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Large Horizontal-Axis Wind Turbines

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DEDICATION

These Proceedings are dedicated to the Smith-Putnam Project Team, sponsored by Beauchamp E. Smith and led by Palmer C. Putnam, pioneers in the technology of this Workshop.

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FOREWORD

The development of large horizontal-axis wind turbines, whose primary use is the powering of electric utility generators, has advanced rapidly in the past five years. In that relatively short time the capacity of experimental wind power plants has been increased by almost two orders of magnitude, from single machines producing 100 kilowatts to a three-unit cluster generating 7.5 megawatts. To document the work of many organizations and individuals who have contributed to this progress and to discuss technical and economic issues, a three-day workshop was conducted by the NASA-Lewis Research Center, under the sponsorship of the U.S. Department of Energy. More than 300 persons met in Cleveland to hear technical papers contributed by manufacturers, government laboratories, electric utilities, and private research organizations.

The technical program of this workshop emphasized recent experience in building and testing large propeller-type wind turbines, expanding upon the proceedings of three previous DOE/NASA workshops at which design and analysis topics were considered (references below). A total of 41 papers were presented on the following subjects:

* Current and advanced large wind turbine systems
* Rotor blade design and manufacture
* Electric utility activities
* Research and supporting technology
* Meteorological characteristics for design and operation
* Wind resource assessments and siting

A highlight of the workshop was the commemoration of the 40th anniversary of the historic Smith-Putnam wind turbine project which produced the world's first megawatt-size wind power plant. Keynote addresses by Messrs. Smith and Putnam are include in these proceedings, together with descriptions of citations presented to them and to members of their project team.

The Workshop Committee is pleased to acknowledge the many contributions of presenters, session chairmen, and staff members which made possible the success of this conference.

References:

Wind Turbine Structural Dynamics, NASA Conference Publication 2034, DOE Publication CONF-771148, 1978.

Large Wind Turbine Design Characteristics and R&D Requirements, NASA Conference Publication 2106, DOE Publication CONF-7904111, 1979.

Wind Turbine Dynamics, NASA Conference Publication 2185, DOE Publication CONF-810226, 1981.

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INTRODUCTION

I was thrilled to receive an invitation to participate in this DOE/NASA Workshop, just as I was to witness the dedication of the Mod-0 in 1975. Unfortunately, circumstances have prevented me from attending this meeting and hearing the many fine papers being presented in the technical sessions. I deeply regret being unable to join my good friend and colleague, Palmer Putnam, and the others who contributed so much to our project forty years ago.

My disappointment, however, is completely overshadowed by the pride and happiness I feel on this memorable occasion. It is truly an honor at this time of my life to receive special recognition from two of the Nation's most respected organizations: The National Aeronautics and Space Administration and the U.S. Department of Energy.

When Joe Savino asked me to be a featured speaker along with Palmer Putnam, I asked what details I could provide that Put could not describe better. After all, it was Put who conceived and led the entire project. My role was to provide the money and other resources. Joe suggested that I tell this audience why my firm, the S. Morgan Smith Co., had undertaken the project at such a terrible time, in the middle of the great depression, and that I describe some of the benefits we derived from this experience. He convinced me that the Workshop attendees would be interested in the project sponsor's point of view, so I consented to say a few words about how those experiences look in retrospect--40 years later.

THE VIEW POINT

In 1939 The S. Morgan Smith Company was in the business of manufacturing water turbines and related machinery for the hydroelectric industry. By the late 1930's, most of the desirable sites for hydroelectric plants in the United States had been developed. As a result, the market for our products was declining. To make matters worse, the depression postponed the development of many of those sites which remained.

There was yet another factor to consider. The S. Morgan Smith Company was a family-owned business that enjoyed the respect and loyalty of its workers. We made every effort to keep our employees working. This was becoming increasingly difficult to do for the reasons I just mentioned. So, in the late 30's, we looked for other areas in which we could utilize our engineering and manufacturing capabilities.

When Palmer Putnam came to us with his concept of using large wind turbines in utility networks as supplemental sources of power, we were interested. There were many small hydroelectric plants in New England and in other sections of the country. Combining them with wind turbines seemed to be an excellent way to boost their capacity. But we were up against some tough competition because the fossil fuels--coal, oil, and natural gas--were very cheap, and seemingly forever abundant. Coal-fired electric power plants were being put up as fast as the demand for electricity increased. The low cost of coal and oil together with the absence of pollution control requirements made the cost of electricity very low. This fact made the development of low-cost wind turbines to compete with fossil fuel plants a real challenge.

Which brings me back to the original question--why did we decide to fund the Putnam project? The answer is simple: It was purely a matter of economic survival that led us to take the chance that this project might lead to a new product line for our company.

Once the commitment was made, we selected Palmer Putnam as the Project Leader, and we proceeded full speed to design, build, and test the 1250-kW machine that became known as the Smith-Putnam Wind Turbine.

I'm not going to discuss our direct experiences with the project in the period from 1939 to 1946. Putnam's book Power from the Wind documents those experiences quite thoroughly. Instead, I'm going to focus on the benefits we realized as a result of our participation in Putnam's concept.

First, we generated work for our company at a time when there was not much work to be had. We were able to keep most of our workers employed until World War II brought about an abrupt surge in demand throughout the economy. Secondly, we received a lot of good publicity. After all, no one had ever built a wind turbine of such a size before. We were the subject of a lot of ridicule too, but the good publicity far outweighed the bad.

The S. Morgan Smith Company also benefited in other ways. Development of new capabilities by our engineering staff was an immediate plus. The fact that this increased capability was noticed by others was evidenced by receipt of contracts to work on projects for which we never before would have considered ourselves qualified.

The long term benefit was an increase in the amount of engineering and manufacturing work our company contracted to perform.

I'd like to give one example--particularly appropriate at this time--of the kind of engineering we were contracted to do as a direct result of our experience with the wind turbine. In the late 40's and early 50's, NASA's Lewis Research Center (then it was known as the NACA Flight Propulsion Laboratory) gave The S. Morgan Smith Company contracts to design, build, install, and put into operation the large air compressors that still power the 10 x 10 and the 8 x 6 supersonic wind tunnels at the Center. I firmly believe my company would never have been asked and would probably never have consented to tackle these jobs if it hadn't been for our experience with the Smith-Putnam Wind Turbine. There are many other examples of projects we were asked to execute because of the added capability we developed meeting the demands of our wind turbine project.

Buried in this account somewhere is the message I wish to impart. We took on a risky project that was beyond our normal engineering experience because we were forced into it by declining economic circumstances. We were very lucky. The risk paid off both immediately and in the long term in ways we had never planned. But as you know, this is not always the case. The message, as I perceive it, is that risks should be undertaken by a private company (and by an individual) when the company is healthy instead of when it is in trouble.

There is a tendency for a healthy company to continue what it is doing as long as the profits are coming in. Private companies in this situation tend not to take on new and different projects. I suggest that the time to strike out in new directions is during a period of strength and profitability. Isn't it possible, for example, that our domestic auto industry would be doing better today if in the period from 1973 to 1980 it had put more of its profits into developing small, reliable, low-cost cars, instead of waiting until people stopped buying the big cars?

Let's apply this message to the wind turbine business; I believe there is a continuing need for a DOE/NASA research program on wind energy. But it is also my belief that now is a good time for private companies to plunge into the development, manufacture, and marketing of these machines. NASA and the Department of Energy have spent a good deal of the taxpayer's money to bring wind turbine technology to the advanced state it is in today. Now is the time for private industry to take this technology, to develop it further and to establish a vital, important, and profitable industry.

By taking this risk, many companies may find themselves far stronger, more diversified, and more profitable. I am told and I have read that there are a few companies that have already gone into the manufacture of wind turbine components, and that they are doing well. That's great and I wish them continued success.

Years ago, I provided some comments that are included in Putnam's book, Power from the Wind. In those comments I expressed the hope that I would live to see the wind turbine market develop. Although it is not yet fully developed, the wind turbine manufacturing industry and the market for these machines is already in the early stages of formation. I am heartened to see this forty-year old dream becoming a reality.

In conclusion, I wish to express my gratitude to the NASA and DOE officials for the honor bestowed on us at this banquet. You have made this occasion one of the most rewarding of my life. In particular, I wish to thank Lou Divone, Ron Thomas and Joe Savino for many personal kindnesses extended to me. Good luck to all of you in your efforts to make the wind one of mankind's major sources of power once again.

Editor's Note: This speech was delivered on Mr. Smith's behalf by his grandson, Frank C. Zirnkilton, Jr. The S. Morgan Smith Company is now the Hydroturbine, Valve, and Nuclear Division of the Allis-Chalmers Corporation.

WIND POWER: YESTERDAY, TODAY, AND TOMORROW

Palmer C. Putnam
Wind Energy Consultant

INTRODUCTION

Officers of the Department of Energy and the National Aeronautics and Space Administration, citizens of Cleveland, distinguished members of this Workshop, and honored guests. Good evening. I have no words to express how honored and happy I am to be here tonight, sharing in this Workshop with all of you and with my colleagues of 40 years ago, who were referred to by Beauchamp Smith on the telephone last night from Seal Harbor, Maine, as "that motley crew of rugged individualists." What's more, we're all still ambulatory!

Joe Savino has asked me to put together a few thoughts on the theme "Wind Power: Yesterday, Today, and Tomorrow." But, before I make my few remarks, I must say that the kingpin of this occasion is Beauchamp Smith. If it hadn't been for his courage and his vision, we wouldn't be here tonight. But his contribution really goes farther than that. He is the true prophet of windpower, and I have to confess that for many years I was the apostate.

Back in the 50's, I had occasion to visit Beauchamp in his home on other matters, and the conversation came 'round to windpower. He astonished me by saying that he expected to live to see windpower come into its own. I had just finished the last chapter of Power from the Wind, the book that he had asked me to write. In that chapter I had tried to gauge the future of windpower. The best that we could do after five years of experiment was to achieve a design that might possibly generate electricity for about 21 mils per kilowatt hour in a reference wind of 14 miles per hour. But, in New England in those days steam stations were operating at 4 mils. I had found that discouraging and had felt that for a long time windpower would be marginal. It seemed to me that under the best of circumstances wind might possibly carry four percent of the national electrical load at some time in the distant future. So I left Beauchamp's house shaking my head in disbelief, and wondering what he saw on the horizon that I had failed to see.

