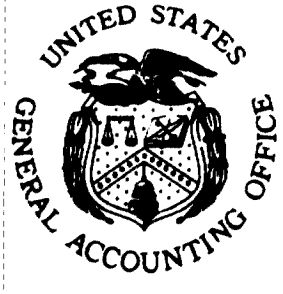
General Accounting Office

NASA Lewis Research Center Attempts To Procure Suitable Wind Turbine Rotor Blades

An economical and serviceable wind turbine rotor blade has yet to be delivered to Lewis Research Center by any contractor. The blades delivered thus far have experienced problems in design, fabrication, or testing. However, Center officials believe that two of their recent blade buys may eventually produce suitable blades.

Although GAO noted some deficiencies in the procurement process for blade contracts, Center procurement policies and practices have not impeded the development of blades for the Wind Energy Program. Rather, the problems in blade development seem to center on (1) the relative slow advancement in the state of the art for windmill blade technology, (2) insufficient analytical tools and facilities to accurately predict blade performance in real-life environments, and (3) the rush to build machines before blade technology has been adequately advanced.



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UNITED STATES GENERAL ACCOUNTING OFFICE
WASHINGTON, D.C. 20548

PROCUREMENT AND SYSTEMS
ACQUISITION DIVISION

B-200286

The Honorable Donald W. Riegle, Jr.
United States Senate

The Honorable Guy Vander Jagt
House of Representatives

We have reviewed the procurement process used by the National Aeronautics and Space Administration's (NASA's) Lewis Research Center to obtain rotor blades for wind turbines. Our review was undertaken in response to your letters and a related letter from Mr. John T. Parsons of Robinson Industries, Inc. At the time of your inquiries, Mr. Parsons had filed a bid protest with us concerning his unsuccessful proposal for design and fabrication of low-cost rotor blades for wind turbines. Mr. Parsons also maintained that deficiencies existed in the management of the rotor blade development program at the Center.

As we informed you in our September 17, 1979, letter, we performed this review separate from the legal matters involved in the bid protest. The protest was denied by Comptroller General Decision (B-194157, Jan. 8, 1980) and after Robinson requested reconsideration, the decision was affirmed (B-194157.2, Mar. 14, 1980).

The Center handles that part of the Department of Energy's Wind Energy Program associated with developing intermediate and large wind turbines for generating electricity. The rotor blade is probably the most critical component of wind turbine machines. Developing low cost, high performance blades continues to be the biggest hurdle in making wind energy systems cost competitive.

This report addresses the technical aspects of soliciting, evaluating, and selecting blade contractors by the Center. In performing our review, we considered Mr. Parsons' specific allegations and also looked at the Center's blade purchases in terms of regulatory compliance and consistency with sound procurement practices. We looked at every blade contract awarded by the Center since it became involved

in the Department of Energy's Wind Energy Program. Twelve such contracts valued at $8.7 million have been awarded. Our review of these contracts and the matters raised by Mr. Parsons is summarized below and discussed in greater detail in appendix I.

SUITABLE BLADE YET TO BE DEVELOPED

Mr. Parsons was correct in stating that an economical and serviceable rotor blade has yet to be delivered to the Center by any contractor. The blades designed or fabricated thus far have not demonstrated their ability to reach program goals of low cost, high performance, and long life. Every blade has experienced problems in design, fabrication, or testing. However, Center officials believe that two of their recent blade buys may eventually produce blades which will meet program goals.

Mr. Parsons stated that the Center's inability to develop suitable blades was due to its reluctance to deal with him to solve blade problems. We found, however, that the Center officials acknowledge Mr. Parsons' background and experience in rotor blades and are impressed with his credentials. We noted that Center officials consulted with Mr. Parsons on numerous occasions and requested that he submit proposals on several of the Center's blade purchases. He responded once--on the low-cost blade procurement which prompted his bid protest.

Mr. Parsons also raised the question of whether Center officials were prolonging the program to protect their jobs. He also maintained that the Center is unqualified to manage the program, has improperly evaluated contractor proposals, and has awarded contracts to unqualified companies. Within the total context of the Center's efforts in the Wind Energy Program, we see little justification for these questions. Our findings on these matters are discussed below.

SOLICITATION, EVALUATION, AND SELECTION OF BLADE CONTRACTORS

The majority of the Center's blade procurements were on a competitive basis and, in our opinion, were generally conducted according to agency regulations and sound purchasing practices, although some of the records we reviewed could have been better documented. The blade contracts awarded noncompetitively had some deficiencies in the procurement process.

Solicitation

The Center has made extensive efforts to solicit prospective contractors for its blade work. Consistent with its procurement policies, most of the Center's blade work has been competitive, with 7 of the 12 contracts and 79 percent of the dollars being awarded in this fashion. The number of solicitations made on these procurements ranged from 20 to 100, with both large and small companies receiving requests. Many of these companies have aircraft and helicopter rotor blade backgrounds, which is the type of experience considered important in the development of windmill blades. To spread the word on the Wind Energy Program and invite additional participation, the Center has also conducted and been involved in numerous industry briefings and conferences. All of its blade requests were advertised in the Commerce Business Daily.

We did identify a few things on the noncompetitive blade buys which probably should have been handled differently. Efforts to locate other sources before awarding sole source contracts, for example, were not sufficiently documented. We found it difficult to determine the extent to which the Center contacted other potential contractors for this work. Further, evaluations of technical proposals for noncompetitive procurements did not appear to be comprehensive, as required.

Evaluation

Evaluations of competitive proposals to determine which contractor(s) would be best qualified for the requested work appeared to be thorough, objective, and conducted by people qualified to identify the merits of the various proposals. We found the evaluation factors and weights to be reasonable and directly related to the procurement objectives. Technical and other evaluation reports indicated that source selection officials were provided a sound basis for selecting those contractors who would perform most advantageously for the Government. In each case, the selections were consistent with these reports. Moreover, awards were made to companies with rotor blade experience or to contractors whose proposed designs and/or fabrication methods looked promising in terms of program goals.

Technical evaluations for the noncompetitive purchases did not appear to be very comprehensive. Unlike the evaluations done on the competitive buys, these tended to be rather cursory--not very penetrating and lacking substantive evaluative comments.

Selection

After reviewing the competitive contract files, we concluded that an impartial observer could substantiate the selections made, although the supporting documents in some instances could have been better. The audit trail was clear for some of the procurements, with every significant action and decision properly and extensively documented. On others, support was in the form of summary reports and other types of surface documents. While these records failed to show the extent to which technical and other evaluations were made, they nevertheless substantiated the decisions made.

