**Optimal** **WindMILL Flow Theory by S. Farthing**

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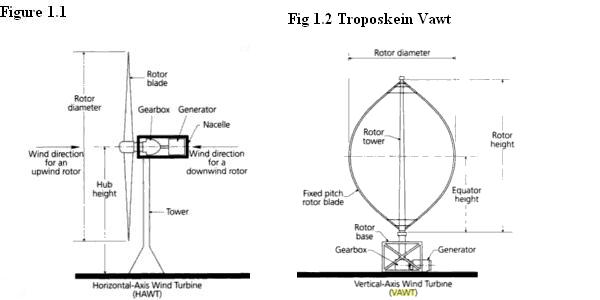
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**Introduction – Use and Analysis of Lift and Drag in Wind and Water**

Humans have used the wind for thousands of years to fly kites by aerodynamic lift and to sail. At first billowing sails simply dragged the boat downwind such as southward on the Nile where the sails were dropped to return northward with the water current. Sails could also be lowered in storms and minimised the overturning weight. Gradually fabrics were improved and sails were flattened to lift crosswind for broadreaching. As hulls were deepened with keels they could also develop hydrodynamic lift perpendicular to their course to allow reaching. Leeboards, weighted keels and Polynesian outriggers were evolved to further reduce the hull leeway and heeling to finally progress the sailboat through the water acutely into the wind. Now planning skiffs, multihulls and land yachts and above all iceboats sail much faster crosswind than the wind, generating extra self wind for larger acute apparent wind by their very forward motion.

Windmills to grind grain and lift water were among the first ‘machines’ with constantly moving parts. At first [Shepherd] they were Persian (differential) downwind drag types with vertical axes (Chapter 1.1) but later the wheels of the towering flour and drainage mills of England and Holland were rotated about the wind by the lift of removable sails over wood frames at typical blade tip speeds equal to windspeed.

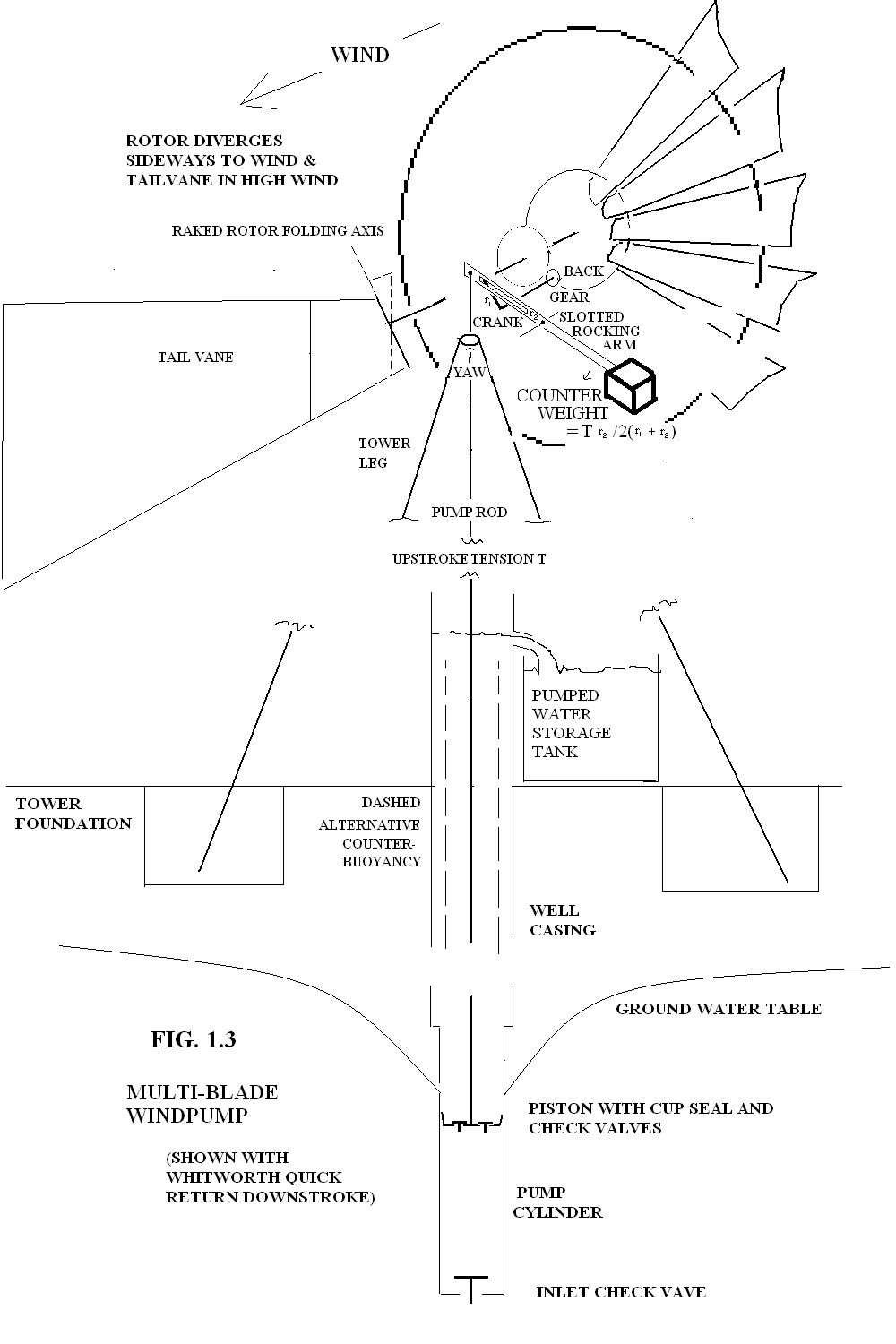
In the 19th century ‘industrial revolution’, boat propulsion progressed from drag oars to engine-driven paddlewheels to higher blade speed lift screw propellers. Marine screws prompted the ‘actuator’ theory of Froude and Rankine. Later Joukowski was the first to understand how lift involved circulation around a blade. Glauert was a leader in analysing the airscrews pioneered by the Wright Brothers and autogiros, (the precursor to the helicopter). Sadly he was tragically killed in a freak accident in 1934 before his first windmill analysis was even published. Nonetheless posthumously Glauert’s few pages have been the foundation for almost all design to the present of Horizontal axis wind turbines (Hawt’s) yawing on towers Figure 1.1