I realize now some of the dimensions of his wisdom, especially at a time when technology was not evolving at today's pace. Obviously, he had had an intuitive feel for the progress of discovery and invention. If he did not specifically foresee that microprocessors would follow William Shockley's discovery of the transistor, or that OPEC would result from aggressive Arab nationalism, he apparently knew intuitively that there would be some developments which would improve the chances for windpower.

Edgar Allen Poe obviously had Beauchamp Smith in mind when he coined his neat paradox: "Wisdom should reckon on the unforeseen."

So, here we are this evening with 81 units in operation, feeding 13.8 MW into high-lines, and with 2100 other units totalling 500 MW under contract or in negotiation. If the new member of the energy family is not yet a mature adult, at least we can say that the infant is struggling to be born. Beauchamp Smith, witnessing the labor pains from Seal Harbor, has sent us that thoughtful and stirring message that his grandson, Frank Zirnkilton, has just read. I think this is very wonderful and that Beauchamp is due a great tribute for his courage, his vision, and his wisdom.

WIND POWER YESTERDAY

Forty-two years ago we had thought there were two questions that had to be answered before we could establish wind as an alternative source of energy.

The first question was, is it possible to convert gusty wind into alternating current so steadily that it will be acceptable to the dispatcher of a utility high-line? This had never been done. No one knew if it could be done. I had kind friends who said it couldn't be done! Second, if it could be done, could the energy be generated at a cost attractive to a utility?

The first major decision we had to make was, what kind of a windmill is the right one to test? Vertical axis or horizontal axis? If vertical, should it be mounted on a track or a pedestal? Should it be Savonius or Darrieus or one of the others? If horizontal, how many blades? One, two, three, or more? Should the generator be aloft or on the ground? Should the drive be mechanical or hydraulic? Should the tower rotate or be stationary? Examples of all of these configurations existed in the literature. Some had been built, but only for the generation of direct current.

Beauchamp Smith and his cousin Burwell reviewed my arguments. They agreed with my parametric selections, namely, the horizontal axis, two-bladed configuration, with a mechanically-driven synchronous generator mounted aloft.

Then came the question: How big shall we make the test unit? Having selected the parameters, I had made two optimization studies with the help of Tom Knight, GE's Vice President for New England. The second study suggested that the optimum size was close to 2 MW, but that the envelope was quite flat in the range of 2 to 3 MW.

At first glance, it seemed sensible to try to get only one answer at a time, and to start out the test with a small unit, say 100 kW. But I was afraid of this. I felt that harnessing gusty winds to produce alternating current smoothly could be so difficult that we might get a false negative answer from a small unit of low inertia, easily accelerated. I argued that it was essential to make the experiment full scale and that this would have the added advantage of giving us both answers at once. Theodore Von Karman backed me in this, and Beauchamp picked 1250 kW as being the smallest unit representative of the optimum range.

Then came the question of site selection. Being sailors, Tom Knight, Vannevar Bush (then Dean of MIT) and I knew that the roaring forties were windy, with strong westerly components. New England lay in the forties. The Green Mountains of Vermont trended north-south. Without discussion, it was tacit among us that the test site should lie somewhere in the Green Mountains.

But specific site selection was quite another matter. In our innocence, we thought we could look at the profile of a ridge and say: "This ridge obviously will accelerate the free air flow while that one won't." Thus, we guessed that Grandpa's Knob would accelerate the free-air wind by a factor of 1.2. After five years of observation we concluded Grandpa's had actually <u>retarded</u> the free-air flow, giving us a factor of 0.9.

Also, in our innocence, we thought that if we tested models of candidate sites in the wind tunnel, we could obtain precise information about the wind velocity over a ridge. Even while proceeding with the selection of Grandpa's Knob, we made four models of other Green Mountain sites. Over 20,000 measurements were taken in the Guggenheim wind tunnel at Akron with inexhaustible ingenuity, under the supervision of Von Karman. Our regretful conclusion, since confirmed in England by Golding, was that model testing of wind sites yields no useful information.

We tried every other method we could think of to evaluate quickly what appeared to be the more attractive sites in New England. Dr. Karl Lange of Harvard, for example, flew balloons in westerly winds over a number of the sites, following their trajectories with range-finders. Because of turbulence, the method proved useless.

In the end, the tool that we discovered to be most useful, short of actual anemometry, was what I called "quantitative ecology," which I worked out with the botanist, Dr. Robert Griggs. He and I discovered that the deformations of evergreens by wind, which are easily observed and which fall into half a dozen readily identifiable categories, were good wind prospector's tools. We found it possible to look at deformed evergreens and say: "At this site the long-term mean annual velocity at a hub height of 140 feet will be 25 miles per hour, with a probable error of about 10 percent." However, until we had taught ourselves this new technique, our only recourse was anemometry, and the constraint of the impending war forced us to select a site for the test unit without waiting for such measurements.

Map and field studies had suggested to Hurd Willet that the four-mile-long Lincoln Ridge should be a powerful site. But it stood at 4,100 feet, and we were all afraid of icing. It seemed to me that the experiment was going to be chancy enough, without the challenge of ice. So I chickened out and joined the opposition to Lincoln Ridge. Now we know that ice is no problem.

We sailors thought that our educated guesses of the output at the 2000-ft. Grandpa's Knob were sufficiently reliable to permit the experiment to proceed. In the end, we obtained only thirty percent of the output we had predicted. So much for the intuitions of sailors about specific site selection!

The next major decision was, how to make the blades and of what? We had several delightful discussions with Frank Caldwell, Chief Engineer of Hamilton Standard Propeller, but he decided that a propeller 175 feet in diameter was too much for the then state of his art.

The Budd Company had been making stainless steel trains and destroyer superstructures under Dick Heckscher, who volunteered to break new ground and make up our blades out of stainless, to the aerodynamic specifications of Von Karman and Homer Joe Stewart.

In 1939 the phony war was already on. Our own eventual entry seemed likely, and American industry was already gearing up for war production. We felt that if we did not order the long lead time items promptly, we might not get them for many years to come. For this reason, the entire project was driven at a fairly fast clip under Bud Wilbur as Chief Engineer, with the assistance of Chris Holley. By the way, Chris said to my wife yesterday that he's been going around this conference feeling like Orville Wright.

The Smiths made the decision to proceed with the project in October 1939. Seventeen months later, Stan Dornbirer had erected the unit, despite a Vermont winter. After some months at slow rotation, followed by more months at speed-no-load, Bill Bagley of GE, on the evening of 19 October 1941, phased the unit into the lines of the Central Vermont Public Service Corporation in a northeast wind gusting to 25 mph.

Within half an hour, while generating 500 kW, we got the answer to our first question. We could indeed make gusty winds generate alternating current smoothly enough to be acceptable to the dispatcher of the high line. In fact, the operation was so smooth that Ralph Durgin, the Chief Engineer of Central Vermont Public Service Corporation, told me later that they took their regulation from Grandpa's Knob rather than vice-versa!

Thereafter the unit was operated for several hundred hours under Grant Voaden's test program until one of the 24-inch main bearings failed. The failure had nothing to do with windpower in general, or with the design of our unit specifically. But, because it occurred during the war, it took many months to replace. The unit was then started up again and in all had logged about 1,100 hours of very smooth operation when we lost a blade.

Many years later I was consoled for the blade loss by Clyde Jones, who had been Howard Hughes' Chief Engineer in the design of the Hughes helicopters. He told me that if we hadn't lost the blade then, we would have been bound to lose it later, because in those days nobody knew anything about the stress analysis or the fatigue factors of helicopter rotor hubs. They didn't become reliable until the mid'fifties.

When I consider the elegant computerized structural stress analyses that today have permitted Hamilton Standard and Boeing and GE and Westinghouse, for example, to reduce or balance out stresses, thus reducing weight with confidence, I am somewhat appalled at the blythe temerity with which we attempted to design our hub in those days. If I had known then what I have learned since, I would hardly have dared recommend the project to Beauchamp Smith.

After the war, in the light of five years' experience and of suggestions from many of the members of the team who are here tonight, two further sets of optimization studies were carried out under the direction of Carl Wilcox, working in the offices of the Budd Company. The final set confirmed the three previous studies and indicated that the optimum capacity would lie somewhere in a range between 1.5 and 3.0 megawatts, but with an envelope that was quite flat at the higher capacities.

Assuming a production run of 100 units, the lowest conceivable capital cost in 1945 was a very uncertain $100 a kilowatt. Installed on Lincoln Ridge, where the velocity at hub height was 27 miles an hour, this would have meant a cost of electricity at the bus of about 5.3 mils a kilowatt hour. But in New England then, as I mentioned, utilities could not afford to pay more than 4 mils for wind energy.

So, we had our two answers. Yes, we could convert gusty wind energy into alternating current smoothly enough for the dispatcher of a high-line. No, we could not do so economically.

Beauchamp asked me to write Power from the Wind. And we all then turned to other things.

WIND POWER TODAY

If NASA's predecessor had held a workshop on windpower 40 years ago, the Smith-Putnam Team would have been the only attendants. But there would have been no papers because nobody knew how to write them.

Here we are today attending this workshop, so beautifully organized by Dave Spera and Joe Savino of NASA and Bob Thresher of Oregon State. We've now spent two stimulating days discussing 23 papers concerning the specifics of windpower today. I'll make no attempt to summarize all this. Instead I'll try to look at windpower in the large, with the fresh eye of someone who has just returned to it after a long absence.

It's a matter of great satisfaction and some astonishment to observe that my parametric selections of 40 years ago have stood up. DOE and NASA have funded parametric studies by GE, Boeing, and others, using computers. These studies have confirmed my parametric selections (Fig. 1). Even the computerized optimization studies gave results that were not dissimilar to ours of 1939 and 1945. The envelope of the capacity curves is still flat, although the minimum point is further to the right.

