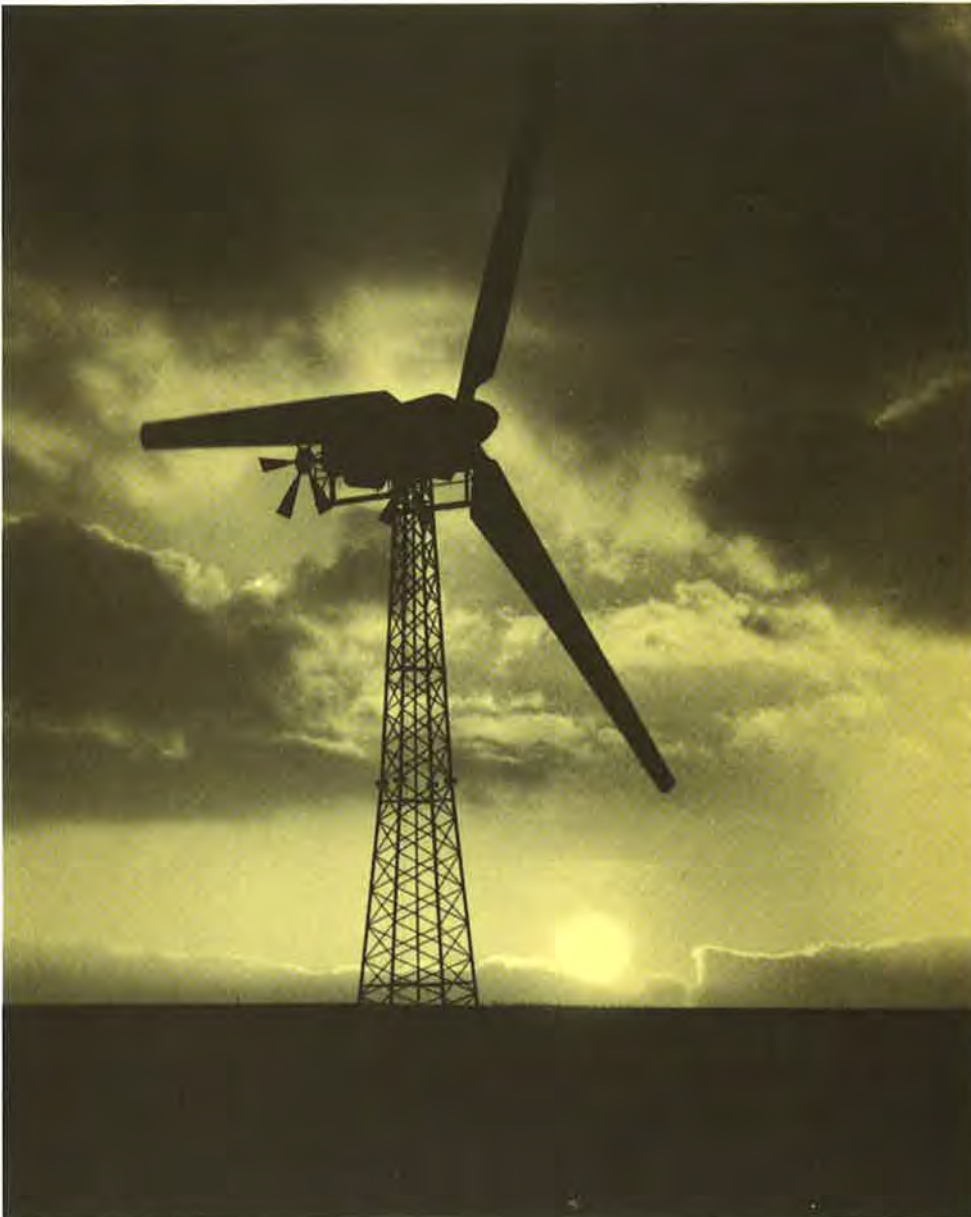


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RAL-94-001



**ENGINEERING DESIGN TOOLS FOR WIND DIESEL
SYSTEMS - FINAL REPORT FOR CEC CONTRACT JOUR-0078.
VOLUME 1 - EXECUTIVE SUMMARY**

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ENGINEERING DESIGN TOOLS
FOR
WIND DIESEL SYSTEMS

FINAL REPORT ON CEC CONTRACT JOUR-0078

VOLUME 1: EXECUTIVE SUMMARY

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Report to the Commission of the European Communities
January 1994

Foreword

This CEC project (JOUR-0078), is unusual in that its purpose has been to develop and make available a software package: the *Engineering Design Tools for Wind Diesel Systems*. Consequently the reports produced, in the main consist of documentation to accompany the software. For that reason the project reporting has been arranged as this first volume comprising an Executive Summary report, plus seven following volumes containing the documentation and other relevant material supporting the package.

This first volume functions as an introduction to the project and summarises its achievements and as an introduction to the following seven volumes.

Full details as to how to obtain the package and all accompanying documentation is given in Section 4 of this report.

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Abstract

This report describes the work undertaken, with support from the CEC under contract number JOUR-0078, to develop *Engineering Design Tools for Wind Diesel Systems*. These tools take the form of software specifically developed to assist the designers of wind diesel systems. They comprise two basic modules: first a *logistic modelling package* for overall system performance assessment, and second, a *modular dynamic model* for investigating the electro-mechanical stability of designs. The background, development and status of both elements is described in this report.

As an executive summary this volume provides an assessment of the project as measured against the original project objectives. It is shown that all the major objectives have been achieved and that an accessible and functional software package has been developed, together with detailed documentation. The validation work, undertaken as an integral part of the project, is reviewed.

The main project achievements are encapsulated in the following three sentences:

- * **The user-friendly software package *Engineering Design Tools for Wind Diesel Systems* has been developed and made available to users together with comprehensive documentation.**
- * **All the software and the models which make up the package have been validated.**
- * **A user testing exercise has been undertaken and the results used to improve the functionality of the package.**

Project management issues are discussed and the widespread dissemination of results is demonstrated. A full list of resulting publications is included. Details are given of a consortium agreement between the partners involved in the project, and a contractual agreement to facilitate public access to the software package. Some mention is made of the scope for further extension of the package.

Details of how and where to obtain copies of the software and documentation are provided.

Accompanying Reports

Final reporting to the European Commission consists of a series of documents, of which this report is in effect the executive summary. The complete list of reports, which include all user and program documentation for distribution with the software, is given below.

D Infield, A Scotney, P Lundsager, H Bindner, J Pierik, K Uhlen, T Toftveaag, M Falchetta, L Manninen, V van Dijk (1994). Engineering Design Tools for wind diesel systems - Final report for CEC Contract JOUR-0078. Volume 1 - Executive Summary. Rutherford Appleton Report RAL-94-001.

P Lundsager, H Bindner, D Infield, A Scotney, K Uhlen, T Toftveaag, J Pierik, M Falchetta (1994). Engineering Design Tools for wind diesel systems - Final report for CEC Contract JOUR-0078. Volume 2 - JODYMOD Dynamic Wind Diesel Simulation Software Package: Model Verification. Rutherford Appleton Report RAL-94-002.

P Lundsager, H Bindner, D Infield, A Scotney, K Uhlen, T Toftveaag, J Pierik, M Falchetta (1994). Engineering Design Tools for wind diesel systems - Final report for CEC Contract JOUR-0078. Volume 3 - JODYMOD Dynamic Simulation Software Package; Model Description. Rutherford Appleton Report RAL-94-003.

H Bindner, P Lundsager, D Infield, A Scotney, K Uhlen, T Toftveaag, J Pierik, M Falchetta (1994). Engineering Design Tools for wind diesel systems - Final report for CEC Contract JOUR-0078. Volume 4 - JODYMOD Dynamic Wind Diesel Simulation Software Package: Program Documentation. Rutherford Appleton Laboratory Report RAL-94-004.

H Bindner, P Lundsager, D Infield, A Scotney, K Uhlen, T Toftveaag, J Pierik, M Falchetta (1994). Engineering Design Tools for wind diesel systems - Final report for CEC Contract JOUR-0078. Volume 5 - JODYMOD Dynamic Wind Diesel Simulation Software Package: User's Guide. Rutherford Appleton Laboratory Report RAL-94-005.

