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STATUS OF THE 4 MW WTS-4 WIND TURBINE

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ABSTRACT

The WTS-4 is a four-megawatt, horizontal-axis wind turbine presently being fabricated for the U.S. Department of Interior, Bureau of Reclamation, by United Technologies' Hamilton Standard division. This unit, called the System Verification Unit (SVU) will be installed at Medicine Bow, Wyoming, early next spring. The specifications, characteristics and features of the WTS-4 are discussed. The major components—such as rotor, nacelle and tower—are described and their status in the fabrication phase is presented.

INTRODUCTION

The Hamilton Standard WTS-4 is a 4 MW, downwind horizontal-axis wind turbine being fabricated for the U.S. Department of Interior, Bureau of Reclamation, for installation at Medicine Bow, Wyoming. This machine, called a System Verification Unit (SVU), is a potential forerunner of a number of wind turbines to be installed in Medicine Bow by the Bureau of Reclamation as part of a long-range plan to integrate wind power with hydroelectric power.

The WTS-4 SVU will be the first 4 MW wind turbine erected anywhere in the world. It reflects the culmination of Hamilton Standard's wind turbine activity under way since the early 1970s. This effort consisted largely of company-sponsored technology development until 1977 when Hamilton Standard joined in association with a large Swedish company to develop a megawatt-scale wind turbine system. After an intense competition involving five European consortium competitors, the team of Hamilton Standard and Karlskronavarvet was awarded a contract to develop the WTS-3, a two-bladed, downwind, horizontal-axis wind turbine rated at 3 MW. This unit is scheduled for installation in the fall of 1981, in the town of Maglarp in south Sweden. It will be grid-connected and operated by Sydkraft, the large, privately-owned utility based in Malmö, Sweden. Hamilton Standard's contribution to this program was the overall system design, the mechanical design of the rotor and pitch change system, and fabrication of the blades. A new factory for the manufacture of large filament-wound blades was dedicated, by Hamilton Standard, in the fall of 1980 and is now in full operation. The two blades for the WTS-3 are essentially complete and will be shipped next month to Sweden.

SVU PROJECT

The SVU project was launched by the Bureau of Reclamation to evaluate the technical and economic feasibility of integrating wind turbines and hydroelectric facilities.

Preliminary studies by the Department of Interior, Bureau of Reclamation, indicate that current state-of-the-art wind turbines may be cost-effective when coupled with existing hydroelectric installations. They have identified the Medicine Bow, Wyoming, area as having the most promising wind resources that could be coupled with the existing hydroelectric system in the Colorado River Storage Project. Their plan is to install SVUs at Medicine Bow to evaluate the technical and economic feasibility, as well as the environmental and social acceptability of this integration concept.

The nature of economic feasibility is the expected cost of electricity for a multi-unit installation of SVU-type machines capable of generating 400,000,000 kW hours per year.

The scope of the SVU project, then, is to install and operate megawatt-scale units at Medicine Bow, Wyoming, and to train DOI personnel to manage wind turbines and future acquisitions. For this purpose, a contract for procurement and installation of a WTS-4 was initiated February 1, 1980. Design work to upgrade the WTS-3 to a WTS-4, meeting the full requirements of the procurement specification, was completed in 1980 and all manufacturing activity, exclusive of the blades, was concluded in early July of this year. Final assembly is currently nearing completion and system testing has been initiated. Present plans are to install and operate the SVU in the early spring of 1982.

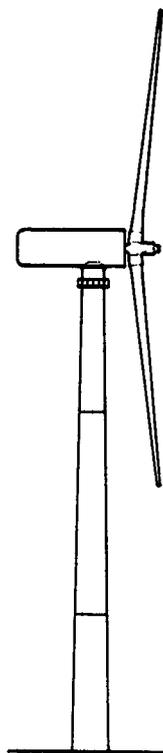
SPECIFICATIONS

The WTS-4 specifications are shown in Figure 1.