As we all know, the most recent optimization studies by GE, Boeing, and Hamilton Standard suggest that the optimum capacity today lies somewhere in the range of 5-7 megawatts (Fig. 1). It has been explained to me that this shifting of the minimum point of the envelope to the right has not been the result of fundamental design changes. It has been in improvements in the past ten years in computerized structural analysis solidly based on a billion flight hours of helicopter experience, and backed up by such inspection techniques as sonic and X-ray examinations. The net result of all of this has been an ability to greatly reduce the weight per kW.

For example, as shown in Figure 2, our Grandpa's Knob machine weighed 598 pounds per kW. Our pre-production design of 1945 brought this weight down significantly, to 470 pounds per kW. But, GE's Mod-5A is now reported at 184, Boeing's Mod-5B at 179, and the others are also under 200 pounds per kW. This paring away of 2/3 of the unit weight is what has permitted a tripling of the optimum capacity, from a little over 2 MW to a little over 7. I've also been told that about 7.2 MW, with its associated diameter of 500 feet, is perhaps an absolute limit today. It's as high as we can go with available bearings.

In 1945, when steel railroad gondolas were selling for 6 cents a pound, our preproduction unit cost 31 cents F.O.B.--a ratio of 5 to 1. In 1981 gondolas are priced at 59 cents a pound, while the 100th unit of GE's Mod-5A is quoted at "less than" $2.95 a pound--also a ratio of 5 to 1. At the other end of the size spectrum, the 25-kW Carter unit is priced at about $4.00 a pound F.O.B.

These ratios suggest that not many manufacturers of intermediate and large wind turbines will be tempted to offer their machines at much over $4.00 a pound, in 1981 money.

In the final sentence of Power from the Wind, I had said in 1945 that it would probably take government help to get low-cost production runs started. Since the oil embargo of 1973, DOE has spent a quarter of a billion dollars to stimulate windpower. Apart from the splendid Battelle 12-volume atlas of the Nation's wind resource, and innumerable studies by such groups as JBF Scientific; Booz, Allen and Hamilton; Arthur D. Little; EPRI; SERI; and others, the bulk of the money has gone to fund the production of hardware, looking to the evolution of a commercial multi-megawatt production unit.

Beginning with NASA's 100-kW Mod-0 at Plum Brook in 1975, continuing through the Westinghouse 200-kW Mod-0A series at Clayton, Block Island, Culebra and Kahuku Point on Oahu, through GE's 2.5-MW Mod-1 at Boone, and Boeing's three 2.5-MW Mod-2's for Bonneville Power, we have just now arrived at the design studies of the first units of the fourth generation. It is hoped that their tests will show them to be mature prototypes, and the basis for production designs. They are the Mod-5's of Boeing and GE, rated up to 7-MW, and the 500-kW of Westinghouse. Also, in the private sector, there is the WTS-4 of Hamilton Standard, rated at 4.8 MW. I am told the first unit of this design should be on line in Sweden in November. And the first WTG 500-kW is in the wings.

In short, the birth of the baby is underway. At this interesting juncture, the administration has been saying that it must turn out the hospital lights and send the staff home, leaving the baby to be weaned while delivery is underway. Can there be a live birth without further help? I don't know. It remains to be seen whether the private sector will take up the slack. In the meantime, what can we say about the infant, from as much as we can see of it? Is it a healthy specimen?

We still have the same two questions that faced us in 1939, but in the reverse order. As I will try to show in the next section, "Windpower Tomorrow", however shaky the transition economics may appear, the ultimate economics are no longer in doubt. It is now the technology as perceived by venture capitalists, whose maturity is in question.

Recently I was talking with the chairman of one of the Fortune 500. He summed up his view of windpower by telling me that windmills either blow down or blow up, or, if they work, they are noisy: To hell with them!

Regrettably, the test record does contain just such episodes, but I seem to remember that some early airplanes failed and some early helicopters did shed blades. If wind turbines appear to have had a very large number of accidental shutdowns, I wonder if this hasn't been due in part to a very general impression that harnessing the wind is child's play? Didn't we have millions of windmills pumping water in the last century? Weren't they reliable work horses, year-in, year-out, often with service lives of fifty years or more? All true, but deceptively irrelevant.

COE in constant dollars, perhaps reaching about 27 mils in 1990 and 24 mils in 2000. By contrast, a specific utility, when peaking with natural gas in 1981, has a COE of 65 mils. But this apparently comfortable margin is not the whole picture.

The U.S. utility industry is having a hard time financing conventional additions to plants. Even if it wished to, a utility would be unlikely to obtain a P.U.C. permit to add an unproven source of energy to its rate base.

At least in its introductory years, therefore, large-scale windpower that is a part of utility's generating mix would require third-party financing. While long-term Treasuries are earning 14 percent, with minimum risk, and until wind technology becomes mature, venture capitalists are going to demand a minimum of 35 percent internal rate of return on their investment. This means that a windfarm generating for three cents at the bus must then add the costs of the venture capital, amounting to several cents more, to arrive at a selling price possibly falling in the range of 5 to 8 cents. (Three windfarms are now venture-capital financed. Rolf Laessig described two of these this afternoon.)

How does this range in the selling price compare with the worth of wind energy to a utility? The principle worth is as a substitute for coal, gas or oil. What can we say about the trends to expect in the costs of these fossil fuels?

Let's look first at crude oil prices. Whether they are trending up or down depends on the expert you consult. A couple of weeks ago a New Jersey think-tank saw crude's prices tumbling down from $40 a barrel to $20 and $10 or less. The argument went like this: Without altering our life-styles very much we have decreased our imports in the last 3 years from 8 million barrels a day to 5. Others can and will continue this process. Non-OPEC production is rising. The conclusion: OPEC has lost its leverage.

But, if you don't care for this scenario, then turn to the Wall Street Journal of a week later. The glut is over. Inventories have been pared down. World demand is increasing. Prices are firming and will go on up.

Fortunately for windpower, and except in special cases, it may not be very important in a general way which scenario proves correct, because the national fuel mix for generating electricity contains only 15 percent oil. One special case of great importance, however, is the West Coast and Hawaii, where utilities are heavily dependent on oil. If oil prices should fall, windpower there would face a very tough challenge.

Apart from nuclear, most generation is by coal. What about the future trend in the price of coal? Those who follow the fortunes of coal estimate that its price may conform to the trend in the inflation rate, within a few percentage points either way.

If the price of coal, especially of sub-bituminous coal, should not escalate at the general inflation rate, then it might be nearly a decade before wind could generate more cheaply, except at the windiest locations. This time-frame does not allow for the monies that wind must earn to reward the venture capitalists.

When natural gas is deregulated, a portion of that fuel may increase in price five times or more. The average price may go up 50 percent, and the Congress, with administration backing, has now rescinded the law that deprived utilities of all natural gas by the year 2000. On balance, therefore, the future of gas prices should help windpower in those localities where utilities burn this fuel (Fig. 3).

Those utilities burning mostly coal and gas have base-load costs of about three cents and peaking costs of perhaps twice as much, or more in some cases. Most of them should be able to pay somewhere between these limits for wind energy. If a levelizing factor of 2 is acceptable, then perhaps several cents more. For preliminary planning we might think of a range, therefore, between levelized base-load costs of about 6 cents and levelized peaking costs of perhaps 10 to 12 cents, yielding a margin that ranges from nothing in some cases to as much as 4 to 5 cents in the most favorable cases.

If aspects of this market seem a bit tight, we may reflect on four additional factors. First, interest rates of 14 percent for long-term Treasury notes are not likely to be permanent. Second, I've been talking averages, but there are some special cases, not only in the continental U. S., but also in the Caribbean, on some oceanic islands, and, perhaps, in certain foreign countries. Third, although it varies from utility to utility, in certain specific cases it will be found that wind can earn a capacity credit. Fourth, windpower almost always earns a KVA or power-factor credit of at least a few dollars a kW.

The costs of venture capital are soon to be a heavy burden in this utility market. Is there any way to avoid the cost of this venture capital assistance? Yes, there is. By selling directly to businesses, institutions and individual ranchers and farmers, who will then harness the wind for their own account, selling the excess to the utility through a two-way meter. Price relief appears at both ends. First, the avoided costs of the individual user are what that user is now paying the utility. These costs may run from 5 to 12 cents or more. Second, the cost of the wind-generated energy will drop by the amount that the venture capital would have cost. As we have seen, that amounts to several cents.

The sum of these two reliefs may amount to 4 to 8 cents or more, creating a total margin that might run from a few cents to 10 or even more in certain special cases. Of course, a part of this larger margin will be needed to defray the extra costs of researching and penetrating this more diffuse market.

How large is this private market? I can't find any close estimates. There are suggestions that it may amount to another 10,000 MW by the end of the century, suitable for the smaller and intermediate size machines.

I've said nothing about government assistance. Just as the airlines needed government subsidies at first but are now on their own, so windpower, having had the government help I asked for 35 years ago, must look forward to ultimate prosperity without help. Has that time arrived? Surely not quite yet. We are in transition barely.

In sum, then, what are the salient points about windpower that offer some clues to its future? I think there are four.

1. Design

   The essential design parameters haven't changed in 40 years. There is nothing in sight to suggest a revolutionary breakthrough. The costs of wind energy in constant dollars have declined 76 percent in 36 years. They may decline a few percentage points further, but a revolutionary decline is not foreseen.

2. Reliability

   Today there are already machines that run silently with a reliability of over 85 percent. Higher reliabilities should result from the orderly development of quality control in production.

3. Economics and the Market

   A. The domestic market for windpower may amount to 30,000 MW by the end of the century, with costs at the bus between 2 and 3 cents in 1981 dollars (Fig. 3). The foreign market is not yet measured. Wind energy financed by venture capital must receive a minimum of 5 to 8 cents a kWh to be profitable.

   B. An additional market consists of direct sales to businesses and individuals, without venture capital. The domestic private market may amount to 10,000 MW by 2000.

