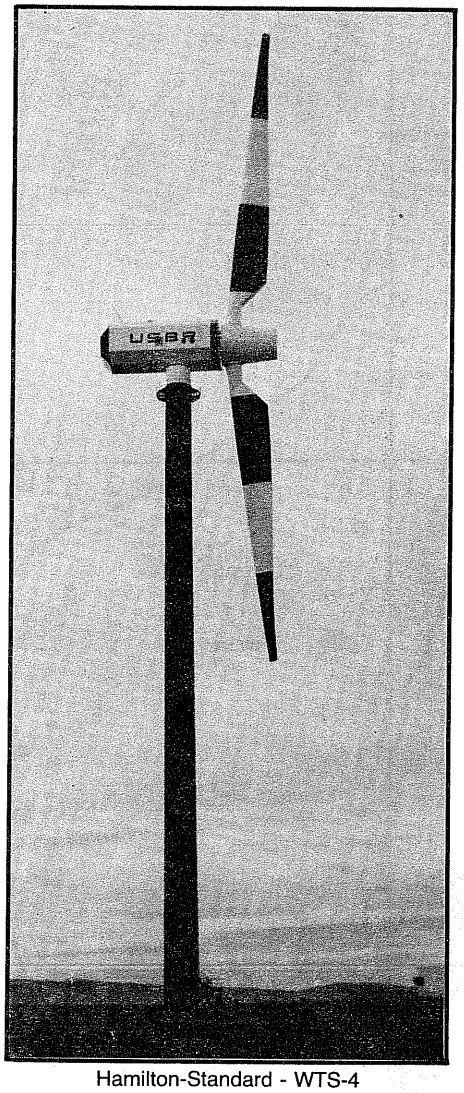
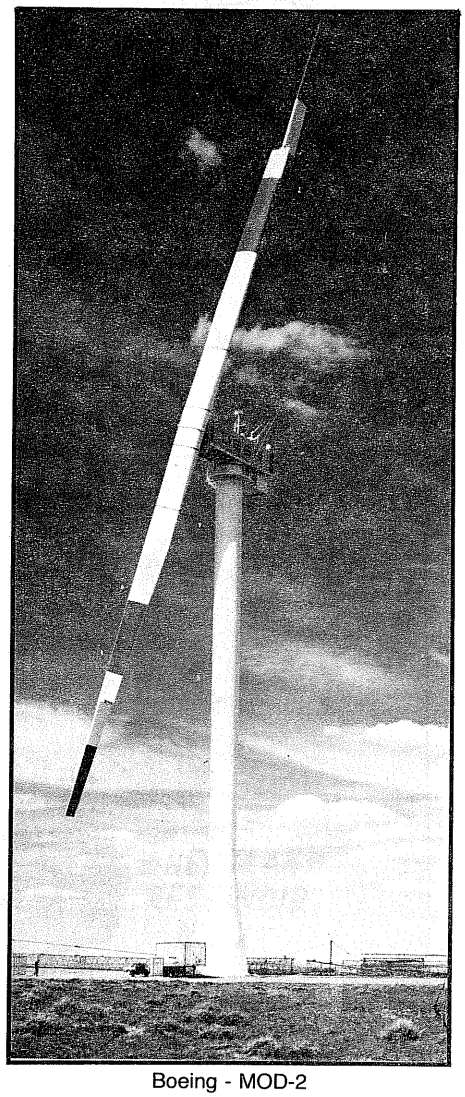
Wind-Hydroelectric Energy Project - Wyoming



Hamilton-Standard - WTS-4



Boeing - MOD-2

Status Report on System Verification Units

September 1984

Department of the Interior
Bureau of Reclamation

CHAPTER III--SYSTEM VERIFICATION UNITS

When the decision was made to procure a wind turbine unit, Reclamation felt it did not have sufficient expertise in the wind technology field and assistance would be needed. NASA Lewis Research Center was agreeable to providing the support needed to procure one turbine and an interagency agreement was executed in May 1979. NASA would provide the technical management for the design, fabrication, installation, testing, and initial operation of the unit. Also, NASA would train Reclamation personnel in the specialized wind turbine technology. A chance to obtain a second SVU arose and Reclamation decided this would be an ideal opportunity to compare two large wind turbines side-by-side in the same wind regime. NASA was agreeable to providing the support and expertise needed for two units.

Figure 7 is the program schedule for both units. Information was provided by NASA.

