How to Train Users of Simulation Based Thermal Performance Analysis Tools

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The efficacy of dynamic thermal simulation tools in practice is dependent not only on the facilities offered by the tools and the rigour of the underlying calculations but also on the skills of the user vis-a-vis abstracting the essence of the problem into a model, choosing appropriate boundary conditions, setting up simulations and interpreting their results. From observations made during training and collaborative working with a range of users generalised conclusions have been drawn on a number of issues relating to formal and informal training techniques and the evolution of tools to better support the novice as well as the experienced user.

INTRODUCTION

The Energy Simulation Research Unit (ESRU) has, over the past four years, been involved in the support of both national and international simulation based programmes, simulation based undergraduate and post-graduate courses as well as being the core group of the ESP-r development consortium. This has included the long term observation of a range of users (post-graduate students, engineers, architects, physicists and academics) attempting a range of simulation tasks, experience of various training techniques, user support and application evolution. In addition to the above activities the author draws from experience with DEROB (Higgs 1984) and the development of a correlation based simplified design tool (Hand 1988).

It has been found that the efficacy of dynamic thermal performance simulation tools in the classroom, laboratory, design office or consulting practice is dependent not only on the facilities offered by the tools and the rigour of the underlying calculations but on the skills of the user vis-a-vis abstracting the essence of the problem into a product model, choosing appropriate boundary conditions, setting up simulations and interpreting their results.

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How users acquire such skills and how simulation tools can be made more accessible is therefore a topic of some importance. Many aspects of simulation training are generic rather than application specific. This paper will concentrate on the generic as much as possible. Where specifics are required the point of reference will be the ESP-r simulation program (Clarke 1985; Aasem et al. 1993).

The more comprehensive the simulation tool the more the assumed user type is that of an expert - one who has opinions as to the nature of the problem, its energy paths and whose task evolves into translating this into the syntax of the tool. Truly elegant use of such tools is by those who are comfortable with acting as a "deity", defining what reality is and driving the tool and machine environment to their purposes. The process gets progressively more difficult as a user has fewer opinions as to the thermophysical nature of the problem.

With reference to current tools and the next generation with intelligent front ends and full knowledge based control - the most powerful user would still be someone who had the above attributes. Unfortunately such people are not in great abundance and it takes considerable effort to reach such a state. The need is to make simulation accessible other user types and alter the learning curve.

Progress is being made - ESRU staff have observed new users undertake moderately complex simulation tasks in weeks rather than months. As always, the most proficient users tend to have been active in simulation for a year or more and have experience in several projects, their management and the applications code structure.

Taking into account the user classes under observation, the range of training techniques used and an admittedly subjective assessment of their success in applying simulation to a range of problem types, recommendations are presented as to how the simulation community might proceed to improve the training of those who wish to make serious use of simulation tools.

HURDLES TO OVERCOME

Many of the difficulties associated with the integration of simulation into the design process can be traced to the following causal factors:

- Focusing training on the mechanics of interaction with the tool at the expense of simulation methodology, project management and interpretive skills.
- Use of "toy" problems as exemplars. Exemplars contorted to show particular features of the underlying data structure or of a highly abstract nature may be taken up literally as the norm by some classes of users.
- Novices attempting complex problems and being swamped by the topology and project management tasks.
- Forgetting the importance of paper, pencil and planning. One of the most irrepressible urges, afflicting the novice as well as seasoned users, is to immediately approach the workstation when given a thermal appraisal to carry out. Without exception this has been observed to be a costly mistake.
- Confidence in the system - not in terms of formal validation exercises, important as they are, but the confidence gained by use over time where the user begins to pay less attention to the interface and more to the purpose of undertaking simulation. At this point users begin to evolve an intuition as to how to construct problems which focus on the question at hand. Many training schemes pay little attention to this most important phase.

