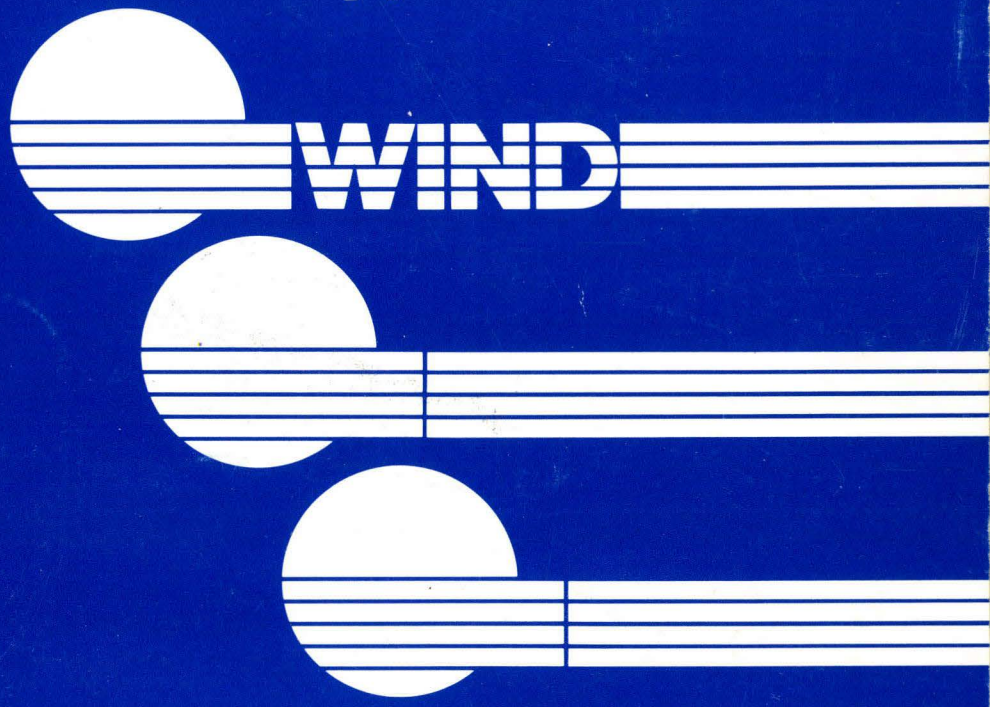
SERI

# Analysis Methods For Wind Energy Applications



# The Solar Energy Research Institute

The Solar Energy Research Institute was created by Congress in 1974 to provide the country with a national center of excellence dedicated to serving the needs of the public and industry in the development of solar energy. SERI began operations in July 1977, in Golden, Colorado. SERI is operated by the Midwest Research Institute for the U.S. Department of Energy (DOE). The primary mission of SERI is to function as the U.S. Department of Energy's lead institution for solar energy research, development, and application.

For information on the general operations of SERI, contact:

Public Information Office
Solar Energy Research Institute
1536 Cole Boulevard
Golden, CO 80401
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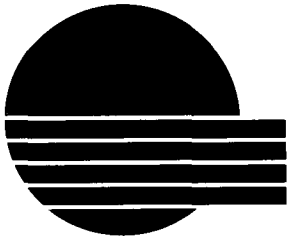
Other publications in this series include:

Analysis Methods for Photovoltaic Applications, SERI/SP-35-230
Analysis Methods for Solar Heating and Cooling Applications, SERI/SP-35-232



This brochure was prepared by the Market Development and Communications Branches, Technology Commercialization Division, under the Systems Analysis and Testing (SAT) Program, funded by the Solar Heating and Cooling Research and Development Branch, Office of Conservation and Solar Applications, U.S. Department of Energy. Responsibility for the technical content of this document as well as for the SAT Program lies in the Systems Analysis Branch, Research Division.

