The Ljungström turbine for aeronautical applications

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Introduction

In the beginning of the 20th century, the production of electricity was mainly provided by steam turbines plants. In that era, even though the electric power production was moderate with respect to present day standards, bulky systems had to be installed because of the significant expansion of steam inside the turbine while performing work. Rather important steam leakage flows were also common and plagued the plant-directors because, after all, steam was money[1].[2]
The Swedish Ljungström brothers came up with a turbine that coped with most of the above mentioned issues. This Ljungström turbine or *STAL*-turbine, lending its name from its inventors or from the company where it was manufactured respectively, is a radial turbine made of two contra-rotative coaxial turbine halves with an outward directed flow, on which multiple blade-crowns are fixed (Fig.1). By splitting the produced power over the turbine halves, two smaller electric generators could be used, while the increase of specific volume of the steam due to its expansion was easier to cope with because of the diverging flow path, peculiar to the geometry of the turbine. The Ljungström turbine could consequently be made smaller than its counterparts[3].[4]
In the mid 20th century, however, the introduction of powerful internal combustion engines, more specifically the reciprocating engine and the gas turbine that drive the generators directly, reduced the primary importance of steam in most of the electricity production processes. Also, the aviation industry urged engine manufactures to develop gas turbine propulsion systems. Turbines for stationary purposes soon became dependent on the advances made in aero-engine technology, since the investments made to improve the efficiency of the latter were paying off. As most research was invested in radial inflow and axial turbines -from now on referred to as the conventional configurations-, other turbine types were soon depreciated or simply fell into oblivion.
Unfortunately, this still existing bias sometimes obscures the superiority an unconventional turbine type might have over conventional turbine configurations on a given application, where configurations with conventional turbines would perform less, or would not be possible at all. The tidal wave turbine of McCormick is such an example[5].[6]The authors believe that this is the case too with the Ljungström turbine. Therefore, the turbine will be revisited, extracting work from hot air or combustion gases.

Helicopter propulsion - Rotor Driven by Embedded Turbine concept (REDT)

Today, the conventional helicopter is hitting the boundaries of its performance.[7] In order to improve cost, safety and performance, it is found natural that an evolution towards other concepts should be made. Helicopter manufacturers are aware of that and several exotic configurations appear such as the Eurocopter X^3 and Sikorsky X2, where performance improvements are mainly addressed.[8] An important component that appeared as a prime concern in deteriorating cost, safety and performance, was the mechanical transmission system.[9] More electric solutions were examined by Buysschaert et al., but appeared not mature for immediate implementation in a helicopter platform.
The introduction of the Ljungström turbine to drive the rotors of a helicopter was discussed for the first time by the Belgian Hubert Antoine.[10] The concept, being called *Rotor Driven by Embedded Turbine* or *Rotor à Entraînement Direct par Turbine (REDT)*, renders the need for a mechanical transmission system obsolete, since coaxial rotors can be driven directly by one Ljungström turbine, integrated in the rotor head. This makes the concept inherently more safe and less costly. An example of such a configuration is shown in Fig.2. Additionally, the concept still allows

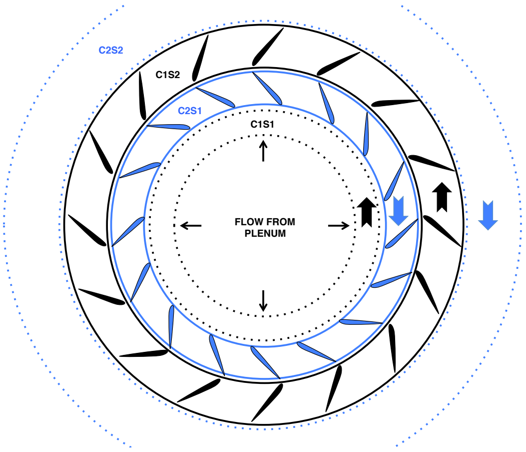

Figure 1: 2D cross-sectional view of the Ljungström turbine

compounding, offering a significant margin for performance improvements. Cycle studies prove that a significant gain in SFC are within reach.

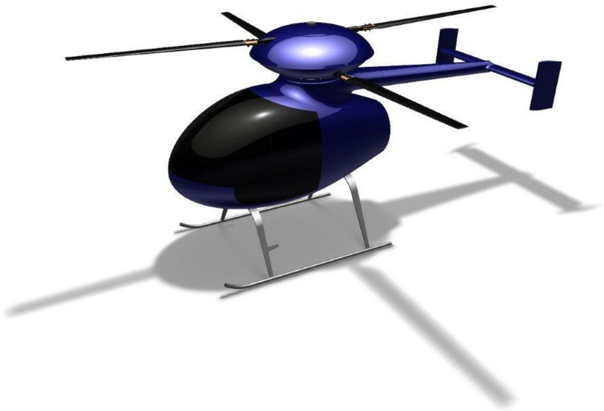

Figure 2: Helicopter with REDT (Embedded Ljungström turbine)

