical Monte Carlo simulation and applies it to complex oil measurement systems with a high degree of success.

3.3 Visual Modelling and Data Visualisation

Data is almost always presented as a data table along with a two-dimensional graph of results as a scatter graph. No other approach is normally taken in presenting flow calibrations. For intercomparison work Youden plots are used extensively with mixed opinions of effectiveness. They are seldom used without accompanying calibration curves. In some areas of multiphase flow measurement three-dimensional surface plotting is being used effectively and several contouring software tools are employed.

3.4 Data Fusion

Data fusion is becoming a feature of many modern flowmeters and flow sensors. In general the number of inputs is small and the data processing relatively simple. Even with the simple systems making the software interact in real time with the user is a problem. Many flow applications are batching systems and the dynamics of this seem to be very difficult to control.

Data Fusion was recognised in the Foresight Programme as one of the most important topics in industrial measurement affecting flow measurement and process control. As a result an NMSPU project was formulated and completed in 1998. SIRA was the main contractor and the final report has been produced. The report also covered the use of Fieldbus in the measurement of flow. The full report is available [3].

In the area of multiphase flow, data fusion, complex algorithms, neural networks and many other techniques are being researched and investigated. Again this has been investigated within the Flow Programme by Cranfield University and a report produced [4]. Further work was proposed for the 1999-2002 programme but will probably not now proceed.

INTErSECT is not seen as having much impact on flow measurement technology at present.

4. Validation and Testing

4.1 Spreadsheets and Other Mathematical Software Packages

1. The most commonly used package in flow measurement is Excel. Virtually no other spreadsheet package is used. For complex work MathCAD is employed in some

laboratories, and for data acquisition, Visual Basic is often used for bespoke programming. Some older Hewlett Packard systems are in use but these are reducing rapidly.

2. Within Excel the simpler functions of Square roots, squares, sums, means and standard deviations are used extensively and without question. Curve fitting is used using 'trendline' but as the coefficients can not be transferred to the spreadsheet directly the uses are limited. No verification has been reported. Regression functions are not often used and appear to be a little unfriendly. Uncertainty of curve fitting is not available to 95% confidence limits.
3. The feature of Excel which provides the biggest advantage is the ability to write functions and routines in Visual Basic for Applications (VBA). This allows traditional programming of calculation routines while maintaining the presentation, data handling and friendliness of a spreadsheet. This eases validation, encourages software reuse, and simplifies many complex calculations and routines. It is noted that VBA is underused by laboratories.
4. Limitations in built-in functions are not generally recognised or documented in the help files or books. Most limitations of the packages are found by accident. Copy/paste errors, random re-calculation when using macros and functions, and misuse of the ability to change data by dragging a graph point are all examples of potential problems in using Excel .
5. No apparent testing of built-in functions is carried out except by accident. User-produced functions are normally well validated by normal software procedures. Spreadsheet testing is always a problem and different validation techniques have been tried. The use of check data is the preferred method but this raises concerns as the check data may not explore some areas of the calculation which may have errors.
6. Some suppliers' advice is sought but usually this advice is only accessed by the 'experts' who know the correct ways to find the information. Help and 'bugs' are usually found documented in the support services but not many staff know how to look.
7. The use of proprietary packages is vital to the traceability from raw measurements to measurement results. All laboratories use proprietary packages to analyse results.

4.2 Model Validation

Model validation takes place at two levels. At the higher level, competent mathematicians are producing good models to explain behaviour of sensors such as orifice plates, or modelling flows using CFD. No obvious problems exist in this discipline, as all the exponents of these techniques are fully aware of the need for validation. At the lower end of the scale, models based on curve fitting are employed to describe or extrapolate flowmeter performance and it is in this area the tools and awareness are found wanting. Staff who are not mathematical experts frequently use curve fitting and statistical tools to describe results with limited understanding of the consequences.