We questioned the awarding of one sole source contract because it appeared to be similar to some work the Center was about to initiate for competitive bidding. This gave the sole source contractor an apparent edge in its successful bid to secure a second contract under the competitive work. The second contract was one of three awarded under the procurement which prompted Mr. Parsons' bid protest. However, even if the successful contractor had not submitted a proposal, Mr. Parsons would not have been within the competitive range on the protested procurement.

BARRIERS TO PROCUREMENT OF SUITABLE BLADES

Notwithstanding the problems we identified, we do not believe the Center's procurement policies and practices have impeded the development of blades for the Wind Energy Program. Nor do we agree with Mr. Parsons' suggestion that the Center is improperly equipped to run this program. While our review did not attempt to identify others who might be better qualified to manage the program, we believe the Center was a logical choice, considering its background in aircraft and rotor technology which Mr. Parsons has indicated is compatible with windmill blade development.

There appears to be no simple solution or single reason why viable windmill blades have not been demonstrated. Some of the reasons do not relate to how or from whom the Center is purchasing blades. The problems we observed seem to center more on (1) the relative slow advancement in the state of the art for windmill blade technology, (2) insufficient analytical tools and facilities to accurately predict blade performance in real-life environments, and (3) the rush to build machines before blade technology has been adequately advanced.

Until the Federal Government became involved in wind energy in the early 1970s, there never had been a sustained research and development effort to improve wind machines of past years. In fact, until 1973 when the Center became involved, few technological developments of past decades had been applied to wind systems. Thus, in the early years of the Federal program, the Center focused its attention on testing state-of-the-art technology. That technology and what has been developed since then has fallen short of the tough program goals.

One key aspect of rotor blade technology is the ability to accurately foretell how a particular blade will react under various loads and stresses encountered in real-life situations. Blade failures which the Center has experienced can be traced, at least in part, to its inability to make these predictions. Center officials admit it has been a learning process, but maintain they are improving their record.

The program's overriding goal of accelerated wind energy commercialization, plus a lack of adequate laboratory testing facilities, has pushed the Center on a course where wind machines are installed in the field to serve as test beds for blades and other components. While the program can point to six wind machines already in operation, with three more planned by the end of the year, blade problems continue and tend to take some of the luster off the program's achievements. The knowledge to economically build suitable rotor blades has not been developed. It appears that systems development has outpaced blade development.

We discussed the above matters with NASA officials and considered their comments where appropriate.

W. H. Shelley, Jr.
Acting Director

Contents

ABBREVIATIONS

DOE	Department of Energy
NASA	National Aeronautics and Space Administration

DETAILS ON GAO'S REVIEW OF THE PROCUREMENT OF WIND TURBINE ROTOR BLADES BY NASA'S LEWIS RESEARCH CENTER

INTRODUCTION

In response to requests by Senator Riegle and Representative Vander Jagt, and because of allegations by Mr. John T. Parsons of Robinson Industries, Inc., we reviewed the solicitation, evaluation, and selection of wind turbine rotor blade contractors by the National Aeronautics and Space Administration's (NASA's) Lewis Research Center. Mr. Parsons had expressed concerns about the adequacy of the Center's efforts in developing suitable rotor blades.

Our objective was to seek answers to the following questions which were raised as a result of Mr. Parsons' request.

--How are contracts awarded for rotor blades?

--Are blade procurement activities (solicitation of bidders, proposal evaluations, and selection of contractors) in consonance with regulations and sound purchasing practices?

--Do procurement practices evidence any protracting of efforts to drag out the development of blade work?

--What progress has been made in developing rotor blades that meet program goals of low cost, high performance, and long life?

We discussed various aspects of rotor blade procurements with cognizant Department of Energy (DOE) and Center officials. To determine the reasonableness and effectiveness of Center procurement practices, we reviewed pertinent procurement guidelines and regulations.

The major thrust of our efforts centered on an indepth review of all Center rotor blade contract awards since the beginning of the program. This entailed various analyses of contract files and related documents covering 12 awards totaling approximately $8.7 million. These contracts are profiled on page 7.

To put the matters discussed in perspective, we are including information on the Federal Wind Energy Program and our observations on barriers to developing suitable wind turbine rotor blades.

FEDERAL WIND ENERGY PROGRAM

Wind energy conversion has long been recognized as a potentially abundant source of clean and renewable mechanical and electrical power. But, compared to other power sources, it has been too expensive. In 1973 the impending worldwide shortage of nonrenewable energy sources and our country's increasing dependence on imported fossil fuels created an energy crunch which led to renewed efforts to look to the winds for an alternative supply for our Nation's energy requirements.

The sizeable resources and the considerable economic risk taking involved in developing wind power required the creation of a Federal program to get some research and development work underway and to coordinate efforts in private industries, universities, and laboratories. The program, initially undertaken by the National Science Foundation, was transferred to the Energy Research and Development Administration in 1975, and has been the responsibility of DOE since October 1977.

The Federal Wind Energy Conversion Systems Program, as it is formally called, has as its overall objective the accelerated development of reliable and economically viable wind energy systems to enable the earliest possible commercialization of wind power. The program, which is centrally managed and funded by DOE's Wind Systems Branch, involves research, development, and demonstration (leading to commercialization) of various size wind machines which are classified according to rated power output, as follows:

Wind machine size	Rated power output
Small	Less than 100 kilowatts
Intermediate	100 up to 1,000 kilowatts
Large	1,000 + kilowatts (megawatt scale)

Because of the relatively advanced state of aerodynamics technology, basic research is not stressed in the program. Instead, the program centers on mission and applications analyses, the development of more effective machines, and the accumulation of wind data to determine the best sites for the machines. The basic technology features horizontal axis,

propeller-type systems--although a variety of other innovative concepts are also being investigated.

While DOE's Wind Systems Branch has overall program management responsibilities for all aspects of the Federal Wind Energy Program, much of the project management and support functions have been delegated to DOE laboratories and other Federal agencies. The U.S. Department of Agriculture, for example, is charged with managing projects to identify requirements for farm and agricultural wind systems. The Battelle Pacific Northwest Laboratory is responsible for research of wind characteristics, useful in site determination. The Solar Energy Research Institute is primarily responsible for developing innovative and advanced wind energy systems. Small machines and vertical axis wind turbines are developed and tested by DOE's Rocky Flats Test Center and Sandia Laboratories, respectively.

Role of the Center

The Center handles the largest segment of the Federal program, which is associated with intermediate and large horizontal axis systems, for DOE. At least 50 percent of all the program's funds are used to design, build and test experimental machines, and provide support in the form of technology development. These efforts, which include preparing project proposals, soliciting, evaluating and selecting contractors, and studying ways to make the systems more effective, are managed by the Center using NASA procurement and contractor selection procedures.

