NREL/TP-257-4492 • UC Category: 261 • DE92001216

SERI Advanced Wind Turbine Blades

J. Tangler
B. Smith
D. Jager

National Renewable Energy Laboratory
(formerly the Solar Energy Research Institute)
1617 Cole Boulevard
Golden, Colorado 80401-3393
A Division of Midwest Research Institute
Operated for the U.S. Department of Energy
under Contract No. DE-AC02-83CH10093

February 1992

On September 16, 1991 the Solar Energy Institute was designated a national laboratory, and its name was changed to the National Renewable Energy Laboratory.

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

Printed in the United States of America
Available from:
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Price: Microfiche A01
Printed Copy A02

Codes are used for pricing all publications. The code is determined by the number of pages in the publication. Information pertaining to the pricing codes can be found in the current issue of the following publications which are generally available in most libraries: *Energy Research Abstracts (ERA)*; *Government Reports Announcements* and Index (*GRA* and I); *Scientific and Technical Abstract Reports (STAR)*; and publication NTIS-PR-360 available from NTIS at the above address.

SERI ADVANCED WIND TURBINE BLADES

J. Tangler, B. Smith, and D. Jager

Solar Energy Research Institute
1617 Cole Blvd., Golden, CO 80401

ABSTRACT

The primary goal of the Solar Energy Research Institute's (SERI) advanced wind turbine blades is to convert the kinetic energy in the wind into mechanical energy in an inexpensive and efficient manner. To accomplish this goal, advanced wind turbine blades have been developed by SERI that utilize unique airfoil technology. Performance characteristics of the advanced blades were verified through atmospheric testing on fixed-pitch, stall-regulated horizontal-axis wind turbines (HAWTs). Of the various wind turbine configurations, the stall-regulated HAWT dominates the market because of its simplicity and low cost. Results of the atmospheric tests show that the SERI advanced blades produce 10% to 30% more energy annually than conventional blades.

KEYWORDS

Airfoils; wind turbine blades; stall-regulated; airfoil roughness; horizontal-axis wind turbines.

INTRODUCTION

Conventional aircraft airfoils have created problems for wind turbines. These problems include excessive power in high winds, which leads to burned-out generators; inadequate energy output when the blade becomes soiled with insect accumulation and airborne pollutants, which reduces revenues; and poor rotor power-to-thrust ratios, which result in high array losses for wind farms. The key to the advanced blades (Fig. 1) is the use of specially designed airfoils that govern the airflow around the blade in a manner substantially different from conventional airfoils.