4.3 Measurement System Validation

For many applications in flow measurement, the use of central flow computers or supervisory computers is standard. All fiscal metering systems have dedicated flow computers. These computers contain software to interrogate numbers of instruments reading flow, temperature and pressure, calculate the flow in engineering units (reduced to specified conditions) and of course display this information in the form of quantity passed for a time, flowrate and total quantity held in non volatile memory. The software is verified by the manufacturers but it is not unknown for major errors to occur. As far as can be ascertained at present no recognised certification of flow computer software is being carried out.

Increasingly flow sensors have microprocessors built in. In the simplest form, the turbine or rotary meter may have a linearisor which will take the calibration errors of the meter at different flowrates of the meter and apply them to correct the output. Invariably these are five point and linear interpolation type corrections. Increasing sophistication adds second sensors to provide temperature and pressure correction and of course communication.

At the higher level some modern meters, for example Coriolis and ultrasonic meters, rely on sophisticated software to operate by converting and correcting the sensor information to engineering units or producing pulsed and current signals. Again the software is not independently checked and in fact could not easily be checked as too much proprietary information on performance is included. For this type of meter, most errors are found to be due to inadequate allowance for changes of fluid parameters or conditions. This could be due to inadequate algorithms or using the device outwith the original design of the software.

Most sophisticated meters of this type are tested by calibration and the internal software does not require separate validation for normal use. It is assumed that manufacturers validate and test the software before release but no information is available for this report on the methods used.

Some Smart instruments have now many flow computer routines built in and validation of these should be possible.

It is interesting to note that most sophisticated flowmeters have many diagnostics built in which if they can be accessed can tell much about the behaviour of the meter in service. Access to these and the meanings is often not well documented by the supplier to the user test laboratory or even the front line service engineers.

Of particular relevance is the relationship between the different response times, operating speeds and update times in a system. Poor performance and calibration can frequently traced to a lack of understanding of the interaction of the process, sensor, microprocessor and software.

Validation of Simulated Instruments

It is not clear for this report if any simulated instruments are used in flow measurement. A possible example has however been identified in a research project where CFD is used to model flow distributions and hence model the performance of multiple path ultrasonic meters hence providing a virtual meter simulation to predict performance in an application.

5. Metrology Software Development Techniques

5.1 Software Development Methods

It is fair to say that in the flow measurement laboratories in UK and Europe the mix of good and bad software practice is apparent.

Many software calculation and data logging routines are in place using bespoke programs, spreadsheets and mixtures of both. These often have not been developed by either formal methods or by trained programmers. Quality assurance through TickIT is but a dream! All software is validated usually by comparison with hand calculation and records kept of status and validation checks.

Examples do exist where professional programmers are employed and full formal methods are used. This is especially true of add-in functions and routines for particular tasks such as calculation of physical properties.

In general, however, the small scientific based laboratories in the flow area have tended toward self generation of software to allow the flexible response required for the wide variation of meters requiring test. The financial burden of professional programming technique is seen as cost prohibitive.

5.2 Software Reuse

The use of software libraries was widespread on mainframe computers in the 1970s to 1980s. Graphing packages, data handling packages and physical properties packages were called, often from FORTRAN based programs. During the 90s the almost exclusive use of PCs has made these packages obsolete and replaced by either the statistical functions in standard packages or by bespoke calculations embedded in spreadsheets.

It is clear that now Excel has become the dominant package, a return to software re-use is possible by sharing macros, templates and VBA functions. Functions for unit conversion, polynomial curve fitting and calculation of physical properties are beginning to be reused as either functions or Add-Ins for Excel. Some are poor quality in programming terms but are reused in many spreadsheets. Other are well constructed, fully verified packages which can be installed with Excel for specific applications. Many packages of this type are mixed language. The calculation engine is often FORTRAN with an Excel VBA interface to the user. This is proving to be very successful in physical properties applications where the calculations are well established in FORTRAN but require use from a spreadsheet.