HAMILTON STANDARD WTS-4

Acquisition

A number of wind turbine manufacturers had indicated an interest in furnishing equipment for the Medicine Bow installation; therefore, the first SVU was obtained through competitive bidding. This resulted in a firm fixed price contract to Hamilton Standard. The chronology of events for the first SVU was:

July 1979	Request for proposals issued
February 1980	Hamilton Standard WTS-4 contract awarded
April 1981	Preconstruction meeting
May 1981	Work site mobilized
June/July 1981	Tower arrived at site
December 1981	Foundation construction, tower, and substation installation completed
May 1982	Nacelle and blade arrived at site
August 1982	WTS-4 first rotation
September 1982	Dedication ceremonies (both units)
December 1982	WTS-4 conditionally accepted by Government

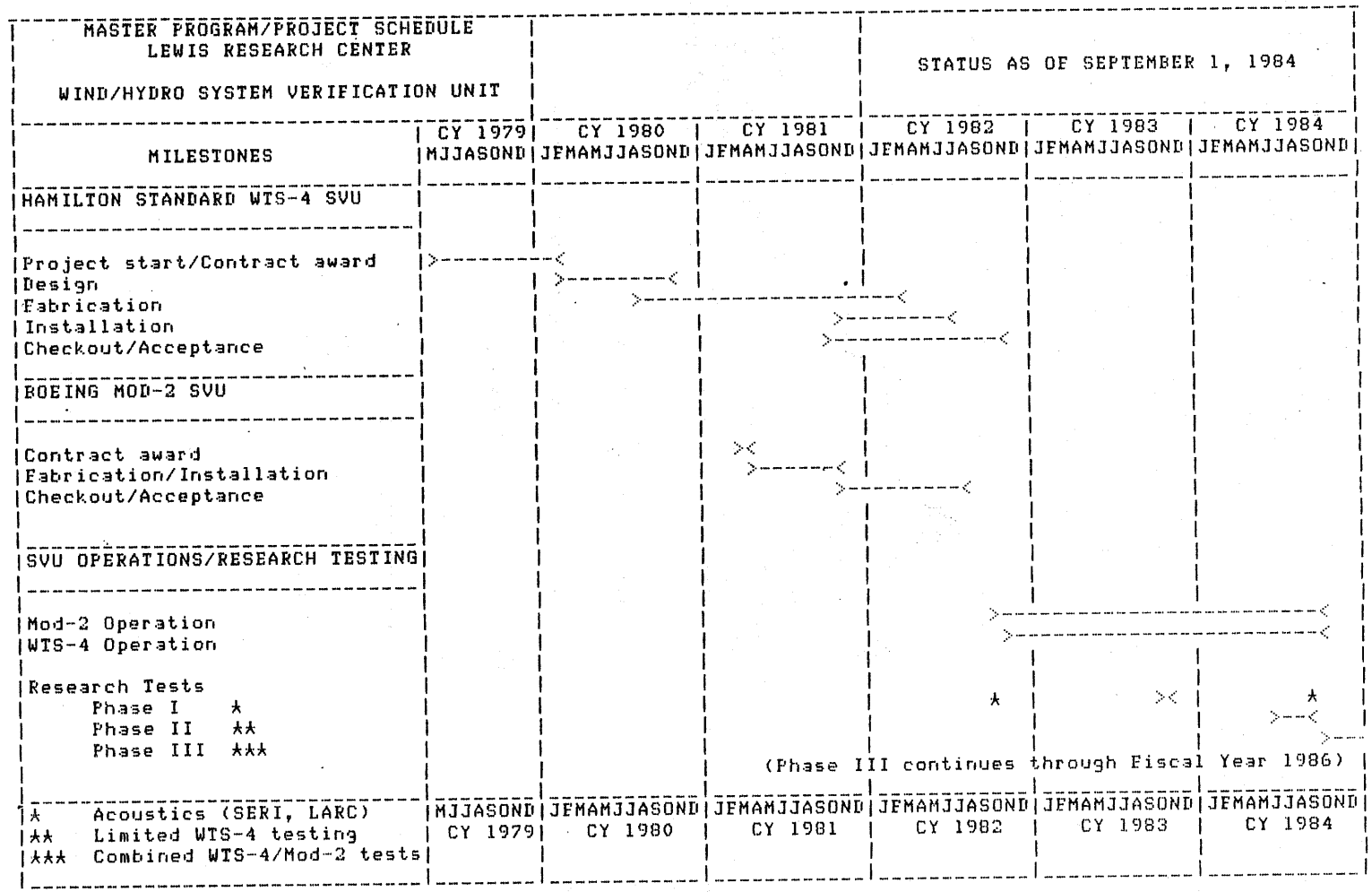

MASTER PROGRAM/PROJECT SCHEDULE
LEWIS RESEARCH CENTER
WIND/HYDRO SYSTEM VERIFICATION UNIT
STATUS AS OF SEPTEMBER 1, 1984
MILESTONES
CY 1979 MJJASOND
CY 1980 JFMAMJJASOND
CY 1981 JFMAMJJASOND
CY 1982 JFMAMJJASOND
CY 1983 JFMAMJJASOND
CY 1984 JFMAMJJASOND
HAMILTON STANDARD WTS-4 SVU
Project start/Contract award
Design
Fabrication
Installation
Checkout/Acceptance
BOEING MOD-2 SVU
Contract award
Fabrication/Installation
Checkout/Acceptance
SVU OPERATIONS/RESEARCH TESTING
Mod-2 Operation
WTS-4 Operation
Research Tests
Phase I *
Phase II **
Phase III ***
(Phase III continues through Fiscal Year 1986)
* Acoustics (SERI, LARC)
** Limited WTS-4 testing
*** Combined WTS-4/Mod-2 tests
MJJASOND CY 1979
JFMAMJJASOND CY 1980
JFMAMJJASOND CY 1981
JFMAMJJASOND CY 1982
JFMAMJJASOND CY 1983
JFMAMJJASOND CY 1984

Figure 7

Late 1983	Dual drive proportional yaw system installed
October 1983 to August 1984	Sporadic spinner support bracket and control system problems caused occasional limited operation
September 1984	Spinner support bracket and blade repair completed. WTS-4 available for resumption of testing

WTS-4 Description

The SVU is a downwind horizontal axis wind turbine with a rated power output of 4 megawatts. The Hamilton Standard designation for this unit is WTS-4 (wind turbine system--4 megawatts). The nacelle sits on top of a 250-foot tubular steel tower with the rotor centerline at 262.5 feet. The rotor, which is 256 feet in diameter, consists of two 125-foot fiberglass blades attached to a steel hub. A hydraulic pitch change system operating in conjunction with an electronic control system provides for full span pitch control of both blades for maximum energy extraction from the wind.