- **Rating — 4.0 megawatts**
- **Wind regime (at hub centerline)**
 - **Cut-in 6.9 m/s (15.4 mph)**
 - **Rated 15.1 m/s (33.9 mph)**
 - **Cut-out 27 m/s (60.4 mph)**
- **Life**
 - **30 years**
 - **Low annual maintenance**

FIGURE 1. WTS-4 SPECIFICATION

The operating range between cut-in and out-out was selected to maximize energy capture tailored to the Medicine Bow site. The characteristics of the machine are shown in Figure 2.



- Rotor
 - Diameter: 78.1 meters (256.4 ft)
 - Speed: 30 rpm
 - Two blades: filament-wound fiberglass
 - Downwind
 - Full-span pitch control
 - Free yaw
 - Teetered with delta-3
- Nacelle
 - Gearbox: Two-stage, 1:80
 - Generator: 1800 rpm, 60 Hz, synchronous
 - Control system: Digital, microcomputer, high reliability
 - Switchgear: Utility standard
 - Housing: Fully enclosed, ventilated
- Tower characteristics
 - Hub centerline height: 80 Meters (262 ft) AGL
 - Construction: Steel shell
 - Diameter: 12 ft. nominal

FIGURE 2. WTS-4 CHARACTERISTICS

The rotor diameter, 78.1 meters (256.4 feet), is identical to the Swedish WTS-3. The WTS-4 has many of the same components as the Swedish WTS-3. The major changes include a larger generator to accomplish 4 MWs and rotor operation at 30 rpm to accomplish the 60 Hz synchronous operation of the generator using the same gearbox. The tower and foundation are also of different design.

Features of the WTS-4 include the following:

- Dynamic force, moment, and torque decoupling of the rotor from support structures.
- Teeter hinge minimizes dynamic loading.
- Delta-3 control permits free yaw operation with accurate weather-vaning.

- Soft-mounted gearbox and fast control for high energy capture and smooth power quality during high gusty winds.
- 4.0 MW synchronous generator with 20% over-rate capability.
- Fully redundant hydraulic control pitch change system and completely autonomous emergency shutdown control system.
- Central electronic computer (nacelle mounted).
- Filament-wound, monolithic fiberglass blades.
- Full span pitch control for maximum control authority, energy capture and minimum drag above cut out velocity.
- Tall, slim, soft/soft tower minimizes turbulence loads, allows higher energy capture in high wind shear locations and provides seismic isolation.
- Fast pitch change rates for quick cut in, cut out operation and high power quality.
- Ramped cut in, cut out loading sequencing.
- High turbulence intensity foundation design.

DESCRIPTION OF WTS-4 WIND TURBINE

The major components of the WTS-4 are common to most horizontal-axis wind turbines. They are the rotor, gearbox and generator mounted on a nacelle at the top of a tower. The rotor consists of two blades and a hub which contains the full span pitch change mechanism. The rotor is mounted to the shaft of the nacelle by means of a teeter pin which is tilted for Delta-3 effect. The nacelle is allowed to yaw freely at the top of the tower.

The blade is a 38 meter (125 ft) long, filament-wound, monolithic fiberglass structure as shown in Figure 3. Filament-wound fiberglass was selected for its low cost and high structural integrity that is resistant to environmental effects such as corrosion. At the root of the blade are steel retention rings which are mounted to a bearing on the hub allowing the blade to completely rotate in pitch.

The hub, shown in Figure 4, is a steel structure containing the teeter and blade bearings, the hydraulic control mechanism, pitch change actuation system and the emergency feather accumulators.