# Analysis Methods for Wind Energy Applications

Enormous currents of air flow over the surface of the continents and oceans. Though sails and windmill blades supplied much of the energy that people used in past centuries, wind power has been largely forgotten until economics and environmental concerns have now dictated that it be "rediscovered." As we rapidly consume limited fuels and pollute the air and water, wind becomes essential in the blend of energy sources now being developed by the federal government and private industry. By the year 2000, wind energy should prove to be an important power generation source, contributing an estimated 1 to 7 quads of energy to our nation's energy supply.

To accelerate the commercialization of wind energy systems, the Solar Energy Research Institute (SERI) is helping researchers, engineers, utility planners, and others gain access to wind energy simulation methods and analytic modeling techniques. This brochure has been prepared to indicate previous work done in developing wind energy simulation methods. This list of methods is not claimed to be all-inclusive; rather, it provides an insight into the variety of tools available.

Certain computer programs listed here are not publicly available at this time; they are included because potential users should be aware of their existence and possible release in the future.

Information on programs not included here and the methodology used in the survey from which this brochure was generated can be found in "Survey of Currently Used Wind Turbine Performance Prediction Computer Codes," by Fred Perkins, SERI/TR-35-225, Solar Energy Research Institute, Golden, Colorado. This brochure is scheduled for periodic review and update. Persons knowing of models or tools not listed here are asked to contact the Design Tool Manager, Market Development Branch, SERI, so that future versions will contain current state-of-the-art information on wind energy analysis methods.

Most reference documents cited in the text are available from the National Technical Information Service (NTIS), 5282 Port Royal Road, Springfield, VA 22161.

## Summary of Analysis Tools

| Program Name | Availability | Documentation | | | Rotor Types | | | Control Strategy | | Inputs | | | Program Type | | | Experimental Verification | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | User's Manual (2) | Program Manual (3) | References | High Speed Horizontal (4) | Darrieus | Giromill | Constant Speed | Constant Tip Speed Rate | Single Wind Speed | Wind Speed Distribution | Weather Tapes | Design Tool (5) | Economic Analysis (6) | Aeroelastic Analysis | Wind Tunnel | Field Data |
| CROFTAN | | ● | | ● | | | ● | ● | | ● | ● | | ● | | | | ● |
| F762 | (1) | ● | | | ● | | | ● | | ● | ● | | | | ● | ● | ● |
| G400 | | ● | | ● | ● | | | ● | | ● | | | | | ● | ● | ● |
| GIROMILL PERF. | | | | ● | | | ● | ● | ● | ● | | | ● | | | ● | |
| GOLDSTEIN P.A. | (1) | | | | ● | | | ● | ● | ● | | | ● | | | ● | |
| OFF DESIGN | | ● | | | ● | | | ● | | | ● | | | ● | | | |
| PAREP | | ● | | ● | | ● | | ● | | | | | ● | | | ● | ● |
| PROP (7) | | ● | | ● | ● | | | ● | | ● | | | ● | | | | ● |
| PROP (8) | | ● | ● | ● | ● | | | | ● | ● | | | ● | | | ● | ● |
| ROTOR | | ● | ● | | ● | | | ● | ● | ● | ● | | ● | | | ● | ● |
| SERIES/WINDS | | ● | | | ● | | | ● | | | | ● | | ● | | | |
| SIMWEST | | | ● | ● | ● | | | ● | ● | ● | ● | ● | | ● | | | |
| UTRC PWPA | (1) | ● | | | ● | | | ● | ● | | ● | | ● | | | ● | |
| VAWTOP | | | | | | ● | | ● | | | ● | | | ● | | | |
| VERSION 16 | | ● | ● | ● | | ● | | ● | | | ● | | | ● | | | |
| WIND OPT | | ● | | | ● | | | ● | | | ● | | | ● | | | |
| WRFP | | ● | | ● | ● | | | ● | | ● | | | ● | | | | ● |

(1) This program is not currently available to the public. See text describing this program for details.
(2) User's manual is defined to be minimum description of the program necessary for its operation.
(3) Program manual is a detailed operations manual including instructions for program modifications.
(4) A high speed wind turbine is one in which the linear speed of some portion of the rotating parts is five times or more the oncoming wind speed during normal operations.
(5) The output of these programs includes the loads and power output of a particular wind turbine. This information is necessary for design.
(6) The output of these programs includes some information on the economic qualities of the considered system.
(7) NASA Lewis Research Center version.
(8) Aerovironment version.