The WTS-4 is controlled by an electronic microprocessor. The microprocessor is designed to allow unattended operation at a remote site by monitoring wind conditions and the operational status of the wind turbine. Equipment failures result in automatic safe shutdown of the unit. The system status is monitored at the Casper Control Center.

Design and Construction

The WTS-4 wind turbine was constructed jointly by Hamilton Standard in the United States and KkrV (Karlskronavarvet AB), Sweden. The design of the nacelle and rotor for the SVU was accomplished under a separate program between Hamilton Standard and KkrV. Only the tower, foundation, site construction, and electrical system were specifically designed for the Medicine Bow SVU.

Hamilton Standard provided systems engineering and program direction while the NASA Lewis Research Center was responsible for managing the technical aspects of the project. In addition, Hamilton Standard (1) designed and fabricated the wind turbine blades in the world's first dedicated wind turbine blade manufacturing facility; (2) specified and/or procured, in conjunction with KkrV, and Stearns-Roger Engineering Corporation, Denver, Colorado, all other hardware and construction services; (3) conducted training sessions for Reclamation personnel; and (4) performed system checkout and acceptance testing.

Concurrent with the design effort, a Product Assurance Program Plan and a Failure Modes and Effect Analysis were developed. Two formal design reviews and two technical exchange meetings were held. Specifications and quality control documents were prepared for the manufacturing. Documentation of the manufacturing and assembly process was provided.

A complete onsite test plan and procedure for the WTS-4 was compiled, performed, and documented.

The data show strong correlation between predicted and measured results for life, control stability, and energy capture as shown in figure 8.

Detailed descriptions are in the preliminary "Final Report of the WTS-4 System Verification Unit, April 1983," provided by United Technologies Corporation, Hamilton Standard Division, Windsor Locks, Connecticut. The information contained in this report does not necessarily reflect concurrence and/or agreement by Reclamation.