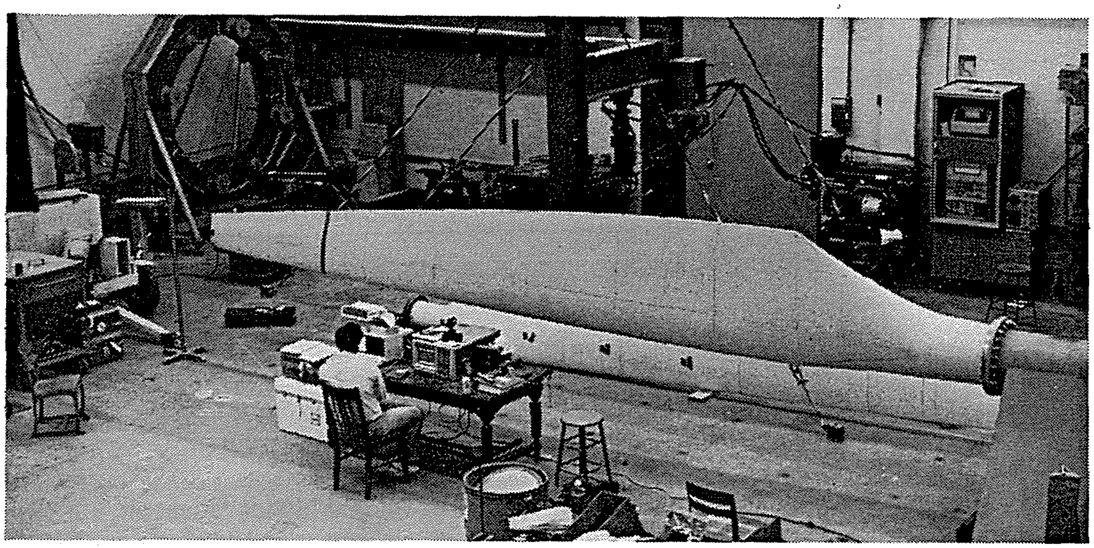

Fig. 1. SERI Advanced Wind Turbine Blade.

To eliminate the performance problems resulting from conventional airfoils, SERI (Tangler, 1987) designed new thin- and thick- airfoil families (Fig. 2) that have the performance characteristics needed to satisfy the requirements of stall-regulated HAWTs. The low drag, thin-airfoil family lends itself to fiberglass rotors that are 10 to 20 meters in diameter. The thick-airfoil family, having slightly more drag, addresses the more demanding structural requirements of either fiberglass or wood composite rotors that are 20 to 30 meters in diameter. Both the thin- and thick- airfoil families have performance characteristics that are tailored to change in a prescribed manner from the blade tip (95% radius) to the blade root (30% radius).

To control peak rotor power in high winds, the airfoil in the tip region of the blade must have a maximum lift coefficient (C_{lmax}) that is about 25% lower than typical aircraft airfoils. Conversely, the airfoil in the root region of the blade must have a high C_{lmax} to aid rotor start-up and energy production at medium wind speeds. Unlike previous wind turbine blades, use of the new airfoil families results in a blade whose C_{lmax} increases in a continuous manner from blade tip to blade root for effective peak power control. In addition, controlling peak power in this way permits the use of 15% greater swept-disc area for a given generator size and results in increased energy production.

Also, designing the airfoil's C_{lmax} to be less sensitive to roughness effects minimizes energy losses resulting from dirty blades. Airfoil roughness insensitivity is achieved through geometric tailoring of the airfoil's shape to force a transition from laminar to turbulent flow on both the upper and lower surfaces of the airfoil as C_{lmax} is approached.