Strategy for developing viable wind energy conversion systems

The difficulty in developing rugged, economical wind energy conversion systems capable of providing up to 30 years of reliable, automatic, and relatively maintenance-free service is the major barrier to the program's overriding long-range goal of accelerated commercialization of wind power. To meet this challenge, DOE and the Center have pursued a strategy which consists of designing, building, and field testing a series of progressively bigger experimental machines with improved capability; and simultaneously developing technological and analytical methods to advance the performance and lower the cost of subsystems and components. This strategy is basically one of parallel systems development and technology development.

Nine intermediate and large horizontal axis wind machines are currently operating or under construction and being

APPENDIX I

managed by the Center as part of the systems development effort. Machines designated as MOD-0, MOD-0A (4 machines), MOD-1, and MOD-2 (3 machines), are experimental machines of various size and configurations for testing proof-of-concept practicality and economic viability for eventual large-scale use. Key profile data for each of these machines are shown in the table below. Brief descriptions of each follow.

MOD-0

MOD-0, which was designed by the Center and started operating in September 1975, is a one-of-a-kind wind machine located at the Center's Plum Brook facility (Sandusky, Ohio), and used strictly as a research test bed to validate wind turbine design techniques and demonstrate new concepts. Technically, the MOD-0 machine is part of the technology development program, not the systems development effort. Unlike the other machines, it is operated and controlled by Center personnel and serves to (1) identify, understand, and resolve problems encountered with machines of this size and larger, (2) investigate the feasibility of advanced design concepts and subsystems, and (3) provide experimental data to verify performance, structural dynamics, and component dynamics.

PROFILE DATA FOR WIND MACHINES

	MOD-0	MOD-0A	MOD-1	MOD-2
NUMBER OF MACHINES	1	4	1	3
SITES	NASA-LeRC Plum Brook Facility Sandusky, Ohio	Clayton, New Mexico Culebra, Puerto Rico Block Is., Rhode Island Kahuku, Hawaii	Boone, North Carolina	Goldendale, Washington (3-machine cluster)
RATED POWER	100 Kilowatts	200 Kilowatts	2,000 Kilowatts	2,500 kilowatts
PRIMARY FUNCTION	Research machine. A test bed to validate design techniques and test new concepts.	Gain early experience with a wind turbine at a utility site.	Gain early experience with a megawatt-size wind turbine at a utility site.	Test a multiple installation system which potentially can be cost competitive with conventional energy sources.
SYSTEM DESIGNER	NASA-LeRC	NASA-LeRC (Built by Westinghouse)	General Electric	Boeing Engineering and Construction Company
GENERATION	First	First	First	Second
KEY FEATURES OF MACHINE	No specific profile since this is a research machine which has gone through many changes and different configurations.	Two blades (125' diameter) located downwind with full pitch control and fixed on a rigid hub on a stiff steel truss tower.	Two baldes (200' diameter) located downwind with full pitch control and fixed on a rigid hub on a stiff steel truss tower.	Two blades (300' diameter) located upwind with tip control and attached to a teetered hub on a soft steel tube tower.
BLADE MATERIAL (primary)	Initially, aluminum aircraft wing configuration. Currently, steel/fiberglass.	Aluminum aircraft wing configuration on first three machines. Wood on fourth machine.	Steel	Steel
BLADE DESIGNER	NASA-LeRC (Built by Lockheed)	NASA-LeRC and Lockheed for first three machines, Dougeon Brothers for fourth machine.	Boeing	Boeing
FIRST ROTATION	September 1975	Clayton 11-77 Culebra 6-78 Block Island 5-79 Kahuku 5-80	May 1979	Machine currently being built.

MOD-OA

To gain early experience with wind machines at utility sites, the Center designed a more powerful (200 kilowatt) scaled-up version of the MOD-0 test machine, with the Westinghouse Corporation being the installation and support contractor. Four of these intermediate-size machines have been installed, one each in Clayton, New Mexico; Culebra Island, Puerto Rico; Block Island, Rhode Island; and Kahuku, Hawaii. Two major purposes are intended for these projects:

1. Involve utility companies to identify their particular requirements while gaining direct operational experience, including public reaction to wind machines.

2. Build up industry capability in designing, fabricating, and operating wind turbine systems.

MOD-1

The Center contracted with the General Electric Company to build and install the first Government-sponsored large-scale wind machine in Boone, North Carolina, in response to various studies which showed that wind energy conversion systems must be large (megawatt size) to be cost competitive with other energy sources. On the basis of MOD-OA technology, this 2,000 kilowatt (2 megawatts) machine was the last of the so-called first generation wind turbines which are characterized by their two-bladed, full-pitch controlled rotors, stiff towers, rigid hubs, and downwind rotors. While much larger than its MOD-OA counterparts, the MOD-1 serves basically the same purposes as the smaller machines.

MOD-2

Located in Goldendale, Washington, and being built by the Boeing Engineering and Construction Company, the 2,500 kilowatt MOD-2 is a second generation wind machine incorporating several advanced concepts and innovations: upwind rotor, soft tower, teetered hub, and tip-controlled blades. This project is also the first Federal attempt to test the practicality of operating large wind turbines in a cluster, as three MOD-2 size machines will be installed at the same site.

DOE strategies for the future include designing, building, and testing one more generation (the third) of wind machines. Labeled as MOD-5 (megawatt-size machine) and MOD-6 (intermediate-size machine), these projects are intended to

be the Government's last major research, development, and demonstration effort leading to commercialization of wind energy conversion systems.

Technology development and the importance of rotor blades

To improve the economic outlook of wind energy, technology development of machine components and subsystems is occurring simultaneously with systems development. A major portion of the Center's efforts is directed at ways to reduce capital and maintenance costs of wind systems while at the same time maintaining or improving their performance, reliability, and service life.

The rotor blade is probably the most critical component and the one receiving the greatest attention. Historically, blades have been the single most costly component of a wind energy conversion system, sometimes comprising about 30 percent of the total cost. Developing low cost, high performance rotor blades continues to be the biggest hurdle in making wind energy cost competitive. Blades have been a high priority technology item throughout the wind energy program.

HISTORY OF ROTOR BLADE DEVELOPMENTS

In our review of the Center's rotor blade procurements, we traced the history of blade developments back to 1974 when the first blades were purchased for the MOD-0 test machine. A listing of all blade contracts is shown on the next page.