In the same period in France, Darrieus patented a vertical axis wind turbine Vawt that used lift and apparent wind to continue rotating in any direction of wind with no stationary tower needed. Figure 1.2. In the 1960’s South and Rangi reinvented Darrieus’ version with extruded blades hooped in a ‘troposkein’ centrifugal catenary. But their aerodynamic analysis was crude and optimistic relative to Glauert’s Hawt analysis. In Chapters 5&6 this text tries to unify the two analyses, so more rational design comparisons can be made, if only in the new area of tidal stream power.

Where it is not feasible or environmentally acceptable to build barrages to store and concentrate flow to turn hydroelectric turbines, underwater windmills(Chapter 7) are a lesser option to recover some of the kinetic energy of a tidal or river flow. These flows can have a considerably lower range of speeds than the wind. For instance a definite maximum tidal speed can be safely predicted from the harmonic decomposition of past currents, whereas windmills must be designed to survive in very high winds.

Since the wind forces vary as windspeed squared and its power as the cube, windmills are trying to tap an extremely variable power source. This problem is accentuated by most power uses not being similarly fluid dynamic and cubic, so the ideal ratio of machine speed to windspeed cannot be maintained. So much so that a windmill cannot be designed separate from its end use (and storm protection) as most vividly illustrated by the multitude of blades required to get waterpumping windmills Fig 1.3 to even start, and their yawing (‘furling’) sideways in high wind. Complicated mechanisms or sophisticated electronic controls are not practical for such vital tasks in the harsh windmill environment necessarily exposed not only to the wind, but also all of the sun and rain. (The corrosion, biological growth and contaminability of tidal saltwater is also a very severe and underestimated design environment.) In chapter 2.2 the inescapable variability of natural currents is expressed by a new very simple design condition that the optimum must be robust to changes in the ratio of blade to windspeed, which opens up new analytical understanding and design avenues...



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