The power and, at the same time, the weakness of ESP-r (and other similar detailed tools) is its ability to offer users multiple ways to represent and analyse problems in an attempt to emphasise particular design aspects and deal with parameter uncertainty. While an expert will derive great power from this, a novice will typically feel unnerved. The differentiation of an concise definition of reality in pursuit of a complex problem (by an expert) from syntactically correct garbage (of the novice) is one area where current tools inevitably fall down as they have no internal capability to check semantics. This problem is to some extent mitigated as applications introduce more mature feedback facilities, but the responsibility is still on the user to confirm the correctness of the model.

THOSE OBSERVED

When the project on which much of this report is based began in 1989 (Hand and Clarke 1993) the initial training idea was to take a broad spectrum of individuals and groups and evolve them into a close approximation of the expert user because there was no resource to change the nature of the simulation tool itself. Within this community several user classes became apparent, each with a different affinity for simulation, differing training needs and varying success in attaining proficiency. The following is a summary of those observed:

- <u>Previous use of simulation:</u> Having absorbed the syntax and the philosophy of one simulation model, such users adapt quickly to the syntax and philosophy of another. Previous exposure to simulation also makes them receptive to ideas of simulation methodology and the problems of creating appropriate product models. If the transition is from a less comprehensive tool most users welcome the increased functionality.
- <u>Background in building physics:</u> This class of user generally has a reasonable aptitude for learning advanced simulation techniques and using them as a tool for investigating specific heat and mass flow issues. Typically, such a user will access source code and produce sophisticated parametric studies but not venture into problem descriptions which have any great geometric or control detail.
- <u>Technicians:</u> Users who absorb the techniques of how to manage data input and run simulations, but are not attracted to higher simulation issues make useful members of a team but are inclined to be ill-equipped to define product models, plan strategies or manage simulation work. Their ability to learn is variable, some are only confident if the product model is closely related to ones they have been trained

on or if they are given specific instructions. The present state-of-the-art in energy modelling requires that problems be realistically constrained in terms of size and number of issues. Knowing how best to effect this is an acquired skill which is best attained by trying alternative modelling approaches to the same problem - technicians have rarely been observed to attempt this.

- Single issue users: This class of user has one overriding use/focus for simulation and it is difficult for them to absorb skills which they label as outside of this focus. As such they often make poor use of a simulation tool. Such users are often experts on one facet of simulation and are able to identify deficiencies in existing facilities. They occasionally contribute improved methods.

- Traditionalists: This group of users, whether building physicists, engineers, or architects do not easily cope with simulation based, building performance appraisal. Careful abstraction of reality and simulation methodology are foreign concepts and, more profoundly, they consistently demand that the new technology be re-expressed in terms of traditional methods. Such a user will inevitably prefer to represent the performance of a building as a limited set of numbers (preferably one) rather than as patterns of temperature or energy use. Having been conditioned by the time constraints found in traditional calculation methods they tend not to consider incremental appraisal or undertake the iterative use of simulation to identify sub-optimal design solutions.

- Students: This class of users are both a bane and a blessing to the application developer. Being truly naive they attempt the impossible, take prompts literally, happily ignore pages of warnings (if it was really wrong it would crash) and believe simulation results are carved on stone tablets. If there is a logic gap they will discover it - they are worth their weight in gold for the robustness they can force on an application. Having no concept of time and an infinite capacity to explore they will eventually be able to navigate almost any simulation tool. Undergrads are often given a set of problems to work out and left to their own devices. On-line tutorials are particularly effective with this group. Postgraduates are usually given more attention as they are the next generation of simulationists.

- Tool-led users have a tendency to evolve overly complex and tedious problem descriptions and brute force simulation approaches. Having little or no understanding of what is the *essence* of the problem, but being nimble of finger, such a user will be inclined to enter details until the descriptive limits of the system are encountered, confident that the problem is well represented. With no concept that some subset of a program's facilities might be sufficient to answer a particular question, such a user will inevitably strive to make sure that every possible toggle is set to "ON". While this description is probably somewhat extreme, this user type may be a liability unless closely supervised.