MOD-0 60-foot aluminum blades

Lockheed Aircraft Corporation beat out four other bidders for this initial blade procurement (September 1974) involving the design and fabrication of three 60 foot blades (one spare) for the MOD-0 test machine at the Center's Plum Brook facility. The primary concern was to get some blades so that testing could begin and more could be learned about wind machines. The Center was interested in testing existing technology and not pushing the state of the art. Accordingly, factors which became more important in subsequent procurements were not of primary concern this early in the program. Low cost, high performance, and 30-year service life were not of great importance with these first blades. Further, companies which were solicited consisted of the aerospace industry, large firms with experience in airframes, helicopter blades, and aircraft propellers.

PROFILE OF ROTOR BLADE CONTRACTS AWARDED BY THE LEWIS RESEARCH CENTER UNDER THE DEPARTMENT OF ENERGY WIND ENERGY PROGRAM

Contract Number	Contractor	Award Date	Type Of Contract	Type Of Procurement	Original Amount	Increases (Decreases)	Total Amount Thru 5/31/80	Type Of Blade Studied And/Or Fabricated	Wind Machine Identification
19235	Lockheed Aircraft Corporation	9-11-74	Firm Fixed Price	Competitive	$ 323,096	$ (8,381)	$ 314,715	60' Aluminum	MOD 0
19773	Hamilton Standard	2-11-76	Cost Share	Competitive	600,598	315,415	916,013	60' Fiberglass	MOD 0
20062	Concept Development Institute	7-16-76	Firm Fixed Price	Unsolicited Proposal	72,775	-0-	72,775	Urethane Blade Study	MOD 0A
20596	Tuthill Pump Co.	12-21-76	Firm Fixed Price	Unsolicited Proposal	93,586	-0-	93,586	Concrete Blade Study	MOD 0A
20600	Kaman Aerospace Corporation	2-14-77	Cost Plus Fixed Fee	Competitive	1,917,159	505,458	2,422,617	150' Fiberglass	MOD 2
20710	Lockheed Aircraft Service Co.	4-22-77	Firm Fixed Price	Competitive	719,187	816,064	1,535,251	60' Aluminum	MOD 0A
20813	Tuthill Pump Co.	8-29-77	Firm Fixed Price	Unsolicited Proposal	43,448	-0-	43,448	Concrete Blade Specimens	MOD 0A
9	Gougeon Brothers	11- 7-77	Firm Fixed Price	Sole Source	36,426	-0-	36,426	Wood Blade Study	MOD 0A
101	Gougeon Brothers	2-21-79	Firm Fixed Price	Competitive	97,600	417,825	515,425	60' Wood	MOD 0A
100	Structural Composites Industries Inc.	4-10-79	Cost Plus Fixed Fee	Competitive	144,870	671,026	815,896	60' Fiberglass	MOD 0A
129	The Budd Co.	5-30-79	Cost Plus Fixed Fee	Competitive	286,850	112,730	399,580	60' Steel	MOD 0A
131	Kaman Aerospace Corporation	6-4-79	Cost Plus Fixed Fee	Sole Source	1,531,666	37,684	1,569,350	100' Fiberglass	MOD 1
TOTALS:	12 Contracts				$5,867,261	$2,867,821	$8,735,082		

APPENDIX I

APPENDIX I

MOD-0 60-foot fiberglass composite blade

Recognizing from the start that the aircraft configuration and labor intensive aluminum blades would probably never be cost competitive, the Center immediately initiated procurement action (1 month before the Lockheed contract) to design, fabricate, and test blades made from composite materials. As early as 1973, the Center recognized the potential of such materials as a low-cost alternative to the state-of-the-art aluminum blades. It decided to exploit composite materials technology to meet program goals of low cost, long life, and high reliability by sending out a competitive proposal to design and fabricate three blades.

Hamilton Standard, a large aircraft propeller manufacturer, won the award in February 1976, out bidding seven others. Its design, which was primarily of a fiberglass composition, apparently was similar to something it had proposed under the first blade buy which went to Lockheed. The Center determined at that time that Hamilton Standard's proposal was not responsive because it did not address the type of blade desired for the initial procurement.

Urethane blade study

Consistent with its technology development operating plan, the Center continued to investigate new concepts to make wind turbines less expensive and more reliable. Five months after the MOD-0 60-foot fiberglass composite blade award, the Center awarded a contract to Concept Development Institute, Inc., a small nonprofit organization managed by a group of businessmen and scientists interested in advanced development.

Like Hamilton Standard had done earlier, Concept Development initially submitted a proposal which was not responsive to the work called for under one of the competitive blade procurements. Instead of proposing to build blades, Concept Development suggested conducting a feasibility study and test program to evaluate the potential of a new concept for rotor blades--poured molded urethane. Although not funded at that time, Concept Development came back with basically the same proposal via the unsolicited proposal route and received the third Center blade contract in July 1976.

Concrete blade study

Intrigued by the potential of adapting heavy construction industry materials and prestressing techniques to rotor blade

fabrication, the Center funded a second unsolicited proposal, received 2 months after the Concept Development award. The contract, awarded to the Tuthill Pump Company (a small management-engineering firm) in December 1976, was in response to the Center's overall technology efforts to keep abreast of promising designs, materials, and fabrication methods which have the potential of substantial cost reductions in the rotor system.

This was basically a feasibility design and analysis project to examine a hybrid blade configuration composed of a prestressed concrete beam (the main structural element), a tubular steel hub, and fiberglass tip and trailing edge. Blade fabrication and testing were not a part of this effort. As with the urethane blade study, the concrete blade study was associated with the MOD-OA program, which was just beginning to get underway.

One hundred fifty foot fiberglass blade

The Center's fifth procurement was its largest single investment in rotor blade technology. This contract, awarded to Kaman Aerospace Corporation in February 1977 involved the design, fabrication, test, and evaluation of an all composite, filament-wound fiberglass blade in a never before attempted size range of 150 feet. In winning this award to support the design study of a 300-foot diameter MOD-2 rotor, Kaman competitively beat out two other large aerospace manufacturers.

This technology effort was in response to previous Government-sponsored studies (one of which was conducted by Kaman) which concluded that the cost of energy decreases with increasing blade size. At the time of this contract, the megawatt-size MOD-2 was already on the drawing board, so the Center was attempting to build an early technology base for rotor blades as a precursor to the MOD-2 project. As was the case in every development since the first procurement of the expensive aluminum blades, the Center was searching for technology that would be compatible with its low-cost goals.

At the time of the 150-foot blade study, the state of the art was still aluminum blades, already determined to be cost ineffective for future wind machines. Composite construction looked like an attractive alternative, particularly in terms of lower blade fabrication costs. Although strictly a research project, the 150-foot blade study did produce one prototype blade of the desired length.