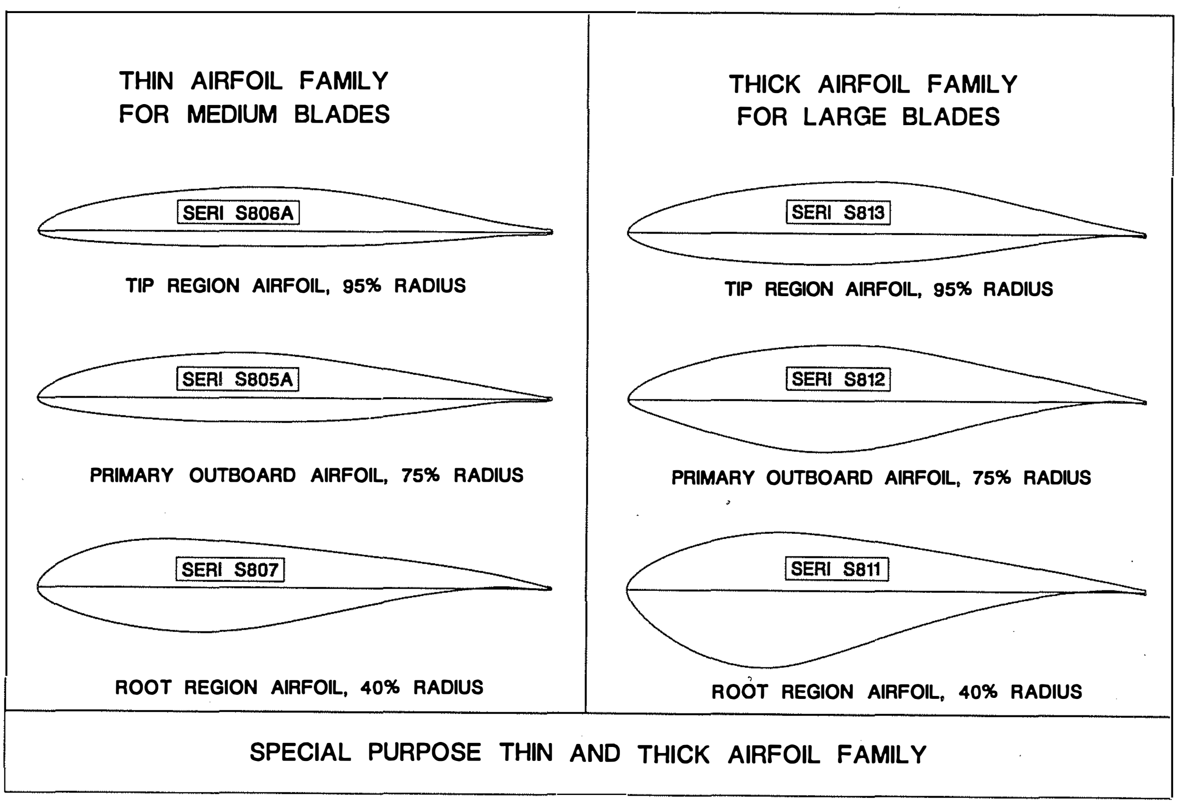

Fig. 2. Special-Purpose Thin- and Thick-Airfoil Family.

Because of the aerodynamic improvements, the SERI advanced blades (Jackson, 1987) produce 10% to 30% more energy annually than conventional blades. These energy gains were verified in a side-by-side atmospheric test (Fig. 3; Tangler, 1989, 1990). SERI advanced blades were installed on one turbine in a wind farm and original equipment blades manufactured by AeroStar were installed on the other identical turbine.

Fig. 3. Side-by-Side Wind Turbine Test.

Over 6700 HAWTs currently operating in California wind farms use 8- to 10-meter blades that produce insufficient energy. Although most of these original equipment blades were made by the now defunct AeroStar company, replacement blades are being supplied by other manufacturers. Most of these replacement blades still use traditional aircraft airfoils. Use of aircraft airfoils on stall-regulated machines results in either excessive peak power at efficient blade-pitch angles or reduced energy production at inefficient blade pitch angles. Blades manufactured using SERI's advanced thin- and thick-airfoil families can be operated at efficient blade-pitch angles to maximize energy production and increase revenues. Replacement of conventional blades with SERI advanced blades provides the following economic benefits:

- Fewer burned-out generators: The excessive peak power produced by conventional blades in high winds burns out generators. By using airfoil families that have a restrained C_{lmax} in the tip region (Fig. 4), SERI's advanced blades control power output at high wind speeds more effectively than conventional blades.

- More consistent power output: By using airfoils whose C_{lmax} is relatively insensitive to roughness effects, SERI's advanced wind turbine blades produce more consistent power output than conventional blades.

- Improved rotor efficiency: Compared to conventional blades, SERI's thin-airfoil advanced blades produce 15% to 20% more power for clean blades and 27% to 35% more power for dirty blades. These improvements are achieved through the use of greater swept-disc area, C_{lmax} roughness insensitivity, and improved aerodynamics (Fig. 5).

- Greater annual energy production: Compared to conventional blades, SERI's advanced thin-airfoil blades are projected to produce 10% greater annual energy when clean and as much as 30% greater energy in the dirty condition (Fig. 6). The projections are based on measured power curves and a standard Rayleigh wind speed distribution. Actual wind farm energy measurements for a complete year resulted in a 30% energy improvement (Powers, 1990).

- Lower array losses in wind farms: The SERI advanced blades achieve this result by operating at a more favorable blade-pitch angle for a given rotor size, which results in a greater rotor power-to-thrust ratio (Fig. 7). The energy in the wind is used more efficiently so that each succeeding row of wind turbines has more available wind energy, and total wind farm array losses are lower.