TRAINING OPTIONS

As with most advanced engineering applications, the learning curve associated with any simulation system which is capable of modelling a diverse set of problem types is non-trivial. Among other skills, the user must acquire 1) basic skills related to the machine environment, 2) command of the syntax and interface interaction skills, 3) knowledge of the descriptive entities which make up the product model and 4) experience with the sequence of tasks required to create a product model, verify it, present it for simulation and explore simulation results.

During the period of this study the system has been introduced to a number of individuals and groups using a range of techniques from formal workshops to on-site training in the context of actual projects. The following discussion highlights experiences to date:

- By the book: Access to a workstation, user manual and sufficient time to 'sort things out' by trial and error are all components of a common training technique. It occasionally works. Without direction most self-taught individuals become "tool led". In recognition of this ESRU has included an on-line tutorial, context sensitive help and documented exemplars in the standard ESP-r distribution. Insufficient time has elapsed to judge the quality of such remote users.

- Formal tuition: As a technique this is particularly good to get users past the initial part of the learning curve. In the case of ESP-r, the quality of the documentation, exercises and interface have evolved to the point where a greater percentage of novices are progressing to an intermediate level during a standard three day course. ESRU has run such courses where all users progress at a constant rate as well as each user at his/her own pace. The latter approach is more exhausting for course staff but allows some users to progress quickly. An instructor to user ratio of 1:4 to 1:7 is sustainable and occasional clustering into small groups is advantageous. Each user should have access to a workstation but new users often work best in pairs.

- Informal tuition: This is a variant wherein the user obtains limited formal training and then intermittent access to expert users as they progress in a self teaching mode, often with a goal of adding new facilities or contributing to a joint project. ESRU has often used this for individuals who visit the University for periods of two weeks to a month. Access to workstations tends to be intermittent.

- Workshops: Simulation has many facets, some of which are best approached after experience with a system. Workshops have been successfully used by ESRU to explore the setting up and interpretation of mass flow networks, simulation of test cells, and the like. An instructor to user ratio of 1:3 to 1:6 is sustainable and occasional clustering into small groups is advantageous. Optimally each user should have access to a workstation.

- Within a project: An organisation which has a "real" simulation based project can train "on the fly" by obtaining the services of an expert who then directs and trains the staff as the project progresses. The staff must have reached a nominal level of competency before the beginning of the project and be willing to put a great deal of effort into their training - if few concessions have been made in the programme schedule the work will be most intense.
Assuming it contains a degree of complexity and diverse simulation goals the expert will have more than enough scope for exploring methodology, problem description techniques and project management skills. The latter topic is particularly difficult to express outside the context of an actual project. Training within a project can result in highly proficient staff who will be well placed to carry on independent work. It demands a true expert and one with considerable energy as any staff deficiencies will likely fall to the expert to correct. An instructor to staff ratio of 1:1 to 1:3 is recommended with the instructor having regular access to a workstation.

EVOLUTION OF ESP-r

Much of the recent evolution of ESP-r was driven by observations (Hand 1991) as well as in-house research and consulting. Being a research group with only a limited mandate to deal with human computer interface issues, initial (pragmatic) assumptions were that the ability of seasoned users to accomplish their goals was only minimally affected by the form of the interface. In one sense this assumption was true but the demands of interacting with the system and the tedium required to evolve models often obscured the essence of the simulation task. It has been found that the novice's demand for clarity in the presentation of simulation concepts and those facilities which support the creation and evolution of models acts as an empowering agent for seasoned users.

One evolutionary demand is to "hide" the structure of the tool - removing the user from interaction with the raw file and database structure, lessening the need for users to remember the names of application modules or of elements of their model. At the same time the highest level of the product model has evolved so that all relevant databases and user supplied documentation are associated with the problem description. The result of this was the creation of project management facilities which, given the name of the problem, allows users to browse through the problem and associated databases, modify and evolved all parts of the problem description and invoke simulation facilities as required.

The interface of all modules has been regularised and a number of facilities which assist in training activities have been added:

- Each request for text or numerical data contains a default value (plus allowed range for numbers), contextual help and all are presented consistently. Basic editing skills are covered via on-line tutorial and this quickly becomes transparent to the user.