4. Government Help

In the multi-megawatt range, public R&D has developed the Mod-5 designs and concepts of Boeing and GE. There remains, however, a 3 to 4 year test program before production. If this minimum remaining public assistance is not forthcoming, large-scale windpower could suffer a set-back and long delay. Even if manufacturers do start production, windpower in general may still need tax relief for perhaps a decade before it can stand alone.

I heartily endorse Belloc's remark about prophecies. I wouldn't ask 10 seconds of your time to listen to a prophecy. But I don't think a dream is in the same category as a prophecy, is it? I do have a dream I'd like to share with you. I dream of a galaxy of windfarms--many thousands of megawatts--deployed in the mid-continent region and along the foothills of the Rockies, in reference winds of 16 to 19 miles an hour, all tied together by upgraded high-lines and feeding into the great power pools and grids of the region; these blocks of power to be amplified by multitudes of units sold directly to private users without the need for venture capital.

My dream has brought me a new partner, Aerovironment. I've metioned that Theodore Von Karman had been our senior scientific advisor and chief aerodynamicist. He was assisted in this by his ablest graduate student, Homer Joe Stewart, who is here tonight. Stewart, succeeding Von Karman at Cal Tech, had an able graduate student in his turn, the amiable Peter Lissaman, Vice President of the Aero Sciences Division of Aerovironment. As most of you know better than I, it was Lissaman's work that has been so fundamental to the design of modern wind turbines and the geometry of windfarm arrays.

I'm so happy to be the beneficiary of this apostolic succession--Von Karman to Stewart to Lissaman. The President of Aerovironment, another student of Homer Joe Stewart, is Paul MacCready, of Gossamer Condor fame, whose Solar Challenger has just flown from France to England. Last year he and Von Karman were each named by the ASME "Engineer of the Century." With such associates, I dare to hope that you'll be hearing more about my dream - soon.

I'm not overlooking environmental resistance. I am an environmentalist. I have to believe that most people want windpower to succeed. A few weeks ago I was in Clayton, N. M., to study Westinghouse's 200-kW Mod-OA, which I found putting out 150 kW in 25 mph of gusty southwest winds. I asked Eli Garcia, the City Manager, if the townspeople were opposed to the unit. He told me that, on the contrary, they were proud of it and proud to be using the wind. We stood beside a house about 800 feet downwind. The unit could not be heard above the rustling of the leaves in the trees!

May I close by quoting the last paragraph of my foreward to the new edition of Power from the Wind, which has been updated by Professor Jerry Koeppl, and is to appear in September. It was written before my visit to Clayton.

> "A seascape or a landscape without a work of man in the middle distance is often thought to be not worth photographing or painting. An expanse of mere ocean does not say much. Put a laboring vessel in the middle distance, and there is a point of interest - dramatic value. A distant mountain range is just there. Add a forest ranger's tower: the composition begins to say something. How much more will it say when a slender tower is seen to support two blades that rotate slowly, gracefully, silently - evidence that man is once again, and at last, using his environment benignly!"

Thank you very much.

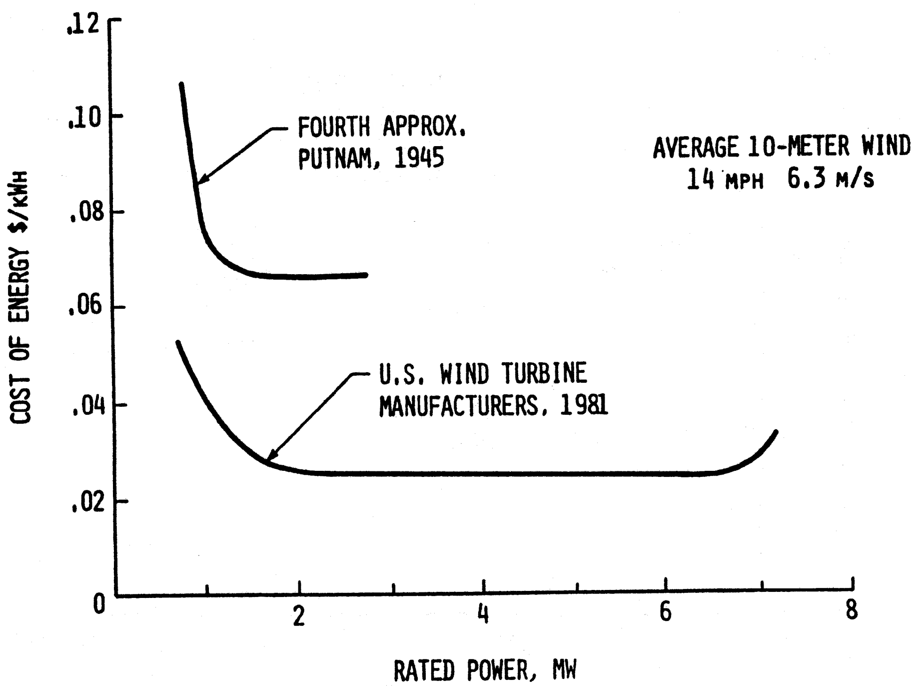


Figure 1. - Effect of turbine size on energy cost

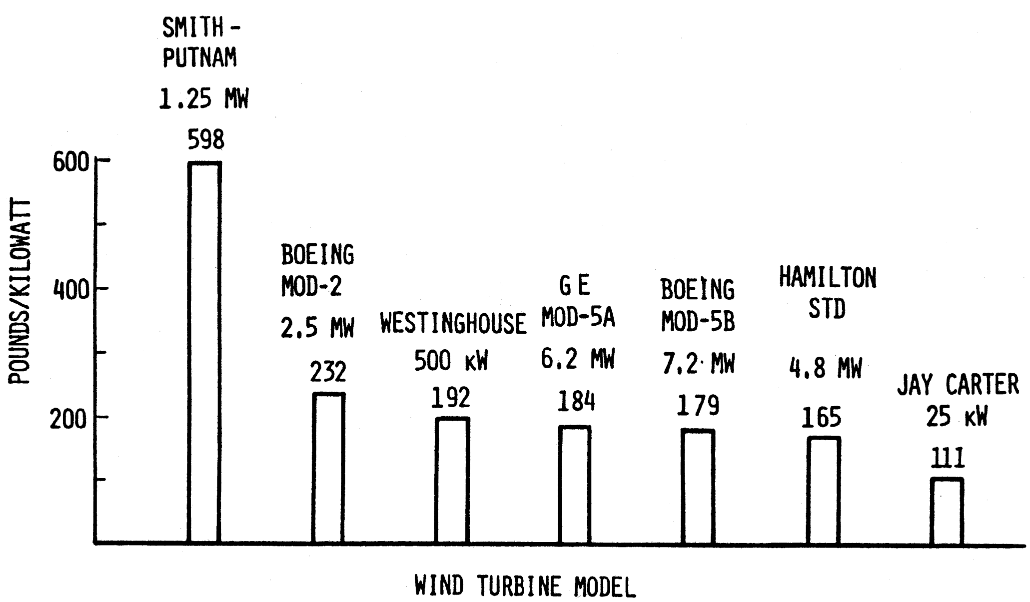


Figure 2. - Weight-to-power ratio of various wind turbines (weight above foundation and rated power).

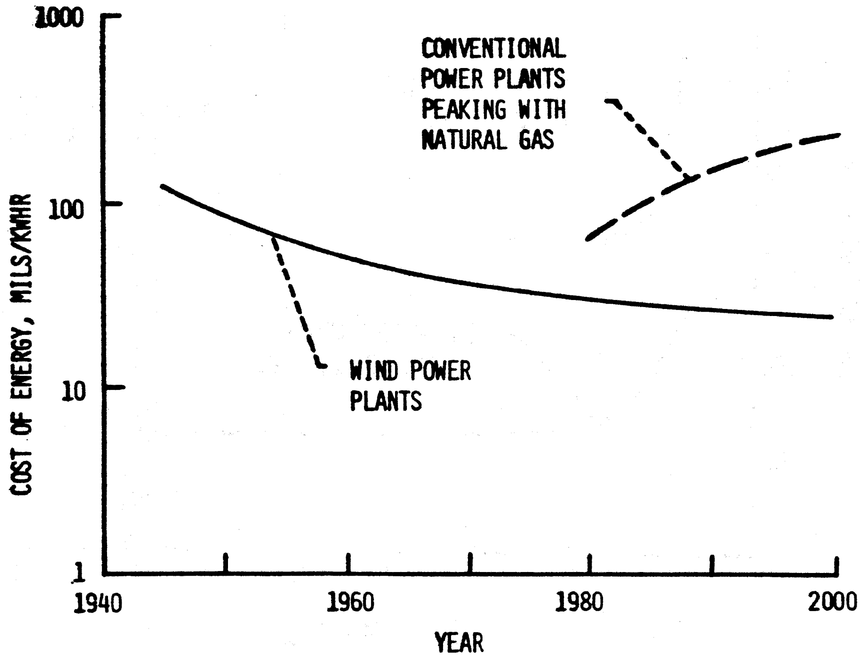


Figure 3. - Possible trends in the cost of energy generated by wind power, compared with conventional plans using natural gas as fuel
(constant 1981 dollars; busbar costs).