MOD-OA 60 foot aluminum blades

Systems development continued to outpace blade technology development, as evidenced by this sixth blade procurement. Anxious to demonstrate wind machines in actual utility applications, the Center upgraded the MOD-O test machine and began preparations for building a series of 200 kilowatt machines (MOD-OA). Rather than delay the program, it was decided to once again use aluminum blades. Technology on the fiberglass blade was not ready and no other blade had been sufficiently developed during the 2-1/2 years which had passed since the first procurement.

The proposal for this effort was formally advertised, but only one of the 20 companies solicited responded with a bid. That company, Lockheed Aircraft Service, received a contract in April 1977 which resulted in the fabrication of six aluminum blades patterned after the MOD-O blades (no technology advancement). These were installed on the MOD-OA machines in Clayton, New Mexico; Culebra, Puerto Rico; and Block Island, Rhode Island.

Concrete blade specimens

This seventh blade development was actually an extension of the earlier feasibility study (see p. 8) to investigate concrete as a low-cost material for blade fabrication. Under this contract, awarded to the Tuthill Pump Company in August 1977, concepts developed in the first effort were further analyzed, blade specimens were fabricated and tested, and a NASA/contractor technology report was prepared disclosing the findings of the two endeavors.

Wood blade study

The eighth blade development was another research project involving low-cost blade design and fabrication technology--this time using laminated wood as the main structural element of the blade. Gougeon Brothers, Inc., builders of custom sailing craft, received a small sole source contract from the Center in November 1977 to conduct a wooden blade feasibility study. Again, this was in conjunction with the Center's technology development program for identifying low-cost promising designs, materials, and fabrication methods.

Although wood had been considered in the past, its susceptibility to warping and cracking discouraged its use in high performance items, such as blades. Recently, developed epoxy sealers reportedly solved these problems,

so the Center decided to apply this new technology to its wind program.

Low-cost MOD-OA 60 foot blades: wood, fiberglass, and steel

Except for the few small blade feasibility studies, the Center's major blade contracts up to now had been with large, aerospace companies. These companies had not produced the type of cost-competitive blades that would be needed to make wind energy attractive as a viable alternate energy source. In an attempt to get low-cost producers into the program, the Center made a concerted effort to attract more small, high technology firms which might offer new ideas, materials, and less expensive processes for building blades. For the first time, solicitations to small firms outnumbered those sent to large companies.

The competitive procurement was planned as two phases in which promising designs (phase I) would be followed by prototype blade manufacture and testing (phase II). This was also the first time that multiple awards were made for blade work. These procurements were intended primarily as a research technology effort and are intended to provide replacements for the aluminum blades on the MOD-OA machines. Three contracts were awarded as follows: (1) February 1979--to Gougeon Brothers, Inc., for a wood blade which was actually an extension of the prior wood blade study, (2) April 1979--to Structural Composites Industries, Inc., for a fiberglass blade using a filament-winding process it had developed and used on the earlier 150-foot fiberglass blade contract with Kaman Aerospace Corporation, and (3) May 1979--to the Budd Company for a stainless steel blade. Two of these three successful bidders are small companies.

MOD-1 100 foot fiberglass blades

The twelfth and most recent Center blade procurement was a sole source contract with the Kaman Aerospace Corporation in June 1979. This was for the design and fabrication of a set of fiberglass composite blades for the MOD-1, 200-foot diameter wind turbine, using the technology base developed for the 150-foot prototype demonstration blade (see p. 9). This contract, along with the three MOD-OA low-cost blade procurements, represents the Center's current efforts to obtain cost-competitive blades for the wind program.

APPENDIX I

Other blade developments

Three other blade developments, not involving direct procurements by the Center, complete the rotor blade history for the DOE/NASA wind program. The first involved a Center in-house effort to build a low-cost blade to simulate the MOD-2 design on the MOD-0 research machine at the Plum Brook facility. This so-called utility pole blade actually used steel utility poles as the main structural element and replaced the original aluminum blades in June 1978.

The 100-foot fiberglass blades being built by Kaman under the previously mentioned Center contract are supposed to replace the steel blades which are currently on the MOD-1 machine. These steel blades were not procured directly by the Center. Instead, they were subcontracted by the MOD-1 contractor that received the overall systems contract from the Center. Likewise, the steel blades which will be installed on the MOD-2 machines were not direct Center procurements, although their design was approved by the Center when it let the systems contract for that project.

Contract types and procurement methods

As profiled on page 7, the Center has issued 12 rotor blade contracts totaling $8.7 million under the Federal Wind Energy Program. These contracts, ranging in dollar value from $36,426 to $2,422,617, have been of various types, as shown below.

Type of contract	Number	Dollar value	Percent
Firm fixed price	7	$2,611,626	30
Cost plus fixed fee	4	5,207,443	60
Cost sharing	1	916,013	10
Total	12	$8,735,082	100

It was the Center's policy to obtain competition whenever possible. While 5 of the 12 contracts were awarded non-competitively, 4 of these were valued at less than $100,000. Summarized in the following table are the various procurement methods on the 12 blade contracts.

Procurement method	Number	Dollar value	Percent
Competitive:	7	$6,919,497	79
Formal advertising	1	1,535,251	
Negotiated	6	5,384,246	
Noncompetitive:	5	1,815,585	21
Unsolicited proposals	3	209,809	
Sole source	2	1,605,776	
Total	12	$8,735,082	100

Nine different companies have received blade contracts, but none have received more than two. Blades have been fabricated and/or studied using aluminum, fiberglass, urethane, concrete, wood, and steel.

The remaining sections of this report discuss the mechanics of these blade procurements: How the Center contracted for these various efforts, what policies and procedures it used, the extent to which its purchasing practices were sound and reasonable, and whether its procurement actions were consistent with the program's overriding goal of accelerated wind energy development. We close with a look at what has been accomplished and what problems have been encountered in attempts to develop blades that meet program goals of low cost, high performance, and long life.

EFFORTS MADE BY THE CENTER TO ATTRACT CONTRACTORS

While responses to its requests for rotor blade work have been somewhat disappointing, the Center has made extensive efforts to solicit prospective contractors to design and build blades for the wind energy program. Especially noteworthy are its attempts to obtain open and widespread bidding on its competitive procurements. Besides advertising proposed blade work and mailing requests to potential contractors, the Center has also conducted bidders' conferences and industry briefings to encourage outside participation and to rouse interest in the wind program.

It is the Center's policy to obtain competition whenever possible. As the table above shows, 79 percent of the funds for the 12 blade contracts have been competitively awarded. Prospective sources for these procurements were generally selected from the Center's extensive research and development

bidders list containing the names and other vital information on 400 to 600 companies which have expressed interest in Center activities. For individual procurements, this list is supplemented by other potential sources which have been identified by Center technical personnel. To further publicize its blade procurement plans, the Center advertised each of the competitive blade requests in the Commerce Business Daily.