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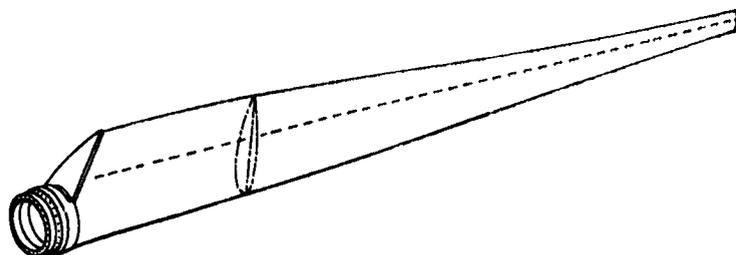


FIGURE 3. THE WTS-4 BLADE FABRICATED OF FILAMENT-WOUND FIBERGLASS FOR STRENGTH, LIGHT WEIGHT AND LONG LIFE

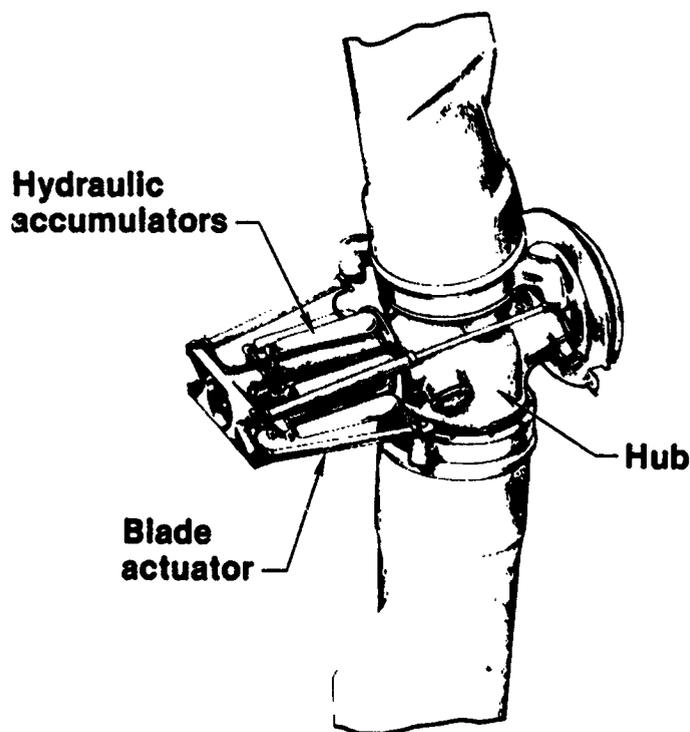


FIGURE 4. THE HUB, A STEEL FABRICATION CONTAINING THE TEETER BEARINGS AND PITCH CHANGE SYSTEM

The nacelle is shown schematically in Figure 5. Shown are the relative locations of the gearbox, generator, and hydraulic supply system. The generator is provided by Ideal Electric of Mansfield, Ohio, and the gearbox by Thyssen Henschel of West Germany. The nacelle, provided by Karlskronavarvet of Sweden, mounts to the top of the tower by means of a cylindrical roller yaw bearing which allows the nacelle rotor assembly to freely rotate in yaw.

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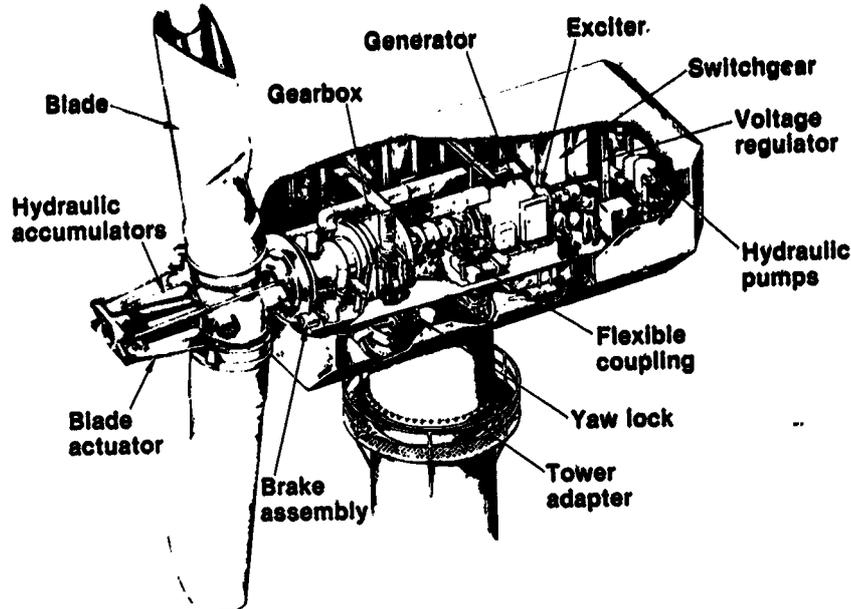