## CROFTAN

This program is useful for the analysis of the aerodynamic performance of a giromill. Manuals have been written for the program. The program is primarily a design tool and has been verified with field data.

**Input Requirements**
Wind speed, rotor geometry

**Output Data**
Loads, power

**Reference**
Walters, R.E. et al., "Vertical Axis Wind Turbine Experiments and Analysis," ORO/5135-78/1, Dept. of Aerospace Engineering, West Virginia University, May 1978. (Contact University Library.)

**Contact**
Richard E. Walters
Dept. of Aerospace Engineering
West Virginia University
Morgantown, WV 26506
(304) 293-2570

## F782 Wind Turbine Aeroelastics/ Aerodynamics Analysis

This program can accommodate only a small amount of linear blade twist. The equations of motion couple the blade deflections with the support flexibility. An equivalent spring and damper is one of the load options. This program is useful for the analysis of high speed horizontal axis wind turbines. The program has been verified with field and wind tunnel data. It is presently proprietary but may be made public within one or two years.

**Input Requirements**
Rotor and support geometry

**Output Data**
Natural modes, natural frequencies

**Contact**
Dr. Richard L. Bielawa
United Technologies Research Center
Silver Lane MS-16
East Hartford, CT 06108
(203) 727-7154

## G400 — Rotor Aeroelastics/ Aerodynamics Analysis

G400 is the successor to F762. Both employ elastic coupling between the blades and support. G400 allows non-linear blade twist and the resolution of more natural frequencies than F762. This program is useful for the analysis of high speed horizontal axis wind turbines. It has been verified with both field and wind tunnel data. A basic rotor version is available from NASA-Langley for a fee.

**Input Requirements**
Rotor and support geometry

**Output Data**
Natural modes, natural frequencies

**Reference**
"Aeroelastic Analysis for Helicopter Rotor Blades with Time Variable, Non-Linear Structural Twist and Multiple Structural Redundance; Mathematical Deviation and Program Users Manual," NASA CR-2638, 1977. (Available from NTIS.)

**Contact**
For information:
Dr. Richard L. Bielawa
United Technologies Research Center
Silver Lane MS-16
East Hartford, CT 06108
(203) 727-7154

For program acquisition:
John Shipley or Gene Hammond
Air Mobility Res. & Dev. Lab.
Langley Directorate
NASA Langley Research Center
Hampton, VA 24015

## Giromill Performance

This program is still under development. It is intended to be a design tool for the analysis of giromill wind turbines. The input options allow the resolution of loads with respect to either a geometrically or aerodynamically constant angle of attack. The program has been verified with wind tunnel data.

**Input Requirements**
Rotor geometry, wind speed, tip speed ratio, desired angle of attack (actual or effective)

**Output Data**
Side forces, axial forces, torque, power

**Reference**
"Giromill Wind Tunnel Test and Analysis," Vol. II, COO-2617-4/2, McDonnell Aircraft Co., St. Louis, Mo., October 1977. (Available from NTIS.)

**Contact**
Prof. H.C. Larsen
A.F. Institute of Technology/END
Area B, Bldg. 640
Wright Paterson AFB, OH 45433
(513) 255-3633

## Goldstein Performance Analysis

This program is used for routine wind turbine and rotor/propellor performance calculations at the United Technologies Corporation when relatively short computer times are desired. This program is a design tool for the analysis of high speed horizontal axis wind turbines; it has been verified with wind tunnel data. The program is not publicly available.