In January 1979 the Center held an industry briefing to inform potential contractors and other interested parties about the Federal Wind Energy Program and how they could participate. A specific segment was set aside just to discuss procurement and selling to NASA. The Center had previously participated in conferences and workshops sponsored by such energy advocates as the American Wind Energy Association. These various forums had been used by the Center to discuss the progress and problems in developing viable wind systems and future directions of the program.

In attempts to increase industry responsiveness to its rotor blade work, the Center also held bidders' conferences for two of the five competitive blade procurements. At these conferences, potential contractors were given opportunities to ask questions about the work being requested which gave them an opportunity to better respond to the Center's requests.

For its five competitive blade proposals (which resulted in seven contract awards), the Center solicited a total of 267 bids, ranging between 20 for the MOD-OA 60-foot aluminum blades to 100 for the low-cost MOD-OA 60-foot blades. While large companies have received the majority of these solicitations, small companies, including universities and consulting firms, have not been overlooked. As the table below shows, 45 percent of the requests have gone to small companies.

Procurement identification	Number of solicitations		
	Total	Large companies	Small companies
MOD-O 60 ft. aluminum blades	33	20	13
MOD-O 60 ft. fiberglass blade	61	40	21
150 ft. fiberglass blade	53	30	23
MOD-OA 60 ft. aluminum blades	20	13	7
Low-cost MOD-OA 60 ft. blades	100	45	55
Total	267	148	119
Percent	100	55	45

While small, specialized companies have never been excluded from competing on these blade contracts, the earlier blade requests appeared to be directed toward large aerospace corporations which were more likely to possess the resources, facilities, and the type of technology needed for the program. These companies usually had impressive aircraft and helicopter rotor blade backgrounds and the type of experience considered important in the development of blades for wind machines.

The Center attempted to increase competition and to involve more small, high technology firms in the program by developing a proposal which appeared to be more attractive to smaller companies--the low-cost MOD-0A 60-foot blade proposal. The Center's experience with the large aerospace companies suggested they had difficulties producing rotor blades which would meet program goals, particularly the overriding goal of low cost. The Center felt that a proposal was needed which would place greater emphasis on low cost and which would solicit new ideas regarding blade materials and fabrication processes.

The so-called low-cost blade proposal differed from other Center requests in that prospective bidders were provided with more information and greater details in terms of blade geometry, design, and aerodynamic calculations. This was intended to make it easier for smaller companies to bid on the work. Also, for the first time, solicitations to small companies outnumbered those going to large companies 55 to 45.

Responses to blade requests have been disappointing

Despite its efforts to obtain widespread bidding on its blade work, the Center has experienced a somewhat disappointing record in terms of contractor responses. Even though over half the requests were acknowledged, only 29 bids were submitted for the 5 proposals. The number of bids varied between a single proposal for the MOD-0A 60-foot aluminum blade work and 12 bids on the low-cost MOD-0A 60-foot blades. From the acceptable bids, the Center eventually awarded contracts to five large contractors and two small companies. The following table highlights our analyses of the responses on these procurements.

Procurement identification	Number of solicitations	Acknowledged	No response	Bids
MOD-O 60 ft. aluminum blades	33	21	7	5
MOD-O 60 ft. fiberglass blade	61	35	18	8
150 ft. fiberglass blade	53	27	23	3
MOD-OA 60 ft. aluminum blades	20	10	9	1
Low-cost MOD-OA 60 ft. blades	100	43	45	12
Total	267	136	102	29
Percent	100	51	38	11

We do not know specifically, why the Center has not been able to elicit more responses for its blade work, but it appears the following factors contributed to the problem. Two of the five requests called for fixed-price contracts, not an attractive procurement for many because maximum risk is placed on the contractor. This, coupled with the fact that wind machine rotor blades, while somewhat related to aircraft rotor technology, are still relatively new. The Center project manager indicated that some companies failed to bid on this work because they were skeptical about the future of the wind program and saw little opportunity for additional contract work. Also, some companies were looking at solar applications where Federal funds and potential payoffs appeared to be greater than for wind.

One of the proposals requested blade fabrication and delivery within 150 days of the contract award. Center procurement people believed this to be insufficient time, but this target date remained. Center technical personnel justified the rather quick turnaround time on the basis that (1) the overall project would be jeopardized and (2) this was basically a fabrication effort, not a research and development project. Notwithstanding the apparent urgency for this work, we believe the time constraints may have discouraged some contractors from bidding, particularly since this was also solicited as a firm fixed-price contract. This was the request which resulted in only one bid being received.

Another proposal allowed prospective contractors only 1 month to submit their bids. At least two companies suggested this was not sufficient time to prepare an acceptable bid. We also noted that this proposal had to be modified 2 weeks after the Center sent it out because of blade design and tower frequency specification errors. Despite this correction half way through the proposal period, the deadline for bid submissions was not extended. While the request for proposal

itself did not appear to limit competition, we believe the denial to grant bidders additional time to prepare their proposals may have discouraged other companies from bidding on the work. We noted that only one other request provided such a short time for proposals to be submitted.

EVALUATIONS OF PROPOSALS FOR COMPETITIVE BLADE PROCUREMENTS

Review and appraisal of contractor proposals for the competitive blade procurements appeared to be thorough, unbiased, and consistent with NASA regulations and sound purchasing practices. Technical and other evaluation reports indicated that source selection officials were provided a sound base of analyses to help them select the contractor(s) likely to perform most advantageously for the Government. However, the contract records did not always contain substantive supporting documentation in sufficient detail to enable an impartial observer to trace various evaluation activities.

Types of evaluations

Determining which contractor(s) proposals will best meet the needs of the Center's blade work is made by senior agency officials specifically designated for that purpose. These source selection officials, in the light of stated work requirements, determine the relative quality and suitability of what is being offered by each proposer, the likelihood of its being delivered, and how much the Government will probably have to pay for each offering. While the ultimate decision rests with the source selection official, deciding which contractor(s) to select for a particular job is not done by this official alone. The actual evaluations are conducted by others.

While NASA regulations allow proposal evaluations to be accomplished in a number of different ways, we noted two basic types were used by the Center for the competitive blade buys. For the 150-foot fiberglass blade, the largest of the competitive buys, the Center used a Source Evaluation Board. Characterized by its more formal mode of operation, its representation by a mix of management, technical, scientific, contracting, and business experts; and its restriction primarily to large dollar contracts, this Board basically served the same purpose as that of the technical evaluation committees which were employed on the other competitive blade procurements.