FIGURE 5. THE NACELLE CONTAINS THE DRIVE TRAIN AND GENERATOR MOUNTED ON THE BEDPLATE

The control system consists of microprocessors located in the nacelle and the base of the tower, as shown schematically in Figure 6. This system provides not only unattended operational capability, but also safety, maintenance, and diagnostic features. It allows operation from a nearby control building and has the capability of being operated from a remote station in Casper, Wyoming.

The tower, as shown in Figure 7, is a hollow steel tube provided by ITT Meyer Industries of Redwing, Minnesota and is fabricated of formed steel plates arranged in a twelve-sided tubular structure and seam-welded, similar to modern transmission tower construction. Cor-Ten steel was selected for its corrosion resistance and low maintenance. The tower contains an elevator, safety ladder, and cable trays for retaining power and control signal cables.

The foundation consists of a single caisson drilled pier construction 70 feet deep and 19 feet in diameter. This construction, shown in Figure 8, was selected as the most cost-effective foundation for the soil conditions at the site. One tower section is embedded in the foundation during construction with the above-ground sections being welded during tower erection. Site and construction work is being performed by Stearns-Roger of Denver, Colorado.

OPERATION

Operation of the WTS-4 is automatic. A start and shutdown sequence is shown in Figure 9. Starting with the standby condition when the measured wind velocity reaches cut-in (the wind speed above which efficient power can be produced),

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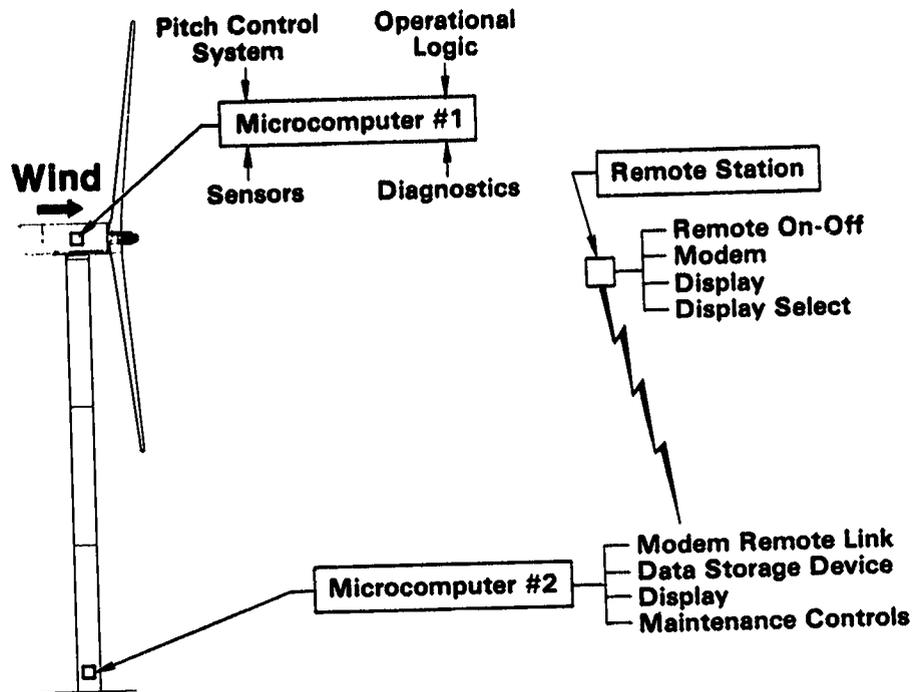


