The Shape of Turbomachines and the Evolving Role of Specific Speed

Paul Gostelow, Department of Engineering, University of Leicester, Leicester, U.K.

Aldo Rona, Department of Engineering, University of Leicester, Leicester, U.K.

Ali Mahallati, Concepts NREC, White River Junction, Vermont, U.S.A.

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Long Abstract

turbo – turbinis (L)___ I spin

A taxonomy of turbomachines is presented in Fig. 1. This permits turbomachines of widely varying geometry and layout to be designed, identified and classified. The process will be illustrated with reference to different configurations of compressors, turbines, fans and pumps.

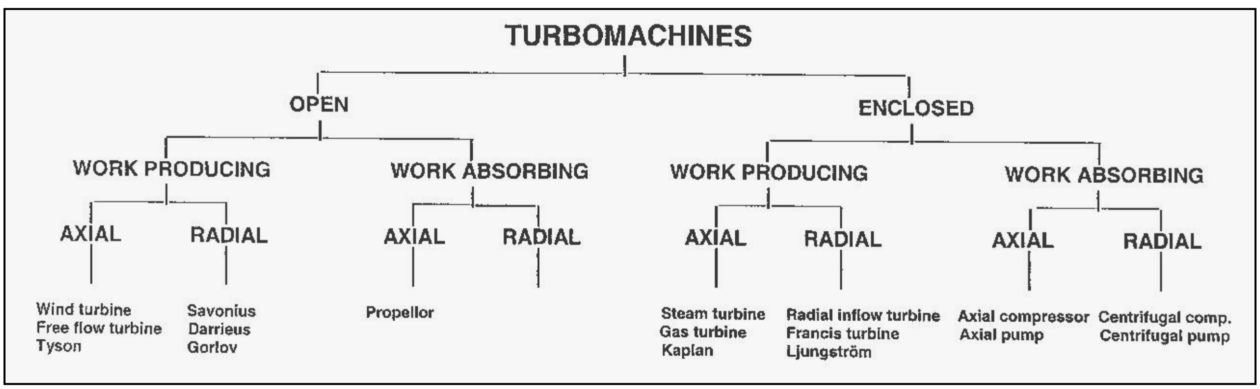


Figure 1. Taxonomy of Turbomachines.

The classification of turbomachines is firstly approached; this is illustrated by some modern examples of hydraulic turbines. The framework employed for analysis and design of enclosed axial turbomachines is introduced. Although the traditional approach to the aerodynamic design of enclosed turbines uses intersecting two dimensional planes, it is recognized that all turbomachinery flows are three-dimensional (3-D) and unsteady. The use of advanced computational procedures is routine but unsteady and 3-D effects, and their impact on performance, are still not well-predicted.

Design methodologies in use for axial flow machines will be outlined and performance issues with the low pressure turbines of modern aircraft engines will be considered. Some research advances in understanding the roles of vorticity and of blade sweep in axial turbomachines will be described. We are used to seeing and analyzing axial turbomachines for aircraft gas turbines. Although these may seem to have converged in shape, exciting advances are being made in design tools and techniques.

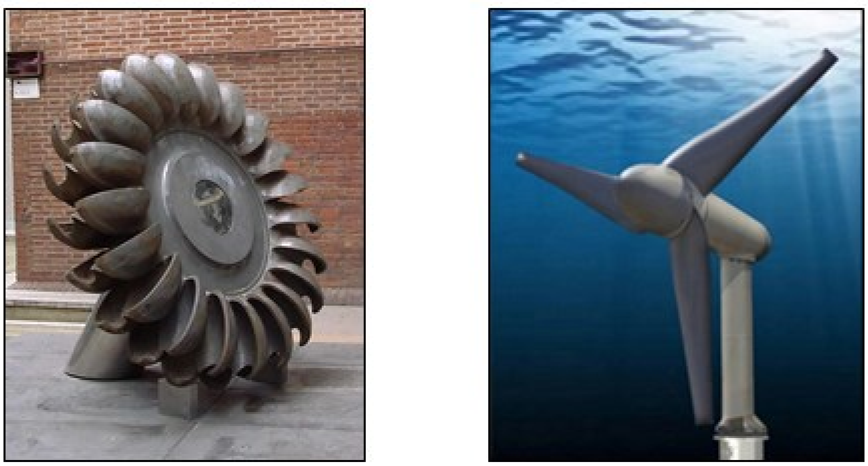
There are still significant challenges, with progress needed for the economy and environment. For instance, the recent growth in intermittent solar and wind power generation increases the duration conventional power turbomachines are run under off-design conditions at high loads. A wider look at some opportunities in newer kinds of turbomachine, for which designs have not yet converged, is resulting in improvements. Universities and industry have collaborated in the last two decades to produce highly-loaded low pressure turbines. These have been deployed in commercial aircraft and major savings in engine weight and cost have been achieved, but with a penalty in turbine efficiency. Research is now aimed at regaining lost efficiency whilst retaining weight and cost advantages.

With this great variety of shapes and sizes how does the designer set about selecting the most appropriate for the application? From dimensional analysis the concept of specific speed is useful. This works for pumps or turbines, air or water, and is very effective for cavitation avoidance.

The specific speed of a **pump** is given by: $Ns = N(Q^{1/2}H^{-3/4})$ and for a **turbine** by: $Ns = N(P^{1/2}H^{-5/4})$.
N is rotational speed, Q is flow, H is head, P is power, p is pressure, v is velocity. In this way the optimum shape of a turbine can be realised, based on the power output, P, and the head, H. Ranges of Ns are: Pelton 10 – 30, Crossflow 20 – 200, Francis 30 – 400, Propeller and Kaplan 200 – 1000. The specific speed and the related flow and load coefficients provide a common analytical framework for characterizing networks of different fluid machines. This extreme variety enables differing configurations of fluid machines to be handled under a common framework.

Dimensional analysis also gives a **cavitation number** $s = (p_{at} - p_v + H)/ (½ \ r \ v^2)$. This is a reliable indicator for cavitation avoidance and can be monitored by real-time signal processing in the operation of water pumps and turbines to prevent unintentional cavitation.

Figure 2 illustrates the enormous difference in configuration between hydraulic turbines with low and high specific speeds.



Low Ns, - Pelton Wheel, or High Ns, - Axial Flow Turbine?

Figure 2. What Specific Speed do the Power and Head Indicate?

The sweep question is particularly relevant for most approaches to the design of free flow and enclosed fans and turbines. Increasing use of sweep is encountered in the design of aircraft engine fan and low-pressure turbine blades. These blades encounter a wide range of subsonic, transonic and supersonic relative velocities; blade sweep is therefore an important part of their aerodynamic analysis. The use of advanced materials and composites is opening new possibilities for turbomachinery aerodynamic design by reducing the constraints of stressing and mechanical considerations; this is increasingly freeing blade design from the traditional radial stacking. Fan and turbine designers are now taking advantage of these exciting design freedoms.

For progress to be maintained it is essential for analytical, computational and experimental work to proceed in a balanced, collaborative and interactive manner. This is best achieved by the relaxation of traditional disciplinary barriers in and between universities and industry.