LARGE HORIZONTAL-AXIS WIND TURBINE WORKSHOP

Ceremonies Commemorating the Fortieth Anniversary of the Smith-Putnam Wind Turbine Project

Awards to the Smith-Putnam Project Team

Beauchamp E. Smith
Palmer C. Putnam
Dr. John B. Wilbur
Grant H. Voaden
Carl J. Wilcox
Stanton D. Dornbirer
Dr. Homer J. Stewart
Myle J. Holley, Jr.
Dr. Hurd C. Willett
Wellman Engineering Company

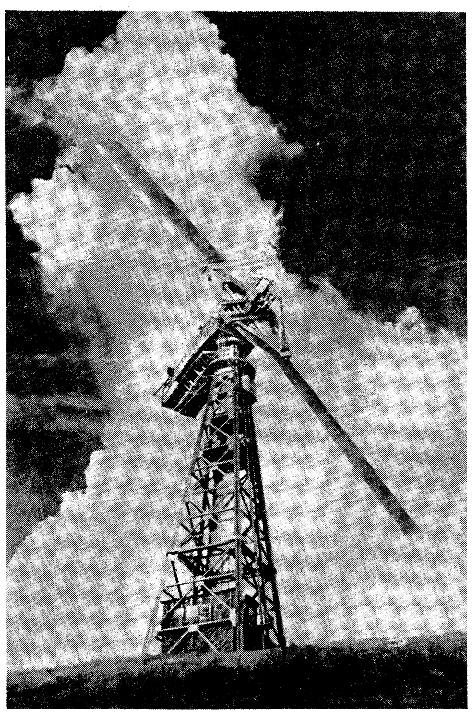
"The Smith-Putnam Wind Turbine"
Grant H. Voaden
Reprinted from Turbine Topics, Volume 1, No. 3, June 1943
A Publication of the S. Morgan Smith Company

FORTIETH ANNIVERSARY AWARDS TO THE SMITH-PUTNAM PROJECT TEAM

This Workshop provided an excellent opportunity for the wind energy community to honor Beauchamp E. Smith, Palmer C. Putnam, and key members of their project team for pioneering achievements in wind power development. Forty years ago, this team designed, built, and operated the world's first megawatt-size wind power plant. On October 19, 1941, the Smith-Putnam 1250-kW wind turbine (below) was brought on-line as a generating station of the Vermont Public Service Corporation. The historic Smith-Putnam project advanced the field of wind power engineering from small DC generators and water pumpers to large AC units capable of integration into electrical supply systems.

To honor these achievements, citations were awarded by NASA, in cooperation with the U.S. Department of Energy, to Messrs. Smith and Putnam, and to the following eight members of their project team: Dr. John B. Wilbur, Chief Engineer; Grant H. Voaden, Assistant Chief Engineer; Carl J. Wilcox, Administrative and Project Engineer; Stanton D. Dornbirer, Manager of Assembly and Operations; Dr. Homer J. Stewart, Aerodynamicist; Myle J. Holley, Jr., Structural Analyst and Designer; Dr. Hurd C. Willett, Meteorologist; and the Wellman Engineering Company of Cleveland, Principal Designer and Manufacturer.

The following pages contain brief descriptions of the award recipients and their roles on the project team.



The Smith-Putnam 1250-kW Wind Turbine
1941-1945

Beauchamp E. Smith
1901 — 1981

National Aeronautics and
Space Administration
Lewis Research Center

in cooperation with

Department of Energy

Honors

Beauchamp E. Smith

a pioneer in the development of large Wind Turbines as a source of clean renewable energy for his leadership, courage, and fore-sight which made possible the construction and operation of the World's First Megawatt-Size Wind Turbine at Rutland, Vermont, from 1941 to 1945.

Cleveland, Ohio
July 29, 1981

Beauchamp E. Smith
Project Sponsor

Beauchamp E. Smith was born in York, Pennsylvania, on October 8, 1901. He attended Haverford School and graduated from Cornell University with a Degree in Mechanical Engineering. During 1924 and 1925 he was employed by the Georgia Power Company, first as a draftsman and later as a field engineer. He joined the S. Morgan Smith Company as a junior engineer on December 1, 1925. From 1927 to 1937 he served as secretary and director of the company. He became vice president and general manager in 1937 and president in 1942.

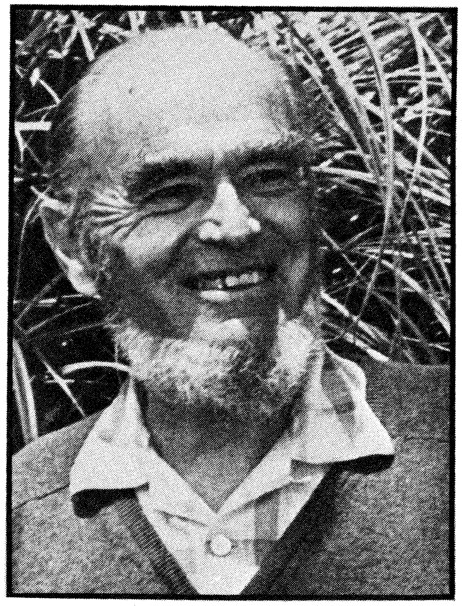
When the S. Morgan Smith Company was acquired by Allis-Chalmers Manufacturing Company in 1959, Mr. Smith became a vice president of Allis-Chalmers and the general manager of the corporation's Hydraulics Division. After his retirement in 1961 he served as a director of the Allis-Chalmers Corporation until 1974.

It was during his tenure as vice president and general manager of the S. Morgan Smith Company that Beauchamp Smith's belief in the feasibility of wind power was put into action. He persuaded the company directors to sponsor Palmer Putnam's unprecedented wind power project. Under his guidance, the company constructed a megawatt-size wind turbine generator in 1941--the first in history.

Speaking at the 1975 dedication of the NSF/NASA Mod-0 wind turbine, Mr. Smith said "I always felt that something good would come out of our tests in the 1940's, even though we were ridiculed at the time. Energy sources seemed then to be more abundant than our country would ever need. We were just ahead of our time. I got a great feeling of satisfaction today when I saw those majestic blades going around."

Beauchamp Smith was always active in the leadership of educational, charitable, commercial, and professional organizations. He served on many boards of directors and trustees, including those of the Massachusetts Institute of Technology, the National Electrical Manufacturers Association, and the Cornell Engineering College Council.

Because of illness, Mr. Smith was unable to attend the Workshop. His citation was accepted for him by his grandson, Frank C. Zirnkilton, Jr. On September 21, 1981, shortly after the Workshop, Beauchamp Smith died at his summer home in Seal Harbor, Maine.



Palmer C. Putnam

National Aeronautics and
Space Administration
Lewis Research Center
in cooperation with
Department of Energy

Honors

Palmer C. Putnam

*a pioneer in the development of large Wind Turbines
as a source of clean, renewable energy and
who conceived and led the construction and operation of the
WORLD'S FIRST MEGAWATT-SIZE WIND TURBINE
at Rutland, Vermont, from 1941 to 1945.*

Cleveland, Ohio
July 29, 1981

Palmer C. Putnam
Project Originator and Leader

Palmer C. Putnam is one of those creative persons of immense energy who cannot be easily classified--his accomplishments are so many and so varied. During World War II, he worked as a special assistant to the director of the Office of Scientific Research and Development, Vannevar Bush. In that position he invented 10 original weapons and directed the development of 22 others. Among them was the well-known amphibian vehicle, the DUKW, which the German General von Rundstedt called "a strategic surprise that assured the success of the Allied invasion of Normandy." Mr. Putnam received the Medal of Merit from President Franklin D. Roosevelt for his contributions to the war effort. The citation accompanying the medal stated that "his efforts undoubtedly resulted in shortening the war and in saving the lives of many American and Allied soldiers."

Mr. Putnam operated his own business and was the president and board chairman of G.P. Putnam & Sons, one of the oldest publishing firms in the country. He has been a consultant on projects too numerous to list here. He is the author of several books, one of them the renowned Power from the Wind. It is not surprising, therefore, that it was Mr. Putnam who conceived and led one of history's most successful attempts to harness the wind on a large scale.

Mr. Putnam's interest in wind power was stimulated in 1934 when he noticed that both the winds and the cost of electricity were high on Cape Cod where he had built a summer home. These two facts prompted him to investigate, with the help of many prominent engineers, the feasibility of generating electricity from the wind. His investigation eventually led to the design of the 1250-kW unit that was built and installed on Grandpa's Knob in 1941 under the sponsorship of the S. Morgan Smith Company of York, Pennsylvania.

By his foresight, creativity, and leadership, Mr. Putnam demonstrated that large wind turbines can be integrated into utility networks as a supplemental source of clean, renewable power. Had today's energy shortages existed forty years ago, there is no doubt that Mr. Putnam's machine would have been followed by thousands of large wind turbines in operation around the country and the world.

Dr. John B. Wilbur
Chief Engineer

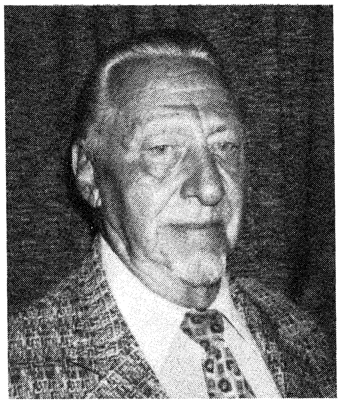
As Chief Engineer of the Smith-Putnam project, Dr. Wilbur coordinated all of the design, fabrication, construction, and testing activities from 1939 to 1945. As he recalled at the Workshop, "The design was being carried out by experts all across the country, from MIT to Cal Tech, from the Budd Company in Philadelphia to American Bridge in Pittsburgh to Wellman Engineering in Cleveland. These were very creative people. My job was to focus all this creativity on one project."

Dr. Wilbur's distinguished career has encompassed a broad range of positions and experience. In 1930 he joined the faculty of the Civil Engineering Department at Massachusetts Institute of Technology. He rose to the rank of full professor and became department head. He is a Fellow of the American Society of Civil Engineers, serving as the president of its Northwest Section. Dr. Wilbur is also a Fellow of the American Academy of Arts and Sciences. In 1947 he received the highest award given by the Boston Society of Civil Engineers for a paper he wrote about the Smith-Putnam wind turbine. Since 1970 he has been Professor Emeritus at MIT and is enjoying life these days in Hancock, New Hampshire.

Grant H. Voaden
Assistant Chief Engineer

Mr. Voaden was employed by the S. Morgan Smith Company from 1925 until 1968. In 1939 he was assigned to work full-time on the Smith-Putnam wind turbine as the Chief Test Engineer, reporting to Dr. John B. Wilbur. Mr. Voaden later became Assistant Chief Engineer. In the early stages of the project, he was involved in the design of the machine and in the selection, coordination, and purchase of the hydraulic and electrical control equipment. He also helped with the assembly on Grandpa's Knob, trained the wind turbine operators, and managed the field-test program.

Since 1968, Mr. Voaden has been enjoying retirement in York, Pennsylvania.