FIGURE 6. THE CONTROL SYSTEM PROVIDES UNATTENDED OPERATION, SAFETY, MAINTENANCE AND DIAGNOSTIC SYSTEMS

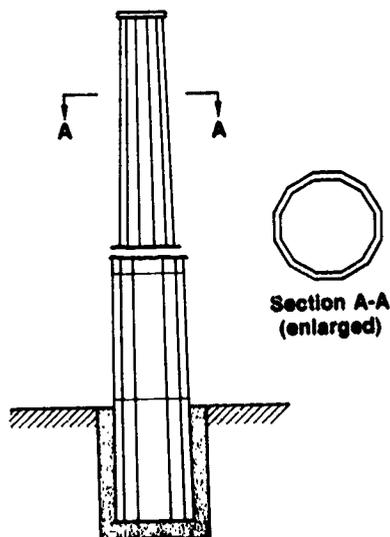


FIGURE 7. THE TOWER IS FABRICATED FROM COR-TEN STEEL FOR MINIMUM MAINTENANCE

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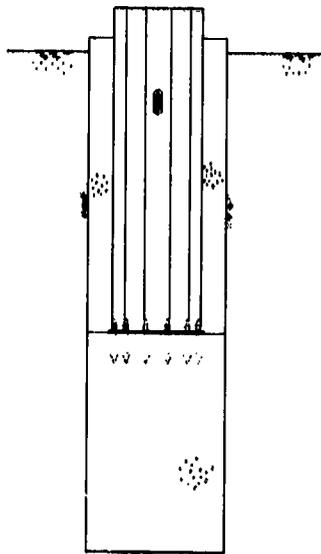


FIGURE 8. THE FOUNDATION WAS SELECTED FOR ITS COST EFFECTIVENESS FOR THE SOIL CONDITIONS AND HIGH TURBULENCE INTENSITY AT MEDICINE, BOW, WYOMING