Operation and Maintenance

The operation and maintenance training for the WTS-4 was provided in September 1982. However, there were seven other training sessions which provided the necessary background information. Listed below is a complete list of the training sessions:

. Overview Training:	November 20, 1980
. Specialized Training:	
- Aerodynamics and Performance:	October 26-27, 1981
- Electrical System and EDS:	October 28, 1981
- Control System:	October 29-30, 1981
- Rotor System:	November 2-3, 1981
- Nacelle, Tower, and Foundation:	November 4, 1981
- Drive Train:	November 5-6-1981
. Familiarization Training:	September 16-17, 20-22, 1982
. Monitoring Training:	September 23-24, 1982

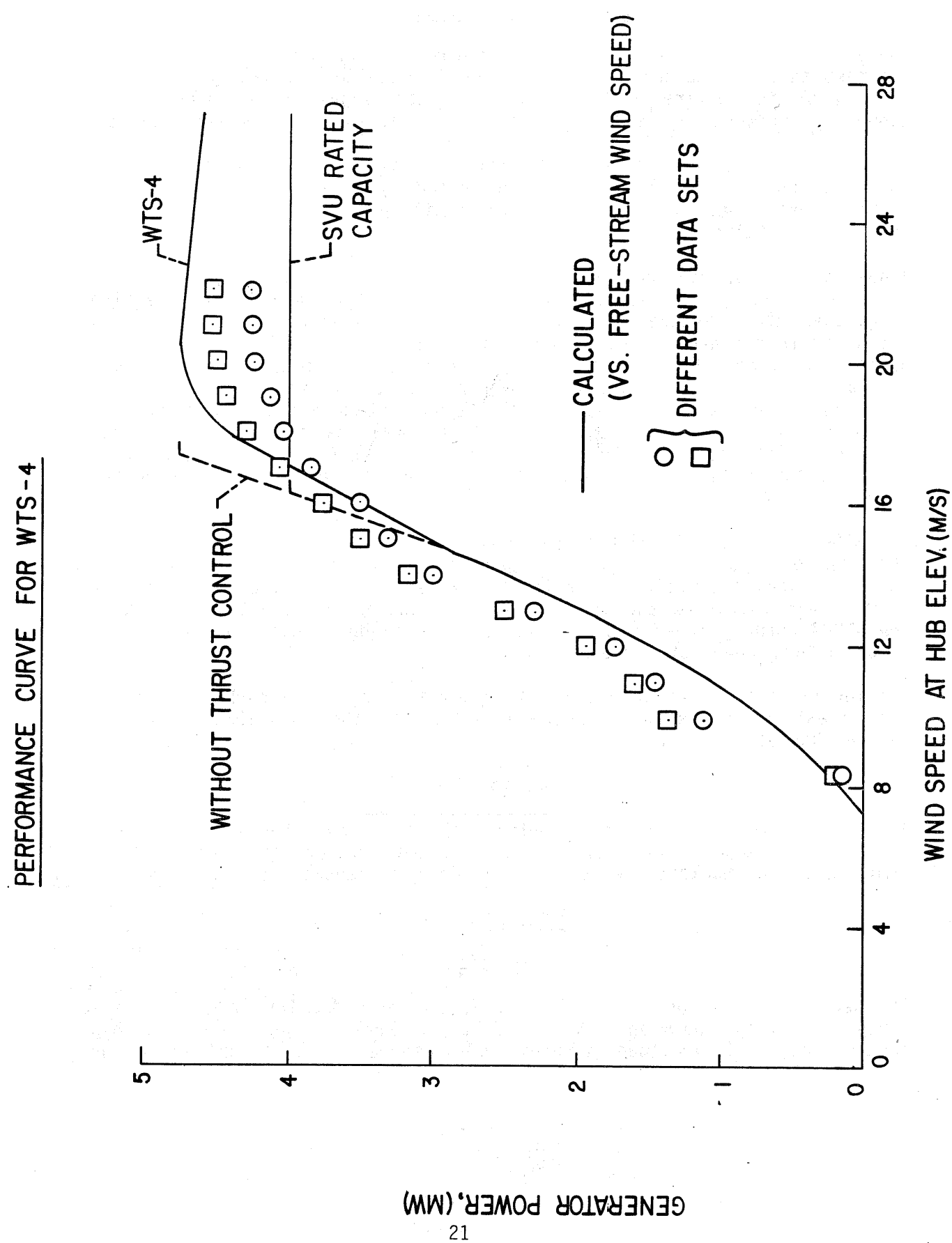
Operation, trouble-shooting, and maintenance manuals have been provided. To further aid in the maintenance of the WTS-4, equipment maintenance reports were prepared for all failed equipment during the onsite system testing.

A blade inspection and maintenance hoist specification was prepared.