Experimentation is about to be carried out at NEL to keep all standard programs, functions etc, on a central server. This will provide a secure and controlled base copy of vital programs, spreadsheets and templates. A user, logging on, would download the software required to the PC, and if required, modify it for use on the particular problem. This modified version would be destroyed at the end of the project. If the modification was useful it would be properly added to the base version, or archived as a future change should it be required. Many control aspects have still to be addressed in particular how to log and save temporary software change to allow data to be recalculated in the future should results require recalculation.

The Year 2000 bug does not seem to be a big problem in this area and appears to be under control. HP software will be doubtful but repairable even if wrong date functions are returned. Confirmation of this appraisal will be given shortly.

5.3 Virtual Instruments

LabView software is little used in the flow laboratories known to NEL within UK. Reference is made in the replies from some European standards but no amplification of this has been obtained. The use of PLCs to provide control and, combined with Visual Basic or VBA routines linking to spreadsheets gives full SCADA capability. This involves bespoke routines to provide interfacing with instruments in the same way as Virtual instrument programs operate. Knowledge of PLC programming is generally low with some experts providing the support. The PLC programming and the DLL production between the segments of the software to provide on one hand a mimic diagram and on the other data sheets and graphs of results is carried out by limited numbers of trained staff and this weakness needs to be addressed..

6. Support for Measurement and Calibration Processes

6.1 Automation of Measurement and Calibration Processes

Laboratory Information Management Systems (LIMS) are, as far as can be ascertained, not used to any great extent in the flow measurement laboratories in UK or Europe. Moves to automate report and data handling in all laboratories are more a gradual change rather than any purposeful move to establish automation. It is a common feeling that either automating the calibration process or reducing the operator skill level because of automation is not necessarily the correct route. Many meter calibrations depend on the operator knowing the process, experiencing the meters being tested, and being able to interpret data as it is produced rather than rely on an automated process where gross errors of curve shape etc. would only be seen on completion and after the meter has probably been removed.

Although automation of data reduction and report preparation is generally seen as a good thing and leads towards reduction in errors, the investment in software to cover the wide range of meter options is definitely the reason for slower than expected progress in this area.

Initiatives from the US led by NIST are being watched with regard to ‘Teleworking’. This involves allowing access by operators, managers or clients, via the Internet, to the calibration process in real time.

6.2 Format Standards for Measurement Data

Standardised data formats have always been a problem within NEL and remain so. A form of data standard is now being introduced in the liquid meter calibration areas but will not find acceptance until the older software packages can be retired. Generally between laboratories no standard data format is used. The different requirements for data output and the different methods which laboratories use to record the data seems to make a common format very unlikely to come to fruition. Is temperature measured upstream and downstream, only downstream, at the meter? Different laboratories use different techniques and these do not lend themselves to common data formats.

For intercomparison work it is usual for the organising laboratory to specify the data they require and frequently to supply a spreadsheet template. A table of reduced data is normally all that is required but providing a template gives the common format and avoids overloading the analyses while still retaining enough information to estimate influence factors.

7. Suggestions for Future Activities

7.1 Expected Benefits of the SSfM Programme

It is believed the flow measurement area should benefit from the SSfM programme through the uncertainty project, the spreadsheet management techniques and perhaps the software control areas. It may also benefit from the investigation into format standards.

7.2 Case Studies and Feasibility Studies

The feasibility of the SSfM Programme identifying software techniques and tools for data handling or analyses used in some areas which could be packaged for use in other areas is attractive.

Packages from one area could be passed on or expertise identified to 'polish' in-house metrology and data routines for other areas to use. For instance, NEL has functions for density of water (three methods), API oil tables as Excel functions, and tables of unit conversions. These could be made available to other laboratories if time was available under the programme to complete these and other tools to the quality required for 3rd party use. The advantages of such an approach are obvious. Standardisation of calculation routines and the use of common fluid properties are vital, and the availability of a library of routines would aid this process.

A metrology users group on the internet where common questions and answers can be aired and help file of the most useful compiled. This could be divided into different sections covering Excel, VBA, Word, etc.

7.3 Future SSfM Topics

The development of software tools to fit mathematically sound curve fits is required.