- Selection of thermal zones, surfaces, primitive materials, constructions, optical properties and command options are via lists of items. Contextual help is provided and lists of arbitrary length can be accommodated. Attribution of zones, surfaces, etc. by name reinforces the ownership of the model, increases the clarity of in-built reporting facilities and eases navigation through the application hierarchy.

- Each command menu is verbose enough to lessen confusion and is backed up by a synopsis of the choices. Most such displays are overloaded to give feedback on current data and option toggles thus allowing reporting, control and editing facilities to merge. This lessens the need to consult user handbooks or the instructor.

- Facilities are provided so that information in each product model data file can be reported in a form which aides quality assurance and which makes full use of user supplied names. Most importantly this is consistent across all modules that make use of that data structure.
- All facilities relating to the product model form and fabric have simultaneous text and image feedback with the focus element usually highlighted.
- A series of exemplars of differing complexity, each with variants which explore common simulation issues and simulation facilities has been provided.
- A separate stand-alone interactive tutorial facility has been enabled which includes core issues from the user's handbook, glossary, discussion of elements of the product model, databases, application modules, available exemplars and a step by step guide to the creation of a small scale model. The structure of the tutorial facility is open and it is possible for users to create bespoke versions or perhaps use a different language.

This evolution has been highly iterative in nature - suggestions are collected from users or in the course of research and consulting - facilities are modified, tested in various contexts and revised as necessary. Formal training sessions and workshops are particularly rich sources of evolutionary demand. While modifications to tutorials, prompts and exemplars may happen during a course, code changes often require weeks as they need to be tested.

This pace of evolution presents a number of problems regarding dissemination of information and updated applications to users. The post is slow and expensive as are manuals, magnetic media and staff time. As much as possible distribution to remote sites is now done via Internet FTP (file transfer protocol) with subsequent support by way of email. Upgrades to tutorials and exemplars are announced by email broadcast to members of the ESP-r consortium (Hensen et al. 1993) and interested parties can download the relevant files at their convenience. This allows organisations with differing simulation interests and staff resources to choose the pace at which they upgrade their software tools.

EMERGING TRAINING TOPICS

As mentioned previously, "toy" problems have only a limited training potential. Much of the art of using simulation is in the composition of problems. ESRU now includes in the ESP-r system distribution documented and annotated exemplars ranging from dwellings to office blocks. Many of these are drawn from consulting projects and, having evolved under time constraints, are concise solutions in support of design. The use of such exemplars is proving to be one of the best vehicles for technology transfer and advanced instruction.

The importance of simulation methodology as a training topic is as great as it is problematic. It could be likened to a strategic plan in the form:

> *In order to answer questions A and B about building X it will be necessary to describe the essence of C and D, determine assumptions about E and F, setup two models, the first emphasising E and the second F.*
> *Simulations will then be invoked for the periods G and H at a level which allows the differences between J and K as well as the overall contribution of L to be discovered.*

Methodology deals with flows of information, decision points, relationships between simulation facilities, generation of patterns and their interpretation. It is methodology which allows users to concisely and cost effectively use simulation to provide support for the design process. It is methodology which gives the expert power and the lack of it which drags the technician down. This requires close interaction with the user and training within a project is the ideal vehicle.

Another issue which is central to generic simulation tools such as ESP-r is how to give users the skills necessary to create models that capture the essence of the simulation problem. There is a point somewhere between excessive abstraction (several levels of an office block as a single thermal zone) and including entities which have only a third-order effect. It requires that users be *au fait* with the descriptive entities of the application (so that they are used appropriately) and that they have explored descriptive variants at a convenient scale so that they have some basis for expecting a particular construct to be of a reasonable granularity vis-a-vis the problem to be solved. Exemplars are a useful resource but experience indicates that users must be pushed into looking at alternative approaches or they will only scratch the surface of what simulation has to offer.

Sometimes it is easer to remove limitations than train users to cope with them. For example, the size and diversity within most thermal performance product models makes quality assurance problematic and a limiting factor as problem complexity grows. ESRU has evolved the application interface and introduced project management facilities rather than expecting the user to make up for such limitations.