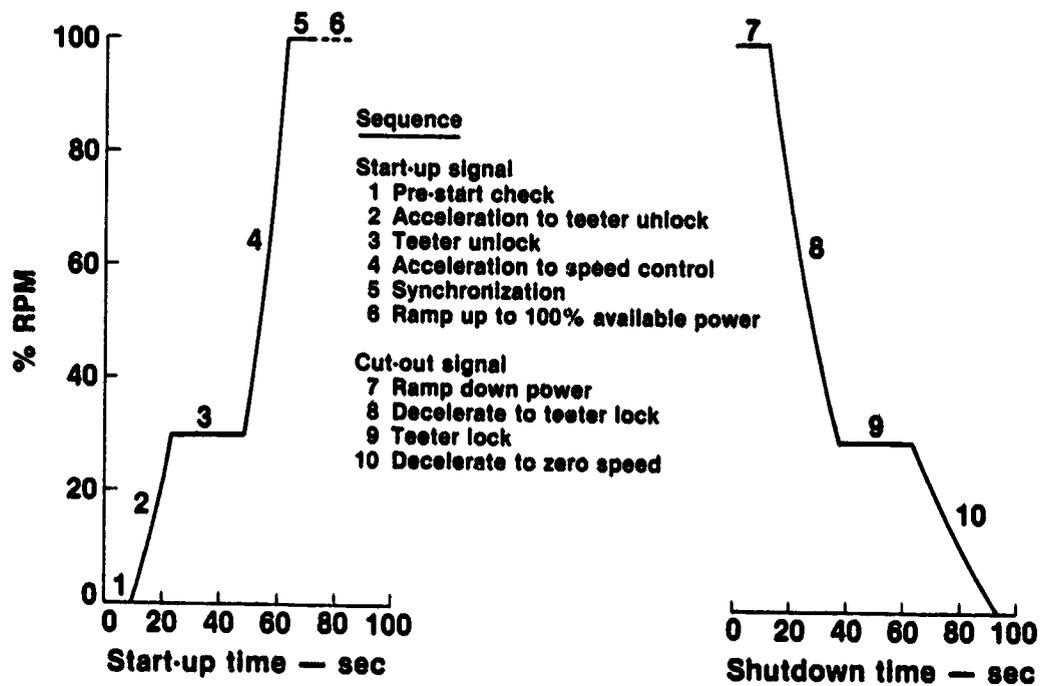


FIGURE 9. AUTOMATIC START-UP AND SHUTDOWN IS SCHEDULED FOR MAXIMUM ENERGY CAPTURE

the control system automatically goes through prestart check to ensure that all normal and emergency features are operational. The blades are then positioned in pitch to achieve maximum rotational acceleration. As rotor rpm increases, the control system controls the pitch to pause at 10 rpm at which time the teeter locks are deactivated. The rotor is then allowed to accelerate to 30 rpm, at which time the speed is controlled by operation of the pitch change system at synchronous speed. The control automatically synchronizes and connects the generator with the grid. The pitch change system is then controlled to achieve 100% of available power or the maximum rating of the generator.

When the winds achieve cut-out velocity (a wind velocity chosen for energy capture and safety reasons), the control system automatically ramps down the power, disengages the generator from the line, implements the teeter locks at approximately 10 rpm, and decelerates to zero speed. When the unit is not operating, the blades are feathered vertically and the wind turbine automatically weather-vanes downwind.

STATUS

The WTS-4 wind turbine design is complete and the components are being manufactured and assembled. Fabrication of the blades is under way. Figure 10 shows the completed spar of the first blade. The nacelle is in the final assembly stages in Sweden and the control system software is being checked out.

The nacelle assembly, prior to having the cover installed, is shown in Figure 11. The tower has completed its factory fabrication and has been delivered to the site in four sections. It will be welded together during erection. The hole for the caisson foundation has been drilled and rebar is being installed prior to pouring the concrete. All the hardware and components will be on-site in early 1982 ready for erection.

The WTS-4 is an advanced design of a large horizontal-axis machine and lends itself to numerous site applications. It has been optimized for high wind sites where wind energy holds the most promise of economical power production. Plans are well advanced to fabricate and install 20 such machines in Hawaii as part of a program with Windfarms Limited of San Francisco. The Kahuku Point project will supply electricity to the Hawaiian Electric Company. A letter of intent has also been signed with Southern California Edison to install five units at San Geronio Pass, California.

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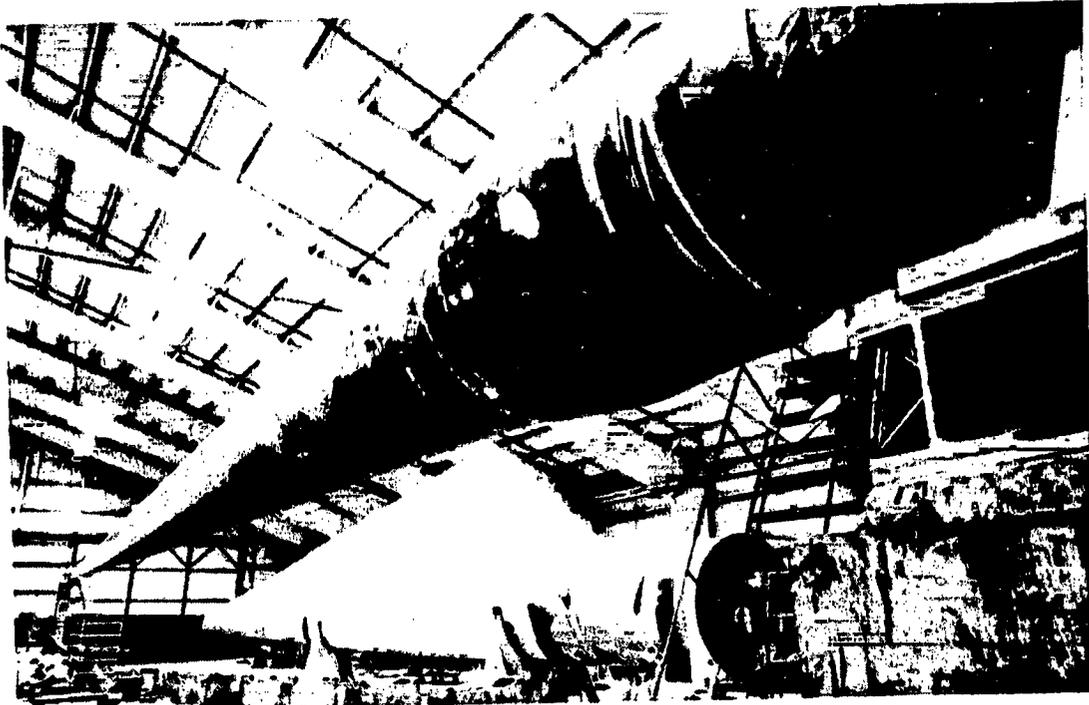