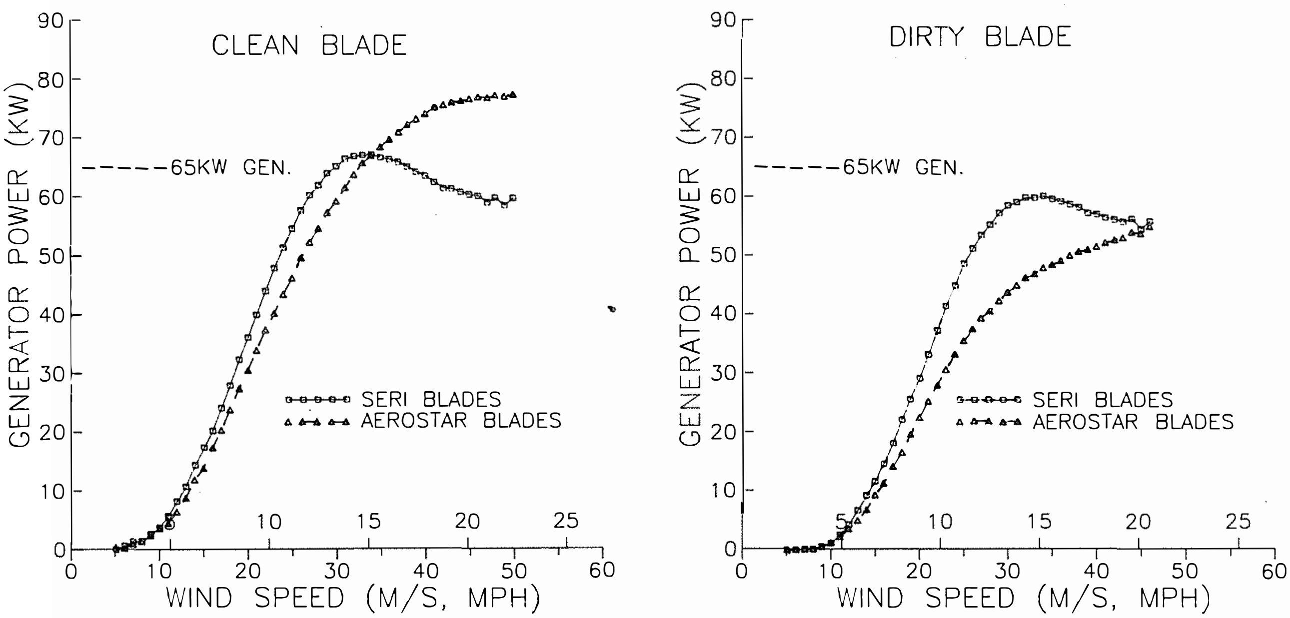

Fig. 4. Clean and Dirty Blade Generator Power.