**Input Requirements**
Rotor geometry, wind speed, angular speed

**Output Data**
Power, loads

**Contact**
Anton J. Landgrebe
United Technologies Research Center
Silver Lane
East Hartford, CT 06108
(203) 727-7358

## Off Design

This is a General Electric Company version of the Wind Optimization Code designed to indicate economic performance away from the design wind speed. It is intended for the prediction of the economic performance of high speed horizontal axis wind turbines.

**Input Requirements**
Wind speed, design wind speed

**Output Data**
Energy cost, energy collected

**Contact**
Frank Barr
General Electric Company
P.O. Box 8555
Philadelphia, PA 19101
(215) 962-2903

## PAREP — Aerodynamic Performance Model for Vertical Axis Wind Turbine Systems

The program models the performance of a Darrieus VAWT constrained to operate at constant rpm in conjunction with a utility grid. It is intended for use in an interactive time sharing mode. A graphics package is included for output formatting. This model has been verified with wind tunnel and field data.

**Input Requirements**
Rotor geometry, rpm

**Output Data**
Power coefficient vs. tip speed ratio

**Reference**
"Economic Analysis of Darrieus Vertical Axis Wind Turbine Systems for the Generation of Utility Grade Electrical Power," SAND/78-0962, Vol. II, 1978. (Available from NTIS.)

**Contact**
W.N. Sullivan
Division 4715
Sandia Laboratories
Albuquerque, NM 87112
(505) 264-6434

## PROP (NASA-LeRC)

This program is a design tool for the analysis of high speed horizontal axis wind turbines. It computes the effects of wake interference and tip losses. The output is in tabular form. A program manual exists. The program has been verified with field data.

**Input Requirements**
Rotor geometry, wind speed, tip speed ratio

**Output Data**
Loads, torque, power

**Reference**
Wilson, Robert E. and Lissaman, Peter B.S., "Applied Aerodynamics of Wind Power Machines," Oregon State University, May 1974. (Contact University Library.)

**Contact**
For questions of use by NASA:
David C. Janetzke
NASA-LeRC MS 49-6
21000 Brookpark Road
Cleveland, OH 44135
(216) 433-4400 X 5102

For acquiring program and manual:
Prof. Robert E. Wilson
Dept. of Mechanical Engineering
Oregon State University
Corvallis, OR 97331
(503) 754-2218

## PROP (Aerovironment)

This is an updated version of PROP (NASA-LeRC). Manuals have been written. The program, useful for the analysis of high speed horizontal axis wind turbines, has been verified with both field and wind tunnel data. It is not publicly available.

**Input Requirements**
Rotor geometry, wind speed, rotational speed

**Output Data**
Loads, torque, power

**Reference**
Walker, Stel N., "Performance and Optimum Design Analysis/Computation for Propellor Type Wind Turbines," Ph.D. Dissertation, Oregon State University, 1976. (Contact University Library.)

**Contact**
Stel N. Walker
Aerovironment, Inc.
145 Vista Avenue
Pasadena, CA 91107
(213) 449-4392

## ROTOR

This program is a design tool for the analysis of high speed horizontal axis wind turbines. It has been verified with both wind tunnel and field data.

**Input Requirements**
Rotor geometry, operation mode, wind speed

**Output Data**
Power, loads

**Contact**
Dr. P.M. Sforza
Polytechnic Institute of New York
Farmingdale, NY 11735
(516) 694-5500

## SERIES/WINDS

This program will use up to 5 years of weather data from the National Climatic Center to establish the performance characteristics of an average wind turbine in an array, taking into account spatial and time variations between individual turbines. It considers only high speed horizontal axis wind turbines. The program has not been experimentally verified.

**Input Requirements**
Five years of wind data, wind turbine power characterisics

**Output Data**
Performance of an average wind turbine in an array

**Reference**
"Wind Energy Systems Application to Regional Utilities," Draft Report, JBFScientific, September 1978. (Contact JBF Scientific.)