FIGURE 10. COMPLETED FILAMENT-WOUND SPAR OF THE FIRST
WTS-4 BLADE

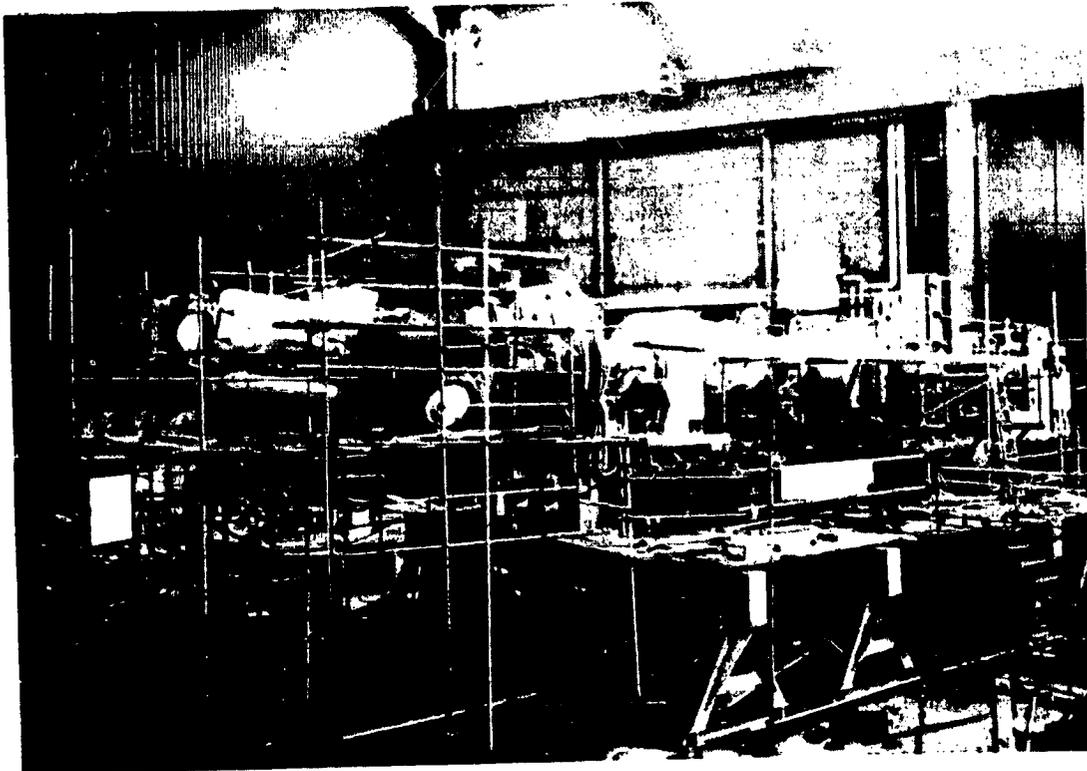


FIGURE 11. NACELLE IN FINAL STAGES OF ASSEMBLY