Current generation simulation tools presume that the user has the background and intuitive or analytical faculties to confirm simulation results as being within the probable. This is problematic for the novice who, unlike the expert, has a tendency not to subject simulation results to critical review. It is mostly beyond the state-of-the-art for the system to recognise non-intuitive results as being from ill-defined problems as from correct interactions within the scheme. Such limitations stem from the inherent interconnectedness of thermal problems. It falls to training to provide the attitudes and skills necessary for users to recognise and cope with the complexity of simulation.

The user has considerable latitude as to the style and organisational structure employed for directory structures, naming conventions and archiving techniques. Such choices have been observed to influence the overall productivity of simulation based programmes, especially as problem complexity grows and thus should be highlighted in training sessions.

A related aspect of training is how to make use of the underlying power of the machine environment, not in terms of raw speed, but in accessing the rich set of tools and interactions possible within a multi-tasking, multi-user environment. Indeed, ESP-r has been designed for such an environment and derives a considerable part of its power and flexibility from it. As users pass beyond the novice stage, where very few UNIX commands are required, tuition should cover methods for automating performance appraisal tasks and using system utilities for report generation. This is particularly important for organisations who wish to undertake large scale simulation programmes.

The evolution of applications and the training techniques reviewed would appear to have contributed to the better use of simulation tools. The next step is to take on aspects of computer-aided learning.

CONCLUSIONS

From the observations of users, success of training techniques and feedback the following conclusions and recommendations are given:

- Anyone contemplating a serious thermal simulation project should not underestimate the need for training and software support or the resources required to become competent with performance assessment tools. Observations indicate a moderate level of proficiency required formal training as well as hands on experience in the order of weeks to months depending on the individual. Those not exposed to expert tuition tended to have difficulty with the creation of models and were more inclined to "stuff in the dimensions and crank the handle".
- Training should begin with an emphasis on simulation methodology, problem abstraction and the rationale/approach of the simulation tool to major performance appraisal topics. Next the focus should shift to the environment within which the simulation tool operates and only when the user appreciates its implications should the user learn the syntax and procedural aspects of the simulation tool and associated productivity aids. Within each exercise, no matter how trivial seeming, the trainee should begin with methodology. The reason for such a methodical approach is that simulation is inherently complex and involves interactions which are complex. This is true for a problem with six surfaces or six hundred, schedules of air changes or solutions of mass flows, ideal controls or networks of detailed plant components.
- In the case of ESP-r the optimal initial investment in training is three days of formal tuition followed by a one or two day workshops once the user has mastered basic techniques. Those with a some prior experience might be comfortable with slightly less time, but groups who have minimal backgrounds in workstations or simulation will require at least one additional day for each topic.
- No vendor of a comprehensive simulation package should claim that users become expert in a few days. It is counterproductive to give the impression that simulation does not require careful attention to detail, that complex

interactions are not involved or that it is a particularly easy task to undertake. The more the user appreciates this and confirms it at a limited scale the more probable that the skills needed to support the design process will be attained.

- Training for management and key consultants is no less important and should focus on techniques for extracting information from models, generating reports and techniques which support quality assurance. Be warned. Managers who are ignorant of the tools used by their staff and who are not able to independently check on the progress of a simulation based programme are in a poor position to ensure the quality of their deliverables. One days training should be sufficient for those who have some related background.

Assuming a simulation team consists of more than one person the following balance of skills is recommended:

- Someone must be in charge of workstation management. This is neither a trivial task or one that can be ignored. It is not necessary to be an expert at system management but to be able to take on occasional responsibilities as the system administrator (superuser on UNIX machines).
- At least one member of the team should be comfortable with simulation methodology and design abstraction issues. It helps if this person has a working knowledge of the simulation program so as to appreciate those aspects of design abstraction which are program specific.
- At least one member of the team should have skills in interpreting simulation results and be able to use the results recovery features of the simulation program. Pattern matching skills and an intuitive grasp of energy flows within buildings and plant systems are essential.

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