Carl J. Wilcox
Administrative and Project Engineer

Mr. Wilcox worked on the wind turbine project starting in early 1940, when he was employed by the Budd Company which built the blades. There he participated in design of the rotor blades, analyzed aerodynamic performance, and conducted some of the first economic studies for large wind turbines. In June 1941 he joined the S. Morgan Smith Company as administrative engineer in charge of the company's Rutland, Vermont office. In this position Mr. Wilcox monitored operations at the test site on Grandpa's Knob, 18 miles away, collected and processed test data, and wrote many of the reports on the Smith-Putnam project. He was also involved in the economic assessment studies which were made for the company after the blade failure in 1945.

From January 1946 to April 1947, Mr. Wilcox assisted Palmer Putnam in the preparation of his book <u>Power from the Wind</u> which has achieved world-wide recognition. From 1947 until his retirement in 1976, he held a number of important management positions at the S. Morgan Smith Company. He continues to live in York, Pennsylvania, his home of 40 years. With his fund of information on the wind turbine and the people who designed and built it, Carl Wilcox is the unofficial historian of the Smith-Putnam project.

Stanton D. Dornbirer
Manager of Assembly and Operations

Most of Mr. Dornbirer's professional career was spent with the S. Morgan Smith Company from the 1930's until his retirement in 1963. He managed the field installation of heavy machinery and equipment across the United States and abroad. In 1940 he was assigned to the wind turbine project, with responsibility for the entire assembly operation, including shop assemblies in Cleveland, Pittsburgh, and Philadelphia, and field assembly on Grandpa's Knob. In spite of bitter winter weather, absence of roads, and an almost impossible schedule, Stan Dornbirer fulfilled his responsibility. After the machine was assembled and in operation, his task was to keep it running and to supervise maintenance and repair work.

Mr. Dornbirer is a native of Cleveland, where he graduated from the Case School of Applied Sciences (now Case-Western Reserve University). Among his many engineering accomplishments are the construction and installation of the huge compressors in two supersonic wind tunnels at the NASA Lewis Research Center in Cleveland. During the Workshop, he inspected these compressors, obviously pleased with their performance during the past 30 years. Mr. Dornbirer is still active as a consulting engineer based in Inglis, Florida, his retirement home.

Dr. Homer J. Stewart
Aerodynamicist

Dr. Stewart's contribution to the Smith-Putnam project was the development of the unique design of the rotor blades. As a graduate student at the California Institute of Technology, he worked closely with Dr. Theodore von Kármán to select an airfoil shape that was both efficient and economical to build. They evaluated many designs, both by theoretical analysis and by wind tunnel testing. Dr. Stewart's studies led to the selection of constant-chord blades each individually hinged to relieve loads. This research on rotor aerodynamics produced some of the most significant contributions which were made by the Smith-Putnam project team.

Dr. Stewart is Professor Emeritus of Aeronautics at the California Institute of Technology. During his long and distinguished career he has made many pioneering contributions to the development of modern rocket engines. In 1958 and 1959 he helped usher in the Space Age as NASA's first director of the Office of Program Planning and Evaluation. Dr. Stewart and his wife Frieda presently reside in Altadena, California.

Myle J. Holley, Jr.
Structural Analyst and Designer

Mr. Holley became a member of the Smith-Putnam team in September 1939, while still a graduate student at the Massachusetts Institute of Technology. One of his first responsibilities was to analyze dynamic loads and stresses in critical components, an effort which was largely without precedence. In 1941, he joined the S. Morgan Smith Company and moved to Rutland, Vermont. There he served as a test engineer and structural analyst.

In 1946, Mr. Holley resigned from the S. Morgan Smith Company to accept a faculty appointment at MIT, in the Civil Engineering Department. There he continued his career as professor, research engineer, and consultant. He retired in 1974 but continues to be very much involved with engineering research and consulting work.

Dr. Hurd C. Willett
Meteorologist

Dr. Willett's specialty is long-range weather forecasting. He has had a distinguished career at the Massachusetts Institute of Technology extending from 1929 to 1973. His research has centered on the relationship between solar activity and weather. He headed a group of four meteorologists on the Smith-Putnam project. Dr. Willett made many site surveys, frequently alone and in the dead of winter, on mountain tops and ridges of the Green and White Mountains of New England. While the wind turbine was in operation, he prepared weather forecasts as a guide to testing. To do this he analyzed many years of data to identify seasonal changes and stratification characteristics of the wind.

Dr. Willett is Professor Emeritus at MIT and still quite active in professional activities. In 1974 he assisted NASA in the selection of a site on Culebra Island, Puerto Rico, for the 200-kW Mod-0A wind turbine which was installed there. Dr. Willett and his wife reside in Littleton, Massachusetts.

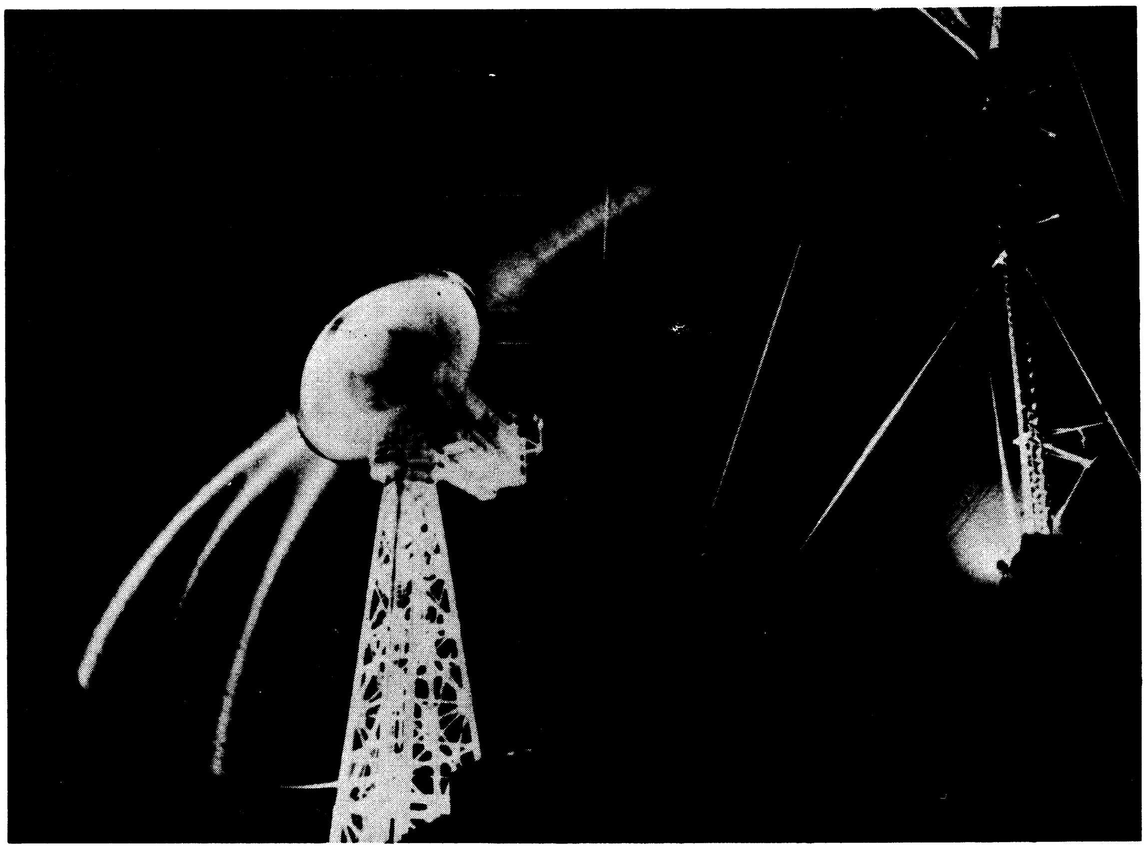
Wellman Engineering Company
Cleveland, Ohio
Principal Designer and Manufacturer

In 1939, the S. Morgan Smith Company selected Wellman Engineering of Cleveland, Ohio, to design, fabricate, and assemble all the equipment in the wind turbine between the tower and the blades. This included the blade A-frame supports with their massive hinges, the rotor hub and turbine shaft, all components of the power train, the blade and power control systems, the bedplate, and the yaw turntable and drive system. All this equipment was assembled and checked out in the company shops in Cleveland in 1941, prior to shipment to Grandpa's Knob.

The Wellman Engineering Company was started in 1896 by Samuel Wellman, a prominent Cleveland industrialist. In the 1930's and 1940's, the firm specialized in the manufacture of heavy equipment for making steel and for handling bulk materials. Mr. Kenneth Webb accepted the citation on behalf of the company which is now known as the Dravo-Wellman Company.

The Smith-Putnam Wind Turbine

Reprinted from "Turbine Topics," Volume 1, No. 3, June 1943



Night Wind

This reprint has been made available through the courtesy of Carl Wilcox, Smith-Putnam project engineer; the NASA Lewis Research Center; and the U.S. Department of Energy. *Turbine Topics* was a publication of the S. Morgan Smith Co.

THE SMITH-PUTNAM WIND TURBINE . . .

A Step Forward In Aero-Electric Power Research

BY GRANT H. VOADEN
Asst. Chief Engineer of the Project

Our company, always in the lead in hydro-electric developments, has been experimenting for the past three years on a new type of unit—an aero-electric unit. Just as a hydro-electric unit consists of a hydraulic turbine driving a generator, so an aero-electric unit is comprised of a wind turbine and a generator.