Both evaluation groups provided technical and other analyses covering various factors likely to be pertinent to

source selection decisions. We noted that both groups conducted their activities according to the principles spelled out in NASA's extensive Source Evaluation Board manual.

While differing in methodology and depth of analyses, both evaluation groups set up a scoring system in which established mission suitability factors were rated for each proposal. These factors generally included an analysis of how well the offeror understood the work requirements, his plan to manage the work, the excellence of his proposal design, key personnel, and corporate resources. These factors generally included numerous subfactors, each of which was weighted and scored by individual Board and committee members. A total of 1,000 points was the maximum attainable score.

In reviewing contractor proposals, Center evaluation groups focused their attention on the mission suitability factors, because this important evaluation provides the source selection official with the information he needs to determine the technical competence of each proposal. Once the proposals were rated on their technical merits, attention was directed to costs, contractor experience and past performance, and other factors such as financial condition and stability. Although these latter factors were not scored, we found them to be considered as much or more than the mission suitability evaluations. This was particularly true in terms of costs.

We noted that cost was a primary consideration in each of the procurements and that low-cost bidders whose proposals were deemed technically competitive received the blade contracts. In fact, four of the contracts went to bidders whose numerical scores were not the highest, but whose proposed costs were the lowest. This is consistent with NASA guidelines which allows source selection officials to exercise judgment when deciding how much weight to place on the technical evaluations compared with cost and other factors.

Contractor experience and past performance also seem to play a significant part in the selection officials' ultimate award decisions, although these factors are not scored. Source Evaluation Board and technical committee reports and presentations often addressed contractor experience and prior work with NASA and other Government agencies. These evaluations centered more on overall corporate expertise and performance, not just the credentials of individuals who would be working on the requested assignments. These individuals generally were evaluated under the mission suitability factor of key personnel.

In summary, every contractor proposal was first judged to be responsive or nonresponsive to the requested work. Those deemed to be responsive were then numerically scored, using mission suitability factors and subfactors as the criteria for rating each proposal on its merits and shortcomings. This technical evaluation determined which contractors were within the competitive range from a technical standpoint. Cost, past performance and experience, and other factors were then considered to decide which among the technically competitive bids should be awarded contracts.

Evaluations appear to be comprehensive, penetrating, and objective

Each of the competitive blade procurements appeared to be subjected to thorough and unbiased evaluations conducted by people adequately qualified to identify the merits of the various proposals. Ranging in size from 3 to 19 people, Center evaluation groups were generally staffed with managers and technicians who, individually and collectively, had many years of experience with rotor blades and related work. Included among the evaluators were people with the following credentials:

--Project manager for 16 years, specializing in composite structures, design, and fabrication.

--Aerospace engineering (with four degrees) experience, with specialties in structural analysis and fatigue research.

--Project manager for 13 years, with emphasis on stress and structural analysis.

--Project manager on blade procurements for MOD-OA machines, with expertise in fracture control.

--Over 5 years experience with composite materials design and characterization, fracture mechanics, and fatigue analysis.

All the evaluation groups were comprised primarily of Center personnel, although others participated as consultants and advisors on two of the procurements. Consultants from NASA's Langley Research Center were used on the MOD-O 60-foot fiberglass composite blade and the 150-foot fiberglass blade procurements. Although the latter procurement also involved DOE and NASA headquarters officials from an advisory standpoint, their participation has been minimal on all the blade procurements. Price and cost analyses were also provided

for contract negotiations by Center pricing specialists and auditors of the Defense Contract Audit Agency. These analyses, which were in addition to the cost reviews conducted by Center technical personnel, appeared to be effectively used in negotiations with the contractors.

Our review of the contract files indicated that the evaluations for each of the competitive procurements were generally well done and consistent with NASA regulations and guidelines. We found the evaluation factors and weights assigned to the various procurements to be reasonable and directly related to the procurement objectives. Evaluation reports from the Board and technical committees provided sufficient information, at least in summary form, to enable the source selection officials to distinguish among the various strengths and weaknesses of each proposal.

We also determined that for each of the procurements, the selection officials' decisions were in line with the evaluative and other data provided by the review groups. As mentioned before, successful contractors were those whose proposals were technically competitive and whose proposed costs were the lowest.

Documentation for evaluation activities and key decisions

Technical evaluations and other analyses should be adequately documented to enable an impartial observer to arrive at basically the same conclusions relative to contractor selection as were reached by the review groups. NASA regulations and guidelines support this doctrine.

After reviewing the Center's contract and related records for the competitive blade purchases, we concluded that the evaluation reports and other documents in the procurement records justified the Center's contractor selection. We recognize, that these decisions required much discretion and judgment on the part of the selection officials, with tradeoffs among such factors as cost and technical competence having to be made throughout the decision process.

In concluding that Center contract and related records tend to support key decisions and evaluation activities, we essentially mean specific evidential matter required by NASA regulations and guidelines. These include such records as Board reports, technical evaluation committee reports, minutes of meetings, scoring sheets, contacts with offerors, and debriefing reports for unsuccessful bidders. Summary records were readily available in each of the contract files we reviewed.

For some of the procurements, the audit trail was clear and easy to trace. Every significant action and decision was properly and extensively documented so that an impartial observer, after reviewing the procurement package, could reach essentially the same conclusions as the evaluators. The contract files for the 150-foot fiberglass blade purchase detailed (1) the criteria and weights assigned not only to the basic mission suitability factors, but also to each of the subfactors used, (2) specific procedures and modes of operation employed throughout the evaluation process, and (3) the numerical scores for each subfactor so one could clearly see how the final composite scores were computed. Further, narrative justifications for every key decision and action were recorded. While it can be argued that such attention to details was because a Source Evaluation Board was used, we noted that another procurement (MOD-0 60 foot aluminum blades) was similarly documented, even though it was reviewed by a more informal technical evaluation committee.

The procurements of the MOD-0 60-foot fiberglass composite blade and the low-cost MOD-0A 60-foot blades were not as well documented. Although summary reports and other surface records provided ample evidence that every proposal was fairly and thoroughly evaluated, the contract files for these two procurements did not contain the extensive documentation we observed for the procurements discussed in the preceeding paragraph.

PROBLEMS IN NONCOMPETITIVE BLADE PROCUREMENTS

Center attempts to identify or locate other potential sources to perform blade work for noncompetitive procurements were not adequately documented. Likewise, evaluations of technical proposals associated with these contracts did not appear to be comprehensive, as required. Further, one sole source contract was funded even though the proposed work appeared to be similar to work requested under a competitive procurement, initiated at about the same time as the noncompetitive award.