Turbine modelling

Knowing the performance characteristics of a component is essential for the engineer. In case of a sophisticated component such as a turbine, performance maps relating mass flow and rotational velocity to efficiency and pressure drop are mandatory. For preliminary design purposes, the literature gives ample solutions to obtain a general idea of axial and radial inflow turbine performance. Most of these models rely on empirical methods, frequently based on, or supported by, cascade testing, and were gradually optimised applying several correction factors.[11] Currently, the models of Craig & Cox[12] and Ainley & Mathieson,[13] the latter almost always used in modified form,[14] are the standard in open literature for axial turbines. The work of Aungier[15] on the other hand is quite instructive for designing radial inflow turbines.

The Ljungström turbine however, is neither an axial turbine, nor a radial inflow turbine. The work explained in the paper will examine an appropriate model for this turbine, and evaluate it by means of CFD calculations using NUMECA software.

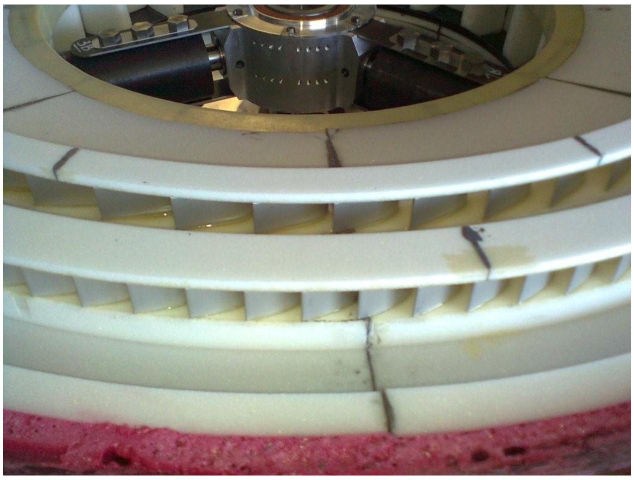

Figure 3: Closeup of a Ljungström turbine-half, integrated in rotor head

References

[1] F. P. G. Van Loenen Martinet. Mededeelingen betreffende de Ljungström turbine, vervaardigd door de Svenska Turbinfabriks Aktiebolaget Ljungström te Finspong, Zweden. *De Ingenieur*, 30(30):601–617, July 24th 1915.

[2] STAL. 10,000-14,000 kW. Ljungström steam turbine, constructed by Svenska Turbinfabriks Aktiebolaget Ljungström, Finspong, Sweden. Reprinted from ”ENGINEERING”, September 30, October 21 and 28 1927.

[3] W. H. Van Zoest. Twee "werkspoor-stal" turbogeneratoren van 17000/22500 kW voor de P.E.N.-Centrale te Velsen. *De Ingenieur*, 51(34):113–118, August 1935.

[4] Aurel Stodola. *Dampf- und Gas-Turbinen*. Springer, 1922.

[5] S.L. Dixon. *Fluid mechanics and thermodynamics of turbomachinery*. Elsevier Butterworth-Heineman, 5th edition, 2005.

[6] Manabu Takao and Toshiaki Setoguchi. Air turbines for wave energy conversion. *International Journal of Rotating Machinery*, 2012.

[7] J.G. Leishman. *The Helicopter. Thinking Forward Looking Back*. College Park Press, 2007.

[8] Douglas Nelms. Speed streak. *Aviation Week & space technology*, pages 64–66, July 9, 2012.

[9] Frank Buysschaert, Patrick Hendrick, and Simon Newman. Conventional helicopters: an adaptiveness study for more electric and alternative propulsion technologies. *Journal of Aerospace Engineering*, 226:1078–1094, 2011.

[10] H. Antoine, G. Dimitriadis, P. Hendrick, E. Kagambage, and T. Rayee. A novel concept for helicopter rotor drives. In *3rd European Conference for Aero-Space Sciences*, Versailles, Paris, France, July 6-9 2009.

[11] Ning Wei. *Significance of loss models in aerothermodynamic simulation for axial turbines*. PhD thesis, Kungl Tekniska Högskolan, 2000.

[12] H.R.M Craig and H.J.A. Cox. Performance estimation of axial flow turbines. In *Proceedings of the Institution of Mechanical Engineers*, volume 185, pages 407–424, 1970-1971.

[13] D.G. Ainley and G.C. Mathieson. An examination of the flow and pressure losses in blade rows of axial-flow turbines. Technical Report 2891, Ministry of supply : Aeronautical research council reports and memoranda, July 1955.

[14] Hany Moustapha, Mark F. Zelesky, Nicholas C. Baines, and David Japikse. *Axial and radial turbines*. Concepts NREC, 2003.

[15] Ronald H. Aungier. *Turbine Aerodynamics. Axial-flow and radial-inflow turbine design and analysis*. ASME press, 2006.