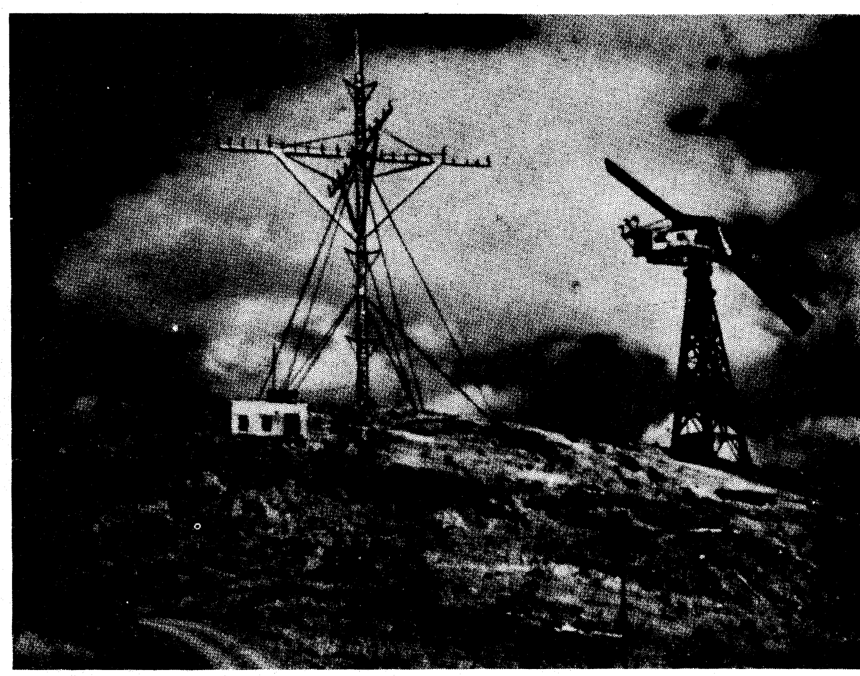
While some of the experimenting done in the early stages was on small scale wooden models made by our pattern shop, it was necessary to have a full scale unit of large dimensions in order to determine whether the project was feasible from a commercial standpoint. For this purpose the building of such a unit was undertaken and on October 19, 1941, for the first time in history an aero-electric unit was synchronized with, was connected to and delivered power to a commercial, alternating current power system. The photograph on the cover shows the unit in operation at night, the stars appearing as horizontal streaks because of the earth's rotation during the time of exposure. This experimental unit is located on the top of a bare mountain known as Grandpa's Knob, near Rutland, Vermont, and is now owned and operated by the Central Vermont Public Service Corporation.

The inventor of the wind turbine, P. C. Putnam, a Boston engineer, now in our country's service, proposed this project to the Management of our company late in the year 1939. After considerable preliminary study by some of our engineers, aided by consultants such as Dr. Theodore von Karman, Director, Guggenheim Aeronautics Laboratory, California Institute of Technology, Dr. S. Petterssen, Aerology Expert of Massachusetts Institute of Technology, now connected with the Norwegian Air Force in England, Dr. John B. Wilbur, Professor of Civil Engineering at M. I. T., and others, the company decided to take up the project. It further decided that the units should be known as Smith-Putnam Wind Turbines and that a test unit should be built of 1,000 K. W. rated capacity, and a blade spread tip to tip of 175 ft.

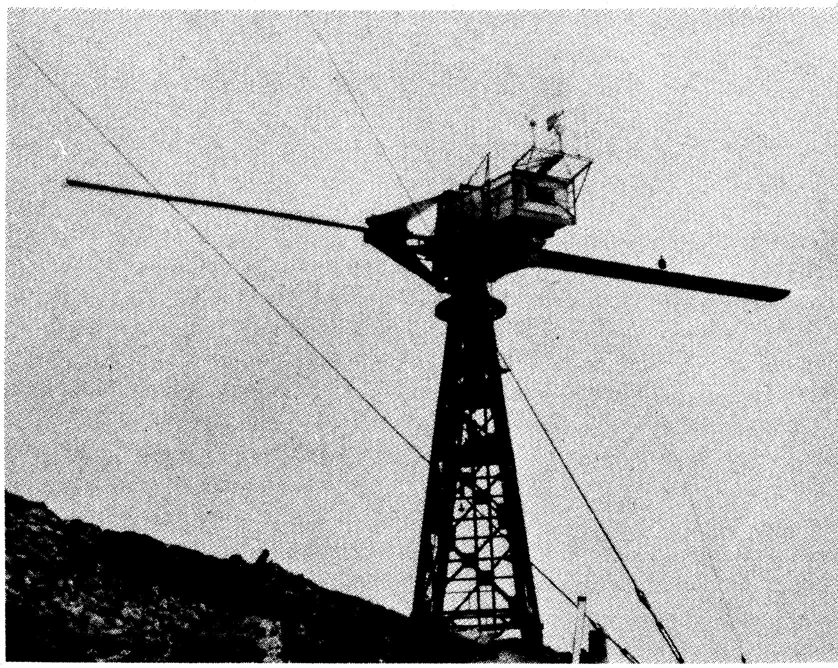
The fundamental basis of the company's interest was the fact that wind power can be used as an auxiliary to water power. Wind power by itself is not prime power; that is, it is not available all the time. A wind of about 20 M.P.H.* is required before any appreciable amount of usable power can be developed. Since sometimes the wind velocity is below this figure there must be other sources of power available to supply the full demand. However, if aero-electric units are added to an existing power system supplied by hydro-electric units or steam driven units or both, then whenever there is sufficient wind a certain number of hydro or steam units can be idled or shut down thereby allowing water to be stored above the dam or coal to be saved.

In the early spring of 1940 Dr. Wilbur accepted the position of

* This figure can be reduced on future units, depending on the wind regime at the site for which the turbines are built.



SMITH-PUTMAN WIND TURBINE installation on Grandpa's Knob near Rutland, Vt., for Central Vermont Public Service Corp. Tower height, 110 ft., weight 125 tons. Blades 175 ft. tip to tip, speed at tip 263 ft. per second. Weight aloft 240 tons. Mast for anemometers in center to measure wind velocity. Concrete control house, transformers and transmission line to Rutland. Capacity 1,000 K. W.



THIS IS THE WAY THE WIND TURBINE LOOKS coming up the path from the control house. How would you like to be up there with "Rosie" Rozell?

Chief Engineer of the Project and an engineering force was organized under his direction. Due to the large amount of work in our own plant, the need for speed due to a number of conditions, and the specialized nature of the various phases of the project, it was necessary to have the design and construction of the unit proceed at the same time, and to have the work done by outside concerns. The design and building of practically all the machinery mounted at the top of the tower, with the exception of the blades themselves, was by The Wellman Engineering Company of Cleveland, Ohio. For a few months a staff of over 150 engineers and designers were working full time on the drawings alone. The blades, which are of stainless steel and shaped like the wings of a bomber, were designed and constructed by Budd Manufacturing Company, Philadelphia. The tower on which the turbine proper is mounted and the anemometer mast as well were fabricated of structural steel and were erected at the site by the American Bridge Company of Ambridge, Pa. The generator and all of the switchgear were designed and furnished by the General Electric Co. Published herewith is a photo of the complete aero-electric test unit installation on Grandpa's Knob. You see the turbine itself mounted on a structural steel tower 110 ft. high, the concrete control house containing switchboards and instruments for remote control and observation, the transformers and poles for the power line, all of which comprise the station proper. The skeleton-like structure in the center supports anemometers to measure wind velocity and would not be necessary in a purely commercial installation. It is a significant feature from the economic standpoint that the above principal component parts do comprise the entire installation, whereas in a hydro-electric plant it is necessary in addition to have a large dam and power house with expensive auxiliary equipment such as penstocks, head gates, valves, cranes, etc. Then too wind turbines have the advantage that the land which a battery of say 20 units would occupy would be of little value for other purposes, whereas the land area flooded by a dam is usually quite extensive and sometimes of relatively high value.

THESE MEN have just completed a thorough inspection of the stainless steel blade skin.

The turbine proper, which is mounted on the tower, is swung about a vertical shaft by a hydraulic motor and gearing in accordance with changes in wind direction so that the turbine shaft is always in line with the wind direction and the blades downwind of the tower. This motion is called "yawing." The rotation of the turbine about its main shaft axis is right-hand when looking at the turbine with one's back to the wind.

The pitch of the blades themselves, which are only two in number, is changed automatically by a mechanism similar to that on a Kaplan turbine to maintain practically constant speed of rotation regardless of wind velocity. Up to about 18 M.P.H., however, the wind is not high enough to make the turbine rotate at full speed. When that velocity is exceeded the generator is connected to the system and as the wind velocity further increases the turbine gives more and more power without any change in blade pitch until at 30 M.P.H. it has reached the 1,000 K.W. rating of the generator. Beyond this velocity the blades are pitched automatically in response to a Woodward governor to keep from overspeeding and overloading the unit.

Another motion of the turbine is "coning." The blades can move up and downwind pivoting on hinges at the hub under restraint of a damping mechanism. This is to provide some "give" to the mechanism in severe gusts of wind; that is, when the wind either increases or decreases suddenly.

The generator is mounted aloft at the upwind end of the pintle girder and operates at 600 R.P.M., 2,400 volts, 60 cycles, being driven through gears which step up the turbine speed from 28.7 R.P.M. Interposed between these gears and the generator is a hydraulic coupling, similar in principle to a "fluid drive"; its

LEFT TO RIGHT: C. J. Wilcox, P. C. Putman, the inventor, G. A. Jessop, B. E. Smith, Llewellyn Evans, W. P. B., S. D. Dornbirer, J. B. Wilbur, C. L. Avery, Woodward Governor Co., M. G. Dow, Central Vermont public Service Corp., M. J. Holley, Jr.

WIND TURBINE WITH BLADES "FEATHERED." From ground to tip of upper blade in this position is about 205 ft.

J. B. WILBUR, CHIEF ENGINEER of the Project; Grant H. Voaden, Asst. Chief Engineer of the Project; George A. Jessop, Chief Engineer of the S. Morgan Smith Co.