Each of the contract files we reviewed contained a justification for going sole source or granting contracts for unsolicited proposals. However, documents supporting these decisions were skimpy. With the exception of an apparent stamp of approval by the Center's Operations Office (which maintains a source list of potential contractors), little evidence could be found to show the extent to which efforts had been made to locate other contractors who might be able to do the requested work.

Documents in the contract files indicated that comprehensive evaluations were not performed even though (1) contractor proposals for the noncompetitive blade work contained adequate technical and other information to permit in-depth evaluations and (2) generally months passed before the contracts were awarded, thus enabling sufficient time to review the proposals.

Technical evaluations for the unsolicited proposals were generally limited to the preparation of a one-page standardized report. The project manager merely checked off on the report as excellent, good, average, or poor, factors related to the proposal, such as value as a research project, understanding the problem, soundness of approach, ability of investigators, realism, and adequacy of facilities. Little, if any substantive narrative comments accompanied these reports. Thus, we were unable to determine what criteria was used in rating these factors or what the factors meant. Although the dollar value of these unsolicited proposals was relatively small, we believe that more penetrating evaluations are needed to assure that only unique and innovative proposals are funded.

Center records for the large sole source procurement (MOD-1 100 foot blades) referred to a joint evaluation of the contractor's proposal by numerous wind energy and other Center personnel. But, we found no backup documents to support such things as: (1) who did the evaluation, (2) the nature of the evaluation, (3) the strengths and weaknesses of the proposal, or (4) how much time and effort were expended in reviewing the proposal. What we found was a brief memorandum from the project manager stating that the proposal was reasonable. Even though this contract was an extension of some blade work that the contractor was doing for the Center at the time, and Center personnel were probably familiar with its capabilities, we believe a more thorough technical evaluation than what was apparent should have been done. The size of the contract (about $1.5 million) should have warranted closer attention by Center evaluators.

Awarding of one sole source contract gave contractor an edge

The noncompetitive sole source contract which the Center awarded for a wood blade study appeared to be very similar to the work the Center was about to initiate for competitive bidding. This gave the sole source contractor an apparent competitive edge in its bid to obtain a second contract under the Center's low-cost MOD-0A 60-foot blade proposal.

In November 1977 the Center awarded a small ($36,426) noncompetitive contract to Gougeon Brothers to study the feasibility of using laminated wood in the low-cost fabrication of rotor blades. Three and one-half weeks earlier, NASA headquarters had authorized the Center to begin action on competitive procurements for low-cost blade designs; and in December 1977 procurement invitations for this work were advertised in the Commerce Business Daily. Our review of the Center's contract files showed much similarity in the two proposed efforts.

Gougeon Brothers were one of three bidders that received contracts from the Center under the low-cost MOD-OA 60-foot blade request for proposal. While we could not determine what effect the earlier noncompetitive work had on this contractor getting another contract, we believe it gave Gougeon Brothers a decided edge in the competition. In fact, the work it has been doing on the competitive procurement is an extension of the work it had started on the sole source contract. Considering the timing of these two procurements, we believe the Center could have used better judgment in making the first, noncompetitive award.

The request for proposal involved in this case was the one which prompted Mr. Parsons' bid protest. However, even if the successful contractor had not submitted a proposal, Mr. Parsons would not have been within the competitive range on the protested procurement.

SUITABLE BLADE YET TO BE DEVELOPED

Despite years of development, millions of dollars of investment, and the extensive teaming of Government and industry experts, the Center is still searching for a rotor blade that will meet wind energy program standards of low cost, high performance, and long life. Although some of the current efforts look promising, only time and testing will tell whether these are an improvement over their predecessor blades. An analysis of the blade efforts we reviewed and the problems which have been encountered on each follows.

APPENDIX I

Blade identifier	Problems encountered
MOD-0 60 ft. aluminum	Labor-intensive fabrication process makes these blades totally impractical from a cost standpoint.
MOD-0 60ft. fiberglass composite	Cost and weight goals of the desired blade design could not be met. Only one of the proposed three blades were ever fabricated.
Urethane blade	No blade ever built. Tests of the design concluded that blade would be too brittle to withstand stresses under real-life situations.
Concrete blade	Indications were that this design would meet cost goals, but the blades themselves were too heavy--about 2-1/2 times heavier than aluminum or fiberglass blades of similar size.
150 ft. fiberglass	Design indicated cost and performance goals are achievable. However, only one blade was built and it was not sufficiently tested to adequately demonstrate a 30-year blade life.
MOD-0A 60 ft. aluminum	As with the MOD-0 blades, these were deemed to be too costly. Also, blade cracks, loose rivets, and general blade deterioration were noted after only 500 hours of operation.
Wood blade study	Design and hardware problems (root end bolts cracked) experienced during fatigue tests. These problems were later corrected.
Low-cost MOD-0A 60 ft. wood, fiberglass, and steel	Three different blade designs, none of which has been successfully demonstrated to date. Wood blade looks promising for intermediate size machines, but may not be suitable for bigger machines. Fiberglass blade experiencing problems meeting cost and weight goals. Design problems, particularly about the spar, are being experienced on the steel blade.
MOD-1 100 ft. fiberglass	Design looks promising and blades expected to be put on the MOD-1 machine, but structural design problems need to be overcome.

In addition to the blade work directly funded by the Center, contractors designing the MOD-1 and MOD-2 systems are also trying to develop viable blades for these machines. They, likewise, have not been too successful. Blade developments under the MOD-1 program have been particularly disappointing. Originally, fiberglass blades were to be built, but problems in fabrication and the inability to meet cost and weight goals led to the termination of this effort. Steel blades were eventually built and installed on the MOD-1. However, the blade life requirements were substantially reduced from the 30-year goal and the Center-funded 100-foot fiberglass blades are expected to replace the original steel blades.

There appears to be no simple solution or single reason why rotor blades have yet to be successfully demonstrated in actual wind machine operations. Center procurement practices do not appear to be a significant contributing factor, although improvements could be made. Problems seem to center more on (1) the relative slow advancement in the state of the art for windmill blade technology, (2) insufficient analytical tools and facilities to predict blade performance in real-life environments, and (3) the rush to get wind machines in the field before they have been perfected.

Notwithstanding the problems we have pointed out in procurements of rotor blades, we do not believe these represent a serious impediment to the development and demonstration of viable blades for the wind energy program. As we have noted, the Center appears to be making extensive efforts to attract competent and experienced firms to develop blades which meet program goals. Tradeoffs must be made to build blades which are lightweight, low cost, able to withstand varying wind and environmental conditions, and which are to be relatively maintenance-free for 30 years.

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