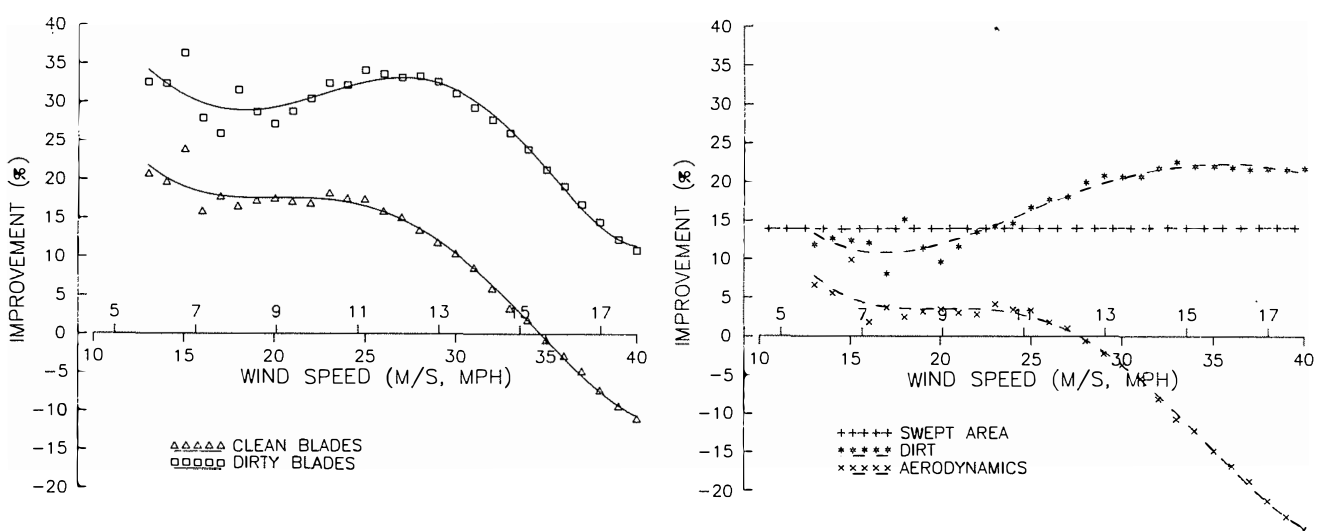

Fig. 5. Generator Output Improvements and Components.

The SERI advanced blades are unique in that they are the only blades using airfoil families specifically designed for stall-regulated HAWTs. Current domestic and foreign wind turbine blades utilize traditional aircraft airfoils. The peak power problem encountered using aircraft airfoils can only be corrected at the expense of energy output and higher mean blade loads (Tangler, 1988). Peak power can be reduced by operating the blades at non-optimum pitch angles (closer to stall). However, this approach typically results in a reduction in rotor performance at low to medium wind speeds along with higher rotor thrust loads for a given power output. Effectively, a larger portion of the wind energy goes into destructive blade loads and the corresponding wake-induced losses rather than useful power output.

The principal application of the SERI advanced blades is for replacement blades on over 6700 existing machines operating in California. Although the SERI advanced blades were designed for the unique performance requirements of fixed-pitch stall-regulated HAWTs, the associated airfoils are also expected to become the airfoils of choice for more expensive *variable*-pitch wind turbines. These turbines would also benefit from the airfoils' greater insensitivity to roughness, which results in more consistent power output. The restrained C_{lmax} for the tip region of the blade might also help mitigate the large peak power spikes, common to variable-pitch turbines, that result from coherent turbulence.

The biggest future application for the SERI airfoil families will be for new advanced stall-regulated HAWTs. With the use of this airfoil technology, these advanced wind turbines are expected to generate electricity at $.04 to .05/kWh in 13-mph wind sites.

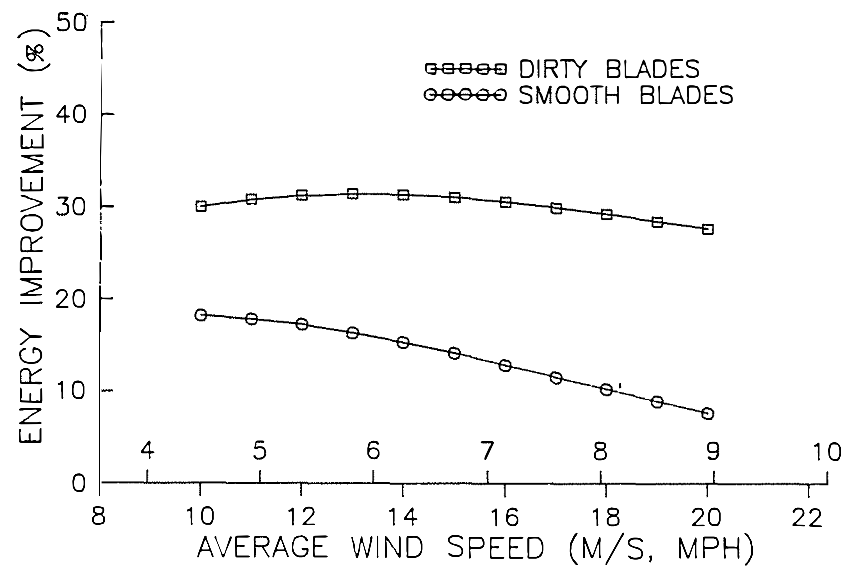

Fig. 6. Annual Energy Improvement: Rayleigh Distribution.