All spare parts were inventoried in November 1982; all parts, except those consumed during site testing, are presently stored at the Mills, Wyoming warehouse.

A complete set of rotor and nacelle assembly and subassembly drawings was provided. In addition, all drawings pertaining to the tower, foundation, site work, and substation were provided.

Figure 8


PERFORMANCE CURVE FOR WTS-4
WTS-4
SVU RATED CAPACITY
WITHOUT THRUST CONTROL
CALCULATED (VS. FREE-STREAM WIND SPEED)
DIFFERENT DATA SETS
GENERATOR POWER, (MW)
WIND SPEED AT HUB ELEV. (M/S)
0
1
2
3
4
5
0
4
8
12
16
20
24
28

Difficulties Experienced

There was a time delay of 12 months during 1981, due to KkrV underestimating time needed to complete fabrication, assembly, and shop testing of the entire nacelle package. Additional delays occurred in debugging software on the control system so that shop testing could begin.

It was determined that the tower/foundation cyclic loading (which was used in designing the tower) had been influenced by high cycle fatigue. The initial tower design was completely modified to accommodate the new loading definitions.

Problems with software and sensor set points too conservatively set caused a large number of nuisance shutdowns. As the operational testing progressed the nuisance shutdowns diminished. A vibration absorber was installed in the nacelle to reduce excessive vibration of the cable trays during operation. However, the absorber has recently been removed because it was found to be unnecessary after the cable tray brackets were modified. Other difficulties which delayed testing were: conversion of the single yaw drive unit to a dual proportional yaw drive unit, nuisance oil leaks from main bearings and gearbox, engineering investigation of tower motion relative to foundation, and structural problems with the spinner assembly.

The WTS-4 has also experienced problems with lightning strikes disrupting the control system. Additional protection is being installed. In addition, struts supporting the rotor spinner cracked. The rotor spinner forms a work platform and instrumentation housing for the teeter area of the WTS-4 rotor. These struts have been redesigned, replaced, and bolted in place with new higher grade bolts.

All modifications were completed in September 1984. The turbine is ready for unrestricted testing and operation during the 1984-1985 high wind season (October-April).

Operation Time

As of September 1, 1984, the WTS-4 has operated 764.1 hours and produced 1 805 050 kilowatt-hours of energy. Western (Western Area Power Administration) markets the power through their transmission facilities.

BOEING MOD-2

Acquisition

The second SVU, a Boeing Company MOD-2, was provided for under a three-party agreement between DOE, NASA, and Reclamation. Under this arrangement, DOE provided surplus MOD-2 spare parts (supplied on an

existing contract) in exchange for technical data from Reclamation on operation and performance of the two units. Reclamation provided the necessary additional funds to complete the procurement, fabrication, assembly, installation, and checkout of this unit at Medicine Bow by exercising an option of the existing NASA MOD-2 contract with Boeing. The following are the highlights of Reclamation's procurement of the MOD-2:

May 1979	Interagency agreement with NASA signed
March 1981	Boeing Company MOD-2 contract awarded
April 1981	Preconstruction meeting
July 1981	Tower construction completed
November 1981	Nacelle and blade installed
December 1981	MOD-2 first rotation
December 1981	Secured in standby due to funding constraints
May 1982	Resumed testing
August 1982	Accepted for operational testing
September 1982	Dedication ceremonies (both units)
October 1983	Severely limited operating schedule initiated until status of low speed shaft repair and responsibility determined. Unit to be operated selectively on highest priority test items only
September 1984	Low speed shaft repair completed. Unit operationally available for resumption of testing

MOD-2 Description

The MOD-2 is a horizontal axis machine utilizing a 300-foot-diameter partial span control, upwind rotor. The rotor's center of rotation is 200 feet above ground level. It is coupled to the low speed shaft through an elastomeric teeter bearing. A 2500-kW synchronous generator is driven via a step-up planetary gearbox and "soft" quill shaft. The generator, gearbox, hydraulic systems, electronic controls, and other support equipment are enclosed in a nacelle mounted atop a cylindrical steel tower. The nacelle can be yawed (rotated) to keep the rotor oriented correctly into the wind as the wind direction changes. A hydraulic pitch control system is used to control the position of the movable rotor tips.

relieve crack stresses and the machine is now operational for the 1984-1985 high wind season (October-April). This repair and modification is similar to the rework of the Pacific Gas and Electric Company Solano County MOD-2 turbine, which has satisfactorily operated approximately 2,000 hours since its repair 1 year ago.