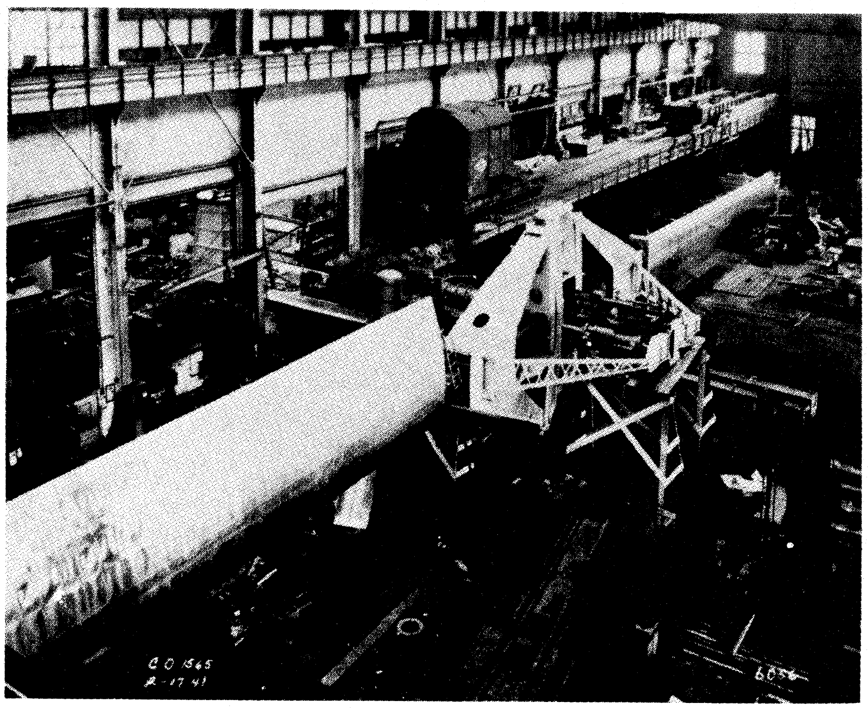
purpose being to allow a certain amount of "slip" or difference in speed between the high speed side of the gears and the generator itself. At zero load this slip is negligible and the two halves of the coupling rotate at the same speed, but as the load on the generator is increased it is necessary to rotate the driving half coupling faster and faster to overcome the slip until at 1,000 K.W. output its speed is 625 R.P.M. while the generator speed is still 600 R.P.M. While this represents a loss it is necessary for two reasons: primarily to provide means for the loading and unloading of the unit by changing the speed adjustment of the governor and, secondly, to provide a cushion between the turbine and generator to take up shocks due to extremely severe gusts which frequently occur and which otherwise would cause the generator to be thrown off the line due to overload.

The normal control of the unit is completely automatic, even to the phasing with the system, and it functions without attendance. Manual control is also provided. The unit can be operated completely from the control house several hundred feet from the base of the tower and partially from aloft. This feature is particularly desirable on this first unit for testing purposes.

This project involves a great many fields of engineering knowledge and endeavor; for example, aerology, aerodynamics, mechanics, structural and electrical engineering, to name only a few. Also in the production of these units every type of worker will find a job—pattern makers, boiler makers, welders, pipe fitters, machinists, electricians and mechanics—all are needed. Some of the pictures on these pages illustrate the different types of shop work that are involved in the manufacture of a wind turbine. It is confidently expected that some day—and it may not be so long—many more wind turbines will be built right here in our own plant and built from drawings made by our own designers.

As was naturally to be expected in a new machine of such magnitude involving so many novel features, frequent troubles developed which were eventually overcome in the two years since erection was first started. However, the unit has proven itself fundamentally sound and practical. Mechanically it is as satisfactory as

STANTON D. DORNBIRER, SUPT. at Erection; Ella Taranovich; Carl J. Wilcox, Office Manager and Test Engineer; Mary Skaza, Myle J. Holley, Jr., Test Engineer; and Arthur H. Cheney who works in our Rutland office.



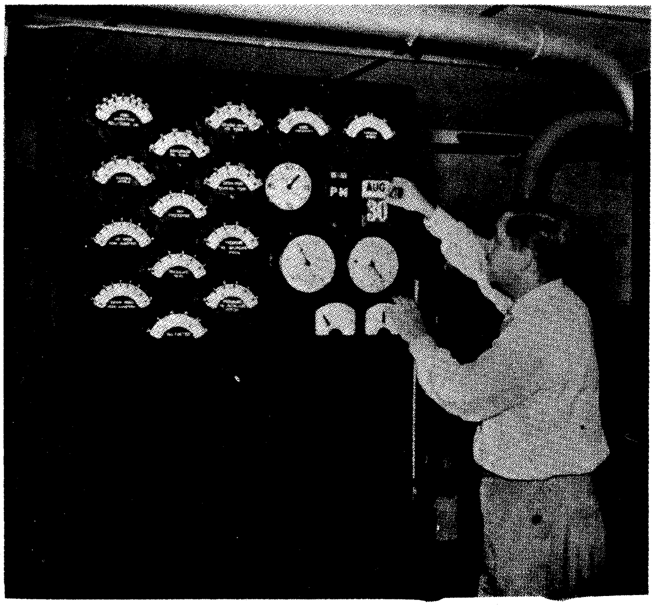
Shop Assembly nearing completion in Wellman Engineering Shop, stainless steel blades in position to give maximum power. Note provisions for "coning" of blades up and downwind in gusts, and cylinders and struts for damping the motion.

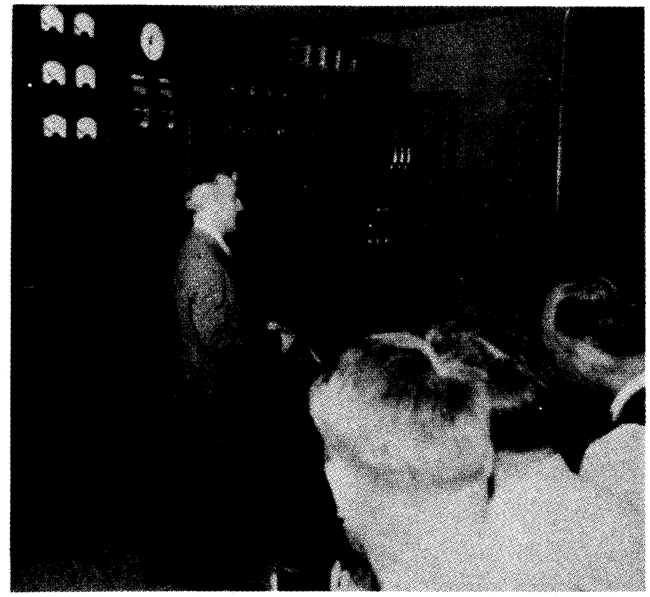
could be expected with an entirely new design having no basis of past experience. The knowledge gained during the process of bringing this unit to a state of successful operation will enable us to design a production unit which should not only be much improved mechanically, but also be capable of producing power on an economically competitive basis in areas with suitable wind regimes.

Ernest Stump, Machinery Erection Foreman.

Harold S. Perry, Steel Work Erection Foreman.

Assembly of tailpiece hub, A-frame and torque tubes (for pitching the blades). Production Units will have Welded construction, not riveted.

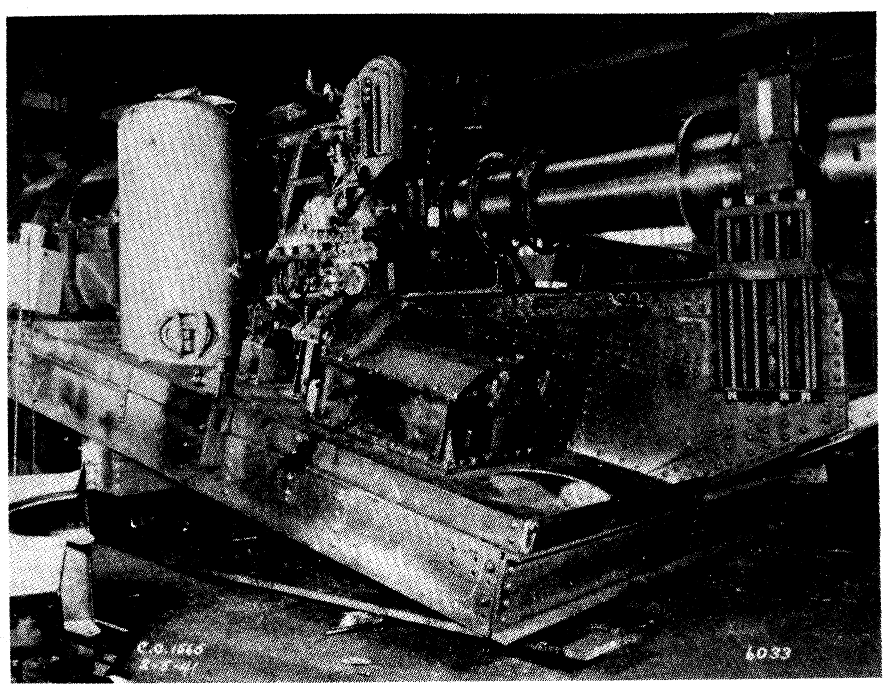




The views above taken inside the control house show on the left the instrument panel which is special for the test unit, and on the right the switchboard.

The eighteen instruments on the test panel indicate the functioning of various parts of the unit, which itself is several hundred yards away, and also the wind velocity at a point approximately on the center line of the turbine and fifty feet upwind of the blades. A few of the indications are blade angle, governor speed adjustment, generator output, turbine speed, coning angle, various oil pressures and temperatures. These instruments not only allow the operators and test engineers to know what the unit is doing even though they are on the ground and several hundred feet from the tower, but also provide a means for recording simultaneously all conditions of a test. This is done by an electrically driven motion picture camera which takes pictures of the entire panel continuously whenever the unit is in operation. These films are later projected on a screen and the readings of the various instruments tabulated and test computations made. An elaborate instrument panel like this would not be required on a production unit.

From the control panel, whenever there is sufficient wind, the unit can be manually started, brought up to speed, phased with the system and loaded. Conversely, of course, the unit can be stopped. Normally, however, all this is done automatically as a function of wind velocity, and the numerous relays, etc., mounted to the right on the larger panel are for this purpose. A 125-volt storage battery provides the basic power for these controls. The right view also shows W. A. Bagley, Switchgear Expert of the General Electric Co., New England District, conducting an Operators' Instruction Class.



PARTIAL SHOP ASSEMBLY showing turbine shaft and outboard roller bearing, oil head, Woodward governor and pump, pressure tank, hydraulic motor and yaw gears all mounted on pintle girder and platform which is mounted on and swings about the top of the tower.