These should be user friendly and give the relatively inexperienced user the ability to fit more complex functions through data and give confidence to the user that these are sound mathematically. Most packages commercially available for this are written for the experienced mathematician or for very simple functions. What is needed is a much more comprehensible lower level of help for the non-expert. Curve fitting should incorporate uncertainty estimates.

Computational methods to assess uncertainties would be very useful. These would support and ease the estimate of uncertainty in both laboratories and industry

The establishment of a register of Excel based functions and routines associated with metrology would be a useful initiative. These could be distributed through a user group either as free software or by indexing and purchase from the author. Knowing these functions are available would save many man hours of software writing and validation. Perhaps a database of metrology users' experience of problems/faults and shortcomings would be possible through the same data base.

7.4 Future Flow Programme Topics

No software topics have been identified as projects for the next three year flow programme under research. A number of software actions will be implemented within the traceability and maintenance part of the programme but cannot be identified individually at this time.

Outside the flow programme but within the industrial flow field, rounding and consolidation of oil flow calculations is a topic of current review. Continuing development of Monte Carlo simulation of uncertainties and indeed automated conventional uncertainty software will be carried out. Again software techniques may be employed to provide automatic estimates of mass balance and uncertainties in the water and process industries. Mass balance is of prime importance to both these sectors to control their business.

7.5 Embedded Software and Intelligent Instruments

An interesting topic which is increasingly being seen in flow measurement is the introduction of extensive amounts of embedded software in instruments which provides them with a wide range of options and intelligence. All the aspects of this has been discussed in this report but not brought together as it is applied in embedded software. In the simplest form scaling and communications can be added to an instrument. This rises in complexity through the introduction of sensor fusion and algorithms to alter the measurement in response to an influence factor. Diagnostic tools can be added to detect sensor malfunction through breakdown or operation outside its range. At the advanced edge of sensor design lies very intelligent instruments which not only include all the features listed above, but also add self learning features which can modify the performance in response to changing operating conditions. It is only now that the capabilities of some of these instruments are being explored by the standards laboratories and coping with them is a new challenge.

8. Summary

This report has consolidated much of the text prepared for the initial report. Little has changed since the preparation of the initial report in the uses or control of software in flow measurement except a growing awareness of the different aspects of software as defined by the SSfM Programme. It is in these minor changes and additions to the initial report that shows that more focus is being applied to the application of software. Industrial metering is moving extremely quickly to incorporate very sophisticated software within sensors and the ability of the NMS to follow this approach has to be strengthened.

Automation of uncertainty, improved analyses and curve fitting tools and data banks for custom software and analyses routines are all topics well worth exploring in the future programmes.

Appendix 1: Glossary of Abbreviations

Abbreviation	Expansion
CFD	Computational Fluid Dynamics
DLL	Dynamic Linked Library
GUM	Guide to the expression of Uncertainty in Measurement [2]
ISO	International Organization for Standardization
LIMS	Laboratory Information Management System
NAMAS	National Measurement Accreditation Service
NEL	National Engineering Laboratory
NIST	National Institute for Standards and Technology
NMS	National Measurement System
PC	Personal Computer
PLC	Programmable Logic Controller
SCADA	Supervisory Control And Data Acquisition
SSfM	Software Support for Metrology
VBA	Visual Basic for Applications

Appendix 2: Bibliography

1. *ISO TR 5168 Measurement of Fluid Flow. - evaluation of uncertainties. ISBN 0580 2755 31*
2. *Guide to the Expression of Uncertainty in Measurement*, International Organization for Standardization, 1993, ISBN 92-67-10188-9.
3. The impact of field bus and sensor fusion on flow Measurement. Flow measurement Guidance Note No 12, 1998. Sira Test and Certification or NEL East Kilbride Glasgow.
4. As above. Full report to NMSPU Sira Test and Certification 1998.
5. Intelligent systems for multiphase flow measurements. Flow Measurement Guidance Note No 14, 1998. Cranfield University or NEL East Kilbride Glasgow.
6. As above. Full report to NMSPU Cranfield University.