Additional difficulties experienced were leaking hydraulic actuator seals on the blade tip sections, erratic control system behavior, and problems with voltage regulation on the generator output.

Operation Time

As of September 1, 1984, the MOD-2 has operated 495 hours and produced 567 420 kilowatt-hours of energy. Western markets the power through their transmission facilities.

PHYSICAL COMPARISON, COSTS, AND OPERATION

Table 2 is a physical comparison and costs through March 1984 of Reclamation's two wind turbines at Medicine Bow, Wyoming. Table 3 is an operation summary of the large wind turbines presently operating.

Both units are computer controlled and can be operated unattended. Information including windspeed and direction is detected by sensors on the units and fed into a computer. In turn, the computer controls the wind turbines to produce the maximum amount of power. The computer immediately shuts down the turbines in dangerously high wind conditions or if a malfunction occurs. The turbines are presently being operated by Reclamation personnel at the Medicine Bow Control Center and monitored from the Casper Control Center.

OTHER FACILITIES

Site Arrangement

The site plan for the first two SVU's is shown in figure 10. The location of the first SVU is about 5-1/2 miles southwest of the town of Medicine Bow, situated 1,400 feet from the existing county road. The distance and bearing from the meteorological tower to the first SVU is 851.24 feet and N. 75.36° E. The control building and visitor center is near the meteorological tower and the edge of the development area to minimize visitor disturbance of private land.

The second SVU MOD-2 is located 4,500 feet (15 blade diameters) downwind from the WTS-4.

The 15-diameter spacing was chosen based on early preliminary estimates of wake effects by various manufacturers of wind turbines. Detailed

Table 2.--Physical comparison and costs of wind turbine units

Feature	WTS-4	MOD-2
Rated power	4000 kW	2500 kW
Rotor diameter	256 feet	300 feet
Rotor type	teetered-free yaw	teetered
Rotor blade material	filament-wound fiberglass	all steel (welded)
Rotor orientation	downwind	upwind
Cut-in windspeed	7.1 m/s	6.7 m/s
Rated windspeed	16.4 m/s	13.9 m/s
Cut-off windspeed	27.0 m/s	26.8 m/s
Rotor tip speed	123 m/s	84 m/s
Rotor rpm	30	17.5
Generator rpm	1800	1800
Generator type	synchronous	synchronous
Gearbox step-up ratio	1:60	1:102.8
Gearbox type	two-stage planetary	three-stage planetary
Hub height	262 feet	200 feet
Tower	hollow steel	steel (shell) type
Total weight	782,000 lbs	580,000 lbs
Costs as of March 1984		
Turbine Cost	$6,241,000	$3,755,000 1/
Other SVU costs	$5,320,925 2/	$1,374,775 3/
Total (rounded)	$16,692,000	

1/ Does not include $1.5 million in parts furnished by DOE under three-party agreement.

2/ Includes road, transmission line, visitor center, and related facilities for both units as well as NASA contract administration costs of $720,000 (contract letting through design and fabrication), and overhead expenses.

3/ Includes NASA contract administration of $275,000 (costs were less than WTS-4 because this was fourth unit instead of first unit fabricated), extension of transmission line, and overhead expenses.

Table 3.--Operation summary for wind energy systems
(week ending August 9, 1984)

Location and type unit	Total oper. time (hours)	Total sync. time (hours)	Total energy (MW/hr)	Average power (kW)	LSS oper. time 1/ (hours)
GOODNOE HILLS, WA					
Mod-2 No. 1 2/	1,008	918	1060	1154	0
Mod-2 No. 2	1,262	1,157	1472	1272	0
Mod-2 No. 3	1,890	1,733	2055	1186	308
Mod-2 Cluster	4,160	3,808	4587	1205	308
SOLANO, CA					
Mod-2 No. 5	3,085	2,942	4786	1626	2239
MEDICINE BOW, WY					
Mod-2 No. 4	-	495	550	1111	N/A
WTS-4 3/	-	850	1679	1975	N/A
MAGLARP, SWEDEN					
WTS-3 4/	-	3,620	5379	1486	N/A

1/ Operational time since the low speed shaft (LSS) was repaired.
2/ MOD-2 (Boeing) 2.5 MW at 12.9 m/s at hub height.
3/ WTS-4 (Ham.Std.) 4.0 MW at 16.1 m/s at hub height.
4/ WTS-3 (Ham.Std.) 3.0 MW at 13.9 m/s at hub height.