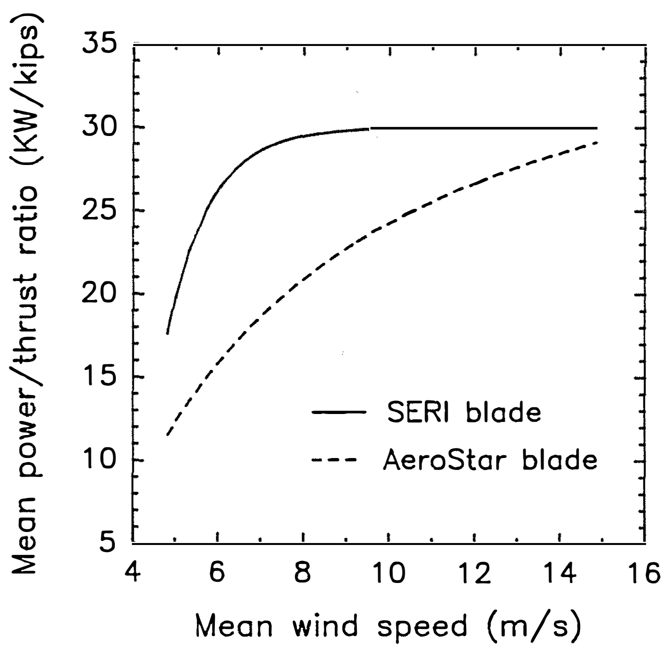

Fig. 7. Power/Thrust Ratio versus Wind Speed.

CONCLUSIONS

In summary, comparative field testing of the advanced thin-airfoil blades on stall-regulated HAWTs has demonstrated the following performance improvements relative to original equipment blades:

- Peak power regulation
- Minimal roughness sensitivity
- Greater annual energy output
- Higher power-to-thrust ratios for reduced mean turbine loads and wind farm array losses

These improvements are attributed to increased swept area, greater airfoil C_{lmax} tolerance to roughness effects, and improved aerodynamics.

The SERI advanced blades directly benefit the wind industry by expanding the viability of wind energy into regions of lower average wind speeds, which could more than double the potential land area for wind farm development in the United States.

ACKNOWLEDGMENTS

The authors wish to acknowledge the contributions of key individuals who participated in the design and development of the thin-airfoil blades. These individuals are D. Somers for airfoil design, M. Zuteck and K. Jackson for structural design, and J. Frerotte (Phoenix Industries, Crookston, Minnesota) for blade fabrication. Appreciation is also expressed to SeaWest Energy Group for support in conducting the atmospheric test and E. McKenna of SERI for instrumentation support. All this work was performed under U.S. Department of Energy Contract No. DE-AC02-83CH10093.

REFERENCES

Jackson, K., and P. Migliore (1987). *Design of Wind Turbine Blades Employing Advanced Airfoils.* Windpower '87 Proceedings 106-111.

Powers, J. (1990). *Promising Results from New Blades.* WindStats, Summer 1990.

Tangler, J., and D. Somers (1987). *Status of the Special Purpose Airfoil Families.* Windpower '87 Proceedings 99-105.

Tangler, J., and Co-Workers (1989). *Atmospheric Performance Testing of the Special-Purpose SERI Thin-Airfoil Family - Preliminary Results.* Windpower '89 Proceedings 115-120.

Tangler, J., and Co-Workers (1990). *SERI Thin-Airfoil Blade Atmospheric Performance Test - Final Results.* Windpower '90 Proceedings 118-125.

Tangler, J., and P. Tu (1988). *Peak Power and Blade Loads on Stall-Regulated Rotors as Influenced by Different Airfoil Families.* SERI/TP-217-3334.