**Contact**
Martin Goldenblatt
JBF Scientific Corporation
2 Jewel Drive
Wilmington, MA 01887
(617)657-4170

## SIMWEST

This program is designed for the simulation of wind energy storage systems. It is a modular program arranged in subroutines representing components (e.g., wind turbines, generator, battery storage, etc.) which may be assembled at the user's discretion. Statistical treatment of the output data and plots of any variable vs. any other variable are available. The program requires a large computer facility. The output requires the use of a line printer for reasonable connect times.

**Input Requirements**
System configuration wind speed, component costs

**Output Data**
Energy cost, energy collected, system status

**Reference**
"A Simulation Model for Wind Energy Storage Systems," NASA CR-135284, August 1977. (Available from NTIS.)

**Contact**
Design Tool Manager
Market Development Branch
Solar Energy Research Institute
1536 Cole Boulevard
Golden, CO 80401
(303) 231-1261

## UTRC Prescribed Wake Performance Analysis

This program is a design tool. Once the wake geometry and rotor geometry are specified, the loads are also specified. This program is useful for the analysis of high speed horizontal axis wind turbines. It has been verified with wind tunnel data. The program could be made available following additional documentation, demonstration, and refinement. The cost to acquire would involve only these activities.

**Input Requirements**
Rotor geometry, wake geometry, wind speed

**Output Data**
Rotor loads, power, torque

**Contact**
Anton J. Landgrebe
United Technologies Research Center
Silver Lane
East Hartford, CT 06108
(203) 727-7358

## VAWTOP

Using prescribed scaling factors, the program optimizes VAWT component sizes with respect to minimum energy cost. The program is dated, so the absolute numbers presented are incorrect. The program is useful for parametric studies, however.

**Input Requirements**
Rated power, design wind speed

**Output Data**
Component costs optimized for minimum electricity cost. Rotor cost, tower cost, gearbox cost, generator cost, blade cost, and energy collected

**Contact**
Frank Barr
General Electric Company
P.O. Box 8555
Philadelphia, PA 19101
(215) 962-2903

## Version 16

This program analyzes the economic performance of a Darrieus VAWT operated at constant rpm in conjunction with a grid. It is intended for use in an interactive time sharing mode. A graphics package is included for output formatting.

**Input Requirements**
System component specifications, rotor geometry, wind speed distribution

**Output Data**
Annual energy, energy cost, peak power, rated power, component cost

**Reference**
"Economic Analysis of Darrieus Vertical Axis Wind Turbine Systems for the Generation of Utility Grade Electrical Power," SAND/78-0962, Vol. II, 1978. (Available from NTIS.)

**Contact**
W.N. Sullivan
Division 4715
Sandia Laboratories
Albuquerque, NM 87112
(505) 264-6434

## Wind Optimization Code

Using prescribed scaling factors, the program optimizes HAWT components with respect to energy cost. The program is dated, so the absolute numbers presented are incorrect. It is useful for parametric studies, however. It is written for the analysis of high speed horizontal axis wind turbines. Cursory manuals only have been written.

**Input Requirements**
Rated power, design wind speed

**Output Data**
Component costs optimized for minimum electricity cost. Rotor cost, tower cost, gearbox cost, generator cost, blade cost, and energy collected

**Contact**
Frank Barr
General Electric Company
P.O. Box 8555
Philadelphia, PA 19101
(215) 962-2903

## WRFP

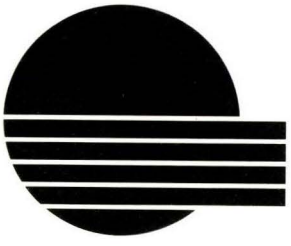
WRFP is a BASIC version of PROP (NASA-LeRC). The program is useful for the analysis of high speed horizontal axis wind turbines and has been verified with field data. This program is not public property.

**Input Requirements**
Rotor geometry, rotational speed, wind speed

**Output Data**
Loads, torque, power

**Contact**
Dr. William Drake
Enertech Corporation
P.O. Box 420
Norwich, VT 05055
(802) 649-1145





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