D Infield, A Scotney, P Lundsager, H Bindner, J Pierik, K Uhlen, M Falchetta, L Manninen, V van Dijk (1994). Engineering Design Tools for wind diesel systems - Final report for CEC Contract JOUR-0078. Volume 6 - Logistic Package: User Documentation. Rutherford Appleton Laboratory Report RAL-94-006. (NB this report includes as a series of annexes the user documentation for the six models: RALMOD, WDILOG, SOMES, VINDEC, EWISDA and TKKMOD written by their program respective authors).

D Infield, A Scotney, P Lundsager, H Bindner, J Pierik, K Uhlen, M Falchetta, L Manninen, V van Dijk (1994). Engineering Design Tools for wind diesel systems - Final report for CEC Contract JOUR-0078. Volume 7 - Logistic Package: Validation Report. Rutherford Appleton Laboratory Report

RAL-94-007.

D Infield, A Scotney, P Lundsager, H Bindner, J Pierik, K Uhlen, M Falchetta, L Manninen, V van Dijk (1994). Engineering Design Tools for wind diesel systems - Final report for CEC Contract JOUR-0078. Volume 8 - Logistic Package: Program Documentation. Rutherford Appleton Laboratory Report RAL-94-008.

Readers are referred to the individual report documents for their contents.

The key members of the participating organisations and the contributions made by them are indicated by the authorship given for the various reports which together comprise the project reporting. The choice of first author generally indicates the major contributor or the manager of that section of the work. Hence the coordinator's name does not always appear first. It does so where Rutherford Appleton Laboratory (RAL) made the major contribution to that element of the work.

1 Introduction

This report describes the work undertaken for the project; 'Engineering Design Tools for Wind Diesel Systems', carried out under contract JOUR-0078 in the JOULE programme. Initially funds were provided to support two years of work, although the level of funding had entailed a restriction of the project objectives in comparison with the original two proposals (from RAL and RISO) which merged to form the project. Additional funds were later provided from the JOULE programme to enable a one year extension and an enlargement of the scope and depth of the work. For clarity the reporting and discussion of the project will refer to the extended three year contract and the revised objectives.

The project participants are:

- * Rutherford Appleton Laboratory, UK (Coordinator)
- * RISO National Laboratory, Denmark
- * ECN, The Netherlands
- * EFI, Norway
- * ENEA, Italy
- * TKK, Finland
- * University of Utrecht, The Netherlands

Technical and economic details follow:

Duration	:	36 months	:	1 October 1990 - 30 September 1993
Total budget	:	1,219,650 ECU		
CEC contribution	:	450,825 ECU (37%)		
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All partners except the University of Utrecht (acting under sub-contract to ECN) were either contractors or associated contractors. Two of the participants: EFI and TKK are based in an EFTA country and participated in the project along the lines agreed between EFTA and the CEC.

1.1 Direct national funding contributions

Only 37% of the total project funds were provided by the CEC, the balance being provided by national funding organisations. These direct national co-funding contributions amount to 768,825 ECU. Rutherford Appleton Laboratory contributed 196,500 ECU on behalf of the UK's Science and Engineering Research Council. Denmark's Ministry of Energy provided 142,000 ECU under ENS Jour No: 1363/90-0008. ENEA contributed 24,000 ECU, and ECN provided co-funding of 88,325 ECU. The EFTA research contribution to the project was fully funded by the countries involved: The Norwegian Research Council provided 175,000 ECU and TKK through Finland's Science Research Fund contributed 143,000 ECU.

2 Project summary

Two distinct software modules have been developed: first a *logistic modelling package* for overall system performance assessment, and second, a *modular dynamic model* for investigating the electro-mechanical stability of designs.

Since the project has developed a substantial amount of new software expressly with the aim of being user-friendly, the reporting of this project includes also the user and program documentation for both modules as well as reports on the validation studies. For convenience these have been included as separate reports as listed early on in this report.

The software has received some degree of user testing as part of the project. As far as possible modifications resulting from user's comments have been incorporated in the final release version. Arrangements have been made for one of the participants (EFI of Norway) to distribute the software and accompanying documentation at a nominal charge to cover copying and distribution costs.

A consortium agreement has been drawn up by the coordinator in conjunction with all the project participants. This has been signed by representatives of all the participating organisations. It specifies the assignment of intellectual property rights (IPR), and the terms and conditions for distribution and further development of the software.

2.1 Comparison of work done with work proposed

It is always important at the completion of a project to assess to what extent the initial objectives, specifically those detailed in the original work plan of the project proposal, have been fulfilled.

2.1.1 Summary of objectives (including those agreed for the extension to the project)

- i) provision of a fully developed and validated software package (the first module) to assist engineers in the design of wind diesel systems with regard to overall (ie logistic) performance with the ultimate aim of evaluating the fuel savings, energy supply capabilities and the economy of prospective wind diesel systems
- ii) develop a modular computer simulation model (the second module) to represent the dynamics of wind diesel systems with the aim of evaluating the frequency and voltage variations as well as system stability and control

Together both modules should enable system designers to proceed in a logical way towards system specification, and in particular to ensure that the sizing, operation and regulation of system components is appropriate to the conditions and requirements of the specific application in question. In turn this will give rise to systems which make the best use of the available hardware and are more cost effective.

2.1.2 Specific tasks for logistic package development

- * development of menu driven user interface, and associated software (known in total as the "shell")
- * further development of the six national models and adaptation to conform to the shell specification
- * specification of component, system and control parameterisation
- * development of algorithms for synthesising wind and load data, and subsequent coding for incorporation into the shell
- * development of simplified wind turbine and diesel generator set parameterisation
- * development of model output routines including interactive graphics
- * development of on-line help facility
- * collection of data from wind diesel systems suitable for model validation - to cover systems with different energy storage systems
- * validation of all six embedded models and further model development where necessary
- * writing comprehensive documentation for all embedded models and for the shell software
- * writing a user guide

All these objectives have been achieved. In addition a user testing exercise and evaluation was carried out. Questionnaires were distributed with an early release of the software. Annex A of this report presents the results of the appraisal. Overall, trial users were very satisfied with the software which they found easy to use and well suited to their needs.

2.1.3 Specific tasks for dynamic model development

- * formulate multi-machine electrical model in a modular form
- * formulate modular description of mechanical components based on finite element formalism
- * appropriately interface mechanical and electrical elements of a system model
- * develop a general single bus-bar representation of the local electricity supply grid
- * provide appropriate wind and load inputs to the model
- * develop a model building algorithm to support a truly modular model
- * facilitate solution of the differential equations using routines from CYPROS (ESIM)
- * develop a component library to cover induction generators, synchronous generator, voltage controllers etc
- * provide a menu driven user interface to the model
- * collect data from wind diesel systems for model validation purposes
- * validate model against experimental data and also against a more detailed (but more restricted) electrical model (AWIDIMOD) developed by ECN
- * write a comprehensive explanation of model including the background theory
- * write a user guide

All of the objectives have been achieved. It was found that the dynamic model (JODYMOD) could be run successfully from MSDOS. Hence, both modules (logistic and dynamic) of the complete package have been implemented for a PC platform operating under MSDOS. Due to the present wider availability of PC's this option was preferred to an application running under UNIX on a workstation. Printing to PC compatible printers is supported (including graphic screen dumps), as is plotting to HPGL compatible plotters.

2.2 Summary of project achievements

- * The PC based user-friendly software package *Engineering Design Tools for Wind Diesel Systems* has been developed and made available to users together with comprehensive documentation.
- * All the software and the models which make up the package have been validated.
- * A user testing exercise has been undertaken and the results used to improve the functionality of the package.

The package consists of two main modules and a range of additional facilities. The main features are listed below.

- * A logistic modelling package (WDL) supporting six wind diesel models (which had previously been developed by the project participants)
- * A modular dynamic model (JODYMOD)
- * Menu driven user interfaces for both modules (Figure 1 shows a menu from WDL and Figure 2, a dialog box from JODYMOD)
- * Comprehensive model output facilities
- * Interactive graphical facilities for both modules (see Figures 3 and 4 for example outputs from WDL and JODYMOD respectively)
- * Routines for synthesising load and wind data
- * Routines for creating realistic components for both logistic and dynamic modelling purposes
- * Facilities to allow the user to create components based on available data
- * Editing routines
- * A facility for importing data files

Arrangements are in place to allow users free access to the complete package (only a

handling charge will be made to cover the cost of printing the documentation and distributing this together with the software). Agreements have been made to ensure that embedded proprietary software can be used at no cost to the user.

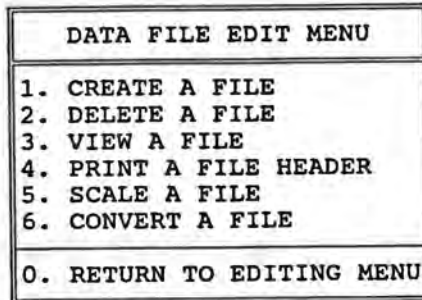


Figure 1 : Menu Driven User Interface for WDL

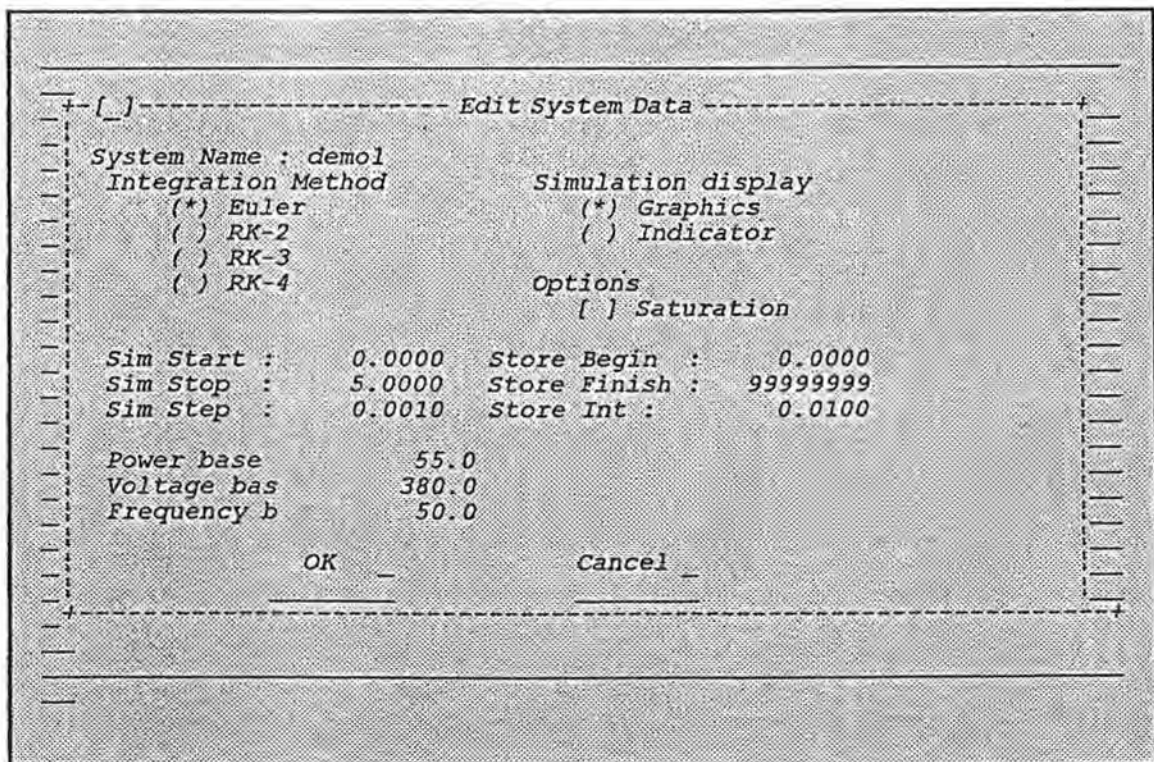


Figure 2 : Dialog Box from JODYMOD

2.3 Brief comment on status of package and future development potential

Trial users covering a wide range of countries, mostly within Europe, but also including some developing countries, considered the logistic modelling software to be both easy to use and effective. The modular dynamic model which was developed from scratch during the project, received less user assessment due to development timescales, but is clearly a very powerful tool for wind diesel designers.

Neither module has benefitted from the attention of professional software designers and hence could not be expected to reach the standards of presentation and robustness of professional software. The CEC's VALUE programme has been contacted to see if support can be found to carry out this last stage of the software development. Whether there is a market for the software depends on the expansion of the wind diesel market itself, which in turn depends on the series production of proven and cost effective designs. It is expected that the software developed in this project will considerably assist manufacturers in this regard.

There is considerable scope for expanding the technical scope of the models, to include for example, photo-voltaics, wave energy and hydrogen systems. Extensions of the component libraries would require further research and development. Potential also exists to extend the scope of the models to cope with more complex systems such as island power systems with a high penetration of renewable energy. This too would require additional research and development but would be well worthwhile.

3 Overview

3.1 Introduction

Worldwide there is a vast potential for renewable energy to supply electricity to communities not connected to a central electricity distribution system. This is sometimes covered by the term: *rural electrification*. Wind diesel technology has a significant role to play as part of meeting this demand.

Wind diesel systems pose significant design problems. To some extent a lack of suitable design tools has inhibited the development of the technology to date. It is essential that the system designer can technically evaluate a design and assess the performance that would be expected if a particular system was to be installed on a specified site for a defined application. Up until now the designers' inability to do this properly has resulted in systems being installed that have not performed as expected. In a number of instances the resulting fuel savings have been too low to result in an economically viable system.

Wind diesel is the term applied to systems in which wind energy accounts for a significant proportion of the total energy supplied such that the wind energy input has a marked impact on the operation of the diesel plant. Indeed it is often necessary to include energy storage in such systems so as to make the operational conditions for the diesel plant acceptable. The interaction between the major system components; wind turbines, diesel generators and energy storage, taken together with the effects of the control system, present a complex problem. Design tools are required to estimate the overall performance in terms of diesel fuel consumption, diesel on/off cycling rate, as well as the stability and quality of supply of these systems and because of this complexity these tools need to be fairly sophisticated.

Also, because wind/diesel systems are applicable to remote sites where assessment of the requirements and the wind resource can be difficult, only limited information will usually be available to the system designer. The situation is further complicated by the range of different wind/diesel system configurations and in particular, a range of different storage technologies with contrasting technical characteristics. All this makes the provision of such design tools an important but technically difficult undertaking.

In order to assist in the provision of suitable design tools the CEC JOULE programme has supported the development of *Engineering Design Tools for Wind Diesel Systems*. These tools take the form of software specifically developed to assist the designers of wind diesel systems.

Two distinct software modules have been developed: first a *logistic modelling package* for overall system performance assessment, and second, a *modular dynamic model* for investigating the electro-mechanical stability of designs.

A project management structure was adopted to reflect the fact that the project resulted from the merging of two proposals. These were to be coordinated by RAL and RISO, and dealt with logistic and dynamic modelling aspects, respectively. It was agreed that RISO

would undertake the day to day management of the dynamic model development. This was consistent with their planned contribution to the programming of the dynamic model user interface. Direct management of the logistic package would be the responsibility of RAL, who were to undertake the programming of the logistic package user interface. Overall project management, including the planning of model validation, was the responsibility of RAL as the coordinating organisation. Figure 5 shows the management structure adopted and the relationship between the participants. Effective project organisation is especially important when many participants are involved. Section 6 deals with this aspect of the project in more detail.

The software has received some degree of user testing as part of the project. As far as possible modifications based on user comments have been incorporated in the final release version. Arrangements have been made for one of the participants (EFI of Norway) to distribute the software and accompanying documentation at a nominal charge to cover copying and distribution costs. Details of how to obtain the *Engineering Design Tools for Wind Diesel Systems* are given in Section 4 of this report. Use of the software is subject to certain restrictions to protect the rights of authors of the software and protect the suppliers of embedded proprietary software. Full details will be supplied with the software and documentation.

The consortium agreement agreed between the participants specifies the ownership of any intellectual property rights (IPR), and the terms and conditions for distribution and further development of the software.

3.2 Logistic modelling package

At the start of the project the individual participants had already developed their own computer models for assessing the overall performance of wind diesel systems. These different models were developed in the context of the various national research programmes and reflect the designs and configurations adopted by the research teams. Furthermore, the models had been developed in the main as research tools with a consequent lack of user interface. A notable exception was the Dutch logistic model SOMES, developed at the University of Utrecht, as a commercial product. The Italian logistic model E_WISDA results from extensive modification (undertaken specifically for this project) of the proprietary code WISDA.

The approach proposed was to take the existing national models (one from each participant) and create a common user interface. This interface should enable the design engineer to create components and systems and model them without having to learn how to use the individual models directly. In addition, the user interface would incorporate many other facilities to assist the user in defining an application for assessment, and for interpretation of results.

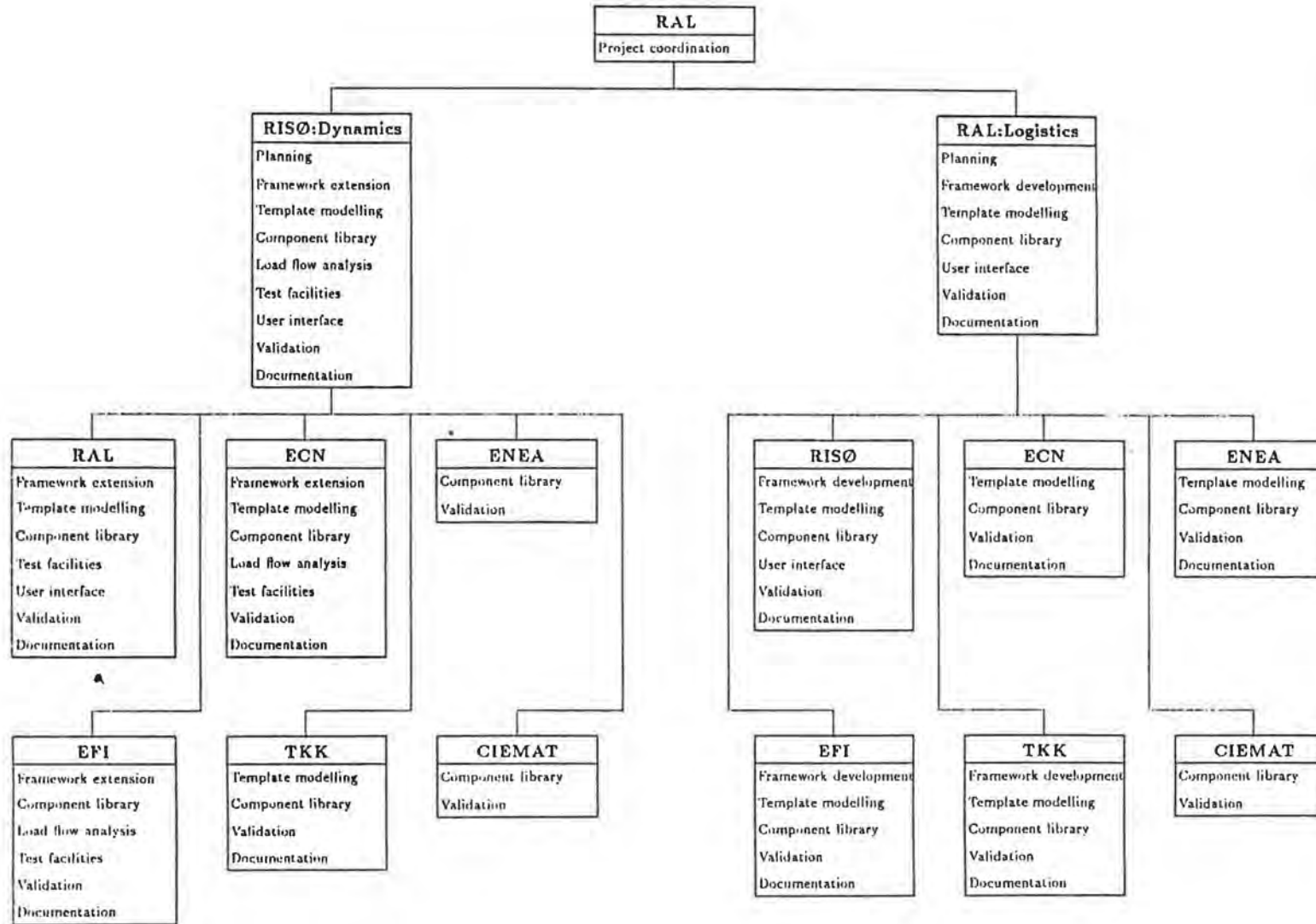


Figure 5 : Project Organisation Schematic

In many instances the system design engineer will have very limited data on the site for which the system is being developed. Remote sites are often very poorly documented with limited, or non-existent, wind and electricity load data. To help the designer around these difficulties the package would incorporate a number of facilities such as data synthesis routines.

In order to satisfy these general objectives and make the package user-friendly a substantial amount of new software has been written. In particular the whole package is menu driven and supports an extensive help facility. Comprehensive documentation has been written as part of the project to complement the software itself.

The logistic modelling package has been subject to extensive validation. Experiments were designed and data collected from two instrumented wind diesel systems, as a major part of the project work. Each model accessible from the package has been individually assessed. The results from this exercise are presented in the RAL report: RAL-94-007.

Overall the conclusions are that considerable confidence can be placed in the prediction of diesel fuel savings by the package. This is the most important parameter the designer needs to know when assessing the economic viability of a given design.

Obviously some of the embedded models perform better than others for a particular application. The strengths of the various models tend to reflect the original systems for which the models were developed. For example a model developed expressly to model systems based on short term flywheel energy storage (such as RALMOD and WDILOG) generally perform better in modelling such a system than models developed with battery storage in mind. The detailed documentation on the individual models, which is included in the user documentation of the package (in the Appendices) assist the user in choosing the most appropriate models.

A strength of the package is, notwithstanding the comment above, that the user can gain an improved perspective by running different models against the same input specification. Provided the models chosen are considered suited to the particular application, the expected consistency of the results should give confidence in the model predictions, and the level of discrepancy can be taken as an indication of the accuracy associated with the predictions. After all a good design engineer will want to know both the predicted performance of the design in question, and the likely error attached to that prediction.

Neither module (Logistic modelling package or the Modular dynamic model) has benefitted from the attention of professional software designers and hence could not be expected to reach the standards of presentation and robustness of professional software. The CEC's VALUE programme has been contacted to see if support is available to undertake this final stage of the software development. Whether there is a market for the software depends on the expansion of the wind diesel market itself, which in turn depends on the series production of proven and cost effective designs. It is expected that the software developed in this project will considerably assist manufacturers in this regard.

There is considerable scope for expanding the technical scope of the logistic packages, to include for example, photo-voltaics, wave energy and hydrogen systems. Extensions of the component libraries would require further research and development. Potential also exists to extend the scope of the logistic package to cope with more complex systems such as island power systems with a high penetration of renewable energy. This too would require additional research and development.

In summary: trial users covering a wide range of countries considered the logistic modelling software to be both easy to use and effective. Both researchers and commercial consultants were involved in the exercise. Both these groups saw the product as being a definite asset to them in their work, and requested access to the package when the final release is made. Some other researchers have expressed an interest in further development of the package so as to assist them in exploring more general systems incorporating renewable power sources such as wave and photo-voltaic.

3.3 Modular dynamic model

From the outset the intention has been to develop a truly modular and fairly general electro-mechanical model suited to the needs of wind diesel systems. Modular electrical models had been available for some time, as had Finite Element models for mechanical analysis. What was not available was a suitable model combining both these elements at a high enough level to allow a proper investigation of stability and power quality issues for a wind diesel design. Over-simplified modelling could be misleading and the experience of the researchers had already indicated that more detailed aspects of electrical generator operation, such as saturation, are most important in a wind diesel context.

The dynamic model JODYMOD (for JOule DYnamic MODular MODEL) is based on a concept similar to the finite element method (FEM) in structural mechanics, where the equations of a model are built by the program according to the user's system specification. The proprietary simulation program Cypros/ESIM has been chosen as the environment for the model. The model is modular in that it gives the user the opportunity to build a system model by combining a set of available component models. The component model library includes mechanical models and electrical machine models. Each component has inputs and outputs, and a connectivity vector is used to connect the outputs to the inputs in order to build the system equations.

The electrical machine models allow the machine equations to be solved in a matrix structure suited for automatic assembly. Synchronous and induction machines are represented, and saturation of the electrical machines is dealt with by an iterative process operating on the entire electrical system equations. Mechanical components such as wind turbine drive trains, diesel generator assemblies etc are represented by FEM type equations. Mechanical components are linked to the electrical machines through the air

gap torque. A routine is included that allows the user to define models of rotational systems with gears, with an option to represent a suspended gearbox and a synchronous flywheel. The user may also input the structural matrices directly.

JODYMOD is able to combine a number of component types into a working model. A pre_release (beta version) of JODYMOD has been tested for some time by selected users as part of a validation exercise. Results from this exercise are included in the dynamic model validation report (RAL-94-002).

The commercially available time history simulation package Cypros/ESIM has been chosen as the environment for the model but the model may be run outside the Cypros environment by users who prefer to establish their own environment. The Cypros environment was chosen as it has already been used by EFI and Risø for some of their models. ESIM provides a number of time integration schemes for solving 1st order differential equations. These are built up by JODYMOD, which itself is written in Fortran 77.

The model provides (via ESIM) a number of data handling and time history processing capabilities in addition to a quite powerful graphics package. The Project has negotiated licensing and application agreements with the proprietors of Cypros, (see Annex C of this report).

Modularity: The function of the model is to combine the components of a given system into a total system. The core of this problem is to combine the equations for each of the components into a total system of equations for the entire physical system in question. This feature is expressed by the term "modular". Each *module* or element within the available range of components may be combined with other *modules* of the same or other types to form a total system. JODYMOD is not a program that needs to be recompiled every time a new model is formulated, and neither is it restricted to a limited number of "precooked" models coded into the program once and for all.

The central activity was to develop JODYMOD's capability to build the system equations in a given run according to the user's specification of the system to be simulated in that particular run. This capability is based on a specification of the structure of the equations of each component type. On this basis JODYMOD assembles the system equations without recompilation, into a structure suitable for numerical solution.

In summary: a fully modular model (JODYMOD) has been developed representing both the electrical, mechanical and control aspects of general systems at a sufficiently high level to make a powerful tool for wind diesel system analysis. A user interface with pull-down menus facilitates access to the model. A successful validation exercise has been undertaken. Comprehensive documentation has been written.

4 Arrangements for software distribution

Since the major activity of the project has been the development of user-friendly software to assist the designers and developers of wind diesel technology considerable stress has been placed by the project team on the arrangements for effective distribution of the software. It has been decided by all the participants that the results of this project should be made available as widely as possible. Many wind diesel applications will be found in the developing world so to restrict use of the software to European nationals would seem unreasonable. Restrictions of this sort would in any case be difficult to enforce.

Although no funds currently exist to enable formal support of the software, informally the project team will remain in contact and seek to regulate future development of the models. Researchers will be dissuaded from circulating locally modified versions of the software. It is hoped that future revisions, if they occur, will be coordinated properly and documented accordingly. The nominated supplier of the authorised version, EFI, should be the only supplier to avoid confusion. It is hoped that future funding from the CEC or elsewhere will enable proper further development of the package. Too often in the past software arising from research projects becomes unusable due to lack of proper support and an appropriate support infrastructure.

Some proprietary software is used or embedded in the package. To protect the suppliers as well as the IPR attached to individual logistic models certain conditions of use will apply. Furthermore, to clarify the IPR and the relationship between the different participants, a consortium agreement has been entered into by all of the contractors and associated contractors. A copy of this agreement is included in this report as Annex B. In addition a draft legal agreement has been drawn up with CAMO, the suppliers of CYPROS. A copy of this is provided in Annex C of this report.

All software and documentation is to be distributed by EFI (the Norwegian Electrical Power Research Institute which is part of the SINTEF group). They will charge a handling fee to cover printing of the documentation and distribution costs (which will periodically be adjusted to reflect changes in these costs). Bearing in mind that the documentation will consist of a number of large volumes, this cover charge would be expected to amount to a few hundred ECU.

The software itself is being provided at no cost to the user. Certain restrictions apply to use of the software, in particular to protect the suppliers of embedded proprietary code. Full details will be supplied with the software and the user will be requested to acknowledge conformity with the conditions of use. It is important that users realise that all use of the software is covered by a disclaimer (see inside front cover of this report, and also overpage).

The software and documentation is available from:

**Engineering Design Tools for Wind Diesel Systems
EFI
DATA SERVICE CENTRE
N-7034 Trondheim
Norway**

***** DISCLAIMER *****

Neither EFI, nor any of the project participants can be held responsible for any actions taken on the basis of results obtained from the models. No guarantee is provided by the coordinator or any of the project participants with regard to any aspect of the software or documentation. The software is being made available at no cost to users on the basis of good will, in the hope that it can assist workers and consultants working on wind diesel design.

Project participants are under no obligation to support the software. No funding has been made available for this purpose. However the contact addresses, telephone numbers and FAX numbers of all participants are presented here. In practice the researchers involved will do their best to deal with specific enquiries. They will also wish to be informed of any difficulties and problems which may be encountered by users so that these could be remedied in any possible future releases of the software.

5 Project management

As indicated in section 3.1, a project management structure reflecting the two, to some extent, distinct elements of logistic and dynamic model development. Most participants were involved with both elements of the project. TKK in Finland and the University of Utrecht of the Netherlands confined their participation to the logistic package development. Figure 5, of Section 3 shows the relationship between the participants.

It will be apparent that the software development demanded a truly collaborative approach. No neat sub-division of activities between participants could always be established. A number of critical, but detailed, developments required contributions from more than one participant working closely together. The project is inherently inter-disciplinary, bringing together as it does key elements from both electrical and mechanical engineering with mathematics and computer modelling at a high technical level.

It is fair to say that no one research group, or sub-group, could have produced the developments alone. The final *Engineering Design Tools Package* is very much a team product. To manage this type of project is not straightforward, especially given the number of participants. Regular project meetings were required. Opportunities were taken to arrange meetings to coincide with European Conferences and Contractors' Meetings so as to minimise costs. Plenary meetings were serious affairs lasting up to four days. A number of sub-group meetings were also found necessary to facilitate solution of particular technical problems. All meetings were documented and minutes with actions and timescales circulated.

Working documents were circulated to all participants involved with the activity. Frequent communication between all participants also took place by FAX and telephone and email.

5.1 List of Project Meetings

- * Plenary project meeting : RAL, Chilton, UK; 29-31 October 1990
- * Plenary project meeting : EFI, Trondheim; 18-22 February 1991
- * Plenary project meeting : RISO, Roskilde, Denmark; 18-21 April 1991
- * Contractor's meeting and plenary project meeting : Maastricht, The Netherlands; 14 June 1991
- * Plenary project meeting : ECN, Petten, The Netherlands; 10, 11 & 14 October 1991.
- * Plenary project meeting : ENEA, Rome, Italy; 28, 29 May & 1 June 1992 linked to contractors' meeting in Algebro.
- * Plenary project meeting : TKK, Helsinki, Finland; 23-26 October 1992

- * Plenary project meeting : Travemunde, Germany; 9 March 1993
- * Plenary project meeting : RAL, Chilton, UK; 9 June 1993
- * Final plenary meeting: ENEA, Rome, Italy; 9-10 September 1993

6 Dissemination of results

Since the *Engineering Design Tools for Wind Diesel Systems* were developed specifically with the potential users in mind, a continuing dialogue between the project team and the emergent wind diesel industry has been essential for the appropriate development of the software. Interested parties have been kept up to date through presentations to national and international wind energy conferences, including the European, EWEA and ECWEC, events. Different members of the team have presented updates on developments to wind diesel workshops in Europe and North America. Direct contact has been kept with the industry through the many contacts of the different members of the project team. A comprehensive list of reports, presentations, conference proceedings and learned journal papers is given in Annex C of this report. The spread and the depth of this activity indicates the commitment to dissemination felt by the team as a whole.

The user testing exercise reported in Annex A is further evidence of the project's determination that the software should receive the widest possible distribution and be developed in accordance with the wishes of potential users as far as possible within the limitations of time and resource.

Contact has been established with the CEC's VALUE programme with a view to market appraisal and possible further development of the package. Prior to any possible commercial distribution the package would need turning into professional software with expected standards of robustness and with state of the art interface. This would probably mean it would need developing as a Windows application of some sort with a fully graphical user interface. The cost of undertaking this development, probably through a software house, should not be underestimated.

7 Recommendations for future work

The recommended future work can be conveniently divided into two distinct activities. First there is the production of a truly commercial product based on the existing software and second, the extension of the scope of the models.

7.1 Production of a commercial version

As has been indicated previously in this report, the software package which will be distributed by EFI on behalf of the project consortium, falls short of being a truly commercial package. This is not to say that the project has failed to deliver a user friendly software package for wind diesel system design, rather that the final product has been developed by engineers, not professional programmers. Consequently the package is not completely robust: a poorly specified input by the user can lead in some instances to run time errors.

Furthermore, the software was developed for a PC platform with widespread and affordable applications in mind. At the commencement of the project it was not feasible to create the package as a Windows application. With suitable programming effort this could now be done, and in particular a graphical user interface could be considered to replace the exclusively menu driven interfaces of the current version. The programming effort required to provide such a professional user interface should not be underestimated. Whether the activity would be justified would depend very much on the demand for such software. As already mentioned the CEC's VALUE programme has been approached to see whether appropriate assistance could be provided to the consortium. Initially market surveys will be required. However, the main uncertainty affecting the need for such software relates to the demand for wind diesel systems.

Currently the vast potential market for wind diesel systems is not being realised for two main reasons. First, there is a lack of replicated, and hence more cost effective, systems; and second, the people who could benefit from wind diesel technology do not have the resources, in particular the capital, required to purchase it. Whether significant progress will be made on the latter front depends much on intergovernmental agencies, lending institutions and organisations with the resources to create a suitable framework for the users to gain access to the technology without incurring crippling debt.

The take-up of the current release of the software will be monitored over time to assess the potential demand for a professional version.

7.2 Extensions to the package capabilities

The software was developed specifically for wind diesel systems. Some of the national models had originally a wider scope but have been deliberately cut down to conform to the shell specification which is consistent with the project remit. However, over the course of the software development, and as a result of dissemination activities, it has become

apparent that other parties would like to see the package extended to cover a wider range of renewable energy systems. The particular technologies that have been mentioned include:

- * photovoltaics
- * hydrogen generation (electrolysis)
- * fuel cells
- * wave energy conversion devices
- * Stirling engine generators
- * mechanical continuously variable transmissions

In addition there is a general pressure to extend the logistic modelling to multi-diesel systems and so extend the range of application up to small island systems. For the dynamic modelling the range of applicability could be widened considerably if multiple bus-bar systems could be modelled. This is not however a straightforward extension.

Whether these further developments should be undertaken should, again, be dependent on the demand from the research, consultancy and industrial sectors.

The software developed so far has been well documented with future developments in mind. Furthermore, it is planned to keep intact the expertise developed jointly by the project team by regular informal contact. A framework has been agreed to facilitate any future updates and releases and to control the development of circulating versions. This will be made clear to all recipients of the software. Necessary restrictions will be specified in the conditions of use, as supplied with the package.

8 Acknowledgements

The work undertaken for this project has drawn heavily on previously funded work in the participating countries. A prior collaborative exercise, supported internationally as part of the International Energy Agency (IEA) Annex VIII on stand alone wind systems, underpinned much of the software development of the present work. The project team was formed out of the larger IEA Annex VIII membership. The debt to all those involved in the IEA activity is acknowledged.

The named participants in this project have in most instances received additional support from colleagues in their own institutions. Their contributions should not be forgotten.

Finally two people were involved in the early stages of this work but were not able to continue with the project team until the completion of the work. Jan de Bonte, formerly of ECN, contributed to the project proposal but then moved on to a new employer. His important contributions to the field of wind diesel are recognised by all of those involved in the subject. Also, Oyvin Skarstein, formerly of EFI, played a significant role in the early phases of the project.

Annex A : User testing report

As already described, the project team decided to send out a prototype version of the Logistic Modelling Package in early 1993. A total of eleven independent users were approached - detailed reports were received from six of them. This Annex lists (in Section 1) the questionnaire which was sent out with the software and (in Section 2) a summary of the answers received. The project team are very grateful to the following individuals and institutions for the time and trouble they took to evaluate the software and to report their conclusions.

Thomas Degner, Universitat Oldenburg, Germany
Ubaldo Ncera, Conphoebus s.c.r.l., Italy
James Manwell, University of Massachusetts, USA
Richard Cullen, Imperial College, London, UK
Hans Belijs, University of Leicester, UK
Jami Hossain, Tata Energy Research Institute, India
CRES, Greece

It can be seen that the general conclusion was that the package was very useful. Some improvements were suggested - indeed, this was to be expected given that the software was a prototype version. Many of these suggestions have been included in subsequent versions of the software, though clearly the more major items, such as moving to a Windows environment, were outside the scope of the current project.

QUESTIONNAIRE ON LOGISTIC MODELLING PACKAGE

BACKGROUND

As part of the development of the Engineering Design Tools (Logistic Modelling Package) a pre-release version is being made available for testing, together with limited documentation. We would like you to assist in this process by completing this questionnaire.

When completed please return to (ideally by 31st May 1993)

Andrew Scotney
Energy Research Unit (R63)
Rutherford Appleton Laboratory
Chilton
DIDCOT
Oxfordshire OX11 OSN
UK

If you have any questions please contact Andrew

FAX:	+44 235 446863
Telephone:	+44 235 446134

USER DETAILS

name

organisation

address

telephone

fax

EMAIL

COMPUTER DETAILS

make and model

DOS version

were there any problems installing the package ? if so please give details

TUTORIAL PACK

did you find the pack helpful ?

any suggested improvements ?

SHELL SOFTWARE

were there any shell runtime errors ?

if so please list them

error code

error address

circumstances of error

How easy to use did you find the shell menu structure ?

What further on-screen aids would facilitate user-friendliness ?

How effective were the shell facilities in the following areas ? please make suggestions for improvement where appropriate:

1 data file handling and creation

2 component specification and editing

3 system specification

4 undertaking a simulation

5 output presentation

6 general comments on shell

HELP FACILITIES

did you find the help structure useful ?

please comment on the contents

SIMULATION MODELS

please list the models you used

please list any model runtime errors

model	error code	error address	circumstances error
--------------	-------------------	----------------------	----------------------------

NB it could help to supply us copies of standard input files which gave rise to model errors

A.2 Summary of User's Views

Item	Degner	Nocera
Ease of installation	No problems	No problems
Tutorial	Useful. A "quick start" procedure could be added	-
Shell runtime errors	None	Two minor errors
Shell	Easy to use when the user is familiar with the package	Easy to use. Suggest that there more graphical output
Component specification	Easy to do. Suggest that a warning be given if wrong components are combined in a system	The shell is very useful in editing and managing the input data. Suggest more graphics be included when configuring the system specification. Could not define a large diesel
Output	Fine. Had minor difficulties with graphics	OK. Suggest could have graphics of time series data, eg power
Help facilities	Very good	-
General comment	Useful package	Appreciate the logic of the shell, though had some difficulty with some of the individual models

Item	Manwell	Cullen
Ease of installation	No problems	No problems
Tutorial	Useful. Request more information about individual models	Useful
Shell runtime errors	1 - when "playing with engine specifications"	Several - notified in detail
Shell	Easy to use. Suggest more graphical displays	Fairly easy to use. Found similar looking menus a little confusing
Component specification	"Overall pretty good". Request more information about requirements of the individual models	"Data handling and file creation aspects are very good". Suggest more "Help" on component specification be included
Output	Nice graphics. Suggest it would be useful to display time series graphs as well	"Good with full analysis".
Help facilities	Would like more information on the various models	Suggest there be more information about individual models
General comment	Suggest should upgrade to a full Windows environment	Suggest should upgrade to a full Windows environment

Item	Bleijs	Hossain
Ease of installation	No problems	No problems
Tutorial	OK. Request graphical display of configurations	Useful
Shell runtime errors	None	None
Shell		"It was fairly easy and trouble free". Suggest pull-down menus
Component specification		Data handling and editing was effective. Suggest help could be enhanced. Could not simulate a large diesel (> 120 kW)
Output		OK. Suggest that the definition of some of the terms, eg Diesel efficiency, could be clarified
Help facilities		OK. Minor improvements suggested
General comment	I am afraid that due to a lack of time, I was unable to test the package as fully as I wished	"The shell works and is a very useful tool for planning hybrid and integrated systems". Suggest clear definitions of technical terms should be included in documentation

Item	CRES
Ease of installation	No problems
Tutorial	Useful. Suggest more graphics could be included and more information on system file creation and control parameter configuration
Shell runtime errors	None
Shell	"Helpful and easy-implemented"
Component specification	"Excellent data file handling and creation". "Component specification rather easy, though some more details regarding help would be useful". Suggest that the meaning of the control parameters should be clarified
Output	OK. Suggest more explicit graphs be included, eg diesel fuel consumption versus diesel power
Help facilities	Suggest more information on system file creation and control parameters should be included
General comment	"Shell was very helpful and easy-implemented"

Annex B : Consortium agreement

A consortium agreement was formed, early on in the project, between all the organisations participating contractually in the project; it takes the form of the document reproduced below. The intention of this legally binding understanding was to provide an agreed formal framework to facilitate the joint development of the software package whilst protecting the intellectual property rights (IPR) of the individual participating organisations. It also, in conjunction with the agreement with CAMO (see Annex C of this report), seeks to lay down a framework for future development and exploitation of the software. Correctly, the CEC stresses the importance of such agreements in order that the best use be made of the developments they have helped to support, in this instance the package known as *Engineering Design Tools for Wind Diesel Systems*.

Since the package is very much a joint product the overall intention is that no one participant (or sub-group of participants) should use the source code, or further developments of that code, for commercial gain, at the expense of or without the agreement of the other participants. This in no way is meant to inhibit project participants from singly, in groups, or together with other researchers who have not been involved with this project, from undertaking further developments of the package. Indeed, as indicated in Section 8, such developments could be most worthwhile, and should be encouraged.

A related informal understanding between all the participants is that further, official releases of the package (ie through the nominated distributor, EFI) should only be made available subject to the agreement of all those having IPR. The circulation of unauthorised versions of the code is discouraged as this could cause confusion amongst users and possibly invalidate the effort that has been put into accurate documentation.

CONSORTIUM AGREEMENT

BETWEEN

The Science and Engineering Research Council (SERC), Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, OX11 0QX, England.

RISO National Laboratory, 399 Frederiksborgvej, 4000 Roskilde, Denmark.

Netherlands Energy Research Foundation, Westerduinweg 3, 1755 Petten Le, The Netherlands.

Helsinki University of Technology, NEMO - programme, Otakaari 3, 02150 Espoo, Finland.

EFI, N-7034 Trondheim, Norway.

ENEA, Vile Regina Margherita 125, 00198 Roma, Italy.

WHEREAS

- The Commission of the European Communities in the frame of its JOULE Programme has awarded a Contract (No JOUR-0078-C) entitled "Engineering Tools for Wind Diesel Systems" to the Parties hereinabove nominated,
- The Parties hereinabove nominated, having a large experience in the field concerned, have decided to execute the Contract awarded by the Commission.
- The Project JOUR-0078-C as defined in Annex I of the EEC Contract comprises the following objectives:-
 - a. The development of a logistic modelling package based on existing national models, embedded in a common programme (some using the package CYPROS).
 - b. The development of a dynamic model making use of CYPROS.
- The Parties hereinabove nominated, wish to define a framework for agreeing on the ownership, exploitation and commercialisation of results arising out of the Project.

Now therefore it is hereby agreed as follows:

1. With regard to the logistic modelling the Parties will retain full rights over their own existing models.
2. The logistic package code together with embedded national models, will be regarded as the joint property of the Parties.
3. Decisions regarding the distribution, sale or use of the logistic package will be made jointly by the Parties and will be finalised prior to completion of the Project.
4. Allocation of the intellectual property rights relating to the logistic package will be decided, if required by the Parties.
5. Decisions regarding the distribution, sale or use of the dynamic model will be made jointly by the parties and will be finalised prior to completion of the Project.
6. Allocation of the intellectual property rights relating to the dynamic model will be decided, if required by the Parties.
7. Any disputes or differences arising in connection with this Agreement which cannot be settled amicably between the parties, shall be finally settled under the Rules of the Conciliation and Arbitration of the International Chamber of Commerce.
8. Nothing in this Agreement shall detract from the rights of the Commission or the Parties under the EEC Contract.

Annex C : Draft legal agreement with CAMO

CAMO are the owners and suppliers of CYPROS/ESIM which is used by WDILOG (the Danish model) and VINDEC (the Norwegian model), by WDL (the logistic modelling package), and more importantly, by JODYMOD the dynamic model. Clearly an agreement with CAMO is required if users of the *Engineering Design Tools for Wind Diesel Systems* package are able to use the code freely without having to negotiate individually with CAMO.

It should be stated that the document copied here is only a draft. Restrictions on users outside the CEC are unlikely to appear in the finalised version. Any relevant aspects of the final agreement will be made clear to recipients of the software.

AGREEMENT ON THE USE OF CYPROS/ESIM WITHIN JOULE PROJECT ON LOGISTIC AND DYNAMIC MODELLING OF COMBINED ELECTRICAL-MECHANICAL SYSTEMS

With reference to earlier communication on the matter, in particular our letter of 14 January 1991 and subsequent communication, we hereby forward our proposal for an agreement on the use of Cypros/ESIM in the context of the inter-european JOULE project.

1. The JOULE project, referred to as "the Project", is executed under contract #JOUR-0078-C(SMA) with DG12 of the EEC. The purposes of the Project are defined by the following two tasks:
 - a) To connect existing logistic models and integrate into a common framework. The models include Risø's logistic model WDILOG, which is based on Cypros/SIM, and EFI's VINDEC, which is based on the Cypros Library.
 - b) To develop a new, modular dynamic model for combined electrical-mechanical systems, in effect wind-diesel systems, for use on PC's. It has been decided to base the model development on Cypros/ESIM.

Rutherford Appleton Laboratory of UK (RAL) is Project coordinator and main contractor to the EEC. Within the Project RAL is responsible for task a), while Risø is responsible for task b).

2. The Project is carried out by a group of European wind energy R&D centres, referred to as "the Project Group". It consists of the following members, referred to as "Participants":

- | | |
|--|----|
| a) Rutherford Appleton Laboratory (RAL)
Dr. David Infield | UK |
| b) Risø National Laboratory (Risø)
Dr. Per Lundsager | DK |
| c) Electric Power Research Institute (EFI)
Mr. Kjetil Uhlen | N |

- | | |
|---|----|
| d) Netherlands Energy Research Foundation (ECN), Petten
Ir. Jan Pierik | NL |
| e) Helsinki University of Technology (TKK)
Mr. Lauri Manninen | SF |
| f) ENEA
Dr. Massimo Falchetta | I |

All parties except Finland participates in both tasks. Finland participated in task 1a) only.

3. The Project Group purchases one beta-version of the enhanced Cypros/SIM, ESIM, including modifications as specified in letters of 14 January 1991 and 27 February 1991, at a cost that constitutes a contribution to CAMO's development costs, ref. CAMO offer of 5 February 1991.
4. For the duration of the Project, this beta-version (and possible versions updated during the duration of the Project) may be used by each Participant at no additional cost for programming and model development work within the Project. When the project is terminated the licensing agreement for this beta-version will be transferred to one of the Participants as decided by the Project Group.
5. When the Project is completed, one result is a dynamic PC-model, referred to as the "Dynamic Model". Another result is the integration into a common framework of a number of national logistic models, altogether referred to as the "Logistic Package".

The Dynamic Model will consist of FORTRAN code developed to run with ESIM. The Dynamic Model will also be available in a run time version, which will consist of one or more executable files, depending on the final layout of ESIM. The run time version of the Dynamic Model will contain the object codes of the Dynamic Model developed by the Project, and of Cypros/ESIM, developed by CAMO.

Two of the models in the Logistic Package have been developed to run in connection with Cypros/SIM or Cypros Library, and the integrating framework itself may be developed to use parts of these CAMO products. Whereas each logistic model may or may not be available in source code from the national centres of origin outside the framework of the Project, the models will in connection with the Logistic Package only be available as run time versions, and only as part of the complete Logistic

Package.

The following is agreed concerning the distribution of the Dynamic Model, and is equally valid for the Logistic Package where appropriate:

- a) A Participant may sell run time versions of the Dynamic Model directly in commercial contexts. In that case a royalty of NOK 2 000,- must be paid to CAMO for the use of ESIM.
- b) A Participant may distribute run time versions of the Dynamic Model free of charge¹. In that case no royalty is paid to CAMO, but the user must agree to give feedback to CAMO, e.g. through interviews or questionnaires.
- c) A Participant may distribute source code of the Dynamic Model for a fee or free of charge, but a Participant does not distribute ESIM object code. CAMO agrees to sell separate ESIM object modules to users for use together with current and updated versions of the Model.
- d) The Project Group is willing to negotiate the rights for CAMO to distribute commercialized, i.e. more user friendly, run time versions of the Dynamic Model. The Project Group is also willing to negotiate a possible cooperation with CAMO on further development, commercialization and market analysis in this context.

Items 5a) to 5d) are similar to the items of the agreement between Risø and CAMO concerning the use of SIM in Risø's logistic wind-diesel simulation model.

¹ A handling fee may be charged to cover the actual expenses of distribution, and copying of the model documentation.

For CAMO Cybernetics AS

*For Netherlands Energy Research
Foundation (ECN)*

Date:

Date:

Sign:

Sign:

Name and position

Name and position

*For Rutherford Appleton Laboratory
(RAL)*

*For Helsinki University of Technology
(TKK)*

Date:

Date:

Sign:

Sign:

Name and position

Name and position

For Risø National Laboratory (Risø)

For ENEA

Date:

Date:

Sign:

Sign:

Name and position

Name and position

*For Norwegian Electric Power Research
Institute (EFI)*

Date:

Sign:

Name and position

Rutherford Appleton Laboratory

Annex D : List of presentations and published papers

- 1 D G Infield, P Lundsager, J T G Pierik, V A P van Dijk, M Falchetta, O Skarstein and P D Lund; Wind/Diesel System Modelling and Design. Proc. EWEC'90, H S Stephens & Assoc, Madrid, 1990.
- 2 L M Manninen, R H Hutka and P D Lund; Wind/Diesel System Analysis with Special Emphasis on Battery Modelling. Proc. EWEC'91 conference of the European Wind Energy Association, October 1991, Amsterdam, Holland.
- 3 P Lundsager; Wind Diesel Modelling Package. Proc. AWEA/CanWEA Fifth International Wind-Diesel Hybrid Power Workshop, Vermont, USA, 24-26 June, 1991.
- 4 Infield D G and Toftevaag T; An approach to the standardisation of Wind-Diesel system testing. Proc. of 5th Int Wind/Diesel Hybrid Power System Workshop, Vermont, 1991.
- 5 Lundsager P, Bindner H, Infield D, Scotney A, Skarstein O, Toftevaag T, Uhlen K, Pierik J, Manninen L and Falchetta M; Progress with the European wind-diesel modelling software package. Proc. EWEC '91, Elsevier, Amsterdam, 1991.
- 6 Infield D G; High penetration wind and diesel systems - operational experience and design assessment. Proc. of CEC workshop Wind Energy for Mediterranean Regions, Rhodes, June 1992.
- 7 Infield D G, Scotney A, Lundsager P, Bindner H, Uhlen K, Toftevaag T and Skarstein O; Wind diesel systems - design assessment and future potential. Proc. of 6th Annual AWEA-CANWEA International Wind-Diesel Workshop, PEI, Canada, June, 1992.
- 8 J T G Pierik; Aspects of Dynamic Modelling in the European Wind-Diesel Software Package. Proc. Sixth International CanWEA-AWEA Wind-Diesel Workshop, June 16 - June 19, 1992, Prince Edward Island, Canada. p.274-293.
- 9 Infield DG, Scotney A, Lundsager P, Bindner H, Uhlen K, Toftevaag T, Skarstein O; Wind Diesel Systems - Design Assessment and Future Potential. Wind Engineering, Vol 16, No 2, 1992.
- 10 H Bindner et al; Power Quality and Grid Stability of Simple Wind-Diesel Systems: Results from Risø's Experimental System. Proc. BWEA'14, Nottingham, UK, 1992.
- 11 P Lundsager; European Wind Diesel Software Package. Proc. of 6th Int. Wind Diesel Conference Mill River Resort, Prince Edward Island, Canada, 1992.

- 12 D G Infield; System Design Considerations for Electricity Generation from Wind and Diesel Combinations. *Int. J. Solar Energy*, 1992, Vol. 13, pp63-72.
- 13 Lundsager P, Bindner H, Infield D G, Scotney A, Uhlen K, Toftevaag T, Pierik J T G and Falchetta M; The JODYMOD dynamic wind diesel simulation program part 1: description of the model and its validation. *Proc. of International Workshop on Wind Energy Penetration into Weak Electricity Networks*, RAL, June 1993.
- 14 V A P van Dijk; SOMESWD Version 1.0. Integration of SOMES in the European Wind-Diesel Software Package WDLTOOLS. Report nr. 93054. Department of Science, Technology and Society, Utrecht University, The Netherlands, August 1993, 12pp.
- 15 P Lundsager and H Bindner; The European Wind Diesel Modelling Package. *Proc. AWEA/CanWEA International Wind-Diesel Hybrid Power Workshop*, Vermont, USA, 1993.
- 16 Infield DG, Scotney A, Lundsager P, Bindner H, Uhlen K, Toftevaag T, Pierik JTG, Manninen L, Falchetta M, van Dijk V; Engineering Design Tools for Wind Diesel Systems: Presentation and Validation of the Logistic Modelling Package. *Proc. ECWEC93*, Travemunde, 1993.
- 17 Uhlen K, Toftevaag T, Bindner H, Lundsager P, Pierik JTG, Infield DG, Scotney A, Falchetta M; Engineering Design Tools for Wind Diesel Systems: Presentation and Validation of the Modular Dynamic Model. *Proc. ECWEC93*, Travemunde, March 1993.
- 18 J T G Pierik, V A P van Dijk; Contribution to the Logistic Model of the European Wind-Diesel Engineering Design Tools Package. SOMES validation results. Technical report ECN--93-054, August 1993.
- 19 J T G Pierik; Contribution to the Modular Dynamic Model of the European Wind-Diesel Engineering Design Tools Package. Modelling and Validation. Technical report ECN--93-053, September 1993.
- 20 J T G Pierik; Short term dynamics of AWIDIMOD compared to measurements. *Proc. BWEA/RAL Workshop on Wind Energy Penetration into Weak Electricity Networks*. June 1993, Abingdon, England. p.161-171.
- 21 P Lundsager et al; The Jodymod Dynamic Wind Diesel Simulation Program. Part 1: Description of the Model and Its Validation. *Proc. of BWEA/RAL Workshop on Wind Energy Penetration into Weak Electricity Networks*. June 1993, Abingdon, UK.

- 22 H Bindner; The Jodymod Dynamic Wind Diesel Simulation Program. Part 2: Presentation of the Program. Demonstration and Examples. Proc. of BWEA/RAL Workshop on Wind Energy Penetration into Weak Electricity Networks. June 1993, Abingdon, UK.
- 23 A Scotney and D G Infield; Wind diesel systems for developing countries. Presented at STD Conference on Science and Technology in Third World Development, Glasgow, April, 1993.

