ROTATIONAL INERTIA & ENERGY

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How Windmills as Wide as Jumbo Jets Are Making Clean Energy Mainstream

By STANLEY REED, CARSTEN SNEJBJERG and RASMUS DEGNBOL APRIL 23, 2018

OSTERILD, Denmark — At the northern end of Denmark's Jutland peninsula, the wind blows so hard that rows of trees grow in one direction, like gnarled flags.The relentless weather over this long strip of farmland, bogs and mud flats — and the real-world laboratory it provides — has given the country a leading role in transforming wind power into a viable source of clean energy.After energy prices spiked during the 1973 oil crisis, entrepreneurs began building small turbines to sell here. "It started out as an interest in providing power for my parents' farm," said Henrik Stiesdal, who designed and built early prototypes with a blacksmith partner.The initial windmills made by small operations had quality problems. Blades — then just 15 feet in length — would break or fall apart. Now, they are giants, made by global players pulling off enormous feats of engineering. Technicians reach the roof of these enormous wind turbines either via an internal elevator or, if the turbine is installed offshore, by helicopters that lower them into the fenced-off area.By Rasmus Degnbol The biggest turbines in Osterild stretch more than 600 feet high. **The largest rotor blades can reach 270 feet in length**, comparable to the wingspan of an Airbus A380, the world's largest commercial plane. **The price tag: Up to 10 million euros, or more than $12 million.** The monstrous scale has helped turn wind into a mainstream form of power.Larger turbines harness more wind, creating more energy. The biggest modern offshore turbines produce nearly 20 times as much power as ones developed three decades ago. The larger the size, the lower the cost of generating energy. In parts of northern Europe, wind is now a major power source. It accounts for 4 percent of overall global energy supply, according to the International Energy Agency. Blades for wind turbines lie outside a factory, waiting to be transported to wind farms. From those early Danish innovators, the industry has grown to be dominated by companies like Vestas Wind Systems and Siemens Gamesa Renewable Energy. The heart of the Siemens Gamesa business lies in Brande, a small Jutland town. It was there in the early 1980s that an entrepreneur named Peter Sorensen founded a wind business called Bonus with a couple of workers from his father's irrigation company. At a cavernous workshop, technicians build custom turbine models and facilities for testing whether components are robust enough to last two decades or more. Inside, the towers are so big that elevators haul engineers up and down. Passengers must wear a climbing harness in case they fail. At a Siemens Gamesa training center, technicians learning how to lower themselves with ropes and harnesses in case elevators inside the turbines fail. The rotors are connected to the windmill tower by a nacelle — a large enclosure the size of a trailer, with plenty of room inside to walk around. Large enclosures, or nacelles, connect a wind turbine's rotors and house its generator and controls.Carsten Snejbjerg for The New York Times Looming over the top deck outside are the rotors. When they whirl, the whole column sways like a ship at sea.A technician walks inside a prototype wind turbine in Osterild, Denmark. These test models help turbine makers boost performance. . Making these blades is difficult and labor-intensive. Teams of workers gradually fill a mold with strips of fiberglass interlaced with balsa wood for strength. They then inject resins and other chemicals into the container to form the hardened structure. The huge size of the blades, and the complexity of the process, mean completely automating it does not make economic sense. **Around 1,300 people work in the factory, and making a single blade can take about three days.**It's a difficult balance for manufacturers to achieve both size and efficiency. **The largest blades already weigh around 30 metric tons,** and making them longer adds to their weight, fast. Overweight blades might lead to turbines being worn down faster, and would put enormous stress on other components.

Questions: (a) Convert 30 metric tons to kg.?, (b) Convert blade length(L) of 270 feet to meters? (c) Find moment of inertia of a blade with axis of rotation at one end? (d) Find total moment of inertia of three blade combination? (e) Blades rotate (frequency = f) between 5 – 20 rpm. Assume the blade frequency to be 10 rpm. Find angular velocity of blade in rad./s.? (f)Find Kinetic energy due to all three blades turning at 10 rpm?,(g) Each complete rotation of three blades takes 10/60 seconds = 1/6 s = t. Find power generated /1 rotation?

HINTS: metric ton = 2200 kg., 0.3048 meters/foot, $I_{ROD\ END} = 1/3\ m\ L^2$,$K = ½\ I\ \omega^2$ Power = work/time= K/t

ANSWERS: (a) m = 6.6×10^4 kg., (b) L = 82.3 m., (c) 1.49×10^8 kg. m.^{2} , (d) 4.4×10^8 kg. m.^{2}, (e) ω = 1.047 rad./s., (f) 2.412×10^8 J, (g) P = 